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Final
Ground Water Monitoring Plan
for the
Ammunition Burning Grounds, Old Rifle Range, and Demolition Range

Naval Surface Warfare Center
Crane Division
Crane, Indiana

VOLUME I OF II - TEXT

Southern Division
Naval Facilities Engineering Command
Contract Number N62467-94-D-0888
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Project Report

GROUND WATER MONITORING PLAN
FOR THE
AMMUNITION BURNING GROUNDS,
OLD RIFLE RANGE, AND DEMOLITION RANGE

NAVAL SURFACE WARFARE CENTER, CRANE DIVISION
CRANE, INDIANA

REVISION 2
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ACRONYMS

ABG	Ammunition Burning Grounds
ANOVA	Analysis of Variance
B&R	Brown & Root
BGS	Below Ground Surface
cc	Cubic Centimeter
cm/sec	centimeter per second
CFR	Code of Federal Regulations
CLEAN	Comprehensive Long-Term Environmental Action Navy
CTO	Contract Task Order
DR	Demolition Range
FSP	Field Sampling Plan
ft	Foot; Feet
GRITS/STAT	Ground Water Information Tracking System/Statistics
GWMP	Ground Water Monitoring Plan
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
HpCDD	Heptachlorodibenzo-p-dioxin
HpCDF	Heptachlorodibenzofuran
HPLC	High-Performance Liquid Chromatography
HxCDD	Hexachlorodibenzo-p-dioxin
HxCDF	Hexachlorodibenzofuran
IAC	Indiana Administrative Code
ICP	Inductively Coupled Plasma
IDEM	Indiana Department of Environmental Management
MCL	Maximum Contaminant Level
ml	Milliliter
NGVD	National Geodetic Vertical Datum
NSWC	Naval Surface Warfare Center
OCDD	Octachlorodibenzo-p-dioxin
OCDF	Octachlorodibenzofuran
ORR	Old Rifle Range
PCB	Polychlorinated Biphenyl
PeCDD	Pentachlorodibenzo-p-dioxin
PeCDF	Pentachlorodibenzofuran

PETN	Pentaerythritol tetranitrate
PVC	Polyvinyl Chloride
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine
RFI	RCRA Facility Investigation
SC	Specific Conductivity
SDWA	Safe Drinking Water Act
SOUTHNAVFACENGCOM	Southern Division, Naval Facilities Engineering Command
SQL	Sample Quantitation Limit
SWMU	Solid Waste Management Unit
SVOC	Semivolatile Organic Compound
TCDD	Tetrachlorodibenzo-p-dioxin
TCDF	Tetrachlorodibenzofuran
TCE	Trichloroethene
Tetryl	Methyl-2,4,6-trinitrophenylnitramine
TOC	Total Organic Carbon; Top of Casing
TOX	Total Organic Halogens
TNT	Trinitrotoluene
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WES	Waterways Experiment Station

1.0 GROUND WATER MONITORING [40 CFR 264 SUBPART F]

This Ground Water Monitoring Plan (GWMP) for the Naval Surface Warfare Center Crane (NSWC Crane), Indiana, was prepared for the U.S. Department of the Navy (Navy) by Tetra Tech NUS, Inc. (TtNUS) under the Southern Division, Naval Facilities Engineering Command (SOUTHNAVFACENGCOM) contract, Contract Number N624467-94-D-0888, Contract Task Order (CTO) 038.

This GWMP outlines the overall scope of the ground water monitoring programs to be conducted in accordance with the Resource Conservation and Recovery Act (RCRA) permit to be issued by the United States Environmental Protection Agency (U.S. EPA) Region 5 to NSWC Crane, located in Crane, Indiana. The RCRA permit contains ground water monitoring requirements for three operating units used for the open burning and open detonation of munitions/explosives at NSWC Crane: the Ammunition Burning Grounds (ABG), the Old Rifle Range (ORR), and the Demolition Range (DR). This GWMP was developed in accordance with the requirements for RCRA ground water monitoring in 40 Code of Federal Regulations (CFR) 264 Subpart F and U.S. EPA technical guidance (U.S. EPA, 1986a). Compliance with 40 CFR Subpart F also results in compliance with Indiana Department of Environmental Management (IDEM) regulations. Groundwater monitoring will be conducted in compliance with the approved Field Sampling Plan (FSP) and the approved Quality Assurance Project Plan (QAPP).

1.1 GROUND WATER MONITORING OBJECTIVES

The primary ground water monitoring objectives for each of the three units were developed to meet the regulatory requirements described in 40 CFR 264 Subpart F. 40 CFR 264.91 identifies three required programs. 40 CFR 264.91(a)(1) requires compliance monitoring under 264.99 whenever hazardous constituents are detected in ground water. Detected is defined as statistically significant evidence of contamination. 40 CFR 264.91(a)(2) requires corrective action under 264.100 whenever a ground water protection standard is exceeded. Exceeded is defined as statistically significant evidence of increased contamination. 40 CFR 264.91(a)(3) requires corrective action under 40 CFR 264.100 whenever the ground water protection standard is exceeded between the compliance point and the downgradient facility boundary. 40 CFR 264.91(a)(4) requires institution of a detection monitoring program under 40 CFR 264.98 in all other cases. In order to achieve these regulatory objectives, supporting objectives (e.g., karst monitoring) must also be achieved in certain cases. Following is a description for each unit (ABG, ORR, and DR) of the regulatory and supporting objectives.

1.1.1 Ammunition Burning Ground

Compliance Monitoring [40 CFR 264.99]

Interim status ground water monitoring results have shown that hazardous constituents consisting of chlorinated organics, explosives, and metals have been detected in the ground water underlying the ABG. 40 CFR 264.92 requires the permit to contain conditions designed to ensure that hazardous constituents found in ground water do not exceed ground water protection standards established in the facility permit, beyond the compliance point. Compliance monitoring will be conducted to determine if the ground water protection standard is being met at the point of compliance.

Corrective Action Monitoring [40 CFR 264.100(d)]

NSWC Crane is conducting compliance monitoring to determine if the ground water protection standard is being exceeded at the point of compliance. Resampling under an approved QAP will establish a new background and plume delineation. Previous sampling quality assurance was not sufficient for risk assessment purposes. 40 CFR 264.91(a)(2) requires institution of a corrective action program under 40 CFR 264.100 whenever the ground water protection standard is exceeded. 40 CFR 264.91(a)(3) requires institution of a corrective action program whenever the ground water protection concentration limit is exceeded at wells between the point of compliance and the facility boundary. Exceeded is defined as statistically significant evidence of increased contamination. Results of the compliance monitoring at the point-of-compliance wells and the wells located beyond the point of compliance will be used to determine if corrective action is required. If corrective action is required, a permit modification to address corrective action will be submitted to the Regional Administrator.

Closure Monitoring [40 CFR 265.117(a)(1)]

Surface impoundments and a waste pile located at the ABG are undergoing closure and are subject to the post-closure care requirements of 40 CFR 265.117. During the post-closure period, ground water monitoring is required. The monitoring system will also serve to meet the requirements for closure monitoring.

Natural Attenuation Monitoring

Chlorinated organics and explosives have been detected in the ground water at the ABG. Preliminary evaluation of existing data indicates that natural attenuation of these compounds may be occurring. In

order to determine if natural attenuation is occurring, ground water will be monitored for chlorinated organics and explosives and their degradation products and indicator parameters. The information will be used to determine if natural attenuation is occurring and if contaminants have been attenuated below the ground water protection standard before reaching the facility boundary. If natural attenuation is occurring but contamination is above the ground water protection standard at the compliance point, a permit modification for a corrective action program meeting the requirements of 40 CFR 264.100 will be requested.

Karst Monitoring

Part of the ABG is underlain by a karst system. Studies have been conducted to determine the behavior of the karst system ground water flow patterns. The identification of the uppermost aquifer system and the number and locations of monitoring wells that meet the regulatory objectives described in 40 CFR 264 Subpart F were based on the results of studies of the karst system. Constituents, which are indicators of karst system behavior, will be monitored to determine if the karst system has changed. If changes occur in the karst system, the ground water monitoring system may have to be changed to meet the regulatory objectives in 40 CFR 264 Subpart F.

1.1.2 Old Rifle Range

Compliance Monitoring [40 CFR 264.99]

Interim status ground water monitoring results have shown that hazardous constituents consisting of explosives and metals have been detected in the ground water underlying the ORR. 40 CFR 264.92 requires the permit to contain conditions designed to ensure that hazardous constituents found in ground water do not exceed ground water protection standards established in the facility permit, beyond the compliance point. Compliance monitoring will be conducted at the ORR to determine if the ground water protection standard is being met at the point of compliance and at wells located beyond the point-of-compliance and the NSWC Crane boundary.

Corrective Action Monitoring [40 CFR 264.100(d)]

NSWC Crane is conducting compliance monitoring to determine if the ground water protection standard is being exceeded at the point of compliance. 40 CFR 264.91(a)(2) requires institution of a corrective action program under 40 CFR 264.100 whenever the ground water protection standard is exceeded. 40 CFR 264.91(a)(3) requires institution of a corrective action program whenever the ground water protection

concentration limit is exceeded at wells between the point of compliance and the facility boundary. Exceeded is defined as statistically significant evidence of increased contamination. Results of the compliance monitoring at the point-of-compliance wells and the wells located beyond the point of compliance will be used to determine if corrective action is required. If corrective action is required, a permit modification to address corrective action will be submitted to the Regional Administrator.

1.1.3 Demolition Range

Detection Monitoring [40 CFR 264.98]

Interim status ground water monitoring results have shown contamination in the active range area. However, contamination was not found at point-of-compliance ground water monitoring wells. Therefore, detection monitoring is triggered.

1.2 RECORDKEEPING [40 CFR 264.77(c) AND 264.97(j)]

NSWC Crane is required to keep records of all ground water monitoring data collected under 40 CFR 264 Subpart F. Records of ground water monitoring at the ABG, ORR, and DR will be maintained at NSWC Crane. All records related to ground water monitoring will be maintained at a central recordkeeping repository. Following is a description of the records that will be kept.

1.2.1 Field Records

Field records will include the following:

- Field notebooks
- Logbooks
- Chain-of-custody receipts
- Sample log sheets
- Sample forms
- Task modification requests
- Field analytical data
- Water levels
- Calibration Forms
- Sample Tags

1.2.2 Analytical Records

Analytical records will include the following:

- Analytical data (hardcopy and electronic)
- Data packages used for validation of laboratory data
- Data validation letters

1.2.3 Statistical Evaluation Records

Statistical evaluation records will include summaries of the analytical data and statistical analyses. Section 10.4 lists the information included in the Statistical Evaluation Record.

1.2.4 Reports

40 CFR Subpart F requires the preparation and submittal of various reports to the Regional Administrator. Specific reports are identified for each type of monitoring program [Detection Monitoring (40 CFR 264.98), Compliance Monitoring (40 CFR 264.99), and Corrective Action Program (40 CFR 264.100)]. Copies of each report will be kept in the recordkeeping repository located at NSWC Crane.

1.3 REPORTS [40 CFR 264.77(c)]

40 CFR 264 Subpart F requires the submission of various reports during the ground water monitoring program. Following, for each type of monitoring program, is a listing of the reports and descriptions of the conditions under which these reports will be prepared and submitted to the Regional Administrator.

1.3.1 Detection Monitoring Program Reports [40 CFR 264.98]

1.3.1.1 Notification of Statistical Exceedences in Detection Monitoring [40 CFR 264.98(g)(1)]

Detection monitoring is being conducted at the DR. Samples are taken semi-annually. Four rounds of data are available. Background will be established and thereafter, after each sampling round, statistical evaluations will be conducted. If there is statistically significant evidence of contamination for any chemical parameter or hazardous constituents, NSWC Crane will notify the Regional Administrator of this finding within 7 days of the receipt of the statistical evaluation report by NSWC Crane. The notification will state what chemical parameters or hazardous constituents have shown statistically significant evidence of contamination.

1.3.1.2 Application to Establish a Compliance Monitoring Program [40 CFR 264.98(g)(4)]

If statistically significant evidence of contamination is found during detection monitoring in compliance with 40 CFR 264.98(g)(2) and (3), the ground water must be sampled in all monitoring wells to determine whether constituents in the list of Appendix IX of Part 264 are present and, if so, at what concentration. For any Appendix IX compounds found, the analysis may be repeated in 1 month. If the analysis is repeated and the results of the second analysis confirm the initial results, then these constituents will form the basis for compliance monitoring. Alternatively, NSWC Crane may elect to have the hazardous constituents found in the initial Appendix IX monitoring serve as the basis for compliance monitoring. Within 90 days after discovery of statistically significant evidence of contamination, NSWC Crane will submit to the Regional Administrator an application for a permit modification to establish a compliance monitoring program meeting the requirements of 40 CFR 264.99. The permit modification application will include the following information:

- An identification of the concentration of any Appendix IX constituent detected in the ground water at each monitoring well at the compliance point [40 CFR 264.98(g)(4)(i)].

- Any proposed changes to the ground water monitoring system at the DR necessary to meet the requirements of 40 CFR 264.99 [40 CFR 264.98(g)(4)(ii)].

- Any proposed additions or changes to the monitoring frequency, sampling and analysis procedures or methods, or statistical methods used at the facility necessary to meet the requirements of 264.99 [40 CFR 264.98(g)(4)(iii)].

- For each hazardous constituent detected at the compliance point, a proposed concentration limit under 264.94(a)(1) or (2) or a notice of intent to seek an alternate concentration limit under 264.94(b) [40 CFR 264.98(g)(4)(iv)].

1.3.1.3 Alternate Concentration Limit /Corrective Action Program [40 CFR 264.98(g)(5)]

Within 180 days after discovery of statistically significant evidence of contamination, NSWC Crane will submit a report to the Regional Administrator containing the following:

- All data necessary to justify an alternate concentration limit sought under 264.94(b) [40 CFR 264.98(g)(5)(i)].

- An engineering feasibility plan for a corrective action program necessary to meet the requirements of 264.100 [40 CFR 264.98(g)(5)(ii)].

The engineering feasibility plan for corrective action will not be submitted under either of the following conditions:

- All hazardous constituents identified during the Appendix IX sampling are listed in Table 1 of 264.94 and their concentrations do not exceed the respective values given in the table [40 CFR 264.98(g)(5)(ii)(A)].

- NSWC Crane has sought an alternate concentration limit under 264.94(b) for every hazardous constituent identified [40 CFR 264.98(g)(2)].

1.3.1.4 Notification of Demonstration that Regulated Unit is not Source of Statistically Significant Differences [40 CFR 264.98(g)(6)(i)]

If statistically significant differences are not due to the DR, within 7 days after the discovery of statistically significant evidence of contamination, NSWC Crane will notify the Regional Administrator that a demonstration will be made that the contamination is not due to the DR.

1.3.1.5 Demonstration that Regulated Unit is Not Source of Statistically Significant Differences [40 CFR 264.98(g)(6)(ii)]

If statistically significant differences are not due to releases from the DR, within 90 days NSWC Crane will submit a report to the Regional Administrator. This report will demonstrate that a source other than the DR caused the contamination or that the contamination resulted from errors in sampling, analysis, or evaluation.

1.3.1.6 Application for Permit Modification to Detection Monitoring Program [40 CFR 264.98(g)(6)(iii) and 264.98(h)]

Within 90 days after the discovery of statistically significant evidence of contamination at the DR that is not due to the DR, NSWC Crane will submit to the Regional Administrator an application for a permit modification to make any appropriate changes to the detection monitoring program for the DR.

If NSWC Crane determines that the detection monitoring program at the DR no longer meets the ground water monitoring requirements in 40 CFR 264 Subpart F, then, within 90 days, NSWC Crane will submit an application for a permit modification to make any appropriate changes to the monitoring program.

1.3.2 Compliance Monitoring Program Reports [40 CFR 264.99]

1.3.2.1 Notification of Additional Hazardous Constituents [40 CFR 264.99(g)]

Compliance monitoring is being conducted at the ABG and ORR. The compliance monitoring program includes hazardous constituents identified during interim status monitoring. Annually, compliance monitoring wells at the ABG and ORR are analyzed for Appendix IX constituents. If these analyses show the presence of hazardous constituents in the ground water that are not already identified in the permit as monitoring requirements, the wells may be resampled within 1 month to confirm the presence of the hazardous constituents. If this is confirmed, NSWC Crane will report the concentrations of these additional hazardous constituents to the Regional Administrator within 7 days and add them to the compliance monitoring list. If NSWC Crane chooses not to resample, the Regional Administrator will be notified within 7 days and the parameter(s) will be added to the monitoring list.

1.3.2.2 Notification of Exceedence of Ground Water Protection Standard [40 CFR 264.99(h)(1)]

The permit contains concentrations limits for hazardous constituents including hazardous constituents detected in ground water at the ABG and ORR. If statistically significant evidence of increased contamination exists and any concentration limit is exceeded for any point-of-compliance well, NSWC Crane will notify the Regional Administrator and IDEM (for the closed units), in writing, within 7 days. The notification will state the concentration limits that have been exceeded after completion of the second confirmation analysis.

1.3.2.3 Request for Permit Modification for Corrective Action Program [40 CFR 264.99(h)(2)]

Within 180 days after the completion of the second analysis that confirms the exceedence of the ground water protection standard for one or more hazardous constituents at the point of compliance, NSWC Crane will submit to the Regional Administrator an application for a permit modification to establish a Corrective Action Program meeting the requirements of 40 CFR 264.100. If an engineering feasibility study was previously submitted under 40 CFR 264.98(h)(5), the application will be submitted within 90 days. The application will include, at a minimum, the following information:

- A detailed description of corrective actions that will achieve compliance with the ground water protection standard specified in the permit [40 CFR 264.99(h)(2)(i)].

- A plan for a ground water monitoring program that will demonstrate the effectiveness of corrective action [40 CFR 264.99(h)(2)(ii)].

1.3.2.4 Notification of Demonstration that Regulated Unit is Not Source of Exceedence at Point-of-Compliance Wells [40 CFR 264.99(i)(1)]

If contamination resulting in exceedences of the ground water protection standard are not suspected to be due to the regulated unit (ABG or ORR) NSWC Crane will notify the Regional Administrator within 7 days after the completion of the analysis that a demonstration will be made that the contamination is not due to the regulated unit.

1.3.2.5 Demonstration that Regulated Unit is Not Source of Exceedence at Point-of-Compliance Wells [40 CFR 264.99(i)(2)]

If exceedences of the ground water protection standards are suspected to not be due to the regulated unit (ABG or ORR), NSWC Crane will submit a report to the Regional Administrator in 90 days. This report will demonstrate that a source other than the regulated unit (ABG or ORR) caused the exceedence or that the apparent contamination resulted from errors in sampling, analysis, or evaluation.

1.3.2.6 Application for Permit Modification to Compliance Monitoring Program [40 CFR 264.99(i)(3) and (j)]

Within 90 days after the discovery of statistically significant evidence of contamination at the ABG or ORR that is not due to the ABG or ORR, NSWC will submit to the Regional Administrator an application for a permit modification to make any appropriate changes to the compliance monitoring program for the regulated unit (ABG or ORR).

If NSWC Crane determines that the compliance monitoring programs at the ABG or ORR no longer meet the ground water monitoring requirements in 40 CFR 264 Subpart F, NSWC Crane will submit an application for a permit modification to make any appropriate changes to the compliance monitoring program.

If NSWC Crane determines that compliance monitoring is no longer required (i.e., there are no longer any statistically significant increases above background or point-of-compliance wells), NSWC Crane may request a permit modification to enter into a detection monitoring program.

1.3.3 Corrective Action Program Reports [40 CFR 264.100]

1.3.3.1 Semi-Annual Report on Effectiveness of the Corrective Action Program [40 CFR 264.100(g)]

Hazardous constituents, including chlorinated solvents and explosives, have been found in ground water at the ABG. Natural attenuation has been proposed as the corrective action program. Semi-annually, a report will be made to the Regional Administrator of the effectiveness of this program.

1.3.3.2 Application for Permit Modification to Corrective Action Monitoring Program [40 CFR 264.100(h)]

Ground water, spring discharges of ground water, and surface water into which the springs discharge have been identified for corrective action monitoring. A list of constituents to be monitored has been identified. If NSWC Crane determines that the corrective action monitoring program no longer meets the requirements for corrective action monitoring, NSWC Crane will submit, within 90 days, an application for a permit modification to make any changes to the corrective action monitoring program.

1.3.4 Annual Ground Water Monitoring Report

NSWC Crane will prepare an annual ground water monitoring report. This report will include the following information for each of the units monitored (ABG, ORR, and DR):

- Ground water elevations to the nearest 0.01 ft for each monitoring well for each sampling event.
- Ground water flow contours for each aquifer monitored, for each unit, for each sampling event.
- A summary of ground water flow conditions for each unit, for each aquifer monitored at the unit.
- A description and explanation of any changes or new interpretations regarding background ground water quality for each unit, for each aquifer.
- An evaluation, analysis, and graphical presentation of any potential contaminant migration.

- An evaluation of the performance of all monitoring devices including detailed proposals of the actions that are needed to restore or establish monitoring effectiveness at a unit or at an individual monitoring point.

- Maps showing the ground water constituent concentrations, flow rate and direction for the uppermost aquifer monitored, including interconnected aquifers.

- Ground water monitoring analytical data for all monitoring points in a tabular form, including methods of analysis.

- Summaries of the analytical data and statistical analyses performed as described in Section 10.4.

1.4 COMPLIANCE PERIOD [40 CFR 264.96]

Hazardous constituents have been detected in the uppermost aquifer underlying the ABG and the ORR. In compliance with 40 CFR 264.92, a ground water protection standard has been established. The standard contains concentration limits for the hazardous constituents. Compliance monitoring is taking place at the ABG and ORR to ensure that the ground water protection standard is not exceeded beyond the point of compliance. Compliance monitoring will take place for the active life of the unit and the closure period. If corrective action is underway at the end of this period, the compliance period will be extended until NSWC Crane can demonstrate that the ground water protection standard has not been exceeded for a period of 3 consecutive years.

1.5 RCRA HAZARDOUS CONSTITUENTS [40 CFR 264.93]

The list of hazardous constituents in 40 CFR 261 Appendix VIII was evaluated to determine if the proposed RCRA Appendix IX analyses described in the approved QAPP included all hazardous constituents that were waste constituents or formed as the result of open burning/open detonation (OB/OD) treatment and potentially emitted. Appendix 1-1 contains a summary of the evaluation.

Information regarding waste constituents and potential emission products was obtained from the approved RCRA Air Quality Assessment at the Ammunition Burning Grounds, Old Rifle Range, and Demolition Ground (TtNUS, 1997). A list of compounds potentially emitted was developed. No Appendix VIII hazardous constituents containing metals were identified as waste constituents or emission products. Three hazardous constituents (2,4-dinitrotoluene, 2,6-dinitrotoluene, and nitroglycerine) were identified as

explosive waste constituents. All are analyzed in the routine explosive analyses conducted for each monitoring event at all three units. Twenty-seven Appendix VIII hazardous constituents were identified as emission products potentially formed during treatment. All of these compounds, except diethylhexyl phthalate, are included in the Appendix IX monitoring list in the approved QAPP. Diethylhexyl phthalate is not a constituent of munitions. It may be emitted at extremely low levels in OD treatments. Due to the extremely low potential for the compound to be present as the result of OD treatment, it was not added to the Appendix IX monitoring list. Table 1-1 lists the Appendix VIII compounds potentially emitted.

1.6 NATURAL ATTENUATION DEMONSTRATION

The ground water underlying the ABG has been contaminated by explosives, chlorinated solvents and metals. A preliminary evaluation of existing data for the ABG indicates that this site is a candidate for natural and/or enhanced attenuation. A review of the hydrogeology at the ABG shows that the primary ground water flow path from the ABG is down the valley of Little Sulphur Creek. The contaminated ground water is moving through the alluvium of Little Sulphur Creek, the fractured sandstone of the Big Clifty, and fractures and solution cavities of the Beech Creek limestone and emerging as surface water in springs and seeps downgradient of the ABG. An area of solution cavities in the Beech Creek limestone acts as a ground water drain to focus contaminated ground water down the valley of Little Sulphur Creek. Drilling shows that the solution cavities are found primarily in the valley of Little Sulphur Creek and were not found in the ground water divides along the valley. The dense Elwren shale underlying the Beech Creek limestone helps to restrict downward flow of ground water in the ABG area and focuses the flow of ground water down the Little Sulphur Creek. Dye tracer tests conducted by Waterways Experiment Station and Indiana University provide data indicating that a large portion of the ground water exiting the ABG emerges as surface flow from Spring A. Ground water also enters Little Sulphur Creek through seeps in the alluvium. The contaminated ground water is attenuated as it moves through the Big Clifty, Beech Creek, and alluvial materials. As the ground water enters the area of the solution cavities, dilution occurs as clean ground water flows in from the sides of the valley. As the ground water and surface water move toward the installation boundary, the contaminants have been reduced to very low concentrations. Natural attenuation is discussed in detail in Section 7.4.

1.7 GROUND WATER PROTECTION STANDARD [40 CFR 264.92]

Hazardous constituents have been found during interim status monitoring in ground water under the ABG and the ORR. 40 CFR 264.92 requires that hazardous constituents detected in ground water from a regulated unit must not exceed concentration limits established under 40 CFR 264.94 in the uppermost

TABLE 1-1

COMPARISON OF RCRA HAZARDOUS CONSTITUENTS (APPENDIX VIII) TREATED OR EMITTED TO APPENDIX IX AND CONSTITUENTS ANALYZED
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

HAZARDOUS CONSTITUENT	CAS NUMBER	RCRA CODE	CONSTITUENT	EMISSION	UNIT	APPENDIX IX ANALYTE	QAPP ANALYTE
Acetophenone	000098-86-2	U004	NO	YES	DR	YES	YES
Benz[a]anthracene	000056-55-3	U018	NO	YES	ABG ORR DR	YES	YES
Benzene	000071-43-2	U019	NO	YES	ABG ORR DR	YES	YES
Benzo[a]pyrene	000050-32-8	U022	NO	YES	ABG ORR DR	YES	YES
Chrysene	000218-01-9	U050	NO	YES	DR	YES	YES
Di-n-octyl phthalate	000117-84-0	U107	NO	YES	DR	YES	YES
Dibenz[a,h]anthracene	000053-70-3	U063	NO	YES	ABG ORR DR	YES	YES
Dibutyl phthalate	000084-74-2	U069	NO	YES	ABG ABG DR	YES	YES
Dichlorobenzene, p-	000106-46-7	U072	NO	YES	DR	YES	YES
Diethyl phthalate	000084-66-2	U088	NO	YES	ABG DR	YES	YES
Diethylhexyl phthalate	000117-81-7	U028	NO	YES	DR	YES	NO
Dimethyl phthalate	000131-11-3	U102	NO	YES	DR	YES	YES
alpha,alpha-dimethylphenethylamine	000122-09-8	P046	NO	YES	DR	YES	YES
2,4-Dinitrotoluene	000121-14-2	U105	YES	YES	ABG DR	YES	YES
2,6-Dinitrotoluene	000606-20-2	U106	YES	YES	ABG DR	YES	YES
Fluoranthene	000206-44-0	U120	NO	YES	DR	YES	YES
Hydrocyanic acid	000074-90-8	P063	NO	YES	ABG ORR DR	YES	YES
Hydrogen cyanide	000074-90-8	P063	NO	YES	ABG ORR DR	YES	YES
Naphthalene	000091-20-3	U165	NO	YES	ABG ORR DR	YES	YES
beta-Naphthylamine	000091-59-8	U168	NO	YES	ABG ORR	YES	YES
Nitroglycerin	000055-63-0	P081	YES	YES	ABG DR	YES	YES
4-Nitrophenol	000100-02-7	U170	NO	YES	DR	YES	YES
p-Nitrophenol	000100-02-7	U170	NO	YES	DR	YES	YES
n-Nitrosodiethylamine	000055-18-5	U174	NO	YES	DR	YES	YES
Phenol	000108-95-2	U188	NO	YES	ABG ORR DR	YES	YES
Toluene	000108-88-3	U220	YES	YES	DR	YES	YES
1,3,5-Trinitrobenzene	000099-35-4	U234	YES	YES	ABG ORR DR	YES	YES
Xylene (mixed isomers)	001330-20-7	U239	NO	YES	DR	YES	YES
m-Xylene	000108-38-3	U239	NO	YES	DR	YES	YES

aquifer underlying the waste management area beyond the point of compliance during the compliance period. 40 CFR 264.93 requires specification of the hazardous constituents to which the ground water protection standards apply. 40 CFR 264.94 contains requirements for establishment of concentration limits. Concentration limits must not exceed background [(40 CFR 264.94(a)(1)] or, if listed in Table 1 [(40 CFR 264.94(a)(2)], the concentration limits in the table. 40 CFR 264.94(b) allows the establishment of alternate limits.

Alternate concentration limits (risk-based target levels) have been established under 40 CFR 264.93(a) for all Appendix IX constituents. The following criteria were considered in determining the alternate concentration limits:

- Region 5 risk-based levels for protection of human health
- Region 5 ecological data quality levels
- IDEM health-based criteria
- Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCLs)
- Federal Ambient Water Quality Criteria

In some cases, the alternate concentration limit was not at the lowest of the listed criteria. Detailed information on the criteria considered in the establishment of the alternate concentration limits can be found in approved QAPP Section 1 and Appendix A.

For certain constituents, the alternate concentration limits are based on laboratory reporting limits for common laboratory methods. In all cases where laboratory reporting limits are used as alternate concentration limits, the constituent will not present a substantial potential hazard to human health or the environment as long as the alternate concentration limit is not exceeded. Table 1-2 lists the alternate concentration limits.

TABLE 1-2

ANALYTICAL METHODS, LABORATORY REPORTING LIMITS, AND ALTERNATE CONCENTRATION LIMITS
NAVAL SURFACE WARFARE CENTER
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Chemical	Laboratory RL[1] (ug/L)	Risk-Based Target Level[2] (ug/L)
EXPLOSIVES (SW-846 METHOD 8330)		
1,3,5-Trinitrobenzene	1.0	1.8
1,3-Dinitrobenzene	0.9	2.36
2,4,6-Trinitrotoluene (TNT)	1.6	2.2
2,4-Dinitrotoluene	1.2	60.8
2,6-Dinitrotoluene	2.0	37
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)	2.0	1800
2-Nitrotoluene	2.0	2.2
3-Nitrotoluene	2.0	370
4-Nitrotoluene	2.0	370
4-Amino-2,6-dinitrotoluene	1.6	--[3]
2-Amino-4,6-dinitrotoluene	0.9	--
Methyl-2,4,6-trinitrophenylnitramine (Tetryl)	1.2	370
Nitrobenzene	1.5	15.2
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	0.61[4]	0.61
Nitroglycerin	13	--
Pentaerythritol tetranitrate (PETN)	26	--
2,4-Diamino-6-nitrotoluene	10	--
2,6-Diamino-4-nitrotoluene	10	--
2,2',6,6'-Tetranitro-4,4'-azoxytoluene	10	--
3,5-Dinitroaniline	10	--
1,3,5-Trinitroso-1,3,5-hexahydrotriazine (TNX)	10	--
1-Nitroso-3,5-dinitro-1,3,5-hexahydrotriazine (MNX)	10	--
EXPLOSIVES (MODIFIED ARMY CORPS METHOD)		
Nitrocellulose	500	--
EXPLOSIVES (LAUCKS HPLC METHOD)		
Picric acid	0.6	--
Picramic acid	0.9	--
APPENDIX IX METALS (SW-846 METHOD 6020 ICP/MS, UNLESS OTHERWISE NOTED)		
Antimony	1.0	6
Arsenic	1.0	2
Barium	1.0	3.9
Beryllium	1.0	4
Cadmium	1.0	1.1
Chromium (total)	5.0	10
Cobalt	3.0	3
Copper	2.0	11
Lead	1.0	2.5
Mercury (SW-846 Method 7470A)	0.2	1.3
Nickel	10	100
Selenium	1.0	5
Silver	3.0	4.1
Thallium	1.0	2
Vanadium	2.0	19
Zinc	10	100
ADDITIONAL METALS (SW-846 METHOD 6010B ICP/AES)		
Calcium	1000	--
Iron	100	300
Magnesium	1000	--

TABLE 1-2

ANALYTICAL METHODS, LABORATORY REPORTING LIMITS, AND ALTERNATE CONCENTRATION LIMITS
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA
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Chemical	Laboratory RL[1] (ug/L)	Risk-Based Target Level[2] (ug/L)
Manganese	15	50
Potassium	1000	--
Sodium	1000	--
APPENDIX IX VOLATILE ORGANIC COMPOUNDS (SW-846 METHOD 8260B WITH 25 ML PURGE)		
1,1,1-Trichloroethane	0.5	88
1,1,1,2-Tetrachloroethane	0.5	5
1,1,2,2-Tetrachloroethane	0.5	5
1,1,2-Trichloroethane	0.5	5
1,2,3-Trichloropropane	1[4]	12.11
1,2,3-Trichlorobenzene	0.5	--
1,1-Dichloroethane	0.5	47
1,1-Dichloroethene	0.5	0.5
1,1-Dichloropropylene	0.5	--
1,2-Dibromo-3-chloropropane	1	1
1,2-Dibromoethane	0.5	1
1,2-Dichloroethane	0.5	1
1,2-Dichloropropane	0.5	380
1,3-Dichloropropane	0.5	--
2,2-Dichloropropane	0.5	--
2-Butanone	10	917.72
2-Chloro-1,3-butadiene (chloroprene)	3	14
2-Hexanone	10	--
4-Methyl-2-pentanone	10	1520
Acetone	10	610
Acrolein	10*	4
Acrylonitrile	3	3.7
Allyl chloride (3-chloro-1-propene)	10	1800
Benzene	0.5	5
Bromochloromethane	0.5	--
Bromodichloromethane	0.5	100
Bromoform	0.5	8.5
Bromomethane	1[4]	8.7
Carbon disulfide	0.5	21
Carbon tetrachloride	0.3[4]*	0.17
Chlorobenzene	0.5	10
Chloroethane	0.5	710
Chloroform	0.3*	0.16
Chloromethane	0.5	1.5
cis-1,2-Dichloroethene	0.5	61
cis-1,3-Dichloropropene	0.3[4]*	0.081
Dibromochloromethane	0.5	1
Dibromomethane	0.5	370
Dichlorodifluoromethane	0.5	390
Ethylbenzene	0.5	17.2
Ethyl methacrylate	1	550
Methacrylonitrile	1	1
Methylene chloride	3	4.3
Methyl iodide	0.5	--

TABLE 1-2

ANALYTICAL METHODS, LABORATORY REPORTING LIMITS, AND ALTERNATE CONCENTRATION LIMITS
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Chemical	Laboratory RL[1] (ug/L)	Risk-Based Target Level[2] (ug/L)
Methyl methacrylate	2	2800
Styrene	0.5	56
Tetrachloroethene	0.5	1.1
Toluene	0.5	253
trans-1,2-Dichloroethene	0.5	100
trans-1,3-Dichloropropene	0.5	0.5
trans-1,4-Dichloro-2-butene	10	10
Trichloroethene	0.5	1.6
Trichlorofluoromethane	0.5	1300
Vinyl acetate	0.5	248.03
Vinyl chloride	0.5	2
Total Xylenes	1	1.8
APPENDIX IX VOLATILE ORGANIC COMPOUNDS (SW-846 METHOD 8015B WITH 10 ML PURGE)		
1,4-Dioxane (SW-846 Method 8015B)	500*	2
Acetonitrile (SW-846 Method 8015B)	40	220
Isobutyl alcohol (SW-846 Method 8015B)	40	11000
Propionitrile (SW-846 Method 8015B)	40	6080
APPENDIX IX SEMIVOLATILE ORGANIC COMPOUNDS (SW-846 METHOD 8270C; 8270C SIM WHERE NOTED)		
1,2,4,5-Tetrachlorobenzene	10	10
1,2,4-Trichlorobenzene	2	70
1,2-Dichlorobenzene	2	14
1,3-Dichlorobenzene	2	71
1,4-Dichlorobenzene	2	5
1,4-Naphthoquinone	10	10
1,4-Phenylenediamine	100	6900
1-Naphthylamine	36*	10
2,3,4,6-Tetrachlorophenol	25*	14.06
2,4,5-Trichlorophenol	5	63
2,4,6-Trichlorophenol	3*	2
2,4-Dichlorophenol	3	18
2,4-Dimethylphenol	5	166.9
2,4-Dinitrophenol	10	10
2,6-Dichlorophenol	5	--
2-Acetylaminofluorene	12	14.86
2-Chloronaphthalene	2*	1
2-Chlorophenol	3*	2
2-Methylnaphthalene by SIM	0.04	9.15
2-Methylphenol	2	1520
2-Naphthylamine	16	--
2-Nitroaniline	2	2.2
2-Nitrophenol	5	13.5
2-Picoline	20	3790
3,3'-Dichlorobenzidine	10	10
3,3'-Dimethylbenzidine	50*	10
3-Methylcholanthrene	12	400
3-, 4-Methylphenol[3]	4	1800
3-Nitroaniline	2	--
4,6-Dinitro-2-methylphenol	10	10
4-Aminobiphenyl	12	--

TABLE 1-2

ANALYTICAL METHODS, LABORATORY REPORTING LIMITS, AND ALTERNATE CONCENTRATION LIMITS
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Chemical	Laboratory RL[1] (ug/L)	Risk-Based Target Level[2] (ug/L)
4-Bromophenyl phenyl ether	2	2
4-Chloro-3-methylphenol	2	34.79
4-Chloroaniline	2	121.6
4-Chlorophenyl phenyl ether	1	1
4-Nitroaniline	2	--
4-Nitrophenol	10	35
4-Nitroquinoline-1-oxide	100	--
5-Nitro-o-toluidine	16	--
7,12-Dimethylbenz(a)anthracene	10[4]	10
Acenaphthene by SIM	0.02	23
Acenaphthylene by SIM	0.04	1
Acetophenone	20	687.89
Aniline	5	5
Aramite	10	10
Anthracene by SIM	0.04	5
Benz(a)anthracene by SIM	0.04	1
Benzo(a)pyrene by SIM	0.04	1
Benzo(b)fluoranthene by SIM	0.04	1
Benzo(g,h,i)perylene by SIM	0.04	1
Benzo(k)fluoranthene by SIM	0.04	1
Benzyl alcohol	10	281.24
Bis(2-chloroethoxy)methane	5	6400
Bis(2-chloroethyl)ether	1[4]	1
Bis(2-chloroisopropyl)ether	3	3
Bis(2-ethylhexyl) phthalate	2	4.8
Butyl benzyl phthalate	2	19
Chlorobenzilate	5[4]*	2.5
Chrysene by SIM	0.04	1
Diallate	10	10
Di-n-butyl phthalate	2	3
Di-n-octyl phthalate	2	30
Dibenz(a,h)anthracene by SIM	0.04	1
Dibenzofuran	1	13.52
Diethyl phthalate	2	220
Dimethoate	10[4]	10
p-(Dimethylamino)azobenzene	15	--
a,a-Dimethylphenethylamine	50	--
Dimethyl phthalate	2	73
Diphenylamine[6]	10	10
Disulfoton	16[4]*	0.3
Ethyl methane sulfonate	16	--
Ethyl parathion	15	--
Famphur	10	--
Fluoranthene by SIM	0.04	8.1
Fluorene by SIM	0.04	10
Hexachlorobenzene	2	2

TABLE 1-2

ANALYTICAL METHODS, LABORATORY REPORTING LIMITS, AND ALTERNATE CONCENTRATION LIMITS
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Chemical	Laboratory RL[1] (ug/L)	Risk-Based Target Level[2] (ug/L)
Hexachlorobutadiene	1[4]	1
Hexachlorocyclopentadiene	2	2
Hexachloroethane	2	4.8
Hexachlorophene	100*	11
Hexachloropropene	20	20
Indeno(1,2,3-cd)pyrene by SIM	0.02	1
Isodrin	10	10
Isophorone	1	71
Isosafrole	20	--
Kepone	25*	0.7
Methapyrilene	40	--
Methyl methane sulfonate	16	--
Methyl parathion	10*	9.1
n-Nitrosodi-n-butylamine	10	10
n-Nitrosodiethylamine	10	10
n-Nitrosodimethylamine	10	10
n-Nitrosodi-n-propylamine	2	2
n-Nitrosomethyethylamine	10	10
n-Nitrosomorpholine	10[4]	10
n-Nitrosopiperidine	10	10
n-Nitrosopyrrolidine	10	10
Naphthalene by SIM	0.04	24
Pentachlorobenzene	10	10
Pentachloroethane	10	14.39
Pentachloronitrobenzene	10	10
Pentachlorophenol	10	10
Phenacetin	10	10
Phenanthrene by SIM	0.04	1
Phenol	5	100
Phorate	10[4]*	3.62
Pronamide	12	160
Pyrene by SIM	0.04	1
Pyridine	10	37
Safrole	20	40
Tetraethyl dithiopyrophosphate (Sulfotepp)	10	10
Thionazin	100	--
o-Toluidine	15	--
O,O,O-Triethyl phosphorothioate	10	10
APPENDIX IX ORGANOCHLORINE PESTICIDES and PCBs (SW-846 METHOD 8081)		
Aldrin	0.01	0.01
Alpha-BHC	0.01	0.01
Alpha-chlordane	0.03	0.03
Beta-BHC	0.03	0.037
4,4'-DDD	0.05	0.05
4,4'-DDE	0.05*	0.01
4,4'-DDT	0.05*	0.01
Delta-BHC	0.05	666.67
Dieldrin	0.02	0.02
Endosulfan I	0.05	0.051

TABLE 1-2

ANALYTICAL METHODS, LABORATORY REPORTING LIMITS, AND ALTERNATE CONCENTRATION LIMITS
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA
PAGE 6 OF 7

Chemical	Laboratory RL[1] (ug/L)	Risk-Based Target Level[2] (ug/L)
Endosulfan II	0.05	0.051
Endosulfan sulfate	0.05	0.05
Endrin	0.06	0.06
Endrin aldehyde	0.05	0.05
Gamma-BHC (Lindane)	0.05	0.052
Gamma-chlordane	0.03	0.03
Heptachlor	0.03	0.03
Heptachlor epoxide	0.01	0.01
Methoxychlor	0.12*	0.05
Toxaphene	3.0*	2.4
Aroclor-1016	0.5	0.5
Aroclor-1221	0.5	0.5
Aroclor-1232	0.5	0.5
Aroclor-1242	0.5[4]	0.5
Aroclor-1248	0.5	0.5
Aroclor-1254	0.5	0.5
Aroclor-1260	0.5	0.5
APPENDIX IX HERBICIDES (SW-846 METHOD 8151A)		
2,4-D	0.2	70
2,4,5-T	0.2	370
2,4,5-TP (Silvex)	0.2	50
Dinoseb	0.2	0.39
DIOXINS/FURANS (SW-846 METHOD 8290)		
2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD)	1E-5*	4.5E-6
1,2,3,7,8-Pentachlorodibenzo-p-dioxin (1,2,3,7,8-PeCDD)	5E-5*	9E-6[7]
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin (1,2,3,6,7,8-HxCDD)	5E-5*	4.5E-5[7]
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin (1,2,3,4,7,8-HxCDD)	5E-5*	4.5E-5[7]
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin (1,2,3,7,8,9-HxCDD)	5E-5*	4.5E-5[7]
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin (1,2,3,4,6,7,8-HpCDD)	5E-5	4.5E-4[7]
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (1,2,3,4,6,7,8,9-OCDD	1E-4	4.5E-3[7]
2,3,7,8-Tetrachlorodibenzofuran (2,3,7,8-TCDF)	1E-5	4.5E-5[7]
1,2,3,7,8-Pentachlorodibenzofuran (1,2,3,7,8-PeCDF)	5E-5	9E-5[7]
2,3,4,7,8-Pentachlorodibenzofuran (2,3,4,7,8-PeCDF)	5E-5*	9E-6[7]
1,2,3,6,7,8-Hexachlorodibenzofuran (1,2,3,6,7,8-HxCDF)	5E-5*	4.5E-5[7]
1,2,3,7,8,9-Hexachlorodibenzofuran (1,2,3,7,8,9-HxCDF)	5E-5*	4.5E-5[7]
1,2,3,4,7,8-Hexachlorodibenzofuran (1,2,3,4,7,8-HxCDF)	5E-5*	4.5E-5[7]
2,3,4,6,7,8-Hexachlorodibenzofuran (2,3,4,6,7,8-HxCDF)	5E-5*	4.5E-5[7]
1,2,3,4,6,7,8-Heptachlorodibenzofuran (1,2,3,4,6,7,8-HpCDF)	5E-5	4.5E-4[7]
1,2,3,4,7,8,9-Heptachlorodibenzofuran (1,2,3,4,7,8,9-HpCDF)	5E-5	4.5E-4[7]
1,2,3,4,6,7,8,9-Octachlorodibenzofuran (1,2,3,4,6,7,8,9-OCDF)	1E-4	4.5E-3[7]
Total Tetrachlorodibenzo-p-dioxin (Total TCDD)	1E-5	NA
Total Pentachlorodibenzo-p-dioxin (Total PeCDD)	5E-5	NA
Total Hexachlorodibenzo-p-dioxin (Total HxCDD)	5E-5	NA
Total Heptachlorodibenzo-p-dioxin (Total HpCDD)	5E-5	NA
Total Tetrachlorodibenzofuran (Total TCDF)	1E-5	NA
Total Pentachlorodibenzofuran (Total PeCDF)	5E-5	NA

TABLE 1-2

ANALYTICAL METHODS, LABORATORY REPORTING LIMITS, AND ALTERNATE CONCENTRATION LIMITS
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA
PAGE 7 OF 7

Chemical	Laboratory RL[1] (ug/L)	Risk-Based Target Level[2] (ug/L)
Total Hexachlorodibenzofuran (Total HxCDF)	5E-5	NA
Total Heptachlorodibenzofuran (Total HpCDF)	5E-5	NA
MISCELLANEOUS PARAMETERS		
Ammonia (EPA 600 Series Method 350.1)	10	--
Chloride (SW-846 Method 9056)	1000	--
Cyanide (SW-846 Method 9012A)	10	10
Dissolved Methane (Microseeps, Inc., Method AM18)	0.015	5[9]
Nitrate (SW-846 Method 9056)	200	58000
Nitrite (SW-846 Method 9056)	100	1000
Phosphorus (Total and Dissolved) (EPA Method 365.2)	100	--
Sulfate (SW-846 Method 9056)	1000	--
Sulfide (SW-846 Method 9034)	1000	--
Total Organic Carbon (TOC) (SW-846 Method 9060)	1000	--
Total Organic Halides (TOX) (SW-846 Method 9020B)	20	--

ug/L micrograms per liter

* Asterisks indicate those chemicals for which the laboratory reporting limit (RL) exceeds the risk-based target level for the project.

1 Method detection limits (MDLs) (all parameters except metals), instrument detection limits (IDLs) (metals only), and RLs as provided by Laucks Testing Laboratories, Inc., Triangle Laboratories, Inc. (dioxins/furans only), and Microseeps, Inc. (dissolved methane only). These values may change throughout the course of the ground water monitoring program as laboratory MDLs and IDLs are updated.

2 Developed using U.S. EPA Region 5 support. Value is based on human health or ecological risk-based criteria or practical quantitation limits (PQLs) for common laboratory analytical methods.

3 Risk-based target level is not provided, since human and ecological risk-based criteria are not available for this chemical.

4 Laucks Testing Laboratories is confident that it can reliably report to this PQL, even though this value is less than two times the MDL.

5 3-Methylphenol and 4-methylphenol coelute. Therefore, one analytical result for 3-, 4-methylphenol will be reported.

6 N-Nitrosodiphenylamine is more toxic than diphenylamine. However, n-nitrosodiphenylamine rapidly degrades to diphenylamine. Therefore, only diphenylamine will be reported, but results for diphenylamine will be treated as n-nitrosodiphenylanine during risk assessment.

7 The target level is calculated using the target level for 2,3,7,8-TCDD and the toxicity equivalent factor (TEF) presented in current U.S. EPA guidance (U.S. EPA, March 1989).

8 Not applicable.

9 The target level for dissolved methane is not a risk-based value, but instead represents the target reporting level for dissolved methane based on its use in evaluating the natural attenuation of TCE.

2.0 INTERIM STATUS GROUND WATER MONITORING DATA [40 CFR 270.14(c)(1)]

This section contains an overview of interim status ground water monitoring data.

Analytical data for environmental media, including ground water, have been obtained from site investigations since the early 1980s. The analytical database consists of three distinct sampling programs:

- Validated historical data
- Halliburton NUS Corporation (HNUS) 1995-1996 supplemental sampling data
- HNUS 1997 supplemental sampling data

VALIDATED HISTORICAL DATA

Environmental media (soil, sediment, surface water, spring water, and ground water) have been sampled since the early 1980s at the ABG, ORR, and DR. Historical ground water monitoring data are available for the ABG for sampling taking place beginning in October 1987. For the ORR ground water monitoring, data are available for sampling taking place since January 1985. For the DR ground water monitoring, data are available for sampling taking place since July 1982.

As part of a risk assessment conducted in support of the permitting of ABG, ORR, and DR, U.S. EPA Region 5 conducted a data quality review of historical environmental media data, including interim status ground water monitoring data (U.S. EPA, 1997). As a result of this review, much of the historical database was found not to be acceptable for use in risk assessments. It was concluded that not all the historical data had undergone a data validation effort of sufficient rigor to produce results that met the minimum data usability standards for risk assessment purposes. Data not meeting usability standards for risk assessment purposes have also been determined not to be usable for 40 CFR 264 Subpart F purposes.

Appendix 2-1 contains a report summarizing historical analytical data for environmental media at the ABG, ORR, and DR. Data meeting usability standards are identified. Appendix 2-2 contains a listing of usable historical environmental media data, including ground water data for the ABG, ORR, and DR.

HNUS 1995-1996 SUPPLEMENTAL SAMPLING DATA

In 1994, in preparation for a risk assessment, historical environmental media data for the ABG, ORR, and DR were reviewed to identify data gaps. This review took place before issues regarding acceptability of historical data had been identified. Therefore, data gaps were identified on the assumption that all historical data were acceptable. These supplemental data, including ground water data, were collected and are summarized in Appendix 2-3.

HNUS 1997 SUPPLEMENTAL SAMPLING DATA

Subsequent to the U.S. EPA data validation technical memorandum (U.S. EPA, 1997), a second round of supplemental data was collected to again "fill in data gaps." Data gaps were identified based on usable historical data and the 1995-1996 supplemental sampling data. These data are listed in Appendix 2-4.

Site investigation data for the ABG, ORR, and DR were summarized in the Current Contamination Risk Assessment (Brown & Root Environmental, 1997). Section 4.2 of the risk assessment contains a summary of usable historical and supplemental environmental media sampling data for the ABG, ORR, and DR. Included in this summary are ground water data. Appendix 2-5 contains a copy of the summary, including relevant tables and figures.

3.0 GENERAL HYDROGEOLOGICAL INFORMATION [40 CFR 270.14(c)(2)]

General hydrogeologic information was obtained from the following documents prepared by the Army Corps of Engineers Waterways Experiment Station (WES), that may be referenced for additional details:

- Draft Report, RCRA Facility Investigation, Phase II Ground Water Release Assessment, SWMU 06/09, Demolition Range and Phase III Release Characterization, SWMU 07/09, Old Rifle Range (Murphy and Wade, 1994).

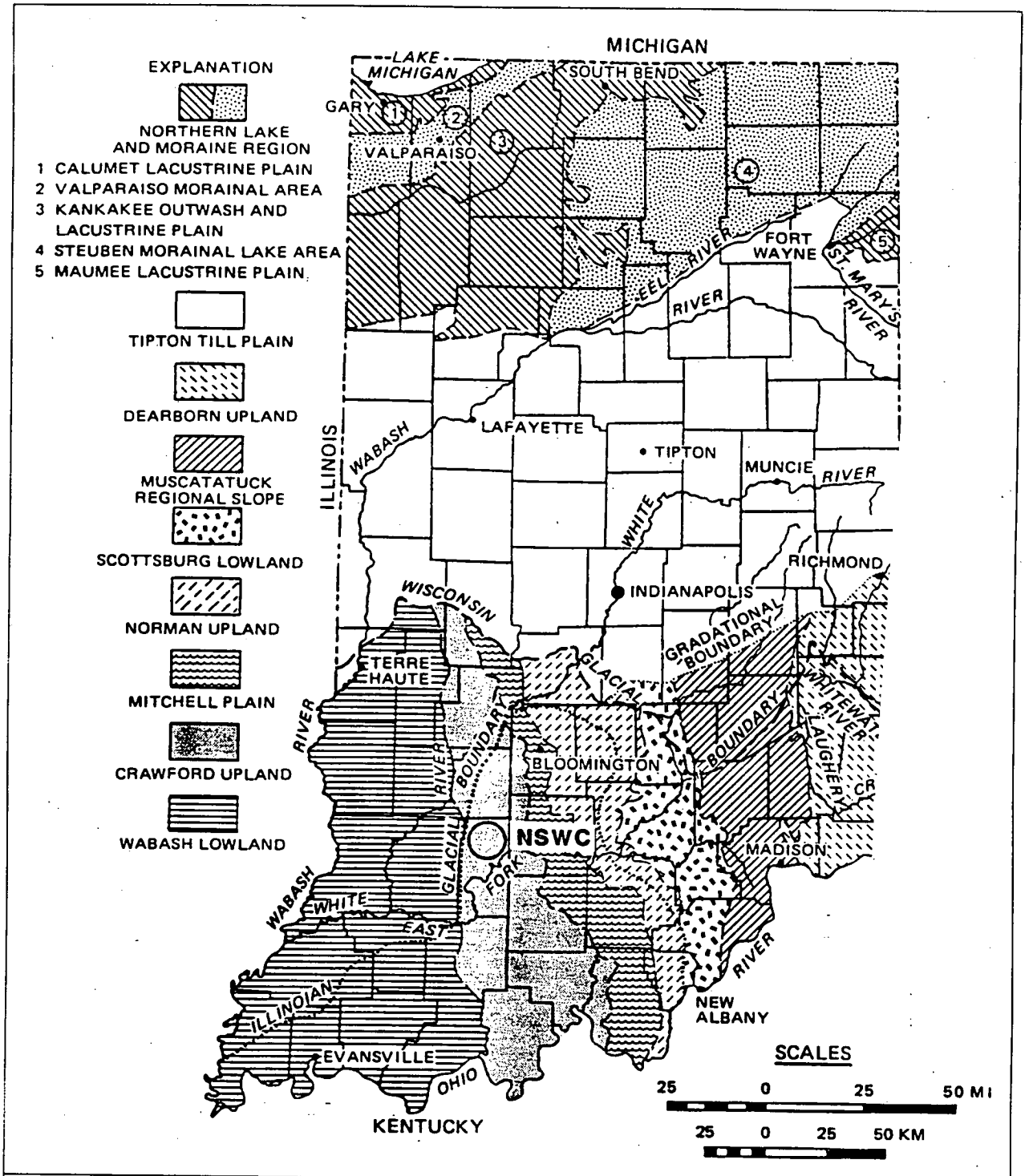
- Final Report, RCRA Facility Investigation, Phase III Ground Water Release Characterization, SWMU 03/10, Ammunition Burning Ground (Murphy, 1994).

- Draft Report, RCRA Facility Investigation Area (Phase II Ground Water Release Assessment, SWMU 06/09, Demolition and Phase III Release Characterization, SWMU 07/09, Old Rife Range (Murphy and Wade, 1995).

3.1 PHYSIOGRAPHY

3.1.1 Regional Physiography

The physiographic divisions of the state of Indiana, the limits of Pleistocene glaciation, and the location of NSWC Crane are shown in Figure 3-1. NSWC Crane lies in an unglaciated area of the Crawford Upland, a rugged, dissected plateau bounded on the east by the Mitchell Plain and on the west by the Wabash Lowland. The Mitchell Plain is a low, dissected limestone plateau characterized by sinkhole topography and other karst features. The boundary between the Crawford Upland and the Mitchell Plain is known as the Chester Escarpment, a highly irregular, eastward-facing cuesta. The escarpment trends northwest-southeast and passes just east of NSWC Crane. Numerous springs, cavern passages, and caves occur along the Chester Escarpment and in the eastern part of the Crawford Upland. Some of these solution features are found in the eastern portion of NSWC Crane. The Crawford Upland grades into the Wabash Lowland near the western NSWG Crane boundary. Elevations on the Crawford Upland at NSWC Crane range from less than 500 ft National Geodetic Vertical Datum (NGVD) to greater than 850 ft NGVD. Relief on the upland varies from about 100 ft to 350 ft, with higher elevations and greater relief occurring generally in the eastern part of NSWC Crane. Surface drainage in the upland is to the south and southwest.



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 8 by William L. Murphy and Roy Wade

Figure 3-1

Physiographic Divisions of Indiana (Source: Perry and Smith, 1958; cited in Murphy and Wade, 1995) Naval Surface Warfare Center Crane, Indiana

The surface drainage along major streams in Indiana is shown in Figure 3-2. With the exception of the extreme northeastern corner of Indiana, all the surface drainage is to the southwest and south. Approximately two-thirds of the state drains into the Wabash River, which in turn empties into the Ohio River. Surface drainage at NSWC Crane eventually flows into the White River and then to the Wabash to the southwest. The major drainage at NSWC Crane is divided into five basins, as shown in Figure 3-3. The DR/ORR sites are located in Basin IV near the confluence of Boggs and Turkey Creeks.

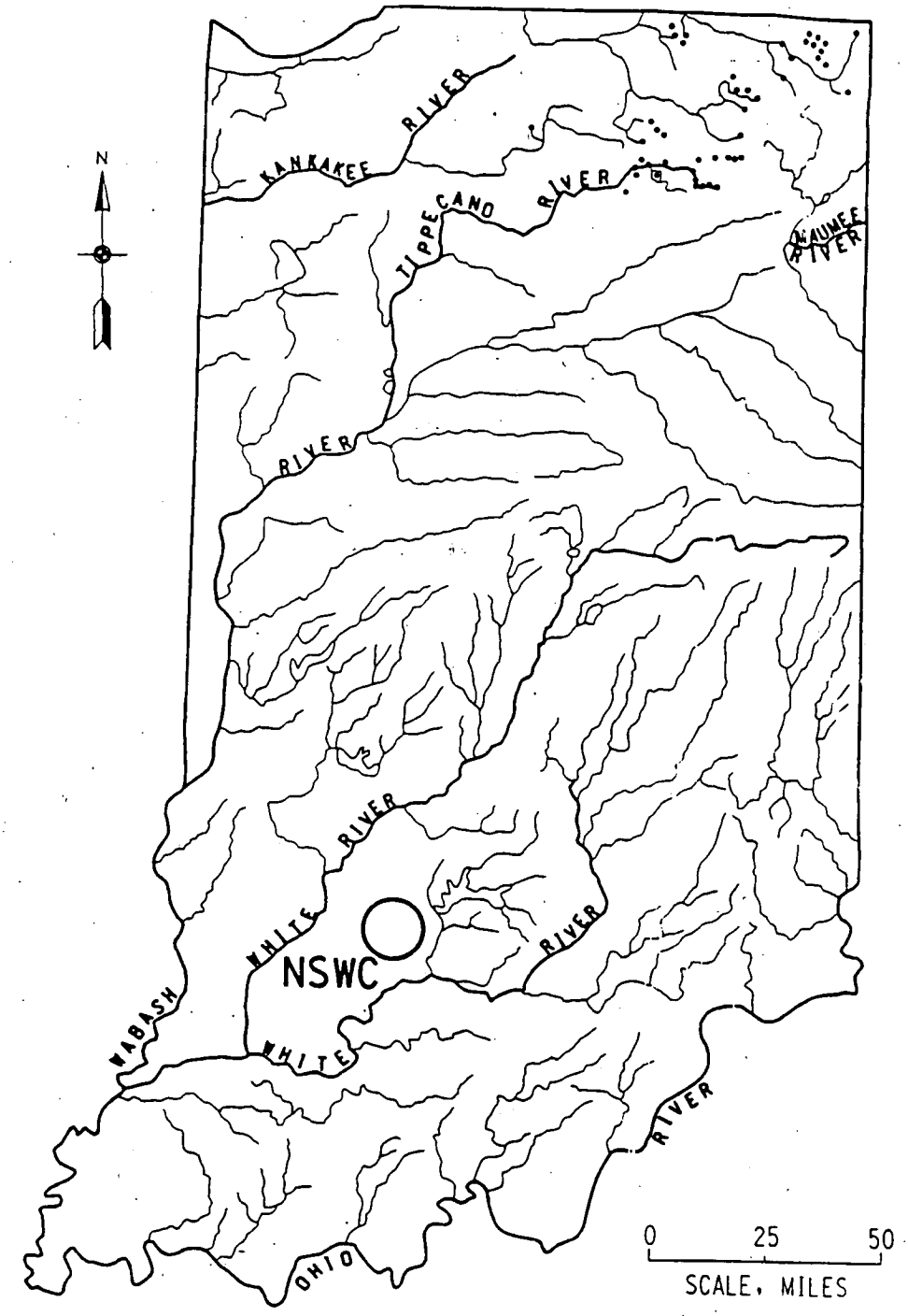
Ground water in the unglaciated southwestern portion of Indiana in general is contained in joint openings of limestone and sandstone aquifers. In the area of the Crawford Upland (Figure 3-1), aquifers are essentially isolated from each other vertically by interlayered shale units, which act as aquicludes. Ground water enters the aquifers through outcrops and flows by gravity down the dip of the strata or locally in directions controlled by the piezometric gradient.

3.1.2 Physiography of the Ammunition Burning Grounds

The ABG is approximately 2,000 ft long by 1,000 ft wide and is situated in the northern reaches of the valley of Little Sulphur Creek. A major drainage divide extends from the southwest to the northeast along NSWC Crane Road 161. Ground surface elevations in the area range from about 480 ft NGVD in the southeast to 845 ft along the major drainage divide. The topography is rugged and the terrain heavily vegetated. East of the divide, approximately two-thirds of the area drains to the south and southeast through Little Sulphur and Sulphur Creek. Ultimate drainage is to Indian Creek, the White River, and then to the Wabash, generally southwestward.

The ABG is in a bowl that opens to the southeast, high on the northwest, northeast, and south and low in the middle where Little Sulphur Creek has incised its valley. Table 3-1 presents the horizontal and vertical survey data for the wells at the ABG. The well locations are correct relative to each other and have been tied to topography. However, the base (topographic) map features (e.g., roads, buildings) are not tied to state plane coordinates. Appendix A plates 2 and 3 show the topography of the ABG study area.

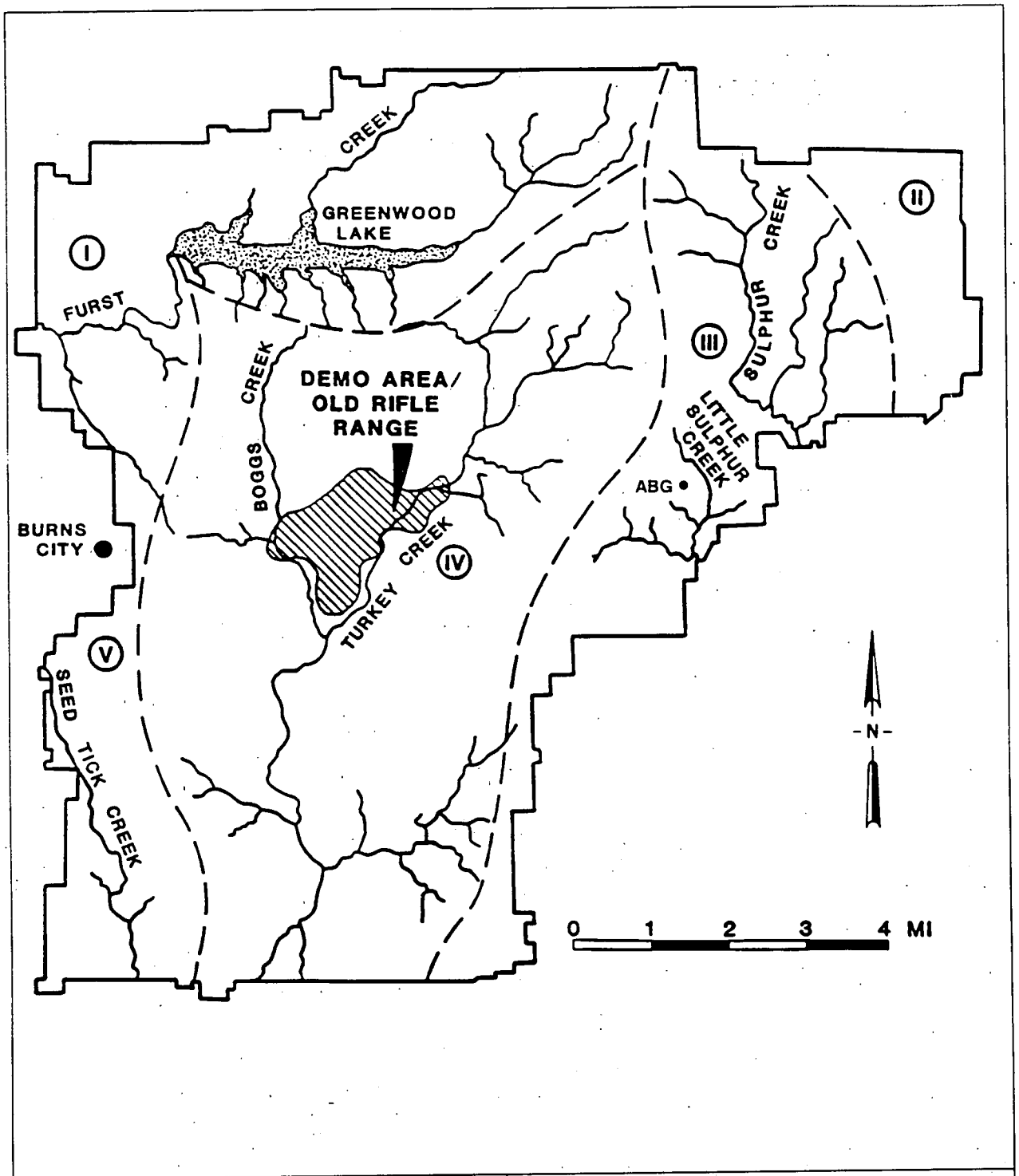
A subset of these wells is used in the long-term ground water monitoring program. These wells have been resurveyed. The new survey data for these wells are presented in Table 3-1 of the approved FSP.



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 9 by William L. Murphy and Roy Wade

Figure 3-2

Surface Drainage in Indiana (Source: Academy of Science, 1966 Cited in Murphy and Wade, 1995) Naval Surface Warfare Center Crane, Indiana



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 10 by William L. Murphy and Roy Wade

Figure 3-3

Water Basins at Naval Surface Warfare Center (Source: Murphy and Wade, 1995) Naval Surface Warfare Center Crane, Indiana

TABLE 3-1

SURVEY DATA FOR AMMUNITION BURNING GROUNDS
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA
PAGE 1 OF 3

Well Number	North Coord, ft	East Coord, ft	TOC Elevation ft NGVD
03-01	490.748	593.688	604.67
03-02	489.940	593.060	622.67
03-03	489.838	594.843	584.29
03-04	498.791	594.610	594.17
03-05	N/A	N/A	595.75
03-06	489.796	594.636	589.71
03-07	487.838	596.316	556.46
03-08	N/A	N/A	586.76
03-09	489.909	593.047	624.72
03-10	487.821	596.515	557.94
03-11	487.709	596.435	553.05
03-12	487.765	596.232	557.99
03-13	487.634	596.377	552.24
03-14	487.673	596.420	552.37
03-15	487.899	596.369	559.09
03-16	488.568	595.788	571.61
03-17	487.650	596.265	553.44
03-18	487.508	596.208	552.80
03-19	N/A	N/A	559.37
03-20	487.674	596.120	554.83
03-21	488.044	596.243	560.12
03-22	487.820	596.405	558.72
03-23	487.933	596.069	562.34
03-24	488.012	596.462	589.04
03-25	487.902	596.498	573.64
03-26	N/A	N/A	595.89
03-27	489.964	593.967	599.08
03-28	489.705	594.006	627.49
03-29	489.992	593.981	598.61
03-30	490.818	593.630	608.60
03-31	498.788	594.804	582.84
03-32	489.857	594.822	583.54
03-33	498.923	594.836	583.39
03-34	489.844	594.662	585.06
03-35	489.830	594.561	586.60

Source: Final Report, RCRA Facility Investigation, Phase III, Groundwater Release Characterization, SWMU 03/10. Ammunition Burning Ground, Volume 1
May 1994 - Table 5
by William L. Murphy

TABLE 3-1

SURVEY DATA FOR AMMUNITION BURNING GROUNDS
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA
PAGE 2 OF 3

Well Number	North Coord. ft	East Coord. ft	TOC Elevation ft NGVD
03-36	489,691	594,603	617.54
03-37	489,890	594,618	586.52
03-38	490,676	593,744	604.74
03-39	490,700	593,792	603.25
03B01	482,590	595,584	504.47
03B02	482,573	595,506	503.96
03B03	482,578	595,406	504.96
03B04	482,631	595,293	506.47
03B05	482,623	595,192	507.05
03B06	482,666	594,960	509.26
03B07	482,672	594,768	510.72
03B08	482,667	594,594	513.40
03B09	482,657	594,417	516.04
03B10	482,607	594,209	561.96
03C01	490,064	593,140	627.28
03C01P2	490,068	593,146	626.85
03C01P3	490,061	593,147	626.50
03C02	489,931	594,793	583.47
03C02P2	489,932	594,798	583.15
03C03	490,203	594,055	600.08
03C03P2	490,208	594,056	599.72
03C04	490,620	594,783	624.42
03C05	489,782	595,114	581.36
03C06	489,581	594,596	625.40
03C07	490,423	594,371	636.47
03C08A	489,680	594,051	630.50
03C08AP2	489,701	594,014	629.34
03C08AP3	489,685	594,047	630.43
03C09	490,615	593,777	603.39
03C09P2	490,619	593,776	603.56
03C10	490,243	593,657	608.03
03C11	490,025	594,441	592.36
03C12	489,957	594,574	587.20
03C13	490,901	593,860	617.75
03C14	489,932	593,575	642.79

Source: Final Report, RCRA Facility Investigation, Phase III, Groundwater Release Characterization, SWMU 03/10. Ammunition Burning Ground, Volume 1
May 1994 - Table 5
by William L. Murphy

TABLE 3-1

SURVEY DATA FOR AMMUNITION BURNING GROUNDS
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA
PAGE 3 OF 3

Well Number	North Coord, ft	East Coord, ft	TOC Elevation ft NGVD
03C15	489,849	593,146	621.34
03C15P3	489,855	593,143	621.11
03C16	490,478	593,362	683.25
03C17	492,764	594,371	696.15
03C18	489,992	592,967	625.09
03C19	491,442	593,351	650.50
03C19P3	491,431	593,354	649.70
03C20	489,880	593,773	646.62
03C21	489,925	593,356	642.22
03C21P2	489,925	593,361	642.22
03C22	490,090	593,319	617.58
03C23	490,259	593,462	618.61
03C24	485,159	592,615	553.24
03C25	487,148	592,606	597.03
03C26	490,695	594,134	640.57
03C27	489,658	594,767	603.84
03C28	489,884	595,269	612.96
03C29	488,529	591,095	797.37
03C30	488,967	592,403	778.91
03C31	488,492	593,743	792.10
03C32	491,056	594,471	711.56
03C33	486,651	594,224	785.03
03C34	487,870	599,301	727.07
03C35	485,347	598,082	697.00
03C36	485,203	599,202	718.74
03C37	483,933	596,471	620.28
03C38	485,309	595,951	572.97

Source: Final Report, RCRA Facility Investigation, Phase III, Groundwater Release Characterization, SWMU 03/10. Ammunition Burning Ground, Volume 1
May 1994 - Table 5
by William L. Murphy

3.1.3 Physiography of the Demolition Range

The DR occupies the crest of a north-south-trending topographic ridge bounded on the east by the southward-flowing Turkey Creek, on the west by the southward-flowing Boggs Creek, and on the south by the confluence of the two creeks. The ridge is 500 to 1,000 ft wide at its crest and slopes steeply to the east, south, and west at approximately a 23-percent grade. Maximum elevation on the ridge crest at the DR is approximately 685 ft NGVD. The peripheral NSWC Crane Roads 333 and 8 follow the base of the ridge at an elevation of about 500 ft NGVD. The minimum elevation in Turkey and Boggs Creeks is about 475 ft NGVD. Maximum topographic relief at the site is approximately 210 ft.

The DR active zone is surface drained by four gullies, two of which drain to the southwest and two to the east. All four drainageways now discharge into sediment retention ponds near the foot of the slope. Other drainages exist farther up the ridge, north of the active zone, but all surface runoff is ultimately to Boggs or Turkey Creeks. Boggs and Turkey Creeks, which are permanent streams, become Boggs Creek at their confluence at the base of the DR ridge. Boggs Creek flows to the south and discharges into the White River approximately 5 miles south of the NSWC Crane boundary.

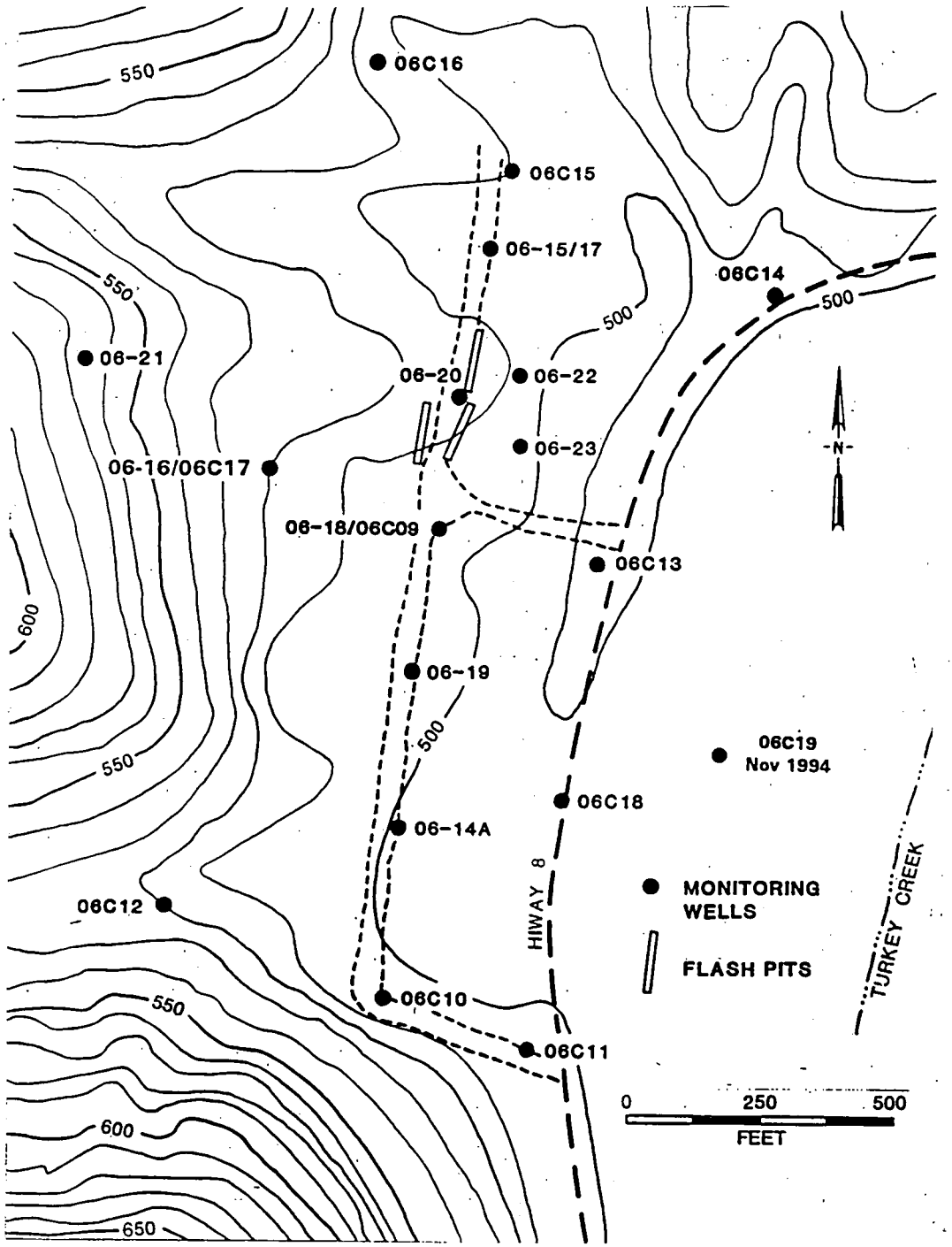
3.1.4 Physiography of the Old Rifle Range

The ORR extends from the foot of the ridge below the DR 1,200 to 1,500 ft east to NSWC Crane Road 8 (Figure 3-4). Maximum elevation within the Old Rifle Range is about 530 ft NGVD at the base of the ridge, and the minimum elevation is about 500 ft NGVD near the road, for a total relief of about 30 ft. The area east of the ORR continues to slope toward Turkey Creek, where the minimum elevation is approximately 485 ft NGVD. The mean slope from the western side of the ORR to Turkey Creek is about 2 percent. The northern end of the ORR is drained by a perennial stream that flows southeast and east into Turkey Creek.

3.2 SURFACE WATER

3.2.1 Surface Water at the Demolition Range and Old Rifle Range

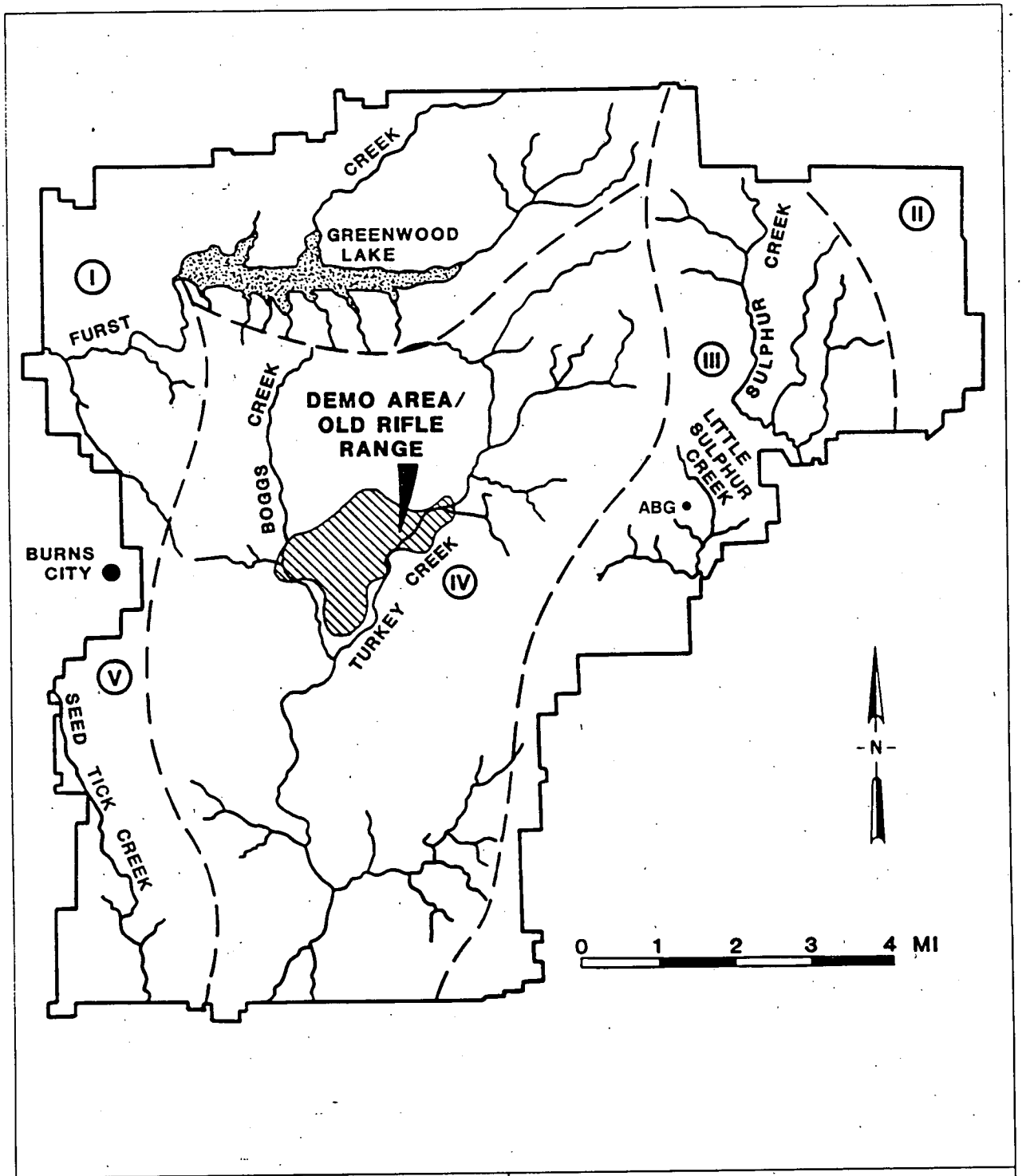
The surface drainage at NSWC Crane has formed a dense, dendritic pattern throughout the installation that flows in a general southward or southwestward direction. Seven creeks in five drainage basins carry surface water off the installation, where it eventually drains into the East Fork of the White River. Figure 3-5 shows the basins and drainages of NSWC Crane. Drainage Basin IV consists of Boggs and Turkey Creeks, which are the primary drainageways for the installation and drain the majority of the area. The northern and northwestern sections (Basin I) are drained by Furst Creek, the eastern portion (Basin III) is



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 4 by William L. Murphy and Roy Wade

Figure 3-4

Locations of Wells and Cluster Wells at Old Rifle Range (Source: Murphy and Wade, 1995) Naval Surface Warfare Center Crane, Indiana



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range Volume 2: Appendices A-H January 1994 - Figure 3 by William L. Murphy and Roy Wade

Figure 3-5

Surface Drainage at the Naval Surface Warfare Center (Source: Murphy and Wade, January 1994) Naval Surface Warfare Center Crane, Indiana

drained by the Sulphur Creek Complex, the extreme eastern portion (Basin II) is drained by Indiana Creek, and the southwestern section (Basin V) is drained by Seed Tick Creek. Also located within the installation are several small ponds and Lake Greenwood, an 800-acre, spring-fed lake in the northwestern portion of the installation.

3.2.2 Surface Water at the Ammunition Burning Grounds

Surface water enters the Big Clifty sandstone outcrop area from two sources within the ABG. [One source is rainfall and the other is two tributary streams that flow into the ABG from the west and the northwest and form the headwaters of Little Sulphur Creek.] These branches join at the ABG but sink into the ground a short distance from the ABG. The tributary flow is derived from ground water in sandstones and possibly from coal seams in the higher Pennsylvanian strata and from seeps from the Golconda/Haney limestone. The flow is primarily down the Little Sulphur Creek drainageway and secondarily down through the Johnson Hollow drainageway, with a low ground water divide separating the two discharge areas along a line running approximately from well 03C26 to well 03C14. Johnson Hollow is an intermittent drainage with recharge occurring from the Beech Creek aquifer. A revised solution zone map was constructed following the acquisition of a new round of ground water elevation data. The revised solution zone map is presented in Figure 3-5a. The map shows cumulative void thickness in affected borings and is contoured on a 2-ft interval (0- to 8-ft contours). Voids include zones of joints widened by solution of the limestone as well as open cavities. The greatest cumulative void thickness was 8 ft, occurring in wells 03C02P2, 03C12, and 03-03. The solution zone elongated to the northwest toward boring 03C07. Figure 3-5a was inferred from a cumulative 1 ft of solution voids in the boring. The voids map provides a more detailed delineation of solutioning beneath the ABG but is still limited (biased) by the distribution of existing borings. The flow then continues out the eastern end of the site and southward down Little Sulphur Creek. During dry seasons and in light to moderate rains, all the surface water in the tributary streams becomes ground water in the Beech Creek aquifer through the Big Clifty sandstone outcrop area within the ABG. During periods of heavier rainfall, the runoff flows out the eastern end of the site as surface flow.

3.3 GEOLOGY AND STRATIGRAPHY

3.3.1 General Geology and Stratigraphy

The United States Department of Agriculture (USDA) identifies three-fourths of Martin County, which contains the major portion of NSWC Crane, as belonging to the Zanesville and Muskingum soil series. These series are identified as a dark brown, organic silt loam at the surface, underlain by 48 inches of mottled tan, gray, and yellow clay with varying percentages of sand and silt. Occasionally, a clay hardpan

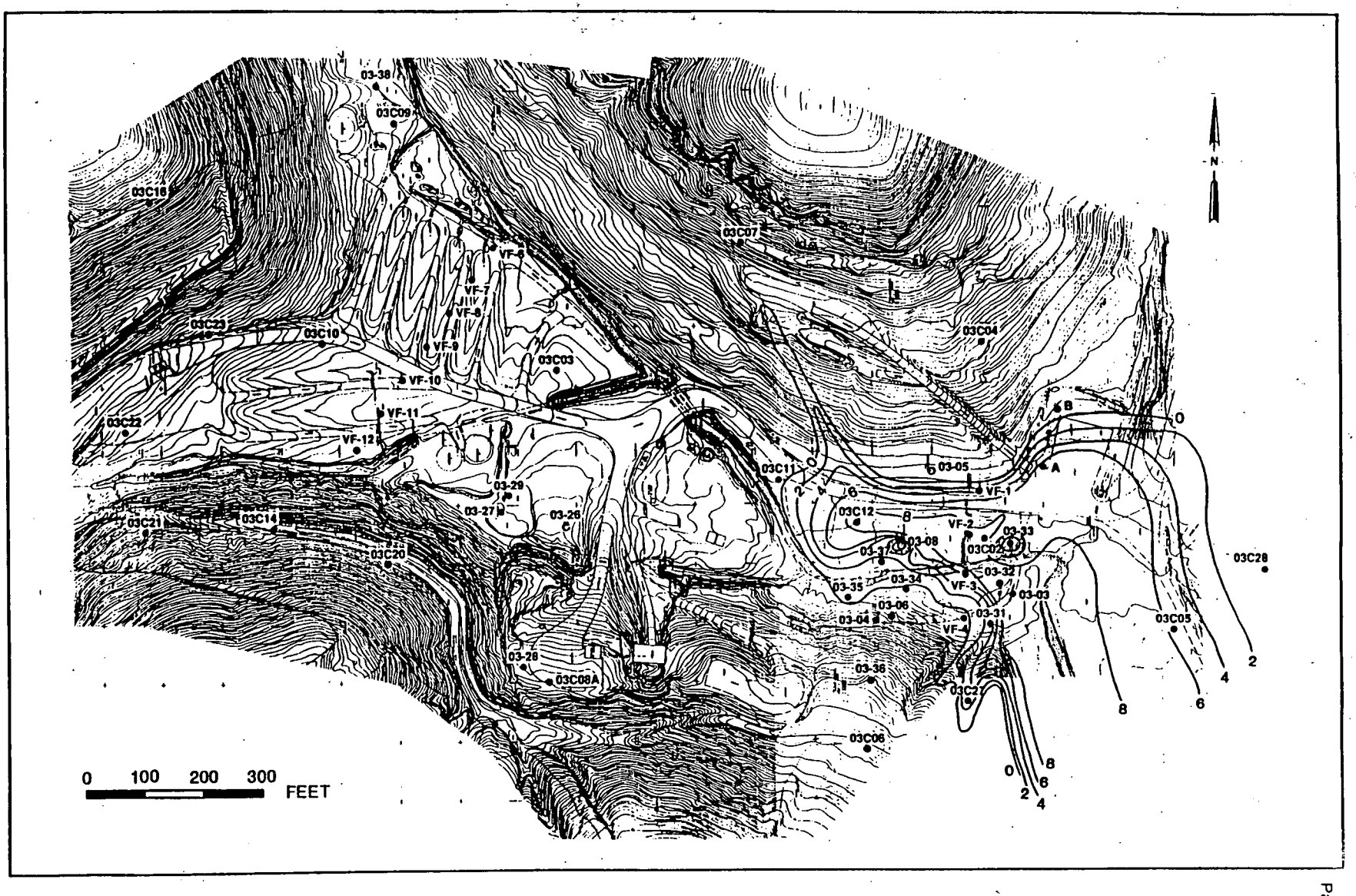


Figure 3-5a Cumulative thickness of solution widened openings in Beech Creek limestone, Ammunition Burning Ground

occurs between 25 and 32 inches below surface. Waterways Experiment Station (WES) borings encountered soil thickness at the NSWC Crane from less than 1 ft to an excess of 40 ft. These borings identified a surficial organic layer underlain by clay, silt, or sand.

NSWC Crane lies in a region of Indiana that was not covered by Pleistocene glacial deposits. The surface deposits are divided into two types: unconsolidated deposits of Recent and Pleistocene age and residual soils formed from the underlying rock. Recent and Pleistocene deposits occur in the many small floodplains throughout NSWC Crane and are composed of alluvial, colluvial, and paludal silt, sand, and gravel and lacustrine clay, silt, and sand. Residual soils at NSWC Crane were derived from the underlying sedimentary rocks of the lower Pennsylvanian Raccoon Creek Group and the upper Mississippian Stephensport and West Baden Groups. These soils are clay, silt, and sand. Lower Pennsylvanian rock at NSWC Crane consists of shale, sandstone, and coal beds, and upper Mississippian rock consists of limestone, shale, and sandstone. Since NSWC Crane lies on the eastern edge of the Illinois Structural Basin, the Pennsylvanian and Mississippian sedimentary rocks dip west-southwestward between 30 and 35 feet per mile into the basin. Figure 3-6 presents the stratigraphic column of units underlying NSWC Crane. Figure 3-7 shows the distribution of these units at the installation.

3.3.1.1 Surface and Near-Surface Geology

The surface exposure (with soil overburden disregarded) of mappable geologic units at NSWC Crane was provided in a map constructed by Erik Kvale, of the Indiana Geological Survey (Kvale, 1992). A field reconnaissance of outcrops within NSWC Crane, which included the vicinity of the DR/ORR, was conducted to map the geologic units. Recognizable formation contacts and formation exposures were plotted on the Indian Springs, Indiana, 7-1/2 minute topographic quadrangle.[1] Figure 3-7A shows the extent of the Golconda/Haney Formation beneath the DR.

The reconnaissance showed that the Quaternary alluvium is characterized by graded sequences of thin gravels that are typically well rounded and that fine upwards to silty loams. The Quaternary sequences generally correspond to the Haymond or Wakeland silt loams of the USDA soils map for Martin County.

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[1] The map portion is presented as Plate 2 in the Draft Report, RCRA Facility Investigation, Phase II Ground Water Release Assessment, SWMU 06/09 Demolition Range and Phase II Release Characterization SWMU 07/09 Old Rifle Range Navel Surface Warfare Center Crane, Indiana, Volume I, William L. Murphy and Roy Wade, November 1995 (Murphy and Wade, 1995).

COLUMNAR SECTION SHOWING BEDROCK UNITS

TIME UNIT: PERIOD	TIME UNIT: EPOCH	MAP UNIT	THICKNESS (FEET)	LITHOLOGY	ROCK UNIT *: SIGNIFICANT MEMBER	ROCK UNIT *: FORMATION		ROCK UNIT *: GROUP
PENNSYLVANIAN	CONEMAUGHIAN	P_5	175+		MEROM Ss.	MATTOON Fm.	MATTOON Fm. (FORMATIONS MAPPED IN ILLINOIS)	MCLEANSBORO
		P_4	150 to 200		LIVINGSTON Ls. / SHOAL CREEK Ls.	BOND Fm.	BOND Fm.	
		P_3 WF	200 to 350		WEST FRANKLIN Ls.	*PATOKA Fm.* / SHELBURN Fm.	MODESTO Fm.	
	ALLEGHENIAN	P_2 V	300 to 400		DANVILLE COAL (VII)	DUGGER Fm.		CARBONDALE
					SPRINGFIELD COAL (V)	PETERSBURG Fm.		
					SURVANT COAL (IV)	LINTON Fm.		
		B	250 to 500		SEELYVILLE COAL (III)	STAUNTON Fm.		*RACCOON CREEK*
	POTTSVILLIAN	P_1			BUFFALOVILLE COAL / LOWER BLOCK COAL	BRAZIL Fm.		
						MANSFIELD Fm.		

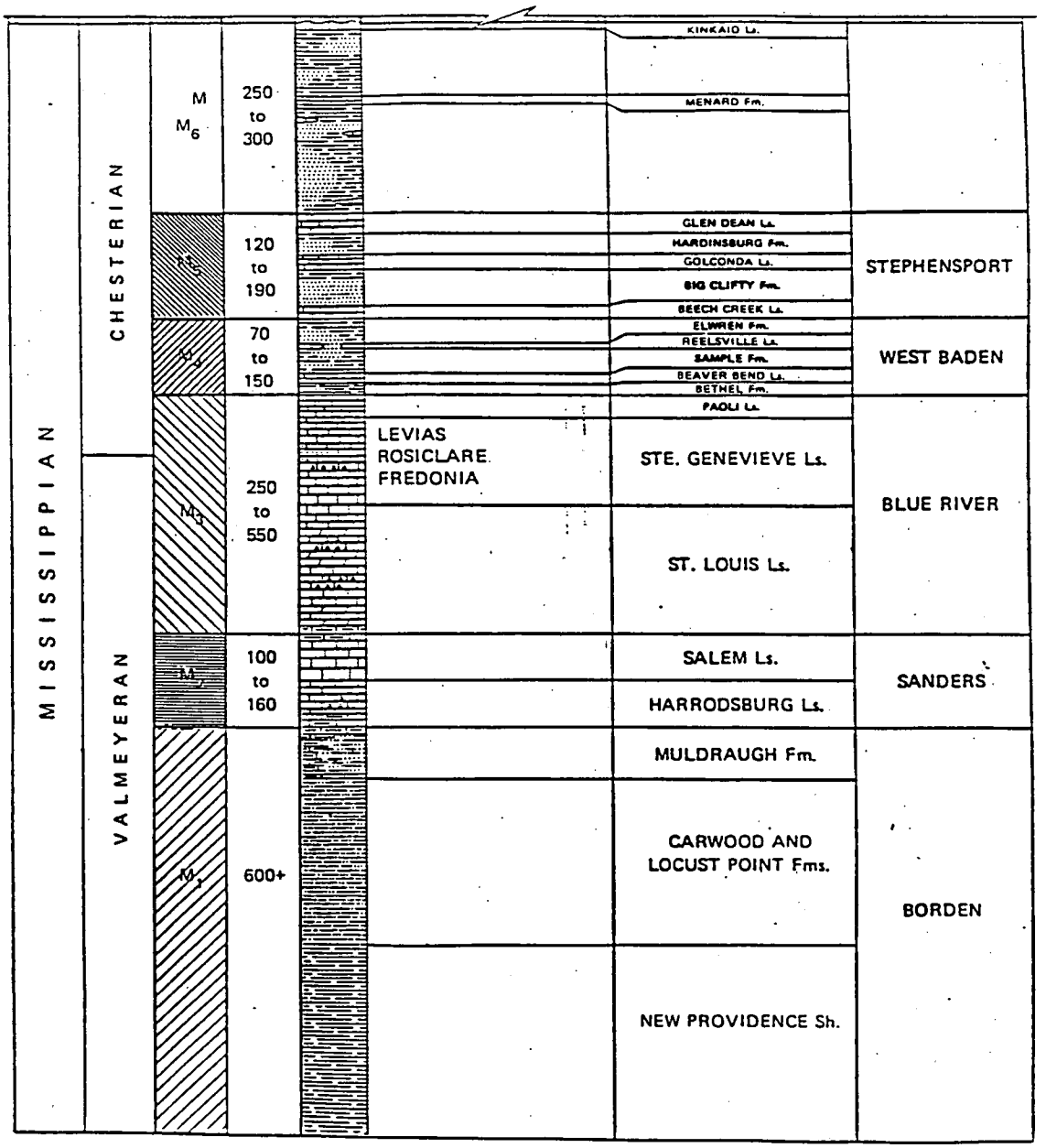
* ROCK-UNIT NAMES FOR PENNYSLVANIAN ROCKS IN INDIANA FOLLOW THE USAGE PROPOSED BY WIER (IN PREPARATION), STRATIGRAPHY OF MIDDLE AND UPPER PENNSYLVANIAN ROCKS IN SOUTHWESTERN INDIANA. NEW NAMES ARE SHOWN IN ITALICS AND ARE TENTATIVE UNTIL FORMAL PRESENTATION.
(After Grey, Wayne, and Wier)

Source: Draft Report, RCRA Facility Investigation
Phase II Groundwater Release Assessment, SWMU 06/09
Demolition Area and Phase III Release
Characterization SWMU 07/09 Old Rifle Range
Volume 2: Appendices A-H
January 1994 - Table 1
by William L. Murphy and Roy Wade

Figure 3-6

Stratigraphy of Naval Weapons Support Center
(Source: Murphy and Wade, January 1994)
Naval Surface Warfare Center
Crane, Indiana
Page 1 of 2

COLUMNAR SECTION SHOWING BEDROCK UNITS (CONT.)

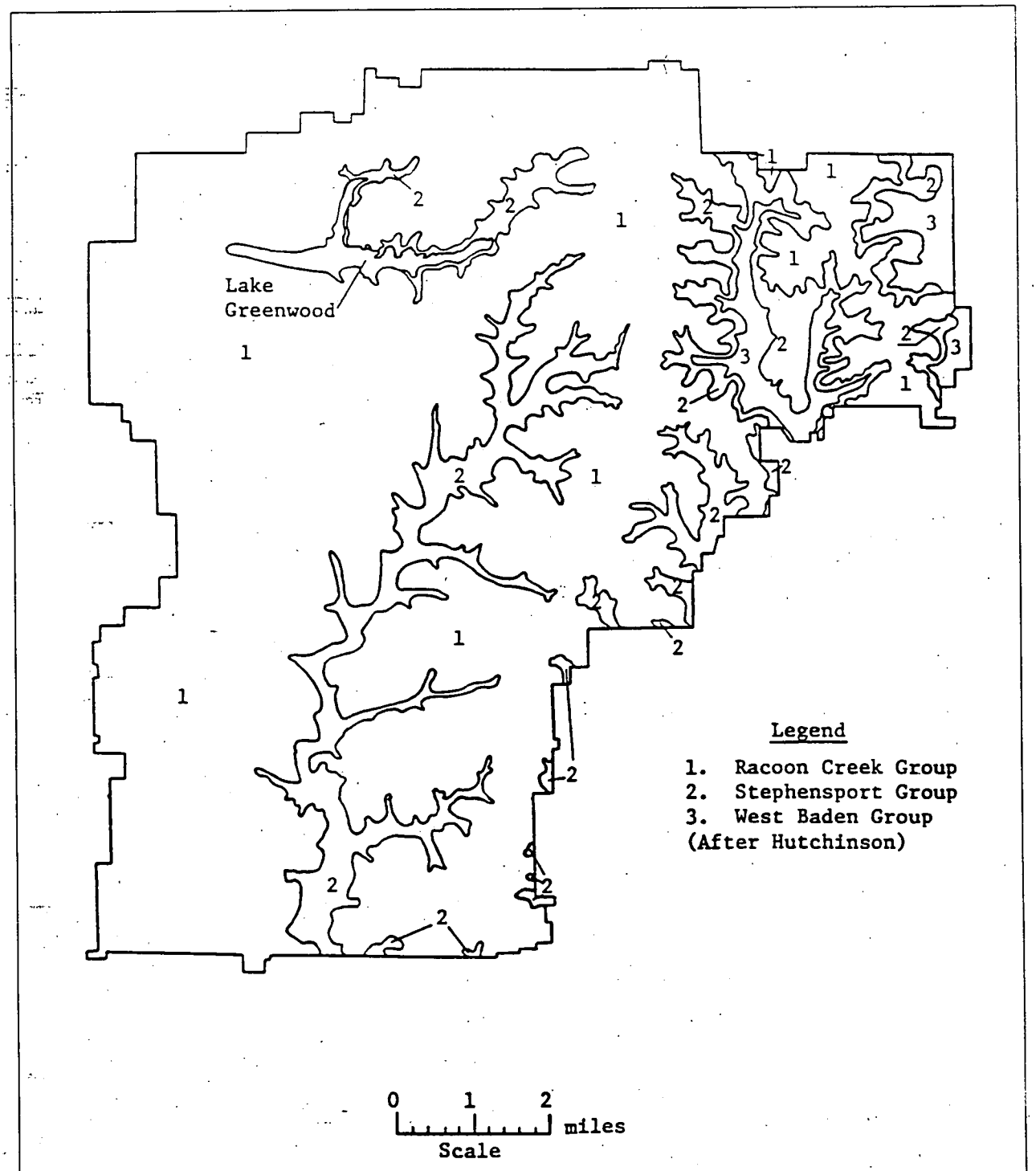


* ROCK-UNIT NAMES FOR PENNSYLVANIAN ROCKS IN INDIANA FOLLOW THE USAGE PROPOSED BY WIER (IN PREPARATION), STRATIGRAPHY OF MIDDLE AND UPPER PENNSYLVANIAN ROCKS IN SOUTHWESTERN INDIANA. NEW NAMES ARE SHOWN IN ITALICS AND ARE TENTATIVE UNTIL FORMAL PRESENTATION.

Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range Volume 2: Appendices A-H January 1994 - Table 1 by William L. Murphy and Roy Wade

Figure 3-6

Stratigraphy of Naval Weapons Support Center (Source: Murphy and Wade, January 1994) Naval Surface Warfare Center Crane, Indiana Page 2 of 2



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range Volume 2: Appendices A-H January 1994 - Figure 2 by William L. Murphy and Roy Wade

Figure 3-7

Distribution of Geological Groups at the Naval Weapons Support Center (Source: Murphy and Wade, January 1994) Naval Surface Warfare Center Crane, Indiana

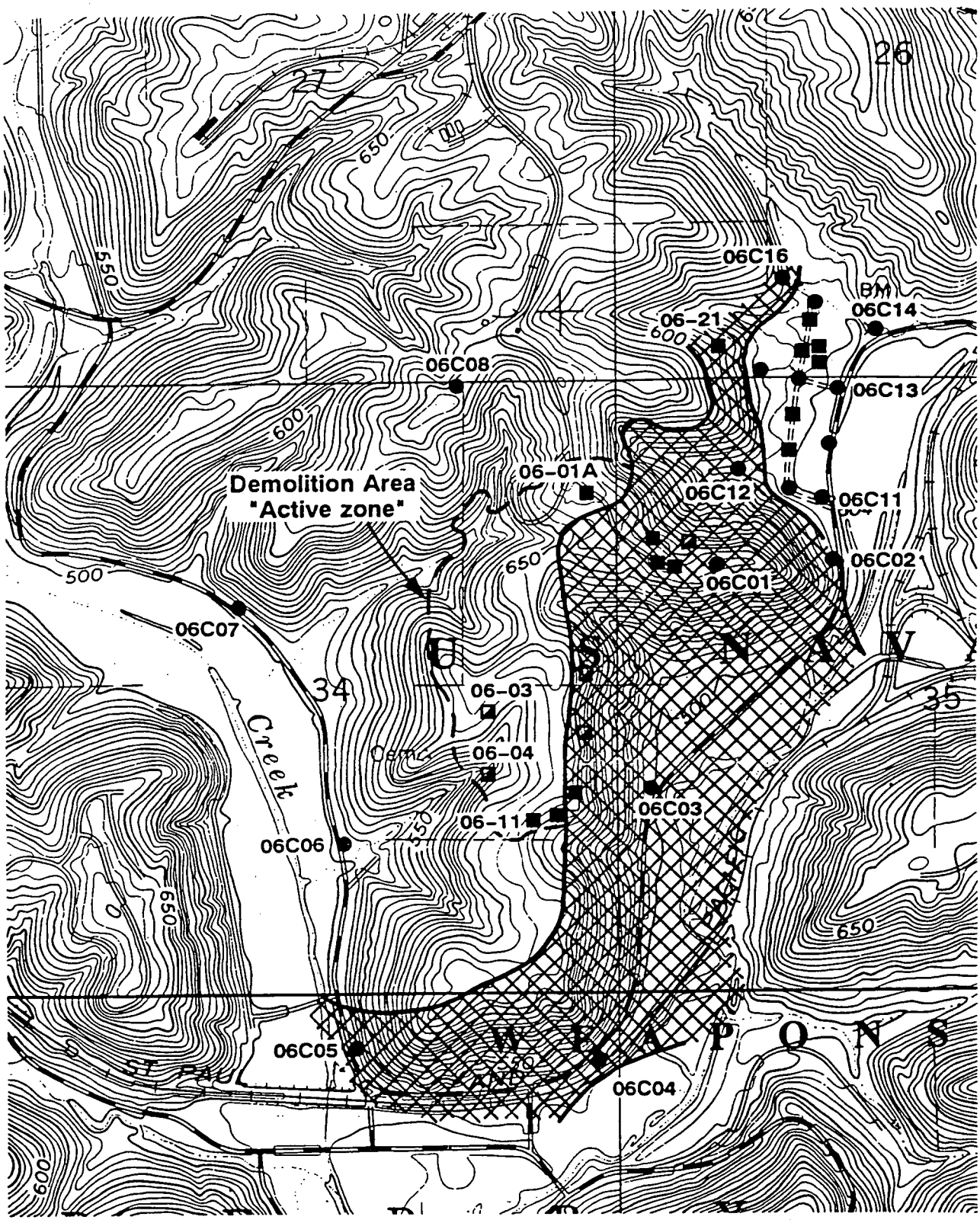


Figure 3-7A Extent of Golconda/Haney formation (shaded) beneath Demolition Area (explanation in text).

The Pennsylvanian Mansfield Formation may be as thick as 220 ft below NSWC Crane. A major paleovalley (ancient stream valley) trending north-northeastward to south-southwestward across the center of the area and beneath the DR has cut out much of the Mississippian section (Golconda/Haney limestone, Indian Springs shale, and Big Clifty sandstone) and replaced it with Pennsylvanian sandstones and shales. Data from monitoring well borings indicate as much as 100 ft of relief on the paleovalley beneath the DR.

The Big Clifty sandstone to the base of the Pennsylvanian unit includes the Indian Springs shale, the Golconda/Haney limestone, the Hardinsburg Formation, and the Glen Dean limestone. These units were included as one because the contacts between them are not usually discernible in outcrops.

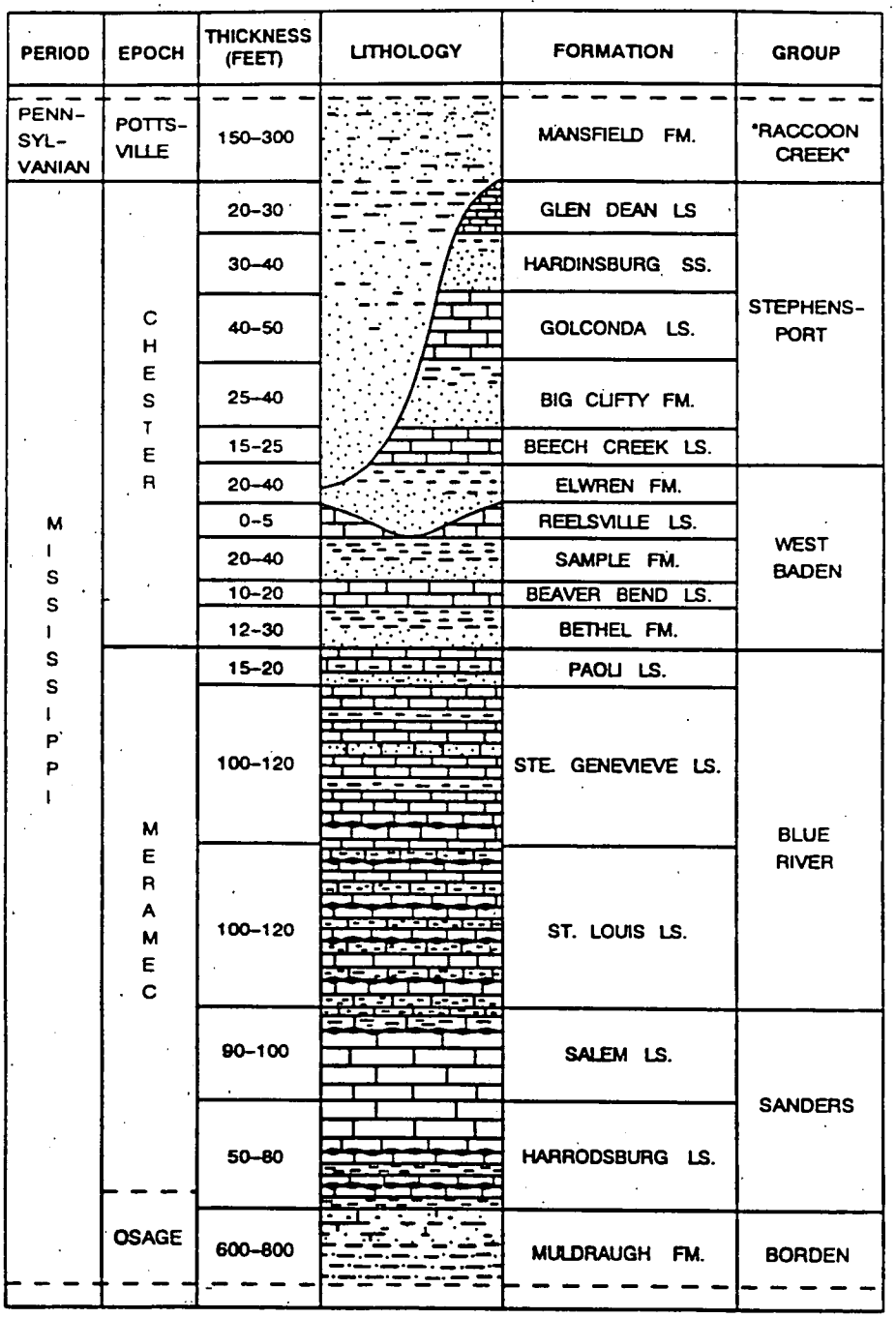
The thick Big Clifty sandstone member varies in thickness from about 30 to 40 ft across NSWC Crane and forms prominent cliffs in outcrop.

The walls of the valley of Turkey Creek are in Mississippian limestones, sandstones, and shales. The valley of Boggs Creek is bordered by Pennsylvanian units. No exposures of Beech Creek limestone were found in the area of reconnaissance.

3.3.1.2 Subsurface Geology

The structure, stratigraphy, lithology, and hydrologic characteristics of the geologic units underlying the DR and ORR were evaluated and described with data obtained from the 26 original confirmation well borings in 1981-1983 and the 34 RFI well borings emplaced in 1989-1990 (Murphy and Wade, 1995).

The geologic units discussed below are described briefly in the stratigraphic column presented in Figure 3-8. The general stratigraphy (sequence of depositional units) was known from previous hydrogeological investigations at other NSWC Crane sites. The geologic units encountered at the DR/ORR are, in descending order (youngest and overlying first), the Pennsylvania Mansfield Formation of the Raccoon Creek Group, the unconformity surface separating the Pennsylvanian from the Mississippian units, the Hardinsburg shale, the Golconda/Haney limestone, the Indian Springs shale member of the Big Clifty Formation, the Big Clifty sandstone member, the Beech Creek limestone, and the Elwren shale. The Elwren shale was the deepest geologic unit encountered for the investigation. Not all the units were encountered in every boring. For example, well 06C03, situated at the base of the ridge, encountered only Golconda/Haney and deeper units because the higher formations have been removed by erosion. Well 6C01, atop the ridge, encountered all the above-mentioned geologic units.



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 13 by William L. Murphy and Roy Wade

Figure 3-8
Stratigraphic Column for Rock Units Encountered at the Naval Surface Warfare Center (Source: Palmer, 1969; Cited in Murphy and Wade, 1995)
Naval Surface Warfare Center
Crane, Indiana

Local stratigraphic units. The geologic formations encountered by borings in the study area are described in the following paragraphs, with younger units first.

a. Mansfield Formation (Pennsylvanian Raccoon Creek Group). The Mansfield Formation comprises most of the ridge on which the DR is situated, attaining a maximum bored thickness of 220 ft in well boring 06C08. The formation was absent at the ORR. The Mansfield consisted of alternating beds or lenses of fine- to medium-grained, cross-bedded, friable sandstones; shaly sandstone to sandy shale; thinly bedded to laminated, fissile to blocky shale; thinly bedded carbonaceous shale; claystone or clayshale; and thin (1 to 2 ft) coal seams. Well screens were emplaced in certain sandstone and coal units of the Mansfield for monitoring aquifers beneath the DR.

b. Hardinsburg Shale Formation (Mississippian Stephensport Group). The Hardinsburg shale occurred in only one boring, 06C01, at elevations from 126 to 130 ft, immediately below the Pennsylvanian-Mississippian unconformity. It was absent by erosion in all other borings. The formation consisted of green, very hard shale.

c. Golconda/Haney Limestone Formation (Stephensport Group). The Golconda/Haney limestone was encountered in several borings at the DR/ORR. Maximum bored thickness was 32 ft in 06C01. The base of the formation was above 482 ft NGVD in all borings emplaced for the DR/ORR study. The Golconda/Haney variably was a fossiliferous, dark green to brown, shaly limestone; green-brown hard crystalline limestone; or, more rarely, beds of limey shale. The site geologist noted solution zones up to 1/2 ft thick in the Golconda/Haney in two borings (06C03 and 06C04); in both, the formation was near the ground surface (shallow) and was weathered. The Golconda/Haney was screened as an aquifer in three RFI wells (06C03P2, 06C04P2, and 06C16P3) at the foot of the DR ridge, on the east side, and in confirmation well 06-21, slightly upslope and west of the ORR. The Golconda/Haney was dry in other well borings in which it was encountered. The boring log for well 06C01 noted that the formation displayed negligible porosity (no jointing or other openings) and did not lose the drilling water even after standing overnight.

d. Indian Springs shale member, Big Clifty Formation (Stephensport Group). The Indian Springs shale was encountered in many of the RFI borings drilled for the DR/ORR study. Bored thickness ranged from 1.6 ft in 06C01 to 16.1 ft in 06C04. The unit was absent by erosion or by unconformity in several wells. The 1.6-ft thickness in boring 06C01 was a depositional thinning of the unit, not a result of the unconformity or erosion. The Indian Springs was an olive green to gray, hard, fissile shale to massive claystone with occasional softer zones.

e. Big Clifty sandstone member, Big Clifty Formation (Stephensport Group). The Big Clifty sandstone was encountered in all RFI deep borings except 06C06 and 06C07, west of the DR. It was absent at this location because of the unconformity. The unit was uniformly about 40 ft thick throughout the study area. It was a tan to green-gray, massive to thick-bedded, rippled, fine- to very fine-grained, well sorted, rounded, friable sandstone with occasional shaly partings. Boring log information indicated that jointing in the Big Clifty was sparse in some borings to numerous in others. Numerous joints noted in two wells were interpreted to be drilling-induced breaks along incipient parting planes. The Big Clifty produced water from several zones and was screened at various depths for monitoring.

f. Beech Creek Limestone Formation (Stephensport Group). The Beech Creek limestone was encountered in all RFI deep borings. The unit was typically 17 ft thick in the DR/ORR study area, but the thickness ranged from 15 ft in 06C08 and 06C09 to 22-1/2 ft in 06C07. The Beech Creek consisted of fossiliferous, hard, dense limestone. The upper 5 to 10 ft were gray to gray-brown, crystalline limestone with occasional styolites. The lower portion was dark gray, crystalline limestone with occasional to numerous shaly partings. Joints in the limestone were sparse to numerous in core recovered from the 18 well borings penetrating the Beech Creek. Drilling water loss through the formation was greatest in borings at the ORR, where the Beech Creek is shallow (see Figure 3-4). Borings 06C12, 06C14, 06C15, and 06C17 each had an open joint, up to 0.2 ft wide, within 3 ft of the top of the Beech Creek, near the contact with the overlying Big Clifty sandstone. Considerable water loss occurred through the open joints. Those borings also exhibited numerous other joints in the Beech Creek. The Beech Creek displayed moderate to extensive solution-enlarged jointing at another site within NSWC Crane (Hunt, 1988). At the DR/ORR, however, the only solution feature noted was in the open joints in two of the four borings listed above. Apparently, the Beech Creek was sufficiently below the level of incision by surface streams that extensive solution of open joints had not occurred in the study area.

g. Elwren shale (West Baden Group). The Elwren shale was encountered in all the deep borings of the 18 well clusters emplaced for the DR/ORR RFI. The Elwren was a hard, dark green to occasionally red-mottled, occasionally fissile shale. Slickensides were evident in some borings. Occasional sandy partings occurred in some borings. The maximum depth penetrated in the Elwren shale was 10 ft in boring 06C01.

Aquifer assignments for DR/ORR wells are presented in Table 3-2 as screened formations.

TABLE 3-2

MONITORING WELL CONSTRUCTION DETAILS
NSWC
CRANE, INDIANA
PAGE 1 OF 4

Well I.D.	North Coordinate (ft)	East Coordinate (ft)	Ground Elevation[b] (ft)	Top of Casing Elevation[b,c] (ft)	Top/Bottom of Screen (ft BGS)	Screened Formation[a]	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)	Comments/ Well Type
AMMUNITION BURNING GROUNDS									
03B02	482573	595506	501.46	503.96	9.6-14.6	Alluvium	15.8	NA	natural attenuation demonstration
03B04	482631	595293	503.97	506.47	9.4-14.5	Alluvium	16.5	NA	natural attenuation
03C02P2	489932	594798	580.65	583.15	38.0-48.0	Beech Creek	49.0	NA	downgradient
03C03	490203	594055	597.58	600.08	139.0-149.0	Beaver Bend	150.7	NA	compliance/ natural attenuation
03C04	490620	594783	621.92	624.42	73.5-83.5	Beech Creek	85.3	NA	downgradient
03C07	490423	594371	633.97	636.47	88.7-98.7	Beech Creek	101.6	NA	downgradient
03C08P2	489701	594014	626.84	629.34	90.0-100.0	Beech Creek	101.6	NA	downgradient
03C09P2	490619	593776	601.06	603.56	62.0-72.0	Beech Creek	73.0	NA	downgradient
03C10	490243	593657	605.53	608.03	66.0-76.0	Beech Creek	78.8	NA	natural attenuation demonstration
03C11	NA	NA	589.86	592.36	47.5-57.5	Beech Creek	59.5	NA	natural attenuation demonstration
03C12	489957	594574	584.70	587.20	39.0-49.0	Beech Creek	51.2	NA	natural attenuation demonstration
03C15	489849	593146	618.51	621.34	88.5-98.5	Beech Creek	101.1	NA	downgradient

TABLE 3-2

MONITORING WELL CONSTRUCTION DETAILS
NSWC
CRANE, INDIANA
PAGE 2 OF 4

Well I.D.	North Coordinate (ft)	East Coordinate (ft)	Ground Elevation[b] (ft)	Top of Casing Elevation[b,c] (ft)	Top/Bottom of Screen (ft BGS)	Screened Formation[a]	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)	Comments/ Well Type
03C17	492764	594371	693.65	696.15	138.5-148.5	Beech Creek	149.5	NA	upgradient
03C20	489880	593773	644.12	646.62	108.0-118.0	Beech Creek	120.0	NA	downgradient
03C25	487148	592606	594.53	597.03	59.7-69.7	Beech Creek	70.7	NA	compliance/ natural attenuation
03C26	490695	594134	638.07	640.57	94.0-104.0	Beech Creek	105.7	NA	downgradient
03C27	489658	594767	601.34	603.84	60.5-70.5	Beech Creek	73.3	NA	downgradient
03C30	488967	592403	776.41	778.91	250.5-260.5	Beech Creek	263.6	NA	compliance
Springs A	NA	NA	NA	NA	NA	NA	NA	NA	downgradient/ surface spring
Springs C	NA	NA	NA	NA	NA	NA	NA	NA	downgradient/ surface spring
OLD RIFLE RANGE									
06C08[d]	485027	570384	NA	709.15	239.8-279.8	Big Clifty/ Beech Creek	283.2	5.8	upgradient
06C11	484003	573448	NA	502.31	36.2-56.2	Big Clifty/ Beech Creek	61.1	24.1	downgradient
06C11P2	484007	573447	NA	502.31	20.0-30.0	upper Big Clifty	30	24.1	downgradient
06C12	484275	572771	NA	522.7	56.5-76.5	Big Clifty/ Beech Creek	82.8	8.5	downgradient
06C13	484932	573573	NA	507.66	35.0-55.0	Big Clifty/ Beech Creek	62.9	22.5	downgradient
06C13P2	484927	573572	NA	507.44	20.0-30.0	Upper Big Clifty	30	22.5	downgradient

TABLE 3-2

MONITORING WELL CONSTRUCTION DETAILS
NSWC
CRANE, INDIANA
PAGE 3 OF 4

Well I.D.	North Coordinate (ft)	East Coordinate (ft)	Ground Elevation[b] (ft)	Top of Casing Elevation[b,c] (ft)	Top/Bottom of Screen (ft BGS)	Screened Formation[a]	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)	Comments/ Well Type
06C14	485445	573908	NA	510.53	28.0-48.0	Big Clifty/ Beech Creek	52.7	14.5	downgradient
06C14P2	485442	573904	NA	510.46	15.0-25.0	Upper Big Clifty	25.0	13.0	upgradient
06C15	485667	573405	NA	513.95	36.0-56.0	Big Clifty/ Beech Creek	62.2	1.5	downgradient
06C16	485884	573139	NA	532.96	63.8-83.8	Big Clifty/ Beech Creek	88.5	8.3	downgradient
06C18	484472	573508	NA	507.74	466.04-446.04 (elevation)	Big Clifty/ Beech Creek	62.4	23.3	downgradient
06C18P2	484478	573508	NA	507.81	23.0-33.0	Upper Big Clifty	33	23.3	downgradient
06C19			NA		35-56	Big Clifty Beech Creek	54.4	18.4	Downgradient
06C19P2			NA		11.5-21	Big Clifty Upper	25	18.2	downgradient
DEMOLITION RANGE									
06C02	483501	573527	NA	512.19	47.1-67.1	Lower Penn/Beech Crk	75.4	4.7	downgradient
06C03	481567	571965	NA	507.43	66.8-86.8	Big Clifty/ Beech Creek	91.8	15	downgradient
06C03P2	481572	571964	NA	507.56	10.0-20.0	Golconda/Haney	20	8.7	downgradient
06C04	479270	571501	NA	520.2	78.0-98.0	Big Clifty/ Beech Creek	103.3	8.8	downgradient
06C04P2	479267	571497	NA	520.39	17.0-27.0	Golconda/Haney	27	8.8	downgradient
06C05	479365	569436	NA	506.93	60.4-80.4	Big Clifty/ Beech	86.4	6.4	downgradient

TABLE 3-2

MONITORING WELL CONSTRUCTION DETAILS
NSWC
CRANE, INDIANA
PAGE 4 OF 4

Well I.D.	North Coordinate (ft)	East Coordinate (ft)	Ground Elevation[b] (ft)	Top of Casing Elevation[b,c] (ft)	Top/Bottom of Screen (ft BGS)	Screened Formation[a]	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)	Comments/ Well Type
						Creek			
06C06	569354	481160	NA	512.19	460.29-440.29 (elevation)	Lower Penn/ Beech Creek	86.4	23.5	downgradient
06C06P2	481156	569357	NA	512.05	22.5-32.5	Pennsylvanian	132.5	23.5	downgradient
06C07	483127	568515	NA	513.26	61.6-81.6	Beech Creek	87.5	3.2	downgradient
06C08P2	485023	570389	NA	709.1	81.5-91.5	Pennsylvanian	91.5	4.7	upgradient

OLD JEEP TRAIL

Monitoring well network to be determined later[e]

(a) Alluvium unconsoldated deposits, shallow aquifer
Pennsylvanian sandstone aquifer
Golcanda/Haney limestone aquifer
Big Cliftysandstone aquifer
Beech Creek limestone aquifer
Beaver Bend limestone aquifer
(b) Elevations measured to National Vertical Geodetic Datum
(c) Vertical elevations of all monitoring wells will be resurveyed after retrofitting for installation of low flow sampling pumps.
(d) 06C08 is listed as an upgradient well for the ORR and a downgradient well for the DR.
(e) Monitoring well network to be determined following additional investigative activities.

NOTES:
All monitoring wells installed in the Ammunition Burning Grounds, Demolition Area, and Old Rifle Range (shown above) are constructed of 2-inch polyvinyl chloride (PVC) casing, riser, and well screens.

BGS = below ground surface.
NA = information is not available.
NT = not tested.

Geologic structure in the study area

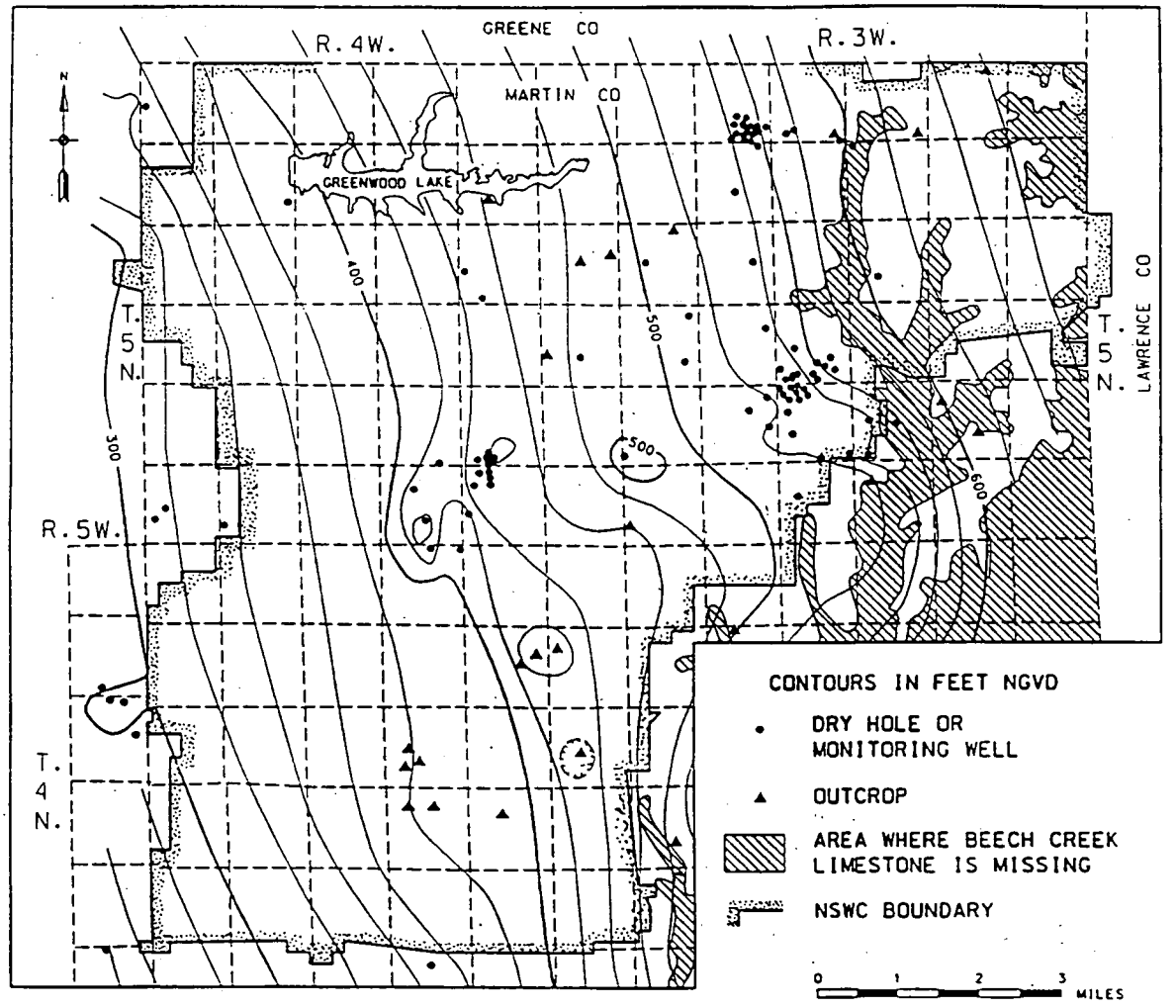
Figure 3-9 presents the structural contour map of the top of the Elwren shale (base of Beech Creek limestone) at NSWC Crane. The base of the Beech Creek limestone was contoured for the DR/ORR study area using elevations from the logs of all borings penetrating the Elwren shale. Elevation contours were plotted on a 5-ft interval. The regionally dominant southwestward dip is preserved in the local contours with the highest elevations in the northeastern corner of the map (the top of Elwren is 463 ft in 06C14). A local anomaly is evident, however, as a saddle-shaped ridge trending northeast-southwest. The saddle structure produces local anomalous dips of geologic units to the northwest and southeast beneath the DR. The contour map is somewhat biased because of a lack of geologic information in the center of the mapped area, where no borings could be emplaced because of active demolition activities. The map represents a computer-drawn, gridding algorithm interpretation of available data. The structural anomaly at the DR is also evident on the regional geologic structure map presented in Figure 3-9.

Geologic cross-sections. Several geologic cross-sections were constructed using graphic boring logs prepared for the DR/ORR (Murphy and Wade, 1995). Most of the boring data were from the RFI cored borings emplaced after 1989. Data from the earlier, predominantly uncored, confirmation borings were used in a few instances to augment the cross-section construction. The sections display the projected formation contacts between borings for the Mississippian units, the projection of the unconformity contact between Mississippian and Pennsylvanian units, and the lithologic contacts in borings penetrating the Pennsylvanian units. Other information provided on the sections includes the positions of well screens, positions of ground water levels for each screened interval, interpolated piezometric surface for selected aquifers, and pertinent geologic or hydrologic features. Contacts of Mississippian units were confidently projected between borings because of the relatively uniform stratigraphy of the Mississippian formations. The Pennsylvanian units vary considerably laterally and were projected only short distances from the borings, if at all.

3.3.2 Stratigraphy and Geology of the Ammunition Burning Grounds

3.3.2.1 Stratigraphy

The sequence of geologic units occurring in the vicinity of the ABG was described in detail in Hunt (1988). Figure 3-8 is a stratigraphic column of rock units encountered in southern Indiana to a depth of several hundred feet. The ABG studies were concerned only with the Chester and Pottsville Epoch of Upper Mississippian and Pennsylvanian age, respectively, representing a maximum depth of investigation at the ABG of about 280 ft from ground surface (about elevation 420 ft NGVD). Four geologic formations important to the hydrogeological investigation of the ABG comprise three aquifers, the Golconda-Haney



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 12 by William L. Murphy and Roy Wade

Figure 3-9
Geologic Structure Map, Base of Beech Creek Limestone of Martin County, Indiana (Source: Indiana Geological Survey, 1980, revised 1991)
Naval Surface Warfare Center Crane, Indiana

limestone (the upper aquifer), the Big Clifty sandstone/Beech Creek limestone (the middle aquifer), and the Beaver Bend limestone (the lower aquifer). The Golconda-Haney and Big Clifty/Beech Creek aquifer are interconnected, forming the uppermost aquifer.

Three shale formations beneath the ABG are important aquicludes (deterrents to vertical movement of ground water and contaminants). The Indiana Springs shale, the upper, 20-ft-thick member of the Big Clifty Formation, underlies the Golconda-Haney limestone in the western half of the ABG but has been removed by erosion in the eastern half. The Elwren shale is 20 ft thick and occurs at the base of the Beech Creek limestone. The Sample Formation is a 40- to 45-ft-thick black shale below the Elwren.

3.3.2.2 Surface Geology

The smallest geologic units are groups (see Figure 3-8). The contact of the Stephensport and West Baden Groups is the base of the Beech Creek limestone.

The regional dip of the rocks is 50 ft per mile. Younger rocks of Pennsylvanian age cap the ridges. Progressively older Mississippian units are exposed in the valleys.

The ABG valley floor is covered by 1 to 15 ft of alluvial (stream-deposited) and colluvial (slope debris) soils. The Big Clifty sandstone has been exposed to surface infiltration in the central part of the site by erosional removal of the overlying Indian Springs shale. The Mansfield Formation of the Pennsylvanian Raccoon Creek Group occupies the higher elevations at the ABG.

3.3.3 Stratigraphy and Geology of the Demolition Range

The active zone of the DR is underlain by 0 to 9 ft of sandy clay or silt, as characterized in the 13 confirmation borings and one RFI cored boring emplaced in or near the active zone. Bare rock is at the surface near the eastern side of the active zone and at the edge of the ridge. The rock underlying the active demolition area is sandstone and shale of the Pennsylvanian Mansfield Formation. The 220-ft-thick sequence of Pennsylvanian sediments and the position of the Pennsylvanian-Mississippian unconformity beneath the ridge are evident in borings 06C087 and 06-21. The abundance of shale units, as much as 55 ft thick, beneath the ridge inhibits vertical infiltration of surface contaminants to the Mississippian aquifers at depth.

The entire ridge is underlain by Pennsylvanian sandstones and shales because the Pennsylvanian paleovalley has cut out the underlying Mississippian units. This illustrates the relative uniformity and

continuity of the Mississippian sequence. The Mississippian aquifers, the Big Clifty sandstone, and the Beech Creek limestone are exposed to surface infiltration in the valley of Turkey Creek north of boring 06C10.

The existence of the saddle structure is evident beneath the DR. Components of dip vary considerably from section to section. The general, regional trend of south to southwest dip is preserved in this area.

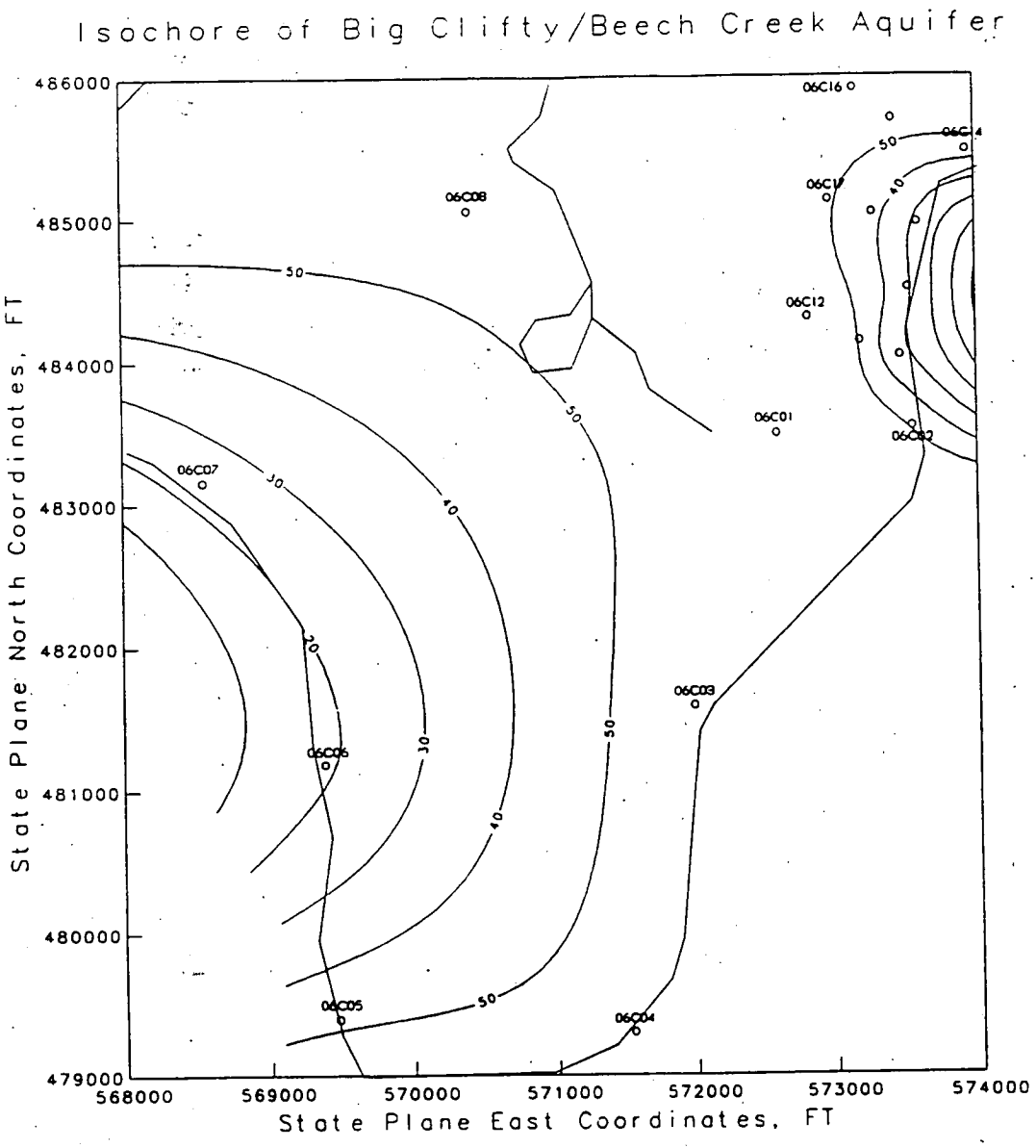
The Big Clifty sandstone/Beech Creek limestone aquifer underlies most of the study area and is the most extensively monitored aquifer present. The thickness of the aquifer penetrated by exploration borings is shown by the isochore (drilled thickness) map of Figure 3-10. The contours are in feet of vertically drilled thickness of the combined Big Clifty sandstone and Beech Creek formations (base of Beech Creek to top of Big Clifty sandstone). The decreasing thickness at the upper right of the figure reflects surface erosion by the modern and ancestral Turkey Creek. The decreasing thickness on the left (west) reflects the increasing depth to the Pennsylvanian erosional surface (the unconformity) to the west. On the west side, the Pennsylvanian thickness increases at the expense of the underlying Mississippian formations.

The Golconda/Haney limestone formation produces water as an aquifer in much of the DR study area. Its position in the subsurface beneath the study area is illustrated in Figure 3-11. The Golconda/Haney's position was plotted by projecting the base of the formation along dip from borings to the nearest erosional surface, either the ground surface or the buried Pennsylvanian-Mississippian unconformity. The shaded area of Figure 3-11 implies that the Golconda/Haney would be encountered in sufficiently deep borings placed within the shading. The Golconda/Haney is projected not to exist outside the shaded area (bounded by the heavy solid line in Figure 3-11), having been removed by erosion.

3.3.4 Stratigraphy and Geology of the Old Rifle Range

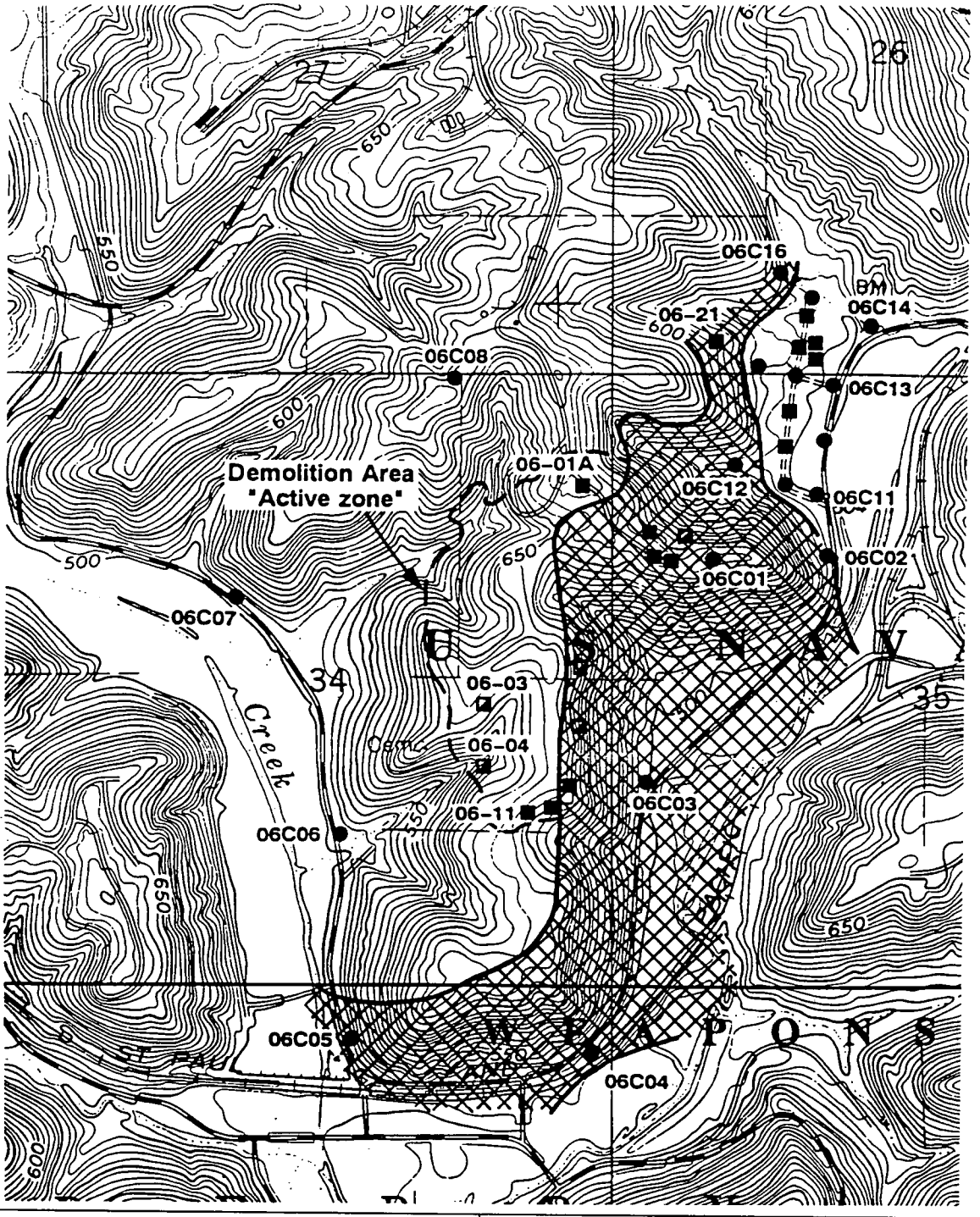
The subsurface of the ORR is characterized by a greater and more variable thickness of soil than that of the DR active zone. A mixture of colluvial (slope debris), alluvial (stream-deposited), and residual soils typifies the section. Soils range in thickness from less than 2 ft at the northwestern corner of the ORR to about 28 ft along the eastern boundary (near NSWC Crane Highway 8). Rock underlying the soil is Mississippian, predominantly Big Clifty sandstone.

A contour map showing the distribution of the thickness of soil in the ORR is presented in Figure 3-12. The contour values represent thickness of soil, which is also the depth from the ground surface to the top of rock. Contours on the top of rock (elevations in ft NGVD) are shown in Figure 3-13. Data for the two maps were obtained from logs of monitoring well borings and soil borings. The thicker soils east of the dashed line



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 17 by William L. Murphy and Roy Wade

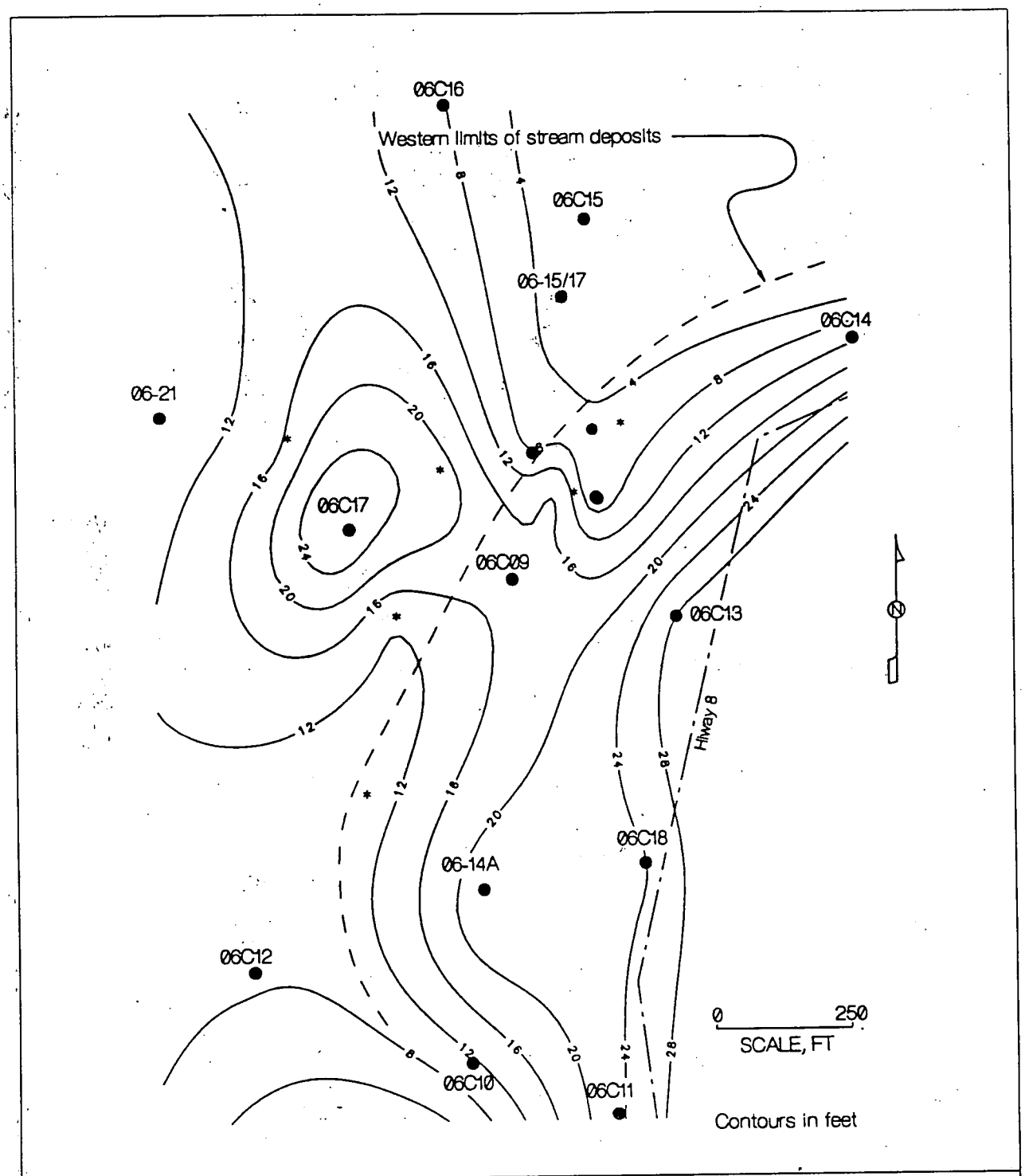
Figure 3-10
Isochore (Drilled Thickness) Map of Big Clifty/Beech Creek Aquifer, Demolition Area/Old Rifle Range. Contours show thickness in feet. (Source: Murphy and Wade, 1995)
Naval Surface Warfare Center
Crane, Indiana



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 18 by William L. Murphy and Roy Wade

Figure 3-11

Extent of Golconda/Haney Formation (Shaded) Beneath Demolition Area (explanation in text) Naval Surface Warfare Center Crane, Indiana



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 19 by William L. Murphy and Roy Wade

Figure 3-12

Contour Map of Soil (Overburden) Thickness, Old Rifle Range Naval Surface Warfare Center Crane, Indiana

of Figure 3-12 were interpreted to be alluvial deposits of the ancestral channel of Turkey Creek. The alluvial soils are clays, sands, and gravels, with the coarser deposits near the base of the soil column. The thick soil area west of the dashed line of Figure 3-12 was interpreted to be colluvial soils derived by mass wasting of the slopes above the ORR to the west. The thick colluvial soils correspond to the deep top-of-rock anomaly west of boring 06C09 in Figure 3-13. The area resembles a region of slope failure that might have been caused by erosion of the toe of the slope by lateral cutting of the ancestral Turkey Creek channel. The area is relatively flat-lying, uniformly thick, continuous Mississippian units beneath the ORR. The Big Clifty sandstone underlies the active area (the area with flashing operations). The Beech Creek limestone is beneath the Big Clifty and is within 12 ft of the base of the soil in boring 06C13. The Indian Springs shale and Golconda/Haney limestone underlie the western slopes of the ORR but are absent by erosion. Figure 3-14 shows the eastern subcrop extent of the Indian Springs and Golconda/Haney at the ORR, as plotted on the top-of-rock contour map. Over most of the ORR, the Big Clifty-Beech Creek aquifer is open to direct infiltration of surface water penetrating the soil cover.

The geologist logging the core at the drill site noted, when possible, the depth at which the rock ceased to show signs of oxidation (such as prominent limonite[2] staining). The position of the base of oxidation is interpreted to be the deepest historical position of the water table, or aeration.

The Big Clifty and Beech Creek formations beneath the ORR were noted to contain more open fractures (joints or bedding planes) than the same formations elsewhere in the DR/ORR study area. All nine core borings emplaced for the ORR assessment recorded many low-angle and some high-angle joints. The abundant low-angle joints are probably bedding-plane relief joints caused by unloading of the rock by erosional processes in the Turkey Creek system. A recurrent open discontinuity or fracture zone with accompanying loss of water return during drilling occurred at or near the top of the Beech Creek limestone in five of the nine cored borings. The presence of the open fractures can be expected to make the formations more transmissive of ground water.

3.4 HYDROGEOLOGY

This section contains a description of the hydrogeology for the ABG, ORR, and DR. The ground water hydrogeology, aquifers and aquitards, and general water flow patterns are described. The uppermost aquifer is defined in 40 CFR 260.10 as the geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically connected.

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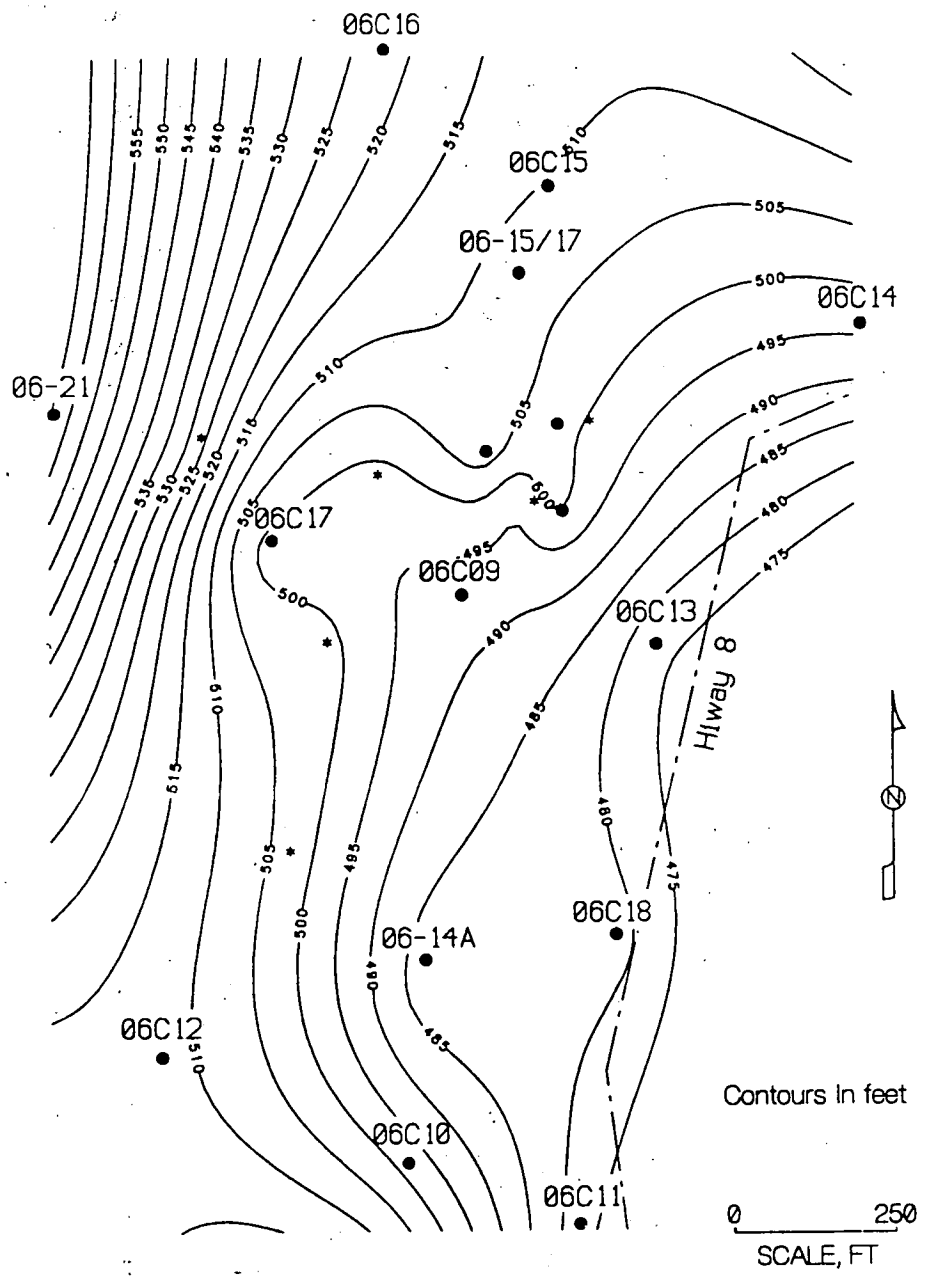
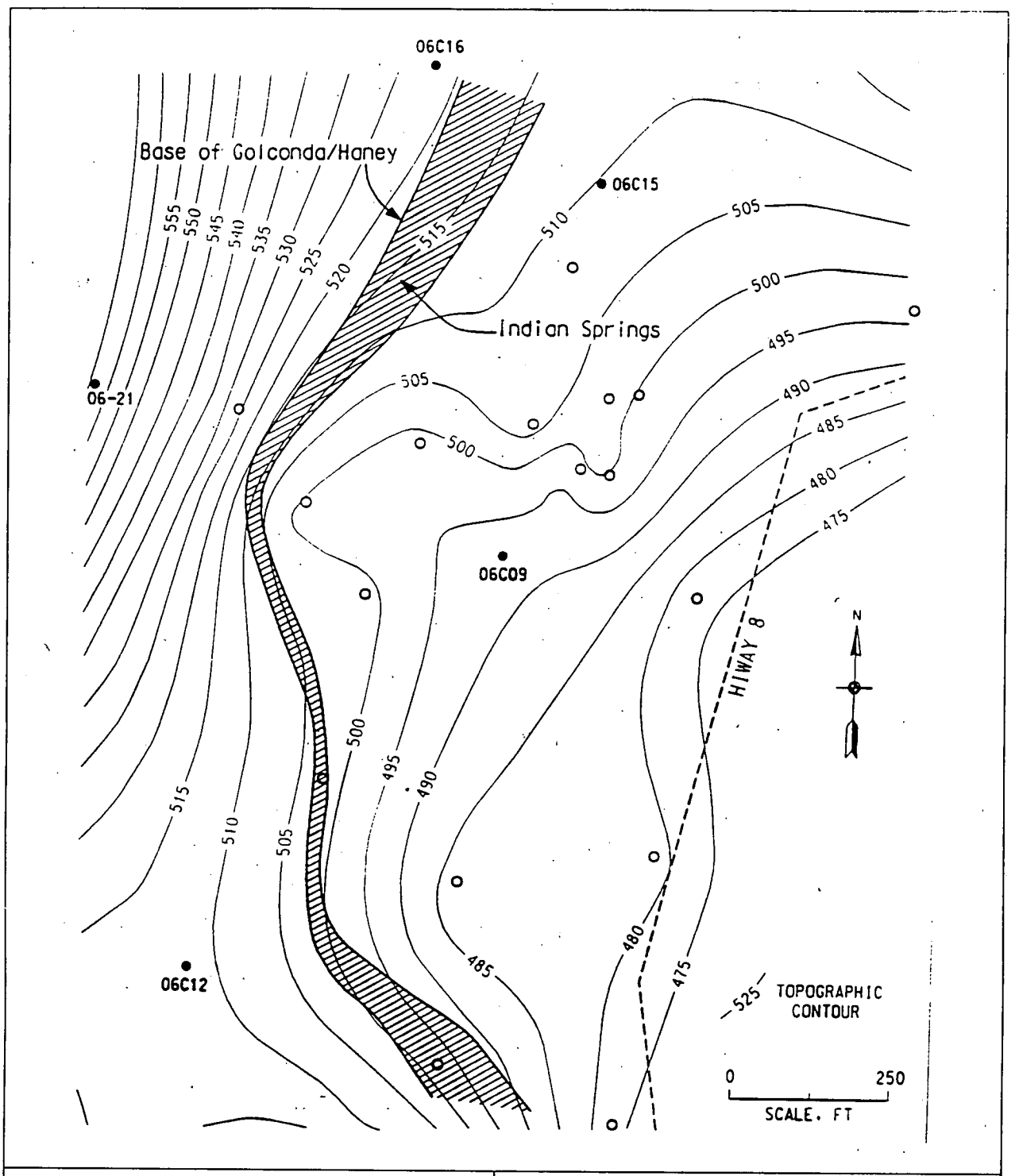
[2] Limonite (primarily the mineral geothite) is an oxide of iron formed by oxidation (weathering) of iron-bearing sediment or rock.



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 20 by William L. Murphy and Roy Wade

Figure 3-13
Elevation of Top of Rock from Soil (*) and Monitoring Well Borings (•), Old Rife Range. Selected Water Well Borings are Labeled. Elevations in FT NGVD.
Naval Surface Warfare Center
Crane, Indiana



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 21 by William L. Murphy and Roy Wade

Figure 3-14

Subcrop Map of Indian Springs and Base of Golconda/Haney, Old Rifle Range Naval Surface Warfare Center Crane, Indiana

3.4.1 Regional Hydrogeology

Detailed ground water information at NSWC Crane is lacking, since potable water is derived primarily from Lake Greenwood, Indiana. Regionally, ground water flow is expected to conform with the westward-dipping bedrock with a gradient approaching the dip. Locally, ground water flow is likely to parallel the surface drainage on the installation. Wells installed by WES for the ground water monitoring network generally showed ground water flow agreed with local drainage. Seasonal fluctuations in the water table are expected to be slight since precipitation is well distributed throughout the year.

3.4.2 Ground Water Hydrogeology of the Ammunition Burning Grounds Site

Previous paragraphs discussed the ground water regime for the ABG study area as revised from data provided by the five additional Beech Creek wells emplaced in 1989. Hunt (1988) presented an analysis of the ground water system within the ABG site proper. The Golconda/Haney limestone is up to 14 ft thick in ABG borings and is exposed in outcrops on the hillsides within the ABG. The Golconda/Haney is underlain by the Indian Springs shale aquiclude. Ground water from the Golconda/Haney flows into the ABG by seepage eastward along the top of rock, prevented from vertical infiltration by the underlying Indian Springs shale. Hunt (1988) showed that ground water seeping from the Golconda/Haney within the ABG eventually infiltrates the Big Clifty/Beech Creek aquifer. There was no evidence that possible contaminants entering the Golconda/Haney aquifer would exit the ABG other than through the Beech Creek aquifer system.

The Big Clifty sandstone is 40 ft thick and occurs directly beneath the soil cover in the eastern half of the ABG in the valley floor. The Big Clifty is hydraulically connected to the Beech Creek limestone, which is 18 to 22 ft thick at the ABG. The Beech Creek limestone contains joints and bedding planes, which have been widened by solution of the limestone by ground water moving through the formation. Some of the solution zones have been enlarged by collapse of Big Clifty sandstone and Beech Creek limestone into the solution voids. The Big Clifty sandstone and Beech Creek limestone are considered one aquifer (the middle aquifer).

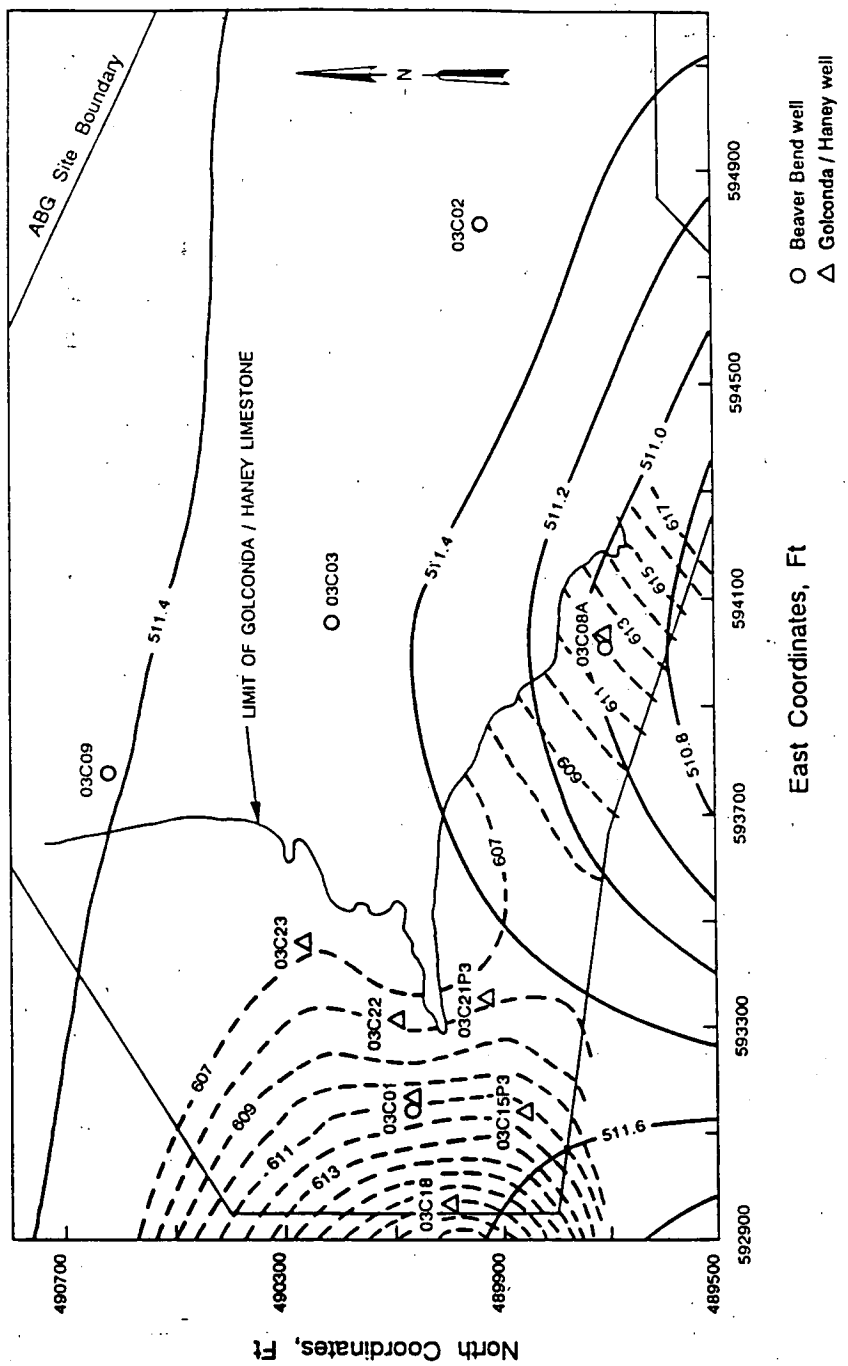
The Beaver Bend limestone is 10 to 12 ft thick and comprises the lowest aquifer considered in the investigation. The Beaver Bend is considered to be isolated hydraulically from the higher aquifers at the ABG but is monitored by five wells at the ABG. The five Beaver Bend wells are 03C01, 03C02, 03C03, 03C08A, and 03C09.

The three shale aquicludes at the ABG were briefly described earlier. The Indian Springs shale is present only in the western half and in the upper slopes to the northeast and southwest of the ABG. The Indian Springs therefore is an effective aquiclude for uppermost and surface water infiltration to deeper aquifers only in the western and upper slopes portions of the ABG. The Elwren shale is an effective hydraulic barrier to ground water moving through the Beech Creek and forces ground water to move laterally along the bedding contact and through joints in the Beech Creek. The Elwren forms the floor of the many springs that drain the Beech Creek aquifer in the valley of Little Sulphur Creek south of the ABG and springs north of the ABG. The Sample shale lies between the Elwren shale and Beaver Bend limestone. The Sample, the Elwren, and other shales of the West Baden Group form a collective 70 ft of aquiclude to separate the lowermost aquifer, the Beaver Bend limestone, from the higher aquifers.

Surface and ground water flow characteristics in and near the ABG were summarized in Hunt (1988). Ground water in the Beech Creek aquifer enters the ABG from the north-northwest. Primary flow out of the ABG is to the east and south down the Little Sulphur Creek drainageway, with secondary flow out to the southwest and then south through Johnson Hollow. A low ground water divide separates the two outflow components along a line running approximately from well 03C26 to well 03C14. Piezometric surface studies indicate the Beech Creek aquifer drains into the enlarged openings of the solution zones in the valley of Little Sulphur Creek. A karst description is included in Section 3.2.2.

Maps of the piezometric surfaces of the Golconda/Haney and Beaver Bend aquifer are presented in Figure 3-15. Water levels from the eight Golconda/Haney wells (03C19P3 is beyond the area pictured) and the five Beaver Bend wells for December 28, 1989, the latest date available for those wells, were used to construct the piezometric contours. Beaver Bend contours are shown as solid lines and Golconda/Haney contours as dashed lines. The Golconda/Haney is absent by erosion in the central portion of the ABG, as shown by the limit line on Figure 3-15. The direction of flow in the Golconda/Haney is predominantly to the east (to the northwest from well 03C08AP3), downslope topographically, as shown by the contours. It therefore drains to the ground surface or along the soil-rock interface into the lower Big Clifty/Beech Creek aquifer. The gradient on the Golconda/Haney piezometric surface is approximately 0.017 ft/ft to the east. The aquifer is artesian (confined) west of 03C22 and 03C23 but becomes unconfined as the aquifer drains to the east. The contour interval is 1 ft.

The Beaver Bend piezometric surface is very flat at the ABG. Note that the contour interval on the surface in Figure 3-15 is only 0.2 ft. Flow is generally to the south at approximately 0.0012 ft/ft. The Beaver Bend is artesian beneath the ABG, with a 55 to 60 ft head above the top of the limestone.



Source: Final Report, RCRA Facility Investigation Phase II Groundwater Release Characterization, SWMU 03/10, Ammunition Burning Ground May 1994 - Figure 9 by William L. Murphy

Figure 3-15

Piezometric Surfaces, Golconda/Haney (dashed) and Beaver Bend (solid) Limestones, Ammunition Burning Ground for 12/28/89 Naval Surface Warfare Center Crane, Indiana

3.4.3 Ground Water Hydrogeology of the Demolition Range

Aquifers and aquicludes

Wells were installed in three Mississippian formations and the Pennsylvanian Mansfield Formation to monitor water quality and ground water flow at the DR. The Big Clifty sandstone and Beech Creek limestone were treated as a single aquifer, a practice established at other SWMUs at NSWC Crane in previous RFI investigations. The Big Clifty and Beech Creek represented the deepest aquifer monitored for the study. Forty-ft screens were placed in the deep wells 06C01 and 06C08. Ten- and 20-ft screens were placed in the Big Clifty-Beech Creek wells. An upper and a lower interval in the aquifer were screened in some well clusters, especially northeast of the DR in the vicinity of the ORR. The underlying Elwren shale was determined during the drilling program to be consistently at least 5 ft thick. The probable total thickness of the Elwren shale is 16 to 20 ft, based on information from borings penetrating the Elwren at the ABG west of the DR. The Elwren thus provides ample retardation of infiltration of ground water to deeper aquifers.

The Mississippian Golconda/Haney Formation, a limestone and limey shale in the DR study area, was monitored with wells in four borings: 06C03P2 and 06C04P2, both at the foot of the ridge southeast of the DR; 06C16P3 at the northwestern end of the ORR (also monitored for the DR); and confirmation well 06-21 in the slope west of the ORR. The greatest thickness of Golconda/Haney penetrated in the study area was 31 ft in deep boring 06C01. However, no well was installed there because there were no indications that the formation was producing water or that there was any usable porosity present.

The Golconda/Haney is separated from the underlying Big Clifty sandstone by the Indian Springs shale, a persistent but variably thick aquiclude. The Indian Springs increases from a few feet thick in borings on the northern end of the DR to 16 ft thick in borings 06C04 and 06C05 on the south. A 6- to 9-ft head difference between cluster wells in the Golconda/Haney and Big Clifty indicates the Indian Springs shale provides hydraulic separation.

Wells were installed in sandstones at several intervals or depths in the Pennsylvanian Mansfield Formation. Of the RFI wells installed in 1989-1990, 06C01P2, 06C01P3, 06C08P2, and 06C06P2 were screened in the Pennsylvanian. The earlier confirmation borings 06-01 through 06-13 were also screened in the Pennsylvanian. Because the Pennsylvanian sediments are so difficult to map (correlate) in the subsurface, monitoring of the Pennsylvanian is at best random. It is unlikely that bodies of ground water in the sediments persist for more than a few hundred ft areally because of the likelihood of encountering occluding shales within that distance. Estimates of hydraulic conductivity of two samples of

a cross-bedded sandstone recovered at depth of 25 and 45 ft from core boring 06C08 were made from laboratory gas permeability tests performed on the two samples (Fisher, 1994). Values of hydraulic conductivity for the two samples were 4.97×10^{-5} and 1.8×10^{-4} centimeters/second (cm/sec), respectively, with corresponding porosities of 23 and 24 percent, respectively. These values indicated poor Darcian conductivity. Ground water movement is less likely to occur within and from the Pennsylvanian sediments than in the more uniform and persistent Mississippian aquifers. The Pennsylvanian contact with the underlying Mississippian intercepts the ground surface on the eastern and southern flanks of the DR ridge and consequently would discharge any migrating ground waters to the surface. The Mississippian-Pennsylvanian contact is buried (i.e., not exposed) on the western side of the ridge. Any migration of contaminated Pennsylvanian ground waters to the west would be more likely than eastward-moving water to escape detection by the monitoring program.

Hydraulic characteristics

Ground water transmission through the limestone aquifers (Beech Creek and Golconda/Haney) is through systems of connected joints. Flow within the Big Clifty sandstone is believed to be both through joints (secondary porosity) and through intergranular pores (primary porosity).

It was not possible to isolate specific joints or zones of ground water flow in the Big Clifty-Beech Creek aquifer. Long screens were necessary in some wells to ensure intercepting all flow zones.

A simple, nonrigorous laboratory test was performed on an unjointed section of sandstone core from the Big Clifty formation of well boring 06C01 to verify that there was effective porosity (intergranular permeability) in the sandstone. Two pieces of the core were weighed air-dry, submerged in water under equal heads for 2 days, and then weighed wet. The difference in weight in grams, representing the weight [and volume in cubic centimeters (cc)] of water absorbed by the rock, was divided by the volume of each piece to yield an estimate of the effective porosity of the rock. A value of 18 percent effective porosity was obtained for both samples of the sandstone. Effective porosity is a measure of specific yield of an aquifer and is also known as the drainable porosity or the percentage of interconnected pore space. The Big Clifty likely can yield ground water even where it is not particularly well jointed.

Ground water flow patterns. Ground water flow patterns could be described only for the two Mississippian aquifers, the Golconda/Haney and the Big Clifty-Beech Creek system. Ground water zones in the Pennsylvanian rock were not sufficiently uniform nor persistent to permit mapping of the piezometric surface.

Figures 3-16 and 3-17 are water-level contour maps of the Big Clifty-Beech Creek aquifer in the DR study area for May/June and November 1991, respectively. Water levels in the wells decreased by about 5 ft between the two measurement periods, but the overall shape of the piezometric surface was unchanged. Ground water levels for the DR are highest in the north and decrease to the south. Flow in the Big Clifty-Beech Creek is generally to the south and southwest but locally flows southeastward toward Turkey Creek near the ORR at the upper right of the map. The flow gradient from the vicinity of wells 06C01 and 06C08 to well 06C05 to the southwest averaged 0.002, or about 10 ft per mile (ft/mile). Locally, the gradient was as high as 0.004 (21 ft/mile). The shape of the piezometric surface is distorted from the regional trend. The distortion is caused by drainage of the Big Clifty-Beech Creek aquifer through that portion of the aquifer that is exposed to near-surface flow through the alluvial soils at the ORR.

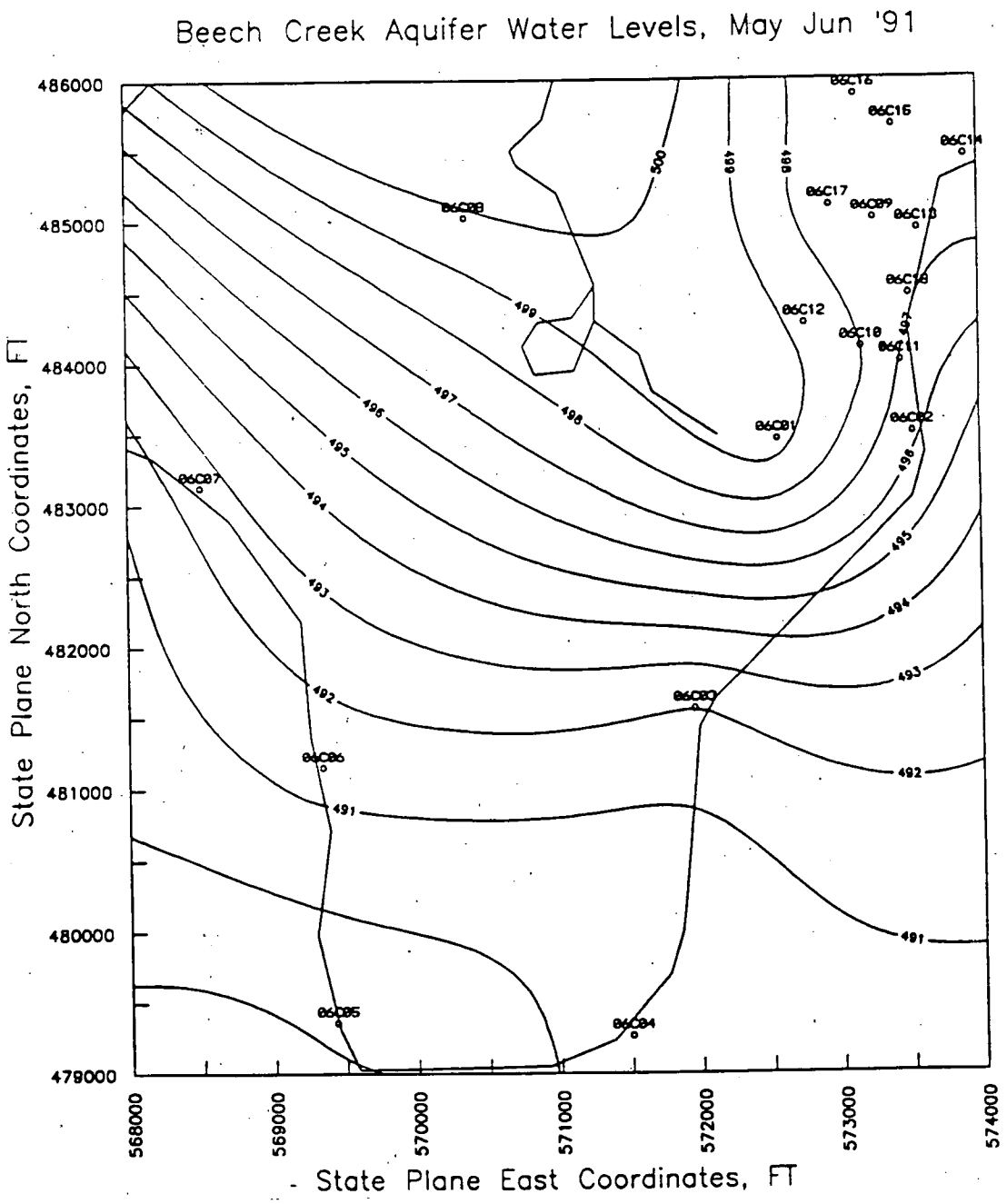
The piezometric surface of the Big Clifty-Beech Creek aquifer was above the top of the Big Clifty (within the overlying shale) beneath most of the DR, a fact that indicates the aquifer was in a confined flow condition. Northeast and below the DR, however, the piezometric surface was below the top of the aquifer. The aquifer became unconfined as it drained toward Turkey Creek through the more permeable soil and rock beneath the ORR. In its unconfined state, the aquifer is a water-table aquifer.

The Golconda/Haney limestone was unconfined in all wells placed in it. The Golconda/Haney intercepts the ground surface in most of the study area and is allowed to free-drain, resulting in the unconfined condition. Water levels in the Golconda/Haney aquifer were also plotted for May-June and November 1991. There were only about 0.5 to 2.5 ft of fall in water levels between the two dates, however, and the corresponding piezometric surface contour maps showed little variation from one date to the other. Only the map for May-June 1991 is shown (Figure 3-18). There were only four data points (wells) with which to plot the surface, with all the points on the eastern side of the DR. The direction of ground water flow in the Golconda/Haney is similar to that in the Big Clifty-Beech Creek: south and southwest with local southeastward flow in the vicinity of the ORR (the upper right quadrant of the map in Figure 3-18). The flow gradient to the southwest across the central portion of the map is 0.012, or about 63 ft/mile.

The distribution of well-screened intervals in the Pennsylvanian rocks was insufficient to permit mapping of the piezometric surface(s).

Potential ground water receptors

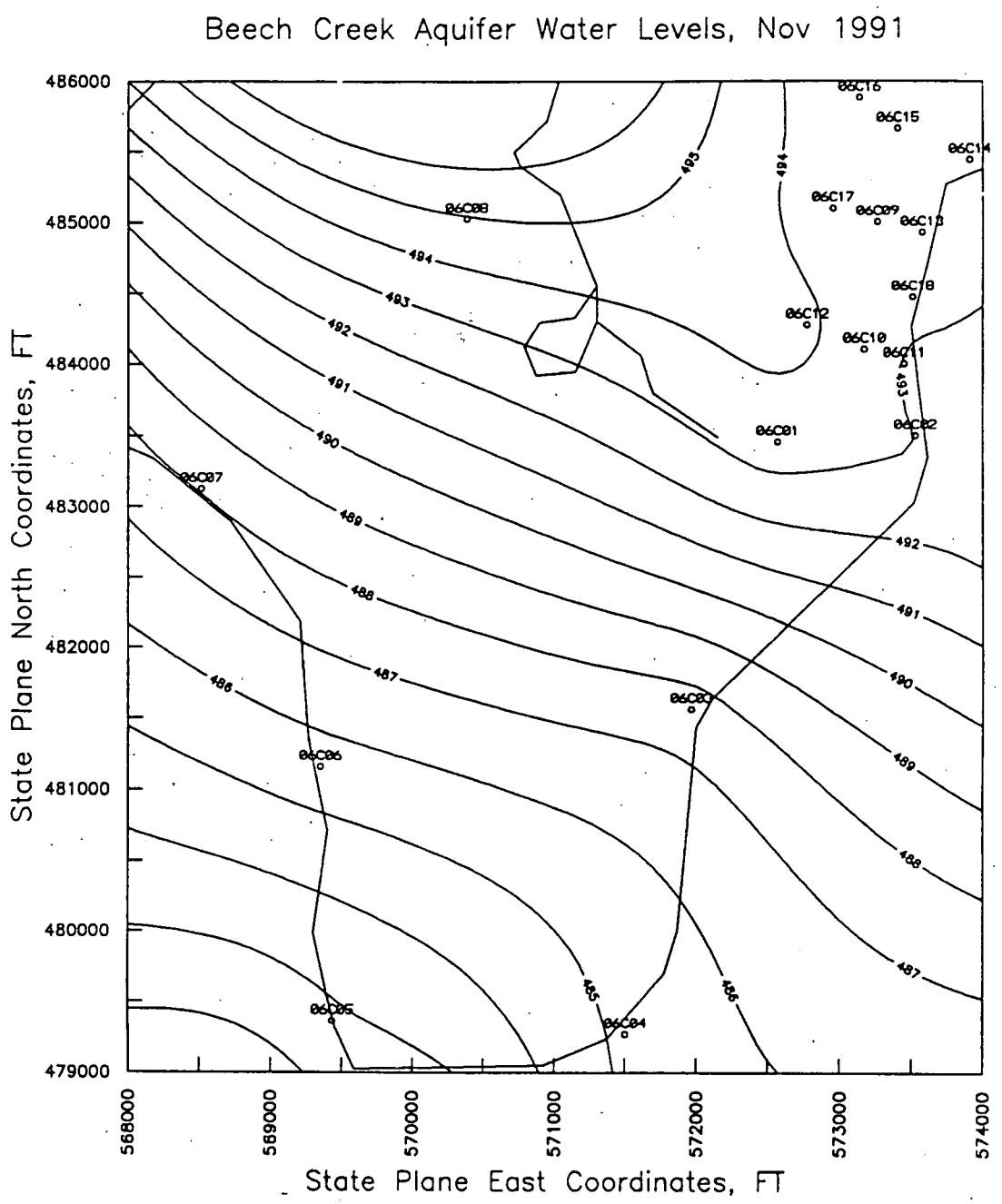
Potential receptors of contaminated ground waters originating at the DR include the Big Clifty-Beech Creek aquifer, the Golconda/Haney limestone aquifer, water-bearing units of the Pennsylvanian sediments, the alluvial/rock water table aquifer in the valleys of Turkey and Boggs Creeks, the surface



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 22 by William L. Murphy and Roy Wade

Figure 3-16

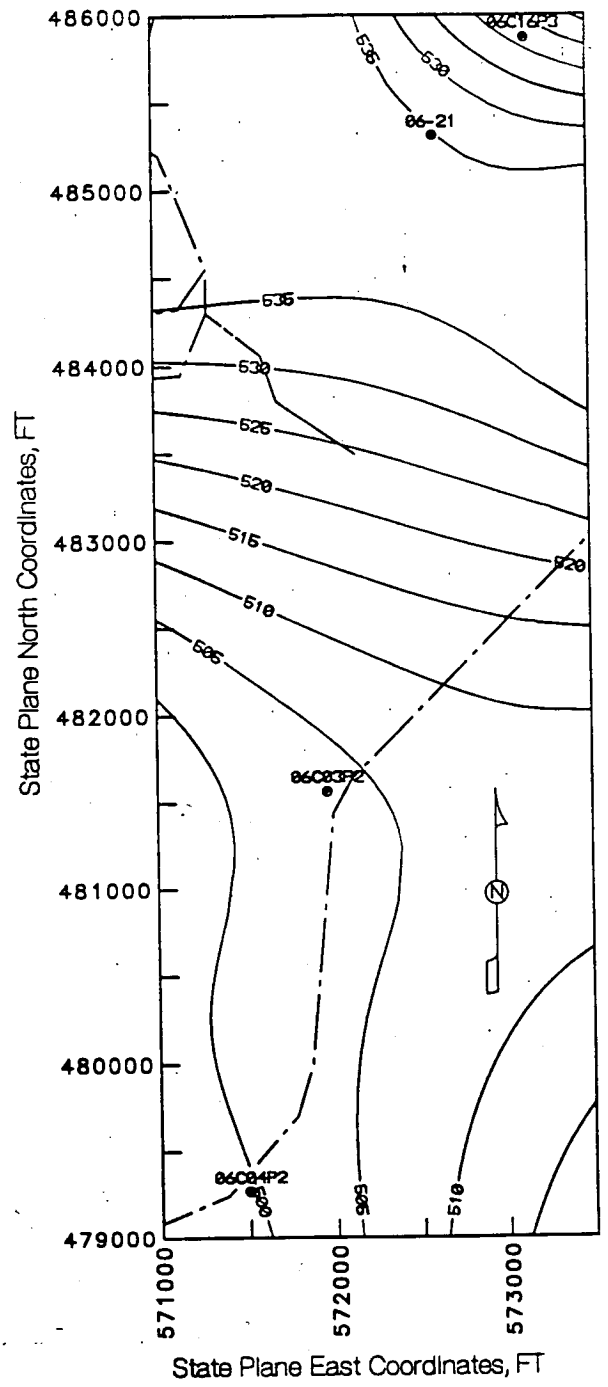
Piezometric Surface of May-June, 1991 Beech Creek Aquifer, Demolition Area Naval Surface Warfare Center Crane, Indiana



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 23 by William L. Murphy and Roy Wade

Figure 3-17

Piezometric Surface of November, 1991 Beech Creek Aquifer, Demolition Area Naval Surface Warfare Center Crane, Indiana



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 24 by William L. Murphy and Roy Wade

Figure 3-18

Piezometric Surface of May-June 1991 Golconda/Haney Aquifer, Demolition Area/Old Rifle Range Naval Surface Warfare Center Crane, Indiana

waters of Turkey and Boggs Creeks, and the sedimentation ponds at the foot of the ridge below the DR. The Big Clifty and Beech Creek formations extend in all directions away from the DR Area. Much of the Big Clifty has been removed by erosion and the formation has been "daylighted" by Turkey Creek to the east of the DR Area. South, north, and west of the DR, however, the Big Clifty and Beech Creek are intact and can transport ground water from beneath the ridge for an undetermined distance downgradient. The water-table aquifer of the valleys is presumed to be at about the position of the water in the permanent streams that flow within the valleys. On the Boggs Creek, or western side of the ridge, the stream valley is in Pennsylvanian rocks. Near the southern end of the ridge, the valley is probably in, and the stream flows on, the Indian Springs shale. The alluvial ground water west of the ridge is subject to contact with ground water issuing from the Pennsylvanian and Golconda-Haney aquifers but probably not with ground water from the Big Clifty-Beech Creek aquifer.

East of the ridge, the valley of Turkey Creek is in Big Clifty sandstone from north of the DR to an area just south of the DR. A south-north line shows that the updip-north component of the Mississippian formations causes the Big Clifty sandstone to be exposed in the stream valley where the ground surface drops below about an elevation of 490 ft. The Turkey Creek alluvial aquifer is especially subject to contact with ground water issuing from the Big Clifty Beech Creek aquifer north of well 06C01. South of well 06C01, the alluvial aquifer is more subject to contact with water from the Golconda/Haney because the Big Clifty dips below the level of the alluvial valley floor. Infiltration of surface runoff from the DR into the alluvial aquifers has probably decreased significantly since the construction of the four retention ponds on the slopes of the ridge. The water of Turkey and Boggs Creeks flows southward around the DR ridge of their confluence south of the ridge. The surface water in the creeks is subject to potential contamination issuing from the formations in the creek valleys, in a manner similar to that discussed in the preceding paragraph. The stream water is also susceptible to airborne contaminants and surface runoff, but that discussion is beyond the scope of this report.

The four sedimentation ponds below the DR intercept surface runoff through four main drainageways. The two ponds on the western side of the ridge receive water flowing over Pennsylvanian sediments. Any ground water that seeps from the Pennysylvanian, where it intercepts the ground surface above the levels of the ponds and within their drainage basins, can collect in the ponds. The two ponds on the eastern side of the ridge receive water flowing over Pennsylvanian rocks and the Golconda/Haney limestone. Any ground water seeping into the pond drainage basins from the base of the Pennsylvanian (for example, along the unconformity or from the Golconda/Haney limestone) can collect in the ponds. No seeps have yet been identified in the slopes above the ponds. The sedimentation pond water is currently monitored under another program.

3.4.4 Ground Water Hydrology of the Old Rifle Range

Aquifers and aquicludes

The Big Clifty sandstone and Beech Creek limestone were monitored as one aquifer at the ORR, as they were for the DR. The Beech Creek limestone was the deepest formation monitored at the ORR. Well screens were placed at two levels within the Big Clifty-Beech Creek. Ten- or 20-ft screens were installed near the base of the aquifer and 10-ft screens were installed near the top. The upper screens monitor the uppermost or water-table aquifer at the ORR. Many of the upper screens partially screen the deep soil zone that exists at the ORR. The maximum thickness of Big Clifty-Beech Creek penetrated was 58 ft in boring 06C16. The least penetrated was 26 ft in 06C13. The deeper wells bottom in the Elwren shale aquiclude, which is persistent beneath the entire ORR.

Two wells were installed in the Golconda/Haney limestone. Confirmation well 06-21 was installed in 1983 and RFI well 06C16P3 in 1990 (two other wells in the DR study area also screened the Golconda/Haney). The Golconda/Haney well positions are shown in Figure 3-4. The Golconda/Haney is absent beneath most of the ORR. The wells are set in or near the Indian Springs shale aquiclude. The greatest thickness of Golconda/Haney encountered was 10 ft in boring 06C16.

The thick alluvial soils that occur over much of the ORR constitute part of the uppermost aquifer. The similarity in water levels in wells installed solely in the soil column and wells installed in the upper Big Clifty sandstone indicate that the soils are hydraulically connected with the Big Clifty-Beech Creek aquifer.

Hydraulic characteristics

Ground water flow through the limestones is through systems of connected joints. Flow within the Big Clifty sandstone at the ORR is believed to be through both joints (secondary porosity) and intergranular pores (primary porosity). As mentioned earlier, the Big Clifty and Beech Creek formations beneath the ORR contained more open discontinuities (joints and bedding planes) than the same formations elsewhere in the study area. Abundant low-angle joints and the prominent open discontinuity near the top of the Beech Creek were expected to increase the aquifer's ground water transmissibility. The distortion of ground water elevation contours in the vicinity of the ORR, shown in the northeastern corner of Figures 3-16 and 3-17, supports the conclusion that flow rates through the aquifer are higher there.

The open discontinuity in the Beech Creek limestone is identified in boring logs of borings 06C12, 06C13, 06C14, 06C15, and 06C17. A loss of drilling water return was experienced in the zone in most of the borings. This indicates that the zone transmits water rapidly through the formation.

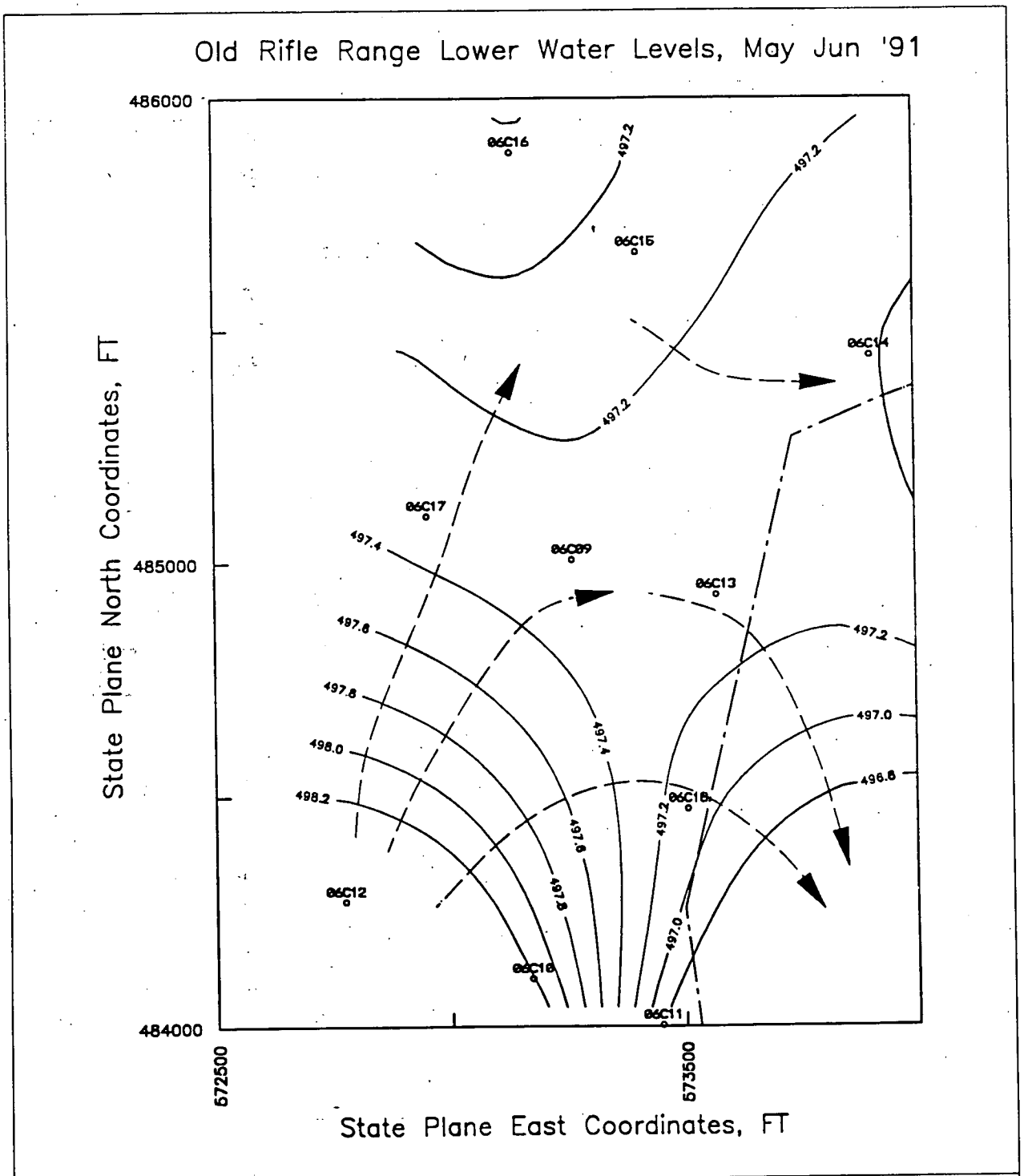
The thick alluvial deposits, which generally occur in the eastern half of the ORR (see Figure 3-12), contain basal gravels expected to have high permeability. The gravel unit is as much as 11 ft thick in borings. Ground water contours indicate some of the ecolluvial soils near the center of the site may also be more permeable to water. The flashing pits are a potential source of ground water contamination. Contaminants would be expected to migrate toward downgradient wells monitoring the sand and gravel unit, possibly wells 06-19, 06C09, 06C13, and 06C18. The statistical and qualitative evaluation of contamination confirmed that those four wells were among the contaminated wells identified.

The top-of-rock (the Big Clifty sandstone) is near the base of the flashing pits and susceptible to infiltration by contaminated runoff. Monitoring well 06-20 and well 06-22 are both screened in the Big Clifty sandstone and are the only wells in which explosives contamination has been detected.

Ground water flow patterns

Ground water flow patterns were determined for the uppermost aquifer (the Big Clifty sandstone and the soils) and the lower Big Clifty-Beech Creek aquifer at the ORR. The levels of the piezometric surfaces are within the Big Clifty and overlying soils over the entire ORR. The aquifer is thus an unconfined, or water table, aquifer and is free to drain under gravity toward lower elevation, in this case, toward the local base level represented by Turkey Creek to the east.

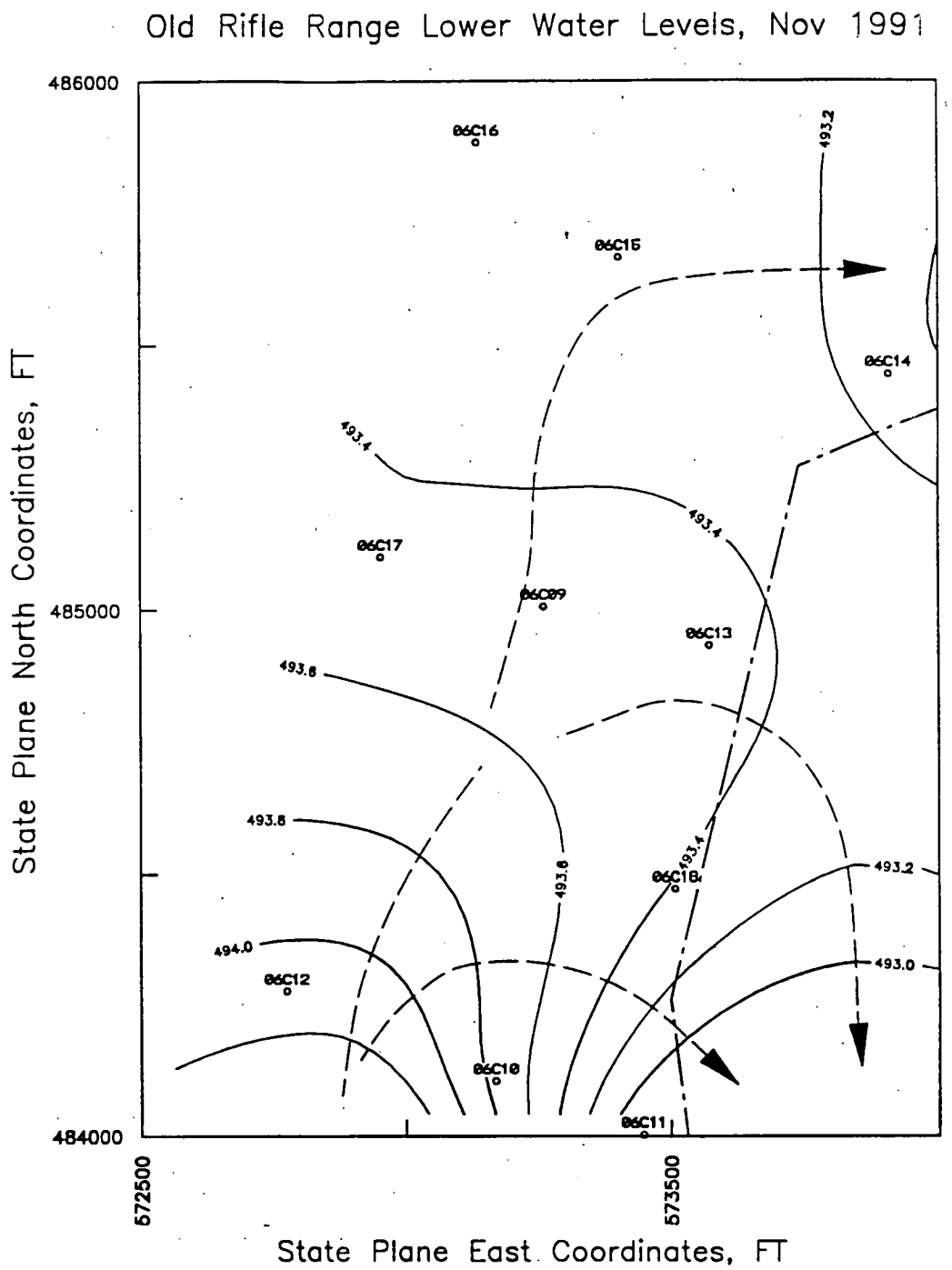
The water-level contour maps for the lower Big Clifty-Beech Creek aquifer at the ORR are presented as Figures 3-19 and 3-20. The lower aquifer at the ORR is the deep aquifer of the DR, discussed earlier. The hydraulic gradient through the lower aquifer is much flatter (little difference in levels between wells) than in the uppermost aquifer (note that the contour interval is only 0.2 ft). The ultimate direction of flow is generally to the southeast. The highest levels are in the southwestern quadrant of the map area near well 06C12, a reflection of local dewatering of the Big Clifty-Beech Creek aquifer from beneath the DR ridge as the aquifer becomes unconfined and free draining. This free-draining aquifer causes the area to be classified as a potential wetland. The hydraulic gradient computed for a lower aquifer flow path from the vicinity of well 06C12 toward the center of the area and out to the southeast was 0.0010 for May-June (Figure 3-19) and 0.0008 for November (Figure 3-21). Flow paths are shown by arrows.



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 27 by William L. Murphy and Roy Wade

Figure 3-19

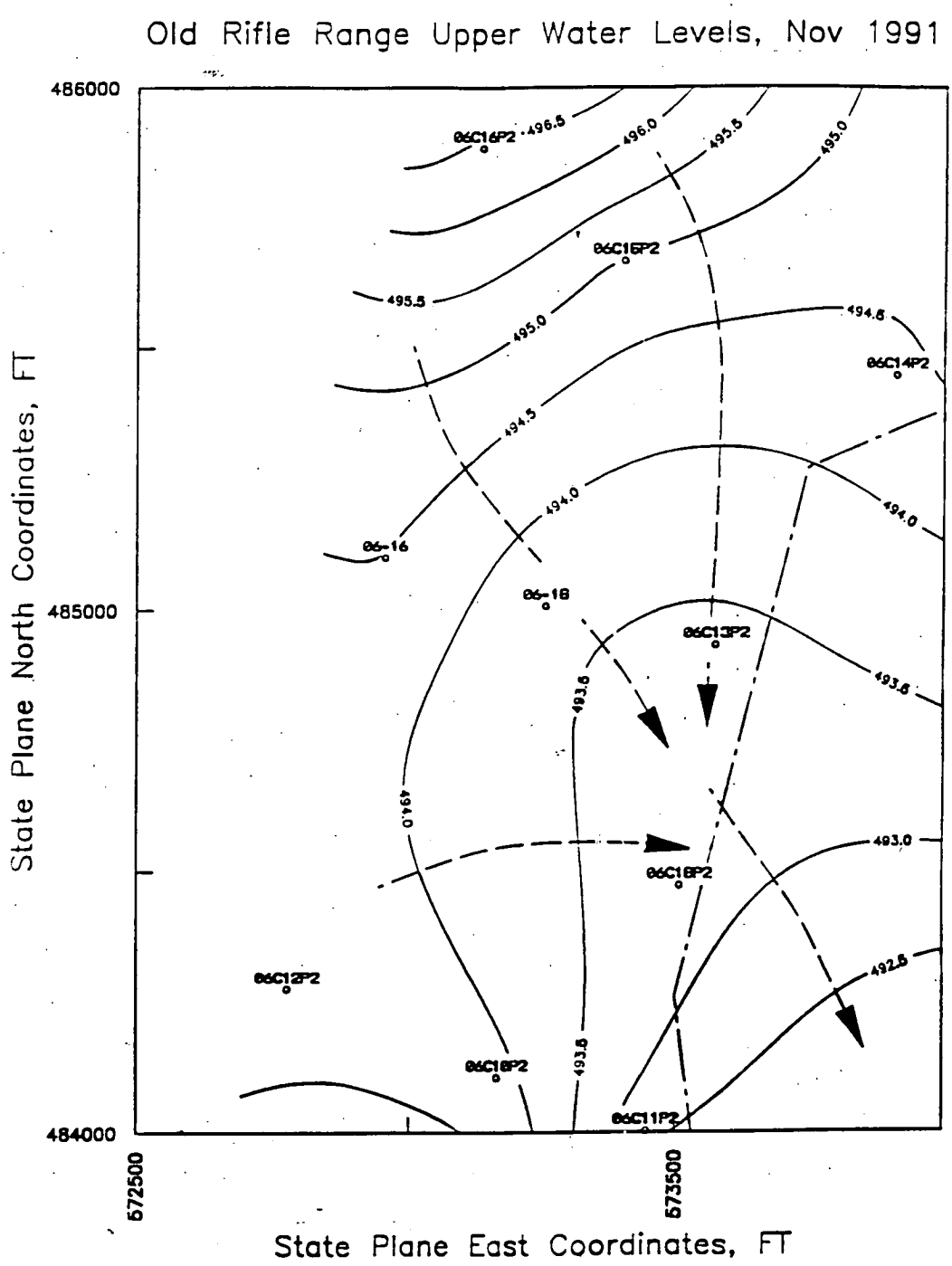
Piezometric Surface, Uppermost Aquifer for May-June 1991, Old Rifle Range Naval Surface Warfare Center Crane, Indiana



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 28 by William L. Murphy and Roy Wade

Figure 3-20

Piezometric Surface for November 1991, Big Clifty/Beech Creek Aquifer, Lower Zone Old Rifle Range Naval Surface Warfare Center Crane, Indiana



Source: Draft Report, RCRA Facility Investigation Phase II Groundwater Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range November 1995 - Figure 26 by William L. Murphy and Roy Wade

Figure 3-21

Piezometric Surface, Uppermost Aquifer for November 1991, Old Rifle Range Naval Surface Warfare Center Crane, Indiana

4.0 TOPOGRAPHIC MAP REQUIREMENTS [40 CFR 270.14(c)(3)]

Topographical map requirements are listed in Section B-2 of the RCRA Part B Permit Application.

5.0 CONTAMINANT PLUME DESCRIPTION [40 CFR 270.14(c)(4)]

This section provides a summary of information on existing plumes of contamination at the ABG, ORR, and DR. This information was obtained from the RFI (Final Report, RCRA Facility Investigation, Phase III, Ground Water Release Characterization, SWMU 03/10, Ammunition Burning Ground Technical Report GL-94-15, May 1994) conducted at the ABG and at the ORR/DR (Draft Report, RCRA Facility Investigation Phase II Ground Water Release Assessment, SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range Naval Surface Warfare Center, Crane, Indiana, William L. Murphy and Ray Wade, November 1995).

5.1 AMMUNITION BURNING GROUNDS

The extent of contamination of ground water by sources at the ABG is discussed for each of the three aquifers described earlier in this report: the uppermost aquifer, the Golconda/Haney limestone; the middle and primary aquifer, the Big Clifty sandstone/Big Clifty limestone; and the lower aquifer, the Beaver Bend limestone. As discussed earlier, the Golconda/Haney limestone and Big Clifty sandstone/Big Clifty limestone form an interconnected aquifer system. The extent of contamination in each aquifer was determined from evaluation of the ground water quality data obtained during the period 1981 through January 1992.

5.1.1 Golconda/Haney Limestone Aquifer

The Golconda/Haney limestone at the ABG was described in Section 3.0. The formation occupies the northern, southern, and western fringes of the ABG site, west and north of the ABG, and south along the ridge between Johnson Hollow and Little Sulphur Creek but is removed by erosion in the center of the ABG site and in the valleys of Johnson Hollow and Little Sulphur Creek to the southwest and east. Ground water flow in the monitored portion of the Golconda/Haney at the ABG is toward the east and north from the west and south, where the formation drains into the valley. Analysis of the Golconda/Haney limestone aquifer indicated that one explosive compound (RDX) was detected, several organic compounds were detected [trichloroethene (TCE), di-n-butyl phthalate, bis(2-ethylhexyl)phthalate, benzene, carbon tetrachloride, and chloroform]. One pesticide (2,4,5-TP) was detected. Four heavy metals (barium, cadmium, mercury, and selenium) were detected. Contamination in the Golconda/Haney, which has been shown to be primarily TCE, is probably limited to the southwestern quadrant of the ABG,

with ultimate migration into the lower Big Clifty/Beech Creek aquifer in the central and eastern portions of the ABG. The detection of TCE may be from well integrity problems. The base of the Golconda/Haney in the vicinity of the ABG is at about 590 ft NGVD minimum, at least 90 ft above the valley floors, and is underlain by the Indian Springs shale aquiclude. Appendix 5-1, plates 19 and 20 show the TCE contamination plumes for the Golconda/Haney wells. Appendix A, plate 1 shows the location of the solvent burn vessels and the well locations.

5.1.2 Big Clifty Sandstone/Beech Creek Limestone Aquifer

The Big Clifty/Beech Creek aquifer, as discussed earlier in this report, is infiltrated, or recharged, by precipitation and runoff in the eastern part of the ABG and is directly accessible by percolating contaminated ground water. In the remaining parts of the ABG, the Big Clifty/Beech Creek Limestone Aquifer is interconnected with the Golconda/Haney Aquifer. The ground water seeping from the Golconda/Haney aquifer eventually infiltrates the Big Clifty/Beech Creek aquifer. There is no evidence that possible contaminants entering the Golonda/Haney aquifer would exit the ABG other than through the Beech Creek aquifer system. Tributary branches join at the ABG but sink into the ground a short distance from the ABG. The tributary flow is derived from ground water in sandstones and possibly from coal seams in the higher Pennsylvania strata and from seeps from the Golconda/Haney limestone. The karst solution channels in the Beech Creek limestone have been shown to transport Beech Creek ground water rapidly to the southeast away from the ABG within the valley of Little Sulphur Creek. The Big Clifty limestone contains joints and bedding planes that have been widened by solution of the limestone by ground water moving through the formation. Some of the solution zones have been enlarged by collapse of the Big Clifty sandstone and Beech Creek limestone into the solution voids. The Sample, the Elwren, and other shales of the West Baden Group form a collective 70 ft of aquiclude to separate the lowermost aquifer, the Beaver Bend limestone, from the higher aquifers. Figure 3-5 shows cumulative void thickness in affected borings. The Elwren shale aquiclude at the base of the Beech Creek disperses the ground water laterally within the Beech Creek. The Beech Creek discharges ground water back to the surface at the springs in the valley of Little Sulphur Creek. The Beech Creek and its springs are exposed in the valley at least as far as 3-1/2 miles south of the ABG. Water discharging from the springs recharges Little Sulphur Creek year round.

Only barium was shown to be present outside the ABG site proper. Spring A was sampled alone in February 1990 following the first dye tracer test. Notable compounds detected were as follows: Spring A recorded detected levels of RDX on five occasions at amounts as high as 0.14 mg/l and TNT on one

event (0.03 mg/l). Spring A also recorded the heavy metal barium three times (maximum level was 0.14 mg/l). Nitrates (as N) were detected in Spring A three times but at levels below the MCL of 10 mg/l. Spring A indicated gross beta radiation greater than the MCL of 4 mrem/y on three occasions. Spring B recorded TCE at 0.139 mg/l once and barium twice. Spring B indicated gross alpha radiation above the MCL of 15 pCi/L once and gross beta once above the MCL. Spring C is located on the eastern side of the valley of Little Sulphur Creek and north of Spring A. Spring C recorded RDX at the detection limit (0.02 mg/l) and TCE on one event each and barium twice. Nitrates (as N) were detected in Spring C three times at about the same levels as in Spring A. Spring C indicated gross beta at 7.7 mrem/y (above MCL) once. Spring C was shown by tracer tests to discharge ground water originating at the ABG only at high flow, for example, following periods of high or extended precipitation. Spring C and other springs would be more effectively monitored by a sampling system or program that sampled on demand, i.e., during high flow conditions. Spring D recorded RDX once at 0.03 mg/l, TCE once at 0.016 mg/l, and barium once. Spring D indicated gross beta above MCL of 4 mrem/y twice and gross alpha at the MCL of 15 pCi/L twice.

Spring E recorded barium and di-n-butyl phthalate once each. Spring E indicated gross beta once above MCL.

Spring F recorded mercury once at 0.002 mg/l and barium twice. Mountain Spring recorded methoxychlor once at 0.100 mg/l and barium twice. Spring F indicated gross alpha and beta radiation above MCL once.

Springs B, D, E, and F showed the high values of gross alpha and beta radiation on the April 1991 sampling date only. The reported values of gross radiation for the date are suspect. Other parameters detected in Springs B, D, E, and F were below primary MCLs. There were some parameters above secondary MCLs on some sampling dates.

The dye tracer test confirmed the hydraulic connection to the ABG of the Beech Creek limestone conduits that feed Spring A. Dye trace results indicated that Spring C was hydraulically connected to the ABG under limited conditions and to Spring B under even more restricted conditions. Springs A, B, and C release their ground water to surface drainage that ultimately enters Little Sulphur Creek south of the ABG. Any remediation or future monitoring of release to the Beech Creek aquifer of ABG contaminants should accommodate the area of Springs A, B, and C and of the surface waters released from them.

Little Sulphur Creek discharges its waters into its alluvium and downstream beyond the boundary of NSWC Crane. The alluvial wells (03B01 through 03B09) have not shown persistently detectable levels of contaminants attributable to ABG activities except for the heavy metal barium. Surface water and bottom sediment sampling of Little Sulphur Creek was conducted in the spring and in the summer (two rounds) of 1992. Preliminary analysis of the data indicates that certain explosives, organic compounds, metals, and nitrates have accumulated in the surface water and bottom sediments of Little Sulphur Creek. Two of 11 surface water sampling sites, located immediately below and 1/4 mile below the ABG site, generally showed higher frequency and quantity of explosives and metals contamination than the other sites. Explosives in sediments generally were detected at more sites and at higher levels within the ABG site than below it. Generally, contaminants were detected more frequently in bottom sediments of Little Sulphur Creek than in its waters.

Contamination by explosives of the ground water of the Big Clifty/Beech Creek system and to the surface water and the alluvial ground water that it recharges south of the ABG extends south beyond the ABG at least as far as the mouth of Spring A and the vicinity of monitoring well 03C38 in Little Sulphur Creek. Other compounds, including certain volatile organics and heavy metals, occur in the waters as far south as the NSWC Crane boundary across Little Sulphur Creek.

5.1.3 Beaver Bend Limestone Aquifer

The Beaver Bend limestone aquifer was shown to be hydraulically separate from the Big Clifty/Beech Creek aquifer, exhibiting a piezometric differential of some 35 to 45 ft (Hunt, 1988). Explosives, organics, and heavy metals were detected in the Beaver Bend but at relatively low concentrations compared to levels in the Big Clifty/Beech Creek. The five wells monitoring the Beaver Bend are in the ABG site proper (wells 03C01, 03C02, 03C03, 03C08A, and 03C09). Table 5-1 lists the detected compounds and their results. It is not possible to determine the extent of contamination in the Beaver Bend beyond the ABG without further well emplacement, if action levels for detected contaminants necessitate expansion of the monitoring program. One of the existing Beaver Bend wells (03C03) will continue to be monitored to determine its ground water quality. Appendix 5-2 contains the full nature and distribution of ground water contamination conducted at the ABG. Appendix 5-1, plates 14 through 18 show the plume, concentrations, and constituents for the Beech Creek wells.

Table 5-1
Group 1: Drinking Water Standards, Number of Times Detected[1]

Well Number	Parameter	As	Ba	Cd	Cr	Pb	Hg	Nitrate-N	Se	Ag	Endrin	Lindane	Methoxychlor	Toxaphene	2,4-D	2,4,5-TP
	DET LIM	0.05	0.05	0.01	0.01	0.05	0.002	0.1	0.01	0.05	0.0002	0.004	0.1	0.005	0.1	0.01
03B01		ND	4	ND	ND	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND
03B02		ND	5	ND	ND	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND
03B03		ND	6	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
03B05		ND	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
03B06		ND	3	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
03B07		ND	1	ND	ND	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND
03B08		ND	1	ND	1	ND	1	ND	1	ND	ND	ND	ND	1	ND	ND
03B09		ND	ND	ND	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND
03B10		ND	ND	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C01P2		ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1	ND	ND
03C02P2		ND	4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C04		ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C07		ND	2	1	ND	1	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C08P2		ND	6	ND	ND	ND	ND	4	ND	ND	ND	ND	ND	ND	ND	ND
03C09P2		ND	ND	ND	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND
03C10		ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

(Continued)

[1] ND: parameter was not detected for any period. Numbers represent the number of periods a parameter was detected.

Table 5-1 (concluded)

Well Number	Parameter	As	Ba	Cd	Cr	Pb	Hg	Nitrate-N	Se	Ag	Endrin	Lindane	Methoxychlor	Toxaphene	2,4-D	2,4,5-TP
	DET LIM	0.05	0.05	0.01	0.01	0.05	0.002	0.1	0.01	0.05	0.0002	0.004	0.1	0.005	0.1	0.01
03C11		ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C12		ND	4	1	ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C13		ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C14		ND	ND	1	ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C15		ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C17		ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C19		ND	ND	1	ND	1	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C22		ND	2	ND	ND	1	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C25		ND	ND	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C27		ND	1	ND	ND	ND	ND	ND	ND	ND	2	ND	ND	ND	ND	ND
03C28		ND	ND	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C29		ND	1	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C30		ND	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
03C31		ND	7	ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

5.2 DEMOLITION RANGE AND OLD RIFLE RANGE

Statistical analysis of metals detected over four rounds of sampling from the DR and ORR monitoring wells provided evidence of contamination in some wells by the following metals: aluminum, arsenic, beryllium, cobalt, manganese, nickel, and zinc at the DR and arsenic, manganese, and nickel at the ORR. The following metals were considered borderline contaminants (i.e., their statistical values were just below tabulated critical values): cadmium and chromium at the DR and zinc at the ORR.

Non-statistical evaluation of explosives and nitrates indicated contamination of a centrally located group of ORR wells by TNT, RDX, and nitrates.

Contamination is limited to specific wells or groups of wells. Two figures (Figures 5-1 and 5-2) are provided to show the location of the named contaminants. Figure 5-1 shows the distribution of contaminants in the DR wells and Figure 5-2 shows the distribution of contaminants in the ORR wells. In addition, Appendix 5-3 contains figures that show the plume distribution of specific chemicals in the ORR. Figure 5-3 shows the TNT plume. Figure 5-4 shows the RDX plume. Figure 5-5 shows the nitrates plume.

Appendix 5-3 contains the full nature and distribution of ground water contamination conducted by the US Army Corps of Engineers.

Summary of Contaminated Occurrence in the Demolition Area

The only contaminants occurring in the DR were metals. Statistical analysis of metals in the lower (Big Clifty/Beech Creek) aquifer of the DR identified only aluminum, arsenic, and manganese as significant contaminants. Although these contaminants were found in the lower aquifer, none of the boundary wells showed the presence of these contaminants. Surface detection monitoring will continue in the DR.

The following contains a detailed discussion of the occurrence of metal contamination in the DR.

Barium, copper, and antimony persisted in four rounds of sampling in Big Clifty/Beech Creek wells monitoring the DR. The initially selected background well, 06C08, was actually as high or higher in several metals (nickel, antimony, copper, arsenic, aluminum, and zinc) than the other wells. Conversely, 06C08 was one of few wells with relatively low levels of the otherwise ubiquitous compound, barium. Metals are persistent in monitoring wells at other SWMUs at NSWC. Certain metals are likely

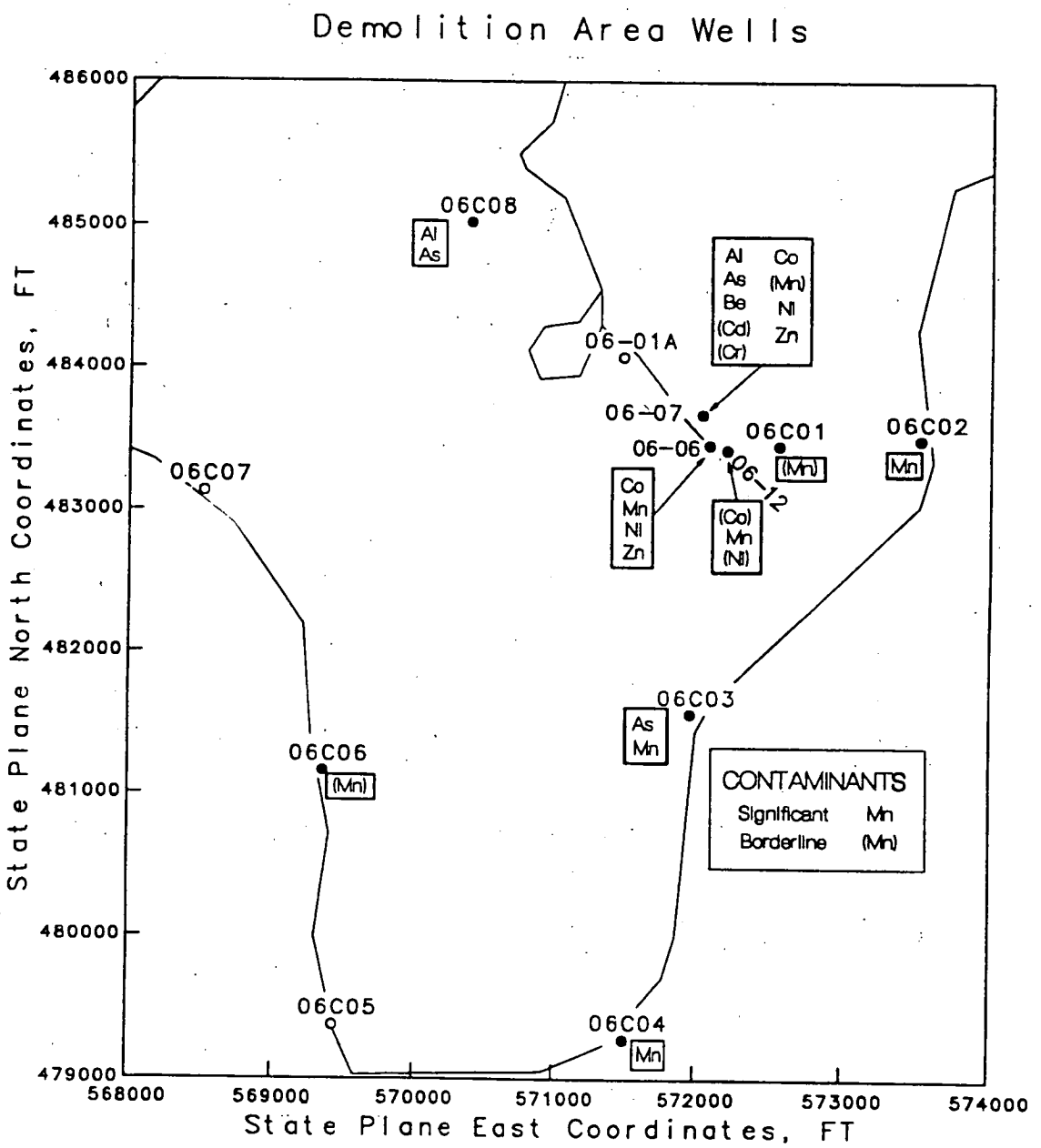


Figure 5-1 Statistically significant and borderline significant contaminants in Demolition Area wells.

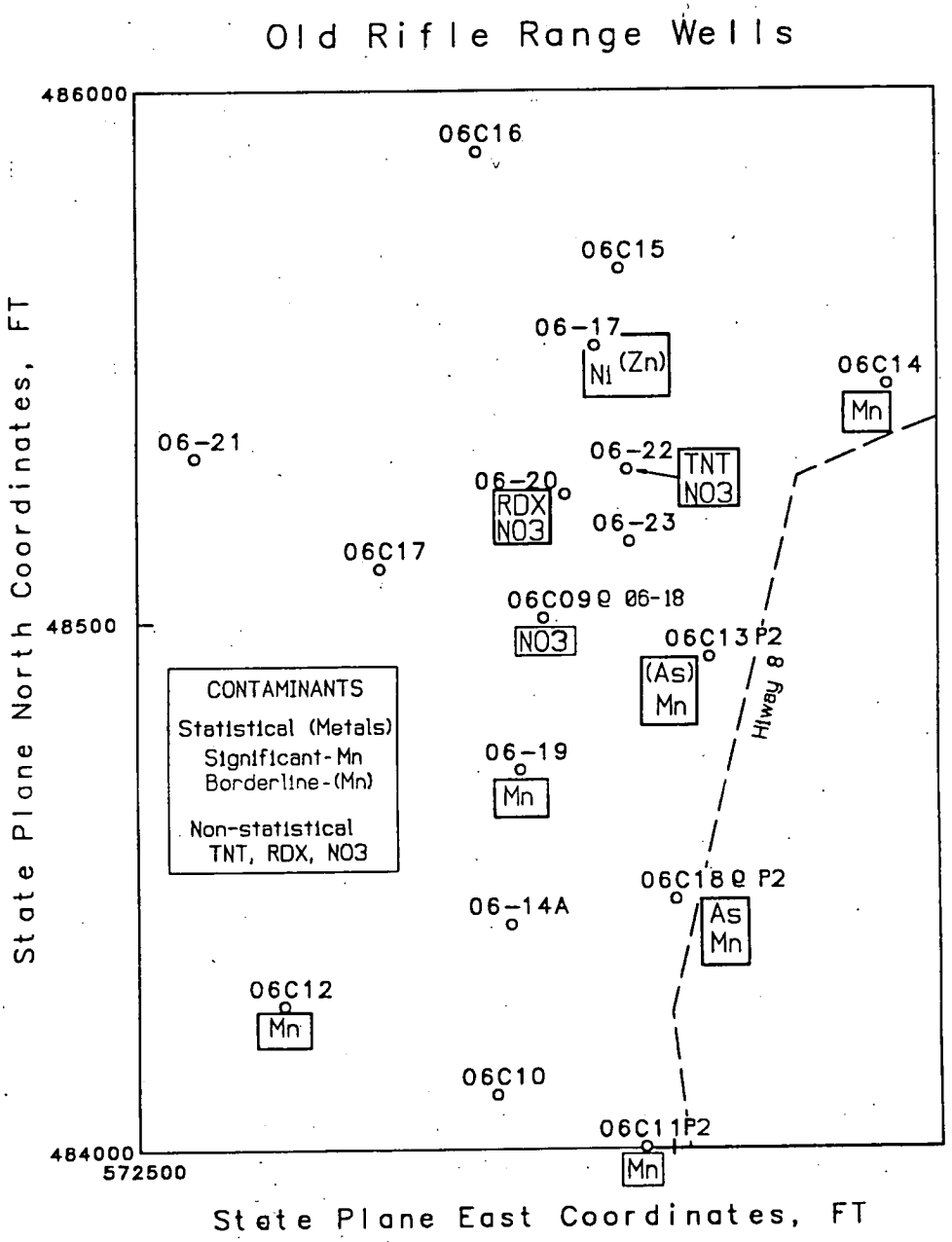


Figure 5-2. Statistically significant and borderline significant, and non-statistical contaminants in Old Rifle Range wells. Results of four rounds of sampling. Explosives shown only for wells with amounts > detection limit.

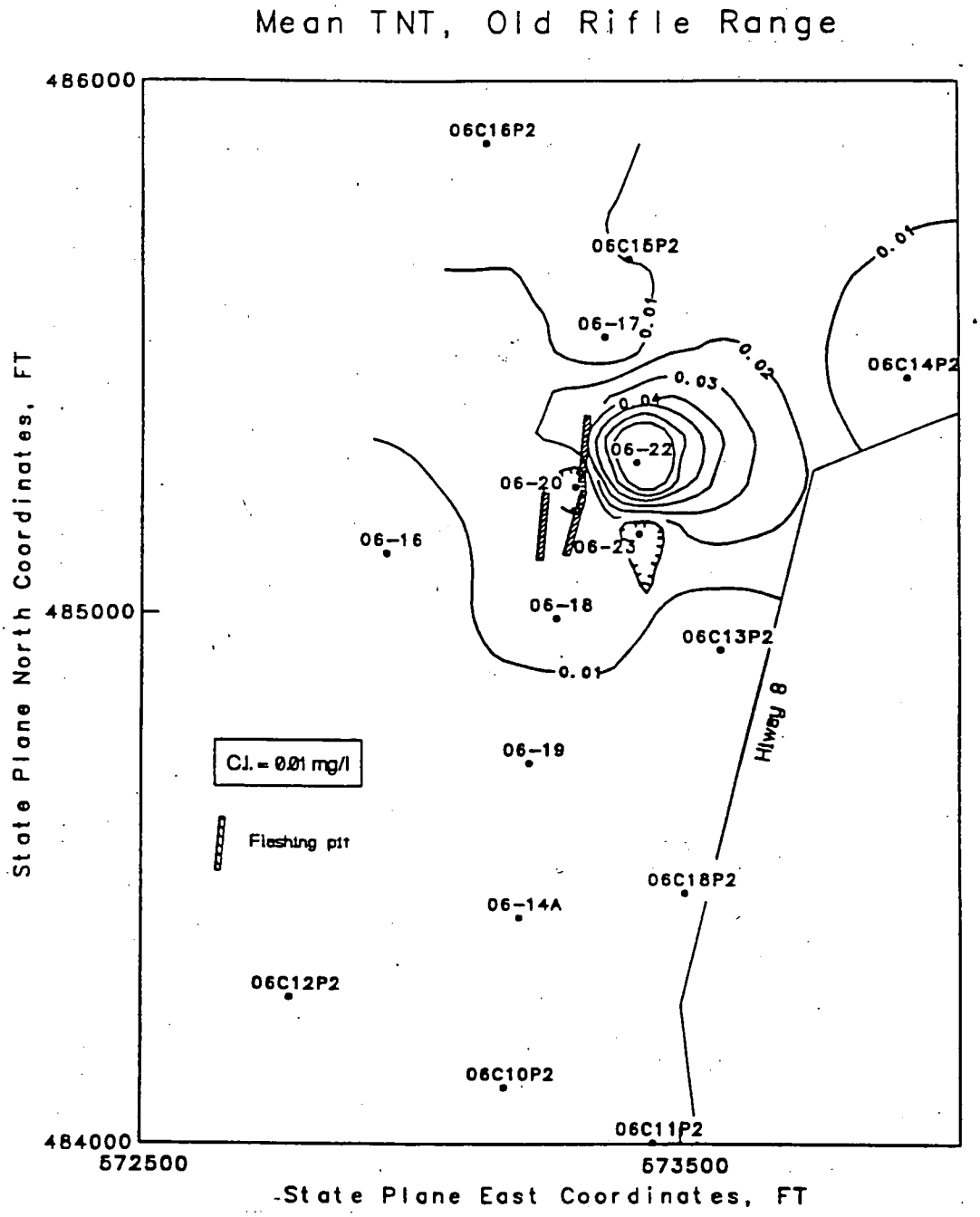


Figure 5-3 Mean values of TNT (four rounds), Old Rifle Range.

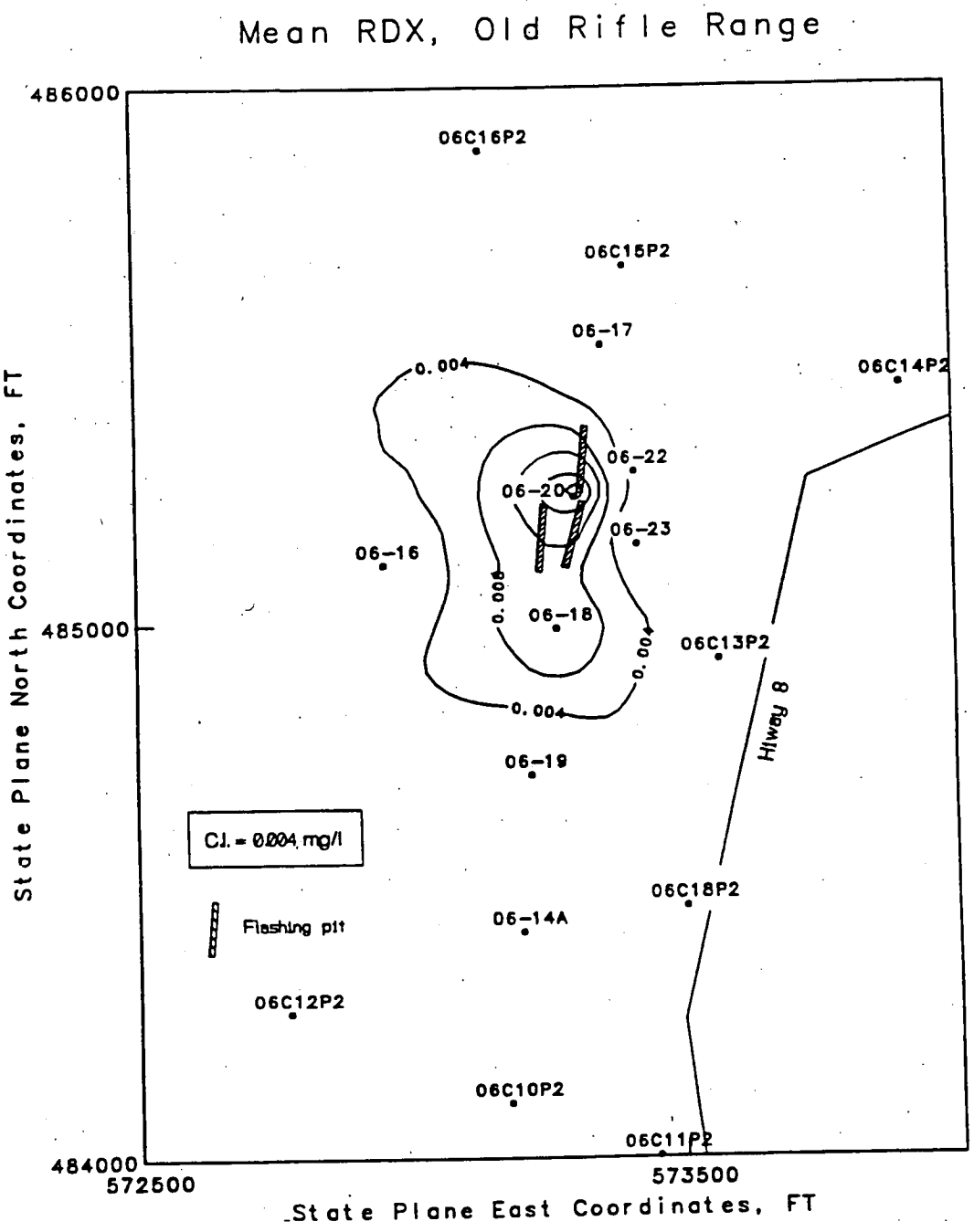


Figure 5-4 Mean values of RDX (four rounds), Old Rifle Range.

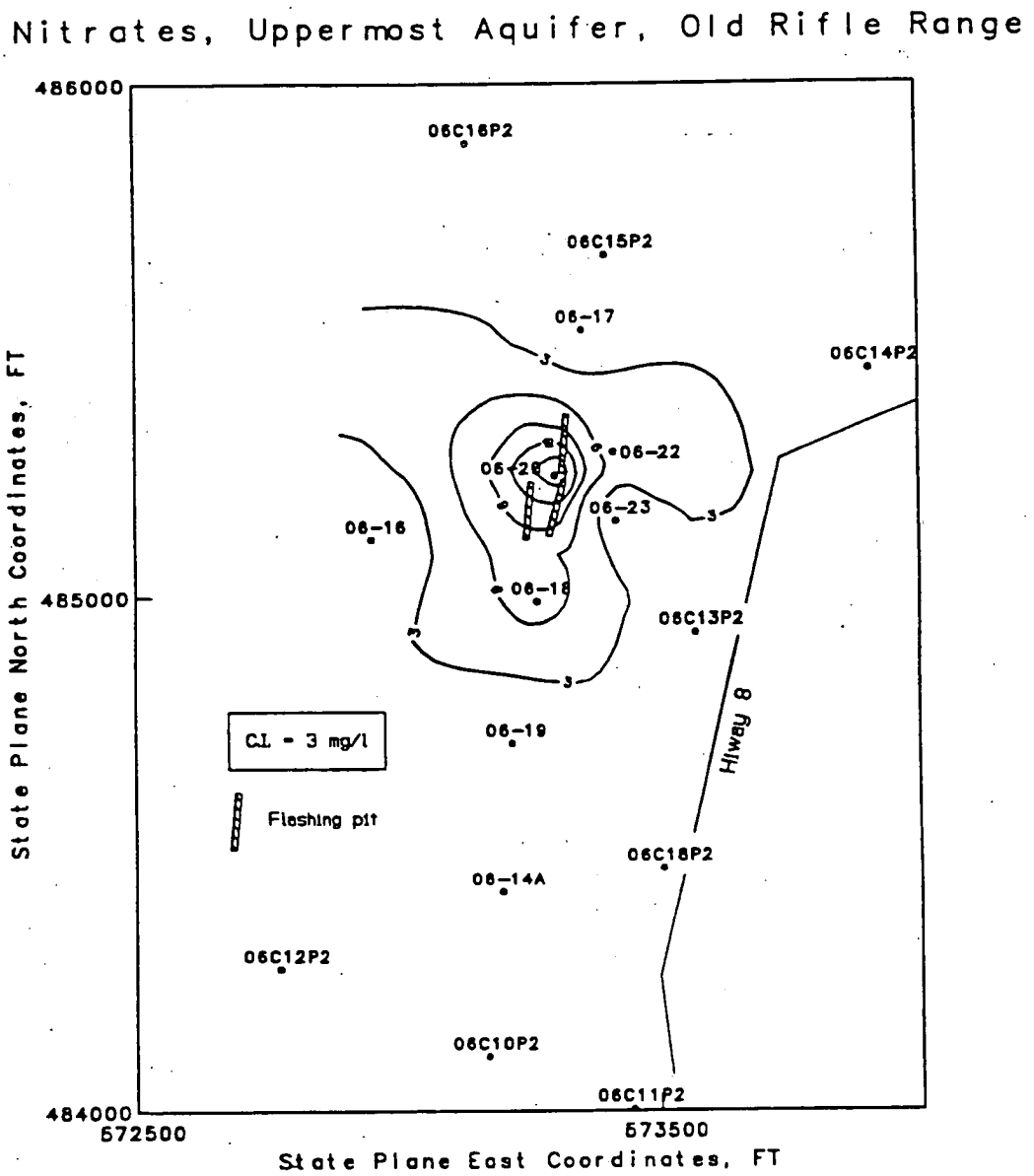


Figure 5-5 Levels of nitrates of at least 3 mg/l, Old Rifle Range (fourth round).

contaminants from the ordnance operations within NSWC, including DR activities, but may be present in the natural rocks and soils as well. Additional background evaluation for metals base-wide is needed.

The persistent metals barium, copper, and antimony are concluded to be naturally occurring (background) components of the Big Clifty/Beech Creek aquifer or artifacts of rinsates and field blanks (copper and antimony occurred in the rinsate blanks at comparable levels). The metal antimony was detected at a level above the MCL (0.01 mg/l) in all wells in the second sampling round (but is probably attributable to sampling artifacts). No other metals were detected at levels above the MCL in Big Clifty/Beech Creek wells.

Occurrence of the metals vanadium, cadmium, and beryllium was limited to the shallow wells in the northeastern portion of the DR operations area. Cadmium and beryllium were above the MCL (0.005 mg/l for cadmium; 0.001 mg/l for beryllium) in well 06-07. The levels and the statistically significant occurrence of these metals and of zinc, nickel, aluminum, arsenic, manganese, and cobalt in wells 06-06, 06-07, and 06-12, which are within 300 ft. of each other, imply that the uppermost ground water in that isolated area is being contaminated by a local source. Wells 06-01A and 06C01P3, which are 650 ft. west and 350 ft. east, respectively, of the group of wells, had essentially no significant levels of the metals (with the possible exception of manganese in 06C01P3). Additional sampling of surface and shallow soils and continued monitoring of the wells will be necessary to confirm contamination and to delineate its source.

Iron and magnesium were markedly high in at least six DR wells.

Summary of Contaminant Occurrence in the Old Rifle Range

Both metals and explosives were identified as contaminants. Statistical analysis identified only arsenic, nickel, and manganese as significant contaminants in the uppermost aquifer. Explosives were detected in only five wells, all within the northern half of the ORR. Because both metals and explosives were detected in boundary wells, compliance monitoring will be conducted in the ORR.

The following is a detailed discussion of the occurrence of contaminants in the ORR.

Barium, copper, and antimony persisted in four rounds of sampling in upper and lower alluvial, Big Clifty and Beech Creek wells monitoring the ORR but are considered background (naturally occurring) or artifacts of sampling rinsates or field blanks. Chromium and arsenic were detected several times in upper

and lower zone wells in the southeastern (downgradient) quadrant of the ORR, and nickel was detected in the upper zone wells of the northern half. Nickel was detected at relatively high values (>0.1 mg/l, where MCL = 0.1 mg/l) one time in two shallow wells close to the flashing pits and consistently and statistically in 06-17, located about 200 ft. north of the pits.

The metal antimony was detected at a level above the MCL (0.01 mg/l) in most of the ORR wells in many sampling rounds (antimony was not statistically significant, however, when compared to background levels). Nickel was detected at levels above its MCL of 0.1 mg/l in three wells on one occasion each (including the two shallow wells near the flashing pits). All other metals detected were below their MCLs.

The secondary MCL metals iron and magnesium were markedly higher in a few wells.

The levels of metals detected in the ground water of the Golconda/Haney were noticeably less than in other aquifers of the study area. Barium, copper, and antimony were most persistent but occurred at lower levels than in other aquifers. Nickel was detected twice in well 06-21, zinc once in 06C04P2, and arsenic once in 06C16P3. Chromium, lead, and aluminum were not detected. Antimony was above its MCL in six samples, but both copper and antimony were determined to be probably sampling artifacts.

Statistical analysis was not conducted for the Golconda/Haney because of the limited number of wells.

Wells 06-21 and 06C04P2 were markedly high in the secondary MCL metal magnesium (means of 84.8 mg/l and 48.7 mg/l, respectively).

Explosives and Related Compounds

Explosives. Eight explosives compounds were monitored for four rounds; nitrates and nitrites were monitored for the fourth round only. TNT, RDX, and HMX were the only explosives detected in the DR/ORR study area, and they were detected in only five wells, all within the northern half of the ORR. Seven of the 13 detection events for explosives were of "J" values (estimated values below detection limit). The only HMX detection was a "J" value in well 06C09.

Values of any explosives above detection limit were recorded only in wells 06-20 and 06-22, both shallow wells near the flashing pits.

TNT occurred in well 06-22 in all four sampling rounds at levels above its detection limit. The highest TNT value was 0.148 mg/l in the first round. Measured TNT levels decreased with each succeeding round. RDX occurred twice above detection in well 06-20. All other explosives recorded were below detection limits.

The highest levels of explosives were in the shallow wells 06-20 and 06-22 near the flashing pits. No explosives compound was detected more than once in deep wells (06C09 and 06C15) and then only at "J" levels. Explosives apparently are migrating from the source area through the aquifer very slowly, if at all.

6.0 GENERAL GROUND WATER MONITORING REQUIREMENTS [40 CFR 270(c)(5), 40 CFR 264.97]

40 CFR 264.97 contains general ground water monitoring requirements that must be followed for any ground water monitoring program that is developed to satisfy Section 264.98 (Detection monitoring), 264.99 (Compliance Monitoring Program), or 264.100 (Corrective Action Program). This section contains a discussion of each of these requirements and how each requirement is met in the ground water monitoring systems at each of the regulated units (ABG, ORR, and DR).

Permitting and closure are also factors at these units. NSWC will operate the ABG, ORR, and DR as permitted facilities, which are subject to 40 CFR 264 Subpart F ground water monitoring requirements. Compliance with 40 CFR Subpart F is also a permit condition. Closed surface impoundments on the ABG are subject to closure/post-closure ground water monitoring requirements. Therefore, at the ABG, the ground water monitoring system will also serve as the closure/post-closure monitoring system for the closed surface impoundments.

6.1 GROUND WATER MONITORING SYSTEM [40 CFR 264.97(a) AND (b)]

40 CFR 264.97(a) requires the ground water monitoring system to consist of a sufficient number of wells, installed at appropriate locations and depths to yield ground water samples from the uppermost aquifer that represent the quality of background water that has not been affected by leakage from a regulated unit; represent the quality of ground water passing the point of compliance; and allow for the detection of contamination when hazardous waste or hazardous constituents have migrated from the waste management area to the uppermost aquifer. 40 CFR 264.97(b) states that, where a facility contains more than one regulated unit, separate ground water monitoring systems are not required for each regulated unit if provisions for sampling the ground water in the uppermost aquifer will enable detection and measurement at the compliance point of hazardous constituents from the regulated units that have entered the ground water in the uppermost aquifer. The uppermost aquifer is defined in 40 CFR 260.10 as the geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically connected.

The ground water monitoring system wells to be sampled under the direction of this Ground Water Monitoring Plan and the Field Sampling Plan (TtNUS, 1998a) were installed as a part of a RCRA Facility Investigation performed at the ABG (Murphy, 1995) and RFIs performed at the ORR and DR (Murphy and Wade, 1994 and 1995). The locations of all existing wells proposed for monitoring at the ABG, DR, and

ORR are provided on Figures 6-1, 6-2, and 6-3, respectively. Further investigations are necessary to determine which wells will be selected for ground water monitoring at the Old Jeep Trail.

All wells at the ORR and DR are installed in the uppermost aquifer. In the case of the ABG, wells are installed in two aquifer systems, the Golconda/Haney and the Beech Creek, which are interconnected aquifers, and the Beaver Bend, the lower aquifer.

6.2 MONITORING WELL CONSTRUCTION DETAILS [40 CFR 264.97(c)]

40 CFR 264.97(c) requires that all monitoring wells must be cased in a manner that maintains the integrity of the monitoring well borehole. This casing must be screened or perforated and packed with gravel or sand where necessary to enable collection of ground water samples. The annular space (i.e., the space between the borehole and well casing) above the sampling depth must be sealed to prevent contamination of samples and the ground water.

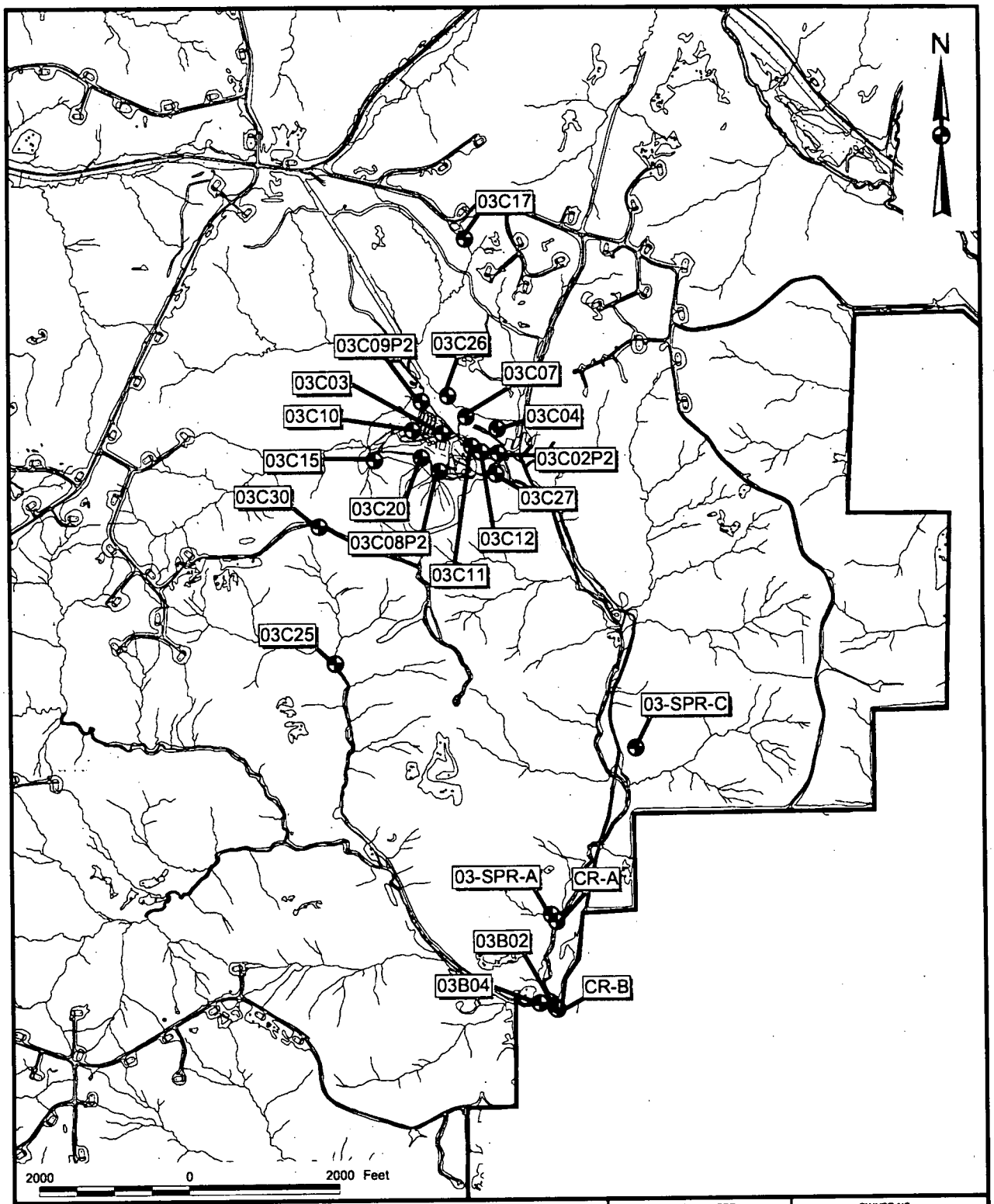
All monitoring well locations at the ABG, ORR, and DR have been surveyed. Monitoring well horizontal locations are surveyed to the nearest 0.10 ft. Vertical elevations are referenced to the NGVP. Monitoring well elevations and ground surface elevations are surveyed to the nearest 0.01 ft. All wells were surveyed vertically at a measuring point where the uncapped well riser is notched and at the top of the protective casing. Appendix C of the approved FSP contains boring logs and as-built well construction diagrams.

6.2.1 Ammunition Burning Grounds Monitoring Wells

A total of 98 monitoring wells have been installed in the ABG as a part of the field investigation for the RFI (Murphy, 1994). Eighteen of the monitoring wells have been selected to be sampled as a part of the long-term ground water monitoring plan at the ABG. Each of these wells was constructed of 2-inch-diameter polyvinyl chloride (PVC) or Teflon riser and well screen. Each of the wells was installed with 10-ft-long well screens. Table 3-2 summarized the ABG ground water monitoring well construction details for the long-term RCRA monitoring program. Figure 6-4 shows a typical well installed at the ABG. Additional information is provided in the RFI report for the ABG (Murphy, 1994).

6.2.2 Old Rifle Range Monitoring Wells

Twelve monitoring wells from the ORR have been selected to be sampled as part of the long-term ground water monitoring plan at the ORR under the RCRA permit. Each of these wells was constructed of



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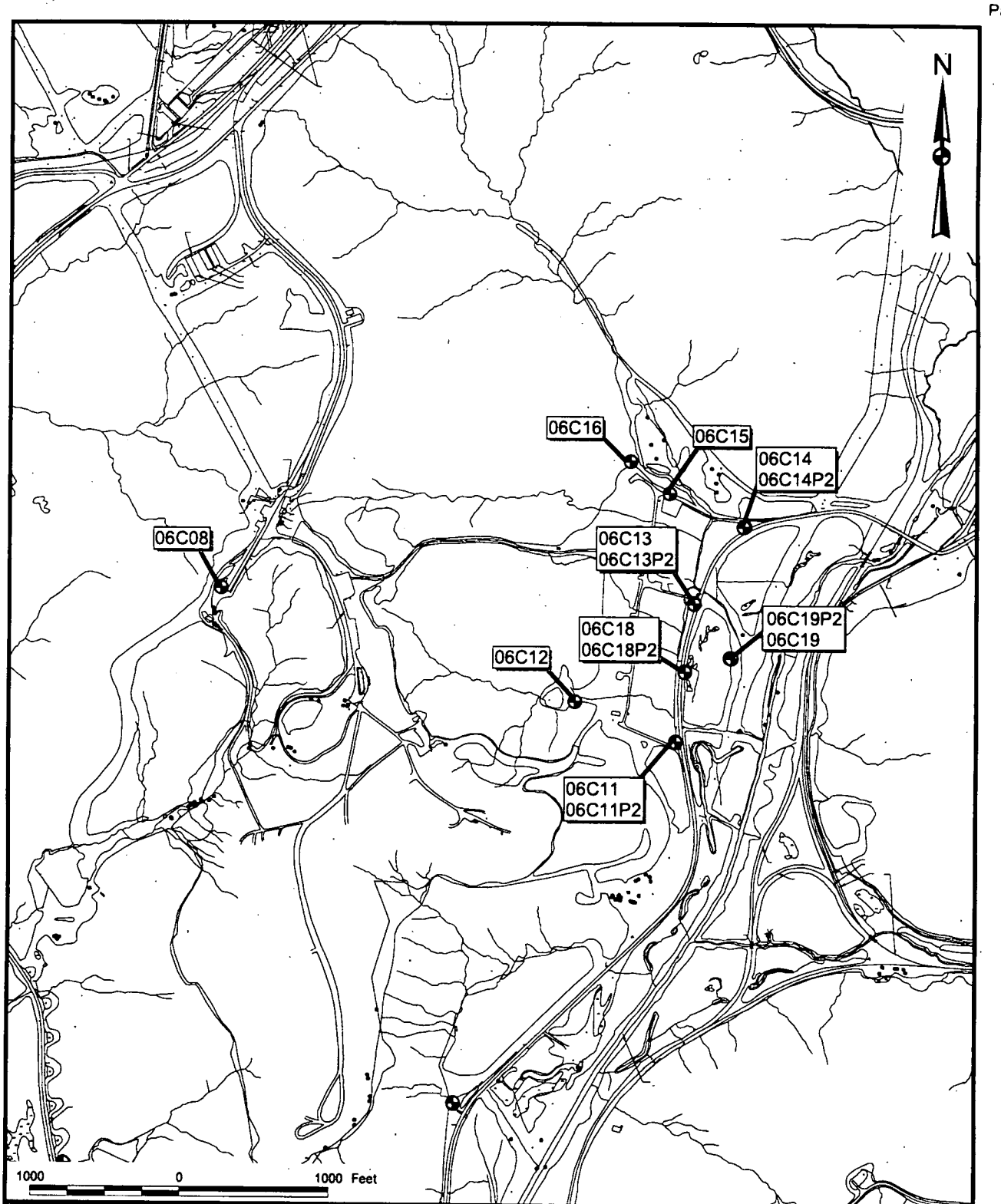
CHECKED BY — DATE —	MONITORING LOCATIONS AMMUNITION BURNING GROUNDS NAVAL SURFACE WARFARE CENTER CRANE, INDIANA	APPROVED BY — DATE —	
COST/SCHEDULE-AREA		APPROVED BY — DATE —	
SCALE AS NOTED		DRAWING NO. Figure 6-1	REV 0

P:\GIS\CRANE\CRANE.APR 5/5/99 JAL Figure 3-1



DRAWN BY S. TABLER — DATE 11/13/97	Tetra Tech NUS, Inc.	CONTRACT NUMBER CTO-038	OWNER NO. —
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COST/SCHEDULE-AREA		APPROVED BY — DATE —	
SCALE AS NOTED		DRAWING NO. Figure 6-2	REV 0

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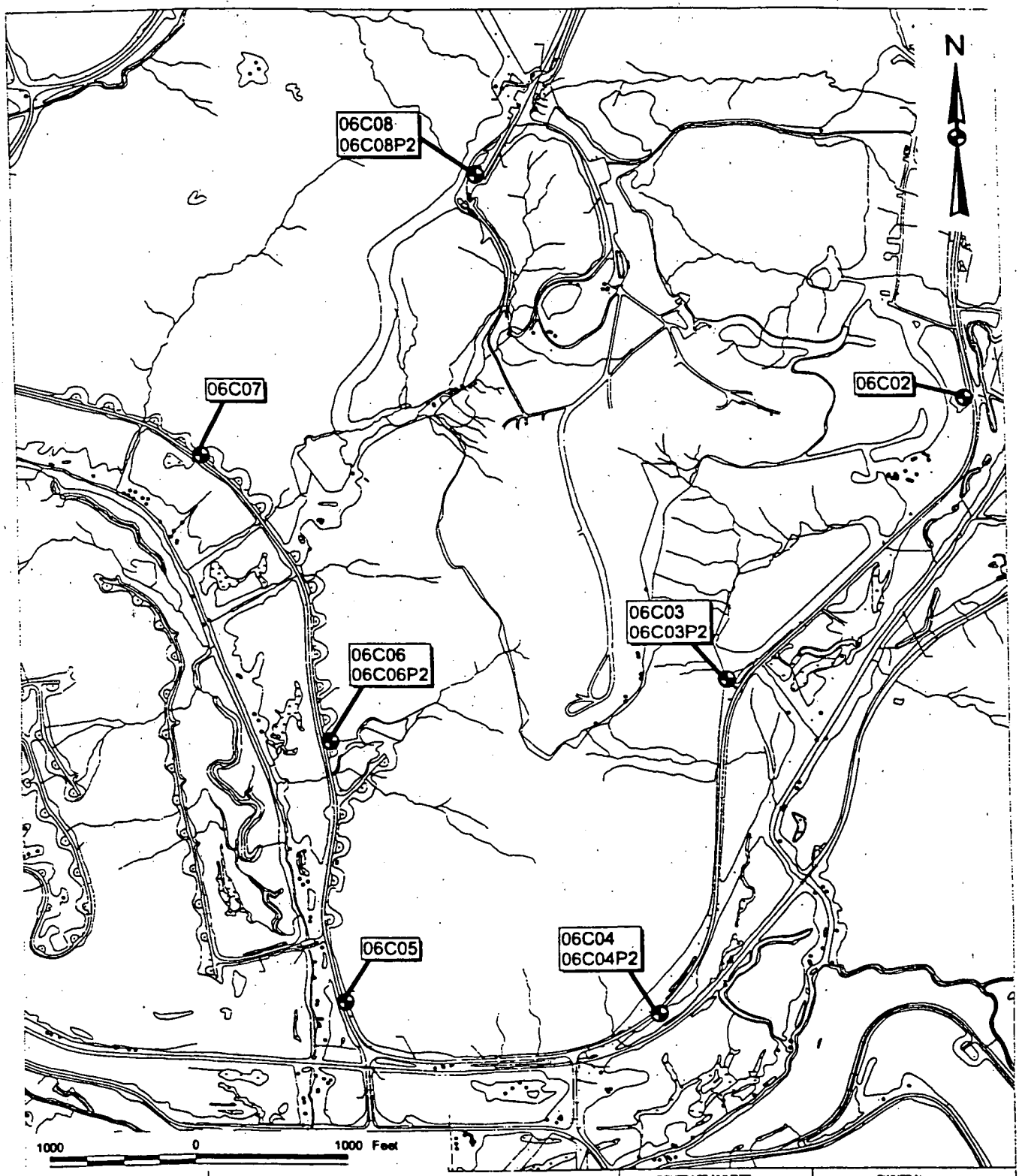

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COST/SCHEDULE-AREA		APPROVED BY — DATE —	
SCALE AS NOTED		DRAWING No. Figure 6-3	REV 0

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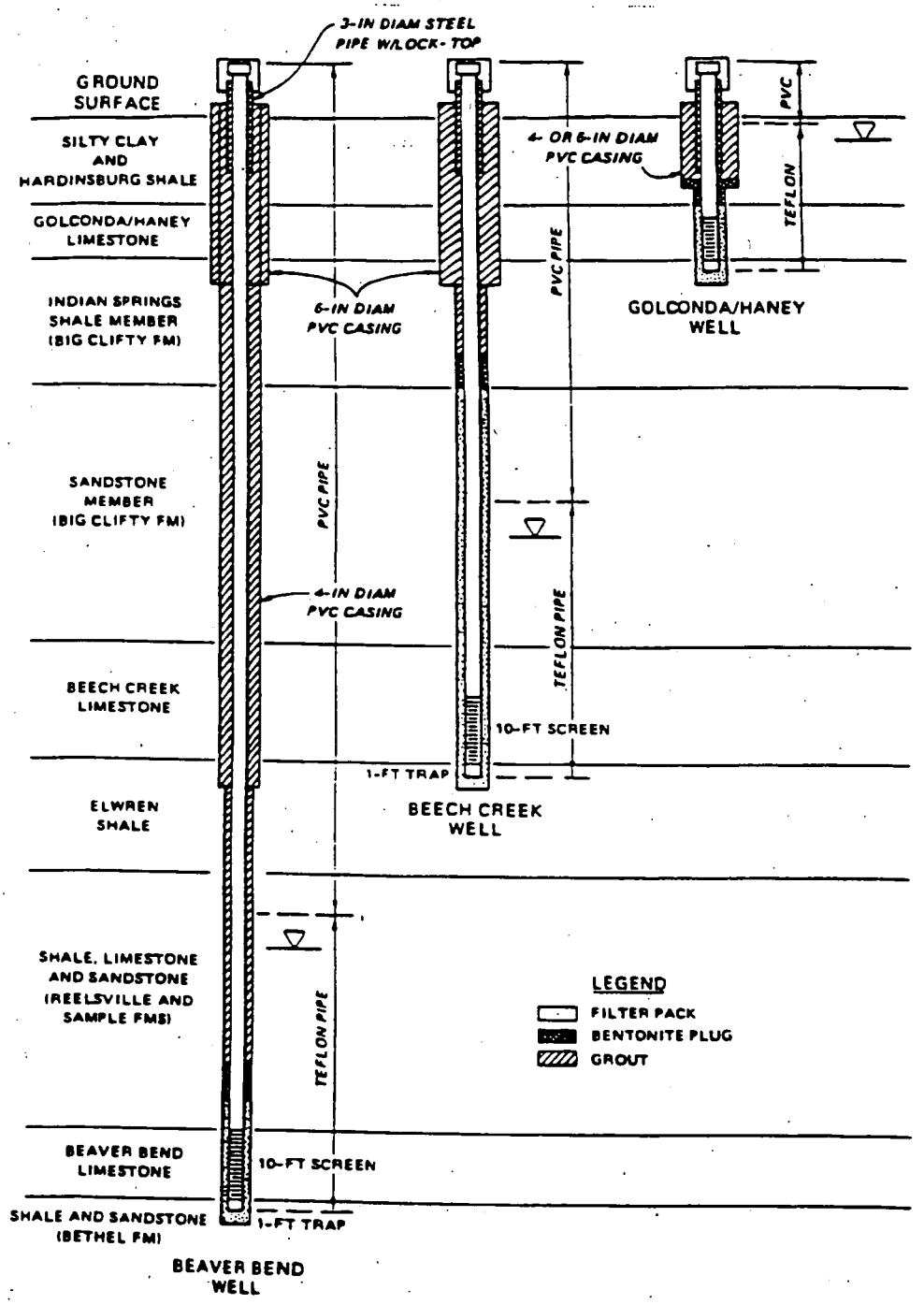


Source: Final Report, RCRA Facility Investigation Phase III, Groundwater Release Characterization, SWMU 03/10. Ammunition Burning Ground Volume I, William L. Murphy, May 1994-Figure 6

Figure 6-4

Well Installation Diagrams for the Ammunition Burning Grounds Naval Surface Warfare Center Crane, Indiana

2-inch-diameter, PVC riser pipe and well screens. The well screens range in length from 10 to 40 ft. A 40-ft well screen was used for monitoring well 06C08 because it was not clear during drilling and logging of the boring where formation water was entering the boring. Twenty-ft screens were used in the Big Clifty/Beech Creek aquifer to ensure interception of flow zones. All other well screens were 10 ft in length. Table 3-2 summarized the well construction details for the long-term RCRA monitoring program wells at the ORR. Figure 6-5 shows typical wells installed at the ORR. Additional information is provided in the RCRA RFI for the ORR (Murphy and Wade, 1995).

6.2.3 Demolition Range Monitoring Wells

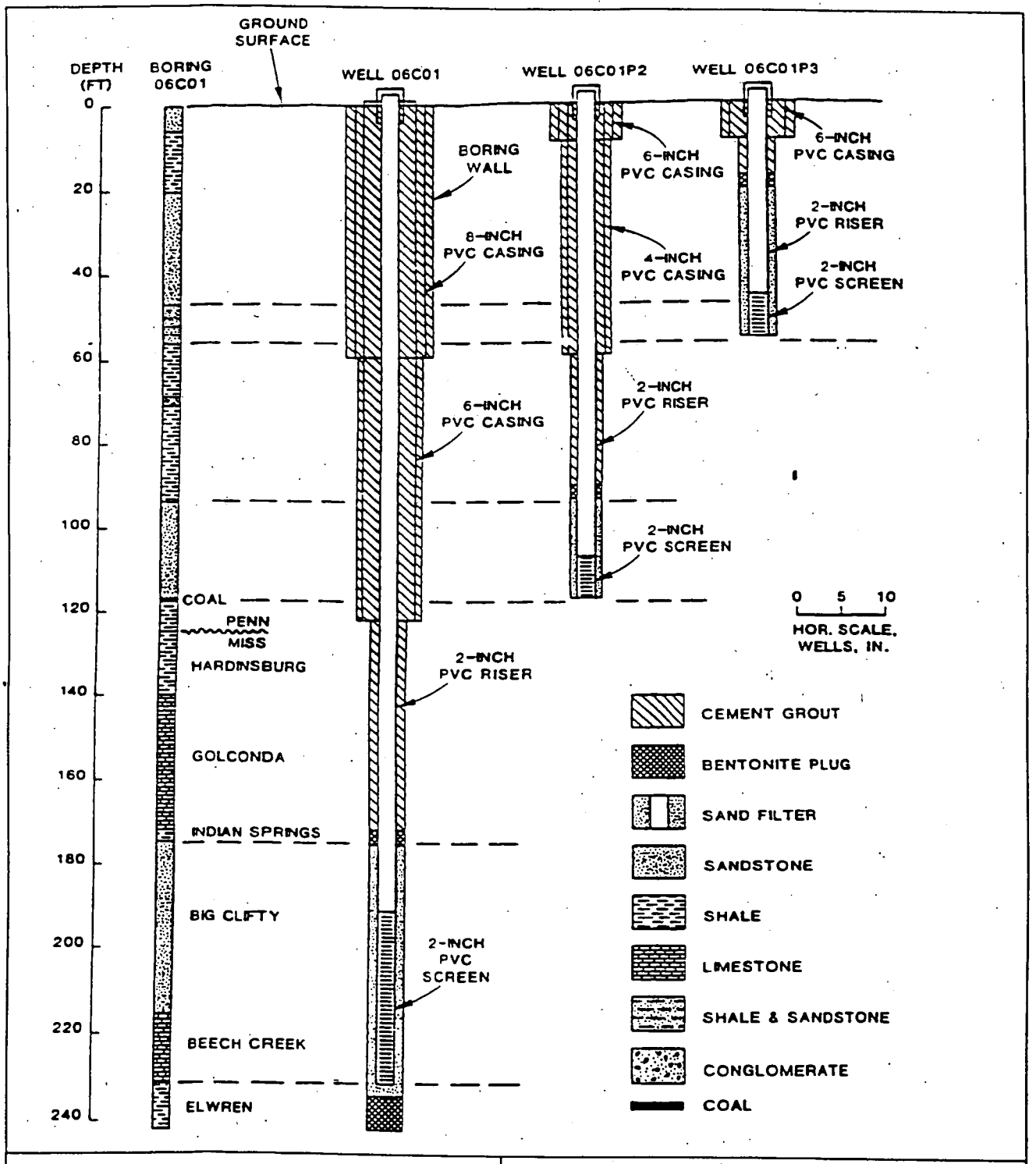
Eleven monitoring wells from the DR have been selected to be sampled as a part of the long-term ground water monitoring plan at the DR under the RCRA permit. One of the upgradient wells (06C08) is also an upgradient well for the ORR. Each of these wells was constructed of 2-inch-diameter, PVC riser pipe and well screens. The well screens range in length from 10 to 20 ft. Twenty-ft well screens were used in the Beech Creek aquifers to ensure interception of flow zones. Table 3-2 summarized the well construction details for the long-term RCRA monitoring program wells at the DR. Figure 6-5 shows typical wells installed at the DR. Additional information is provided in the RFI report for the DR (Murphy and Wade, 1995).

6.2.4 Old Jeep Trail Monitoring Wells

Currently, insufficient information is available on which monitoring wells will be sampled at the Old Jeep Trail Area. Further investigative activities must be performed to determine a proper monitoring network to meet the objectives of this investigation. Once a monitoring well network is determined, a long-term ground water monitoring plan for this site will be included as an addendum to this report.

6.3 GROUND WATER SAMPLING AND ANALYSIS [40 CFR 264.97(d) AND (e)]

40 CFR 264.97(d) requires that the monitoring program must include consistent sampling and analysis procedures that are designed to ensure monitoring results that provide a reliable indication of ground water quality below the waste management area. At a minimum, the program must include sample collection; sample preservation and shipment; analytical procedures; and chain-of-custody-control. 40 CFR 264.97(e) requires that the ground water program must include sampling and analysis procedures.



Source: SWMU 06/09 Demolition Area and Phase III Release Characterization SWMU 07/09 Old Rifle Range Naval Surface Warfare Center Crane, Indiana, William L. Murphy and Roy Wade November 1995 - Figure 5

Figure 6-5

Well Installation Diagrams for the Old Rifle Range and Demolition Range Naval Surface Warfare Center Crane, Indiana

The approved FSP contains sample collection procedures in Sections 4.2.6 and 4.2.7, sample preservation and shipment procedures in Section 4.2.11, and chain-of-custody control in Section 4.2.12. The approved QAPP details analytical procedures and analyses in Table 1-3 and laboratory Standard Operating Procedures in Appendix B. The analytical procedures were chosen to accurately measure hazardous constituents in ground water samples.

Analytical procedures must accurately measure hazardous constituents that may be present in the ground water either as the result of being present in the treated waste or that are formed during the treatment process. An evaluation was conducted to determine if the Appendix IX analytical analyzes all Appendix VIII hazardous constituents that are present in the treated waste or formed in the treatment process procedures described in the approved QAPP. The evaluation was conducted by comparing the list of RCRA Appendix VIII constituents to those contained in the treated waste or formed in the treatment process to those analyzed. The RCRA Air Quality Assessment at ABG, ORR, and DR (TtNUS, 1997) was used as the source of information on the composition of the wastes treated and potential emission constituents. The results showed that all hazardous constituents present in the wastes were analyzed by the Appendix IX procedures. The results of this evaluation are discussed in Section 1.5.

6.4 GROUND WATER SURFACE ELEVATIONS [40 CFR 264.97(f)]

40 CFR 264.97(f) requires that the ground water monitoring program must include a determination of the ground water surface elevation each time ground water is sampled. The sampling procedures in the approved FSP include determinations of ground water surface elevations each time any monitoring well is sampled (See FSP Tables 4-1, 4-5, and 4-8).

The ground water elevation data along with hydraulic conductivity data are used to annually establish ground water flow rates and direction and develop ground water contour maps. Appendix 6-1 contains the procedures to be used to develop ground water contour maps and flow rates.

6.5 SAMPLING PROCEDURE AND INTERVAL [40 CFR 264.97(g)]

40 CFR 264.97(g) requires that, in detection monitoring or where appropriate in compliance monitoring, data on each hazardous constituent specified in the permit will be collected from background wells and wells at the compliance point(s). The numbers and kinds of samples collected to establish background will be appropriate for the form of statistical test employed. Sample size will be as large as necessary to ensure, with reasonable degree of confidence, that a contaminant release to the ground water from the

facility will be detected. The sampling procedures will be a sequence of at least four samples, taken at an interval that assures, to the greatest extent technically possible, that an independent sample is obtained by reference to the uppermost aquifer's effective porosity or that an alternate sampling procedure is proposed by the owner or operator and approved by the Regional Administrator.

Detection monitoring is conducted semi-annually at the DR. Compliance monitoring is conducted quarterly at the ABG and ORR. Annually Appendix IX monitoring is conducted at the ABG and ORR.

6.6 STATISTICAL METHOD [40 CFR 264.97(h)]

40 CFR 264.97(h) requires that statistical methods for evaluating ground water quality be specified for use in evaluating ground water monitoring data for each hazardous constituent. 40 CFR 264.97(i) contains performance standards for statistical methods used to evaluate ground water monitoring data. Section 10 of this ground water monitoring plan contains the statistical procedures to be used in evaluation of ground water monitoring data.

6.7 MAINTENANCE OF DATA IN OPERATING RECORD AND REPORTING [40 CFR 264.98(j)]

40 CFR 264.98(j) requires that ground water monitoring data, including actual levels of constituents, must be maintained in the facility operating record, and the Regional Administrator must specify in the permit when the data must be submitted for review. Section 1.2 of the GWMP describes recordkeeping. Section 1.3 describes the submitted reports and the schedule of reporting.

7.0 AMMUNITION BURNING GROUNDS

This section contains a description of the ground-water monitoring programs at the NSWC Crane ABG. Ground water monitoring is being conducted at the ABG to meet the requirements of 40 CFR 264 Subpart F.

7.1 GROUND WATER MONITORING PROGRAMS AT AMMUNITON BURNING GROUNDS [40 CFR 264 SUBPART F]

Following is a listing of the ABG ground water programs required in order to meet 40 CFR 264 Subpart F requirements.

Compliance Monitoring [40 CFR 264.99]

Interim status ground water monitoring results show that hazardous constituents have been detected in the ground water. Therefore, in compliance with 40 CFR 264.99, a compliance-monitoring program is being implemented at the ABG to determine whether the ABG is in compliance with the ground water protection standard established under 40 CFR 264.92.

Corrective Action Monitoring [40 CFR 264.100]

There is an existing plume of TCE and explosives within the ABG. A compliance-monitoring program has been established. In compliance with 40 CFR 264.100, corrective action monitoring is conducted to determine if this plume has moved beyond the point of compliance and a need exists for corrective actions.

Natural Attenuation Monitoring

Tetrachloroethylene, explosives, and metals in the ground water may be undergoing natural attenuation. Therefore, monitoring is being conducted to determine if natural attenuation is occurring and if monitored natural attenuation may constitute corrective action.

Karst Monitoring

Three aquifers are present at the ABG, one of which is a karst system. The locations of the monitoring points in the three aquifers and the frequency of monitoring are based on current understanding of the behavior of the aquifers, including the aquifer in the karst system. In order to determine if the aquifers, including the karst system, are behaving as currently understood, karst parameters are being monitored.

Closure Monitoring [40 CFR 264.117(a)(1)]

A waste pile and surface impoundments located within the ABG have been closed. These closed units are located among the active units. 40 CFR 264.117(a)(1)(i) and the closure permit issued by IDEM require closure monitoring. The ground water monitoring system at the ABG also serves closure-monitoring requirements.

Table 7-1 lists the wells, springs, and surface water monitoring points and describes the objectives for each monitoring point. Table 7-2 lists the monitoring points and analyses for each monitoring point for the first eight quarters. Figure 7-1 shows the locations of each monitoring point. Figure 7-2 is a close up of the wells located at the point of compliance and shows details of existing and closed treatment units at the ABG. Table 7-3 lists the monitoring points and analyses for each monitoring point for quarterly monitoring after the first eight quarters. Table 7-4 lists the compliance monitoring points for the annual Appendix IX monitoring. Following is a discussion of the regulatory requirements applicable to ground water monitoring and how these regulatory requirements are met.

7.2 COMPLIANCE MONITORING [40 CFR 264.99]

Compliance monitoring programs at the ABG must meet the requirements of 40 CFR 264.99.

40 CFR 264.99(a) requires that ground water be monitored to determine whether regulated units are in compliance with ground water protection standards under 264.92. The permit must specify the following: 1) A list of hazardous constituents identified under 264.93; 2) Concentration limits under 264.94 for each hazardous constituent. Concentration limits must not exceed background at the time that limit is specified in the permit, or the specified concentrations for constituents listed in Table 1 of 264.94, or alternate limits established by the Regional Administrator; 3) The compliance point under 264.95; and 4) the compliance period under 264.96.

NSWC Crane meets these requirements. Hazardous constituents identified under 40 CFR 264.93, which will be monitored, include metals, explosives, and TCE and degradation products. A detailed listing of constituents, including hazardous constituents, in each of these categories is included in Table 1-2.

Alternate concentration limits (risk-based target levels), established under 40 CFR 264.94(a)(3), are also listed in Table 1-2. The compliance point at which the ground water protection standard applies is the vertical surface located at the hydraulically downgradient limit of the waste management area. Figure 7-1 shows the compliance point. The period of compliance will include the entire active life of the ABG and the closure period. The compliance period will be extended if corrective action is occurring at the ABG until it is demonstrated for a period of 3 years that the ground water protection standards (risk-based target levels listed in Table 1-2) are attained.

40 CFR 264.99(b) requires the installation of a ground water monitoring system at the compliance point. The ground water monitoring system must represent the quality of ground water passing the point of compliance [264.97(a)(2)]. Where the facility contains more than one regulated unit, separate ground water monitoring systems are not required for each regulated unit if the provisions for sampling will enable detection and measurement of hazardous constituents that have entered the ground water. The waste management area is described by an imaginary line circumscribing the several regulated units (40 CFR 264.95(b)(2). Monitoring wells must meet the casing, screening, and annual space sealing requirements in 40 CFR 264.97(c). NSWC Crane meets these requirements. Compliance ground water monitoring wells at the ABG are placed at the edge of the waste management area and monitor ground water in the uppermost aquifer system. Table 7-1 lists the ABG compliance wells. Figure 7-1 shows the locations of these wells at the compliance point. The ABG contains several waste management units. Figure 7-1 shows that a line circumscribing the regulated units describes the waste management area. The ABG monitoring wells meet the construction requirements of 40 CFR 264.97(c). ABG monitoring well construction diagrams are shown in Figure 6-4.

40 CFR 264.99(c) requires the specification of sampling procedures and statistical methods appropriate for the constituents and the facility, consistent with 264.97(g) and (h). 40 CFR 264.97(g) requires that data be collected on each hazardous constituent specified in the permit at background and compliance point wells. The number and kinds of samples collected to establish background will be appropriate for the form of statistical test employed. The sampling procedure must consist of a sequence of at least four samples taken at intervals sufficient to assure that an independent sample is obtained that considers the aquifer's characteristics and the fate and transport characteristics of the potential contaminants. 40 CFR

264.97(h) contains requirements for statistical evaluations. NSWC Crane will collect data each quarter at the ABG background and compliance-point wells listed in Table 7-1. After four rounds of data are available, background will be re-established and statistical comparisons will be made to downgradient wells. Statistical procedures are described in Section 10 of the GWMP.

40 CFR 264.99(d) requires the determination, at the frequency specified in the permit, of whether there is statistically significance evidence of increased contamination for chemical parameters or hazardous constituents specified in the permit. The statistical method must meet 40 CFR 264.97(h) requirements. A time period for completion of statistical evaluations must be included in the permit. NSWC Crane will conduct four rounds of ground water sampling and re-establish background concentrations for the ABG. After background is re-established, statistical evaluations will be conducted each quarter. The statistical evaluation procedure contained in Section 10 meets the requirements of 40 CFR 264.97(h). Results of the statistical evaluations will be submitted to the Regional Administrator within 45 days of the date that the complete analytical results are available from the laboratory.

40 CFR 264.99(e) requires annual determination of ground water flow rate and direction in the uppermost aquifer. NSWC Crane will prepare an annual ground water monitoring report, as described in Section 1.3.4. This report will include maps showing ground water flow rate and direction in the Beech Creek Aquifer (uppermost aquifer). Appendix 6-1 describes how the ground water flow rates and direction will be determined.

40 CFR 264.99(f) requires specification in the permit of the frequencies for collecting samples and conducting statistical tests in accordance with 264.97(g). NSWC Crane will collect data each quarter at the ABG background and compliance-point wells listed in Table 7-1. After four rounds of data are available, background will be re-established and statistical comparisons made to downgradient wells. Once background is re-established, statistical evaluations will be conducted every quarter.

40 CFR 264.99(g) requires analysis of samples, at least annually, from all wells at the compliance point for all constituents contained in Appendix IX, Section 264, to determine whether additional hazardous constituents have entered the ground water. Requirements for confirmation analysis, reports to the Regional Administrator, and additions of new hazardous constituents to the monitoring list are included. NSWC Crane will monitor wells annually at the ABG compliance point for Appendix IX constituents. If these analyses show the presence of hazardous constituents in the ground water that are not already identified in the permit as monitoring requirements, the wells may be resampled within 1 month to confirm

the presence of the hazardous constituents. If confirmed, NSWC Crane will report the concentrations of these additional hazardous constituents to the Regional Administrator within 7 days and add them to the compliance-monitoring list. If NSWC Crane chooses not to resample the wells, the concentrations will be reported to the Regional Administrator within 7 days and added to the monitoring list.

40 CFR 264.99(h) contains requirements for notification and submission for a permit modification for establishment of a Corrective Action Program where concentration limits established under 264.94 are being exceeded. NSWC Crane will implement the procedures described in Section 1.3.2.3 if it is determined that the alternate concentration limits (risk-based target levels) listed in Table 1-2 are exceeded for any compliance well at the ABG.

40 CFR 264.99(i) contains procedures for demonstrations that sources other than the regulated unit caused the exceedence at the compliance point. NSWC Crane will notify the Regional Administrator that a demonstration will be made that the contamination is not due to the regulated unit If contamination resulting in exceedence(s) of the ground water protection standard at the compliance point is not due to the regulated unit (ABG). This notification will be made within 7 days after the completion of the analysis.

40 CFR 264.99(j) requires that, if it is determined that the compliance monitoring program no longer meets the requirements of Subpart F, within 90 days a permit application must be submitted for a permit modification for appropriate changes. NSWC Crane will evaluate the compliance monitoring program at the ABG each quarter. If it is determined that the ABG compliance monitoring program no longer meets 40 CFR 264 Subpart F requirements, NSWC Crane will submit a permit application to modify the ABG ground water monitoring program to meet the requirements of 264 Subpart F.

The ABG compliance-monitoring program must also meet the general ground water monitoring requirements described in 40 CFR 264.97. Compliance with general ground water monitoring requirements is described in Section 6.

7.3 CORRECTIVE ACTION MONITORING [40 CFR 264.100]

There is an existing plume of contamination within the ABG within the Beech Creek aquifer system. Compliance monitoring is being initiated at the point-of-compliance wells. Two downgradient Beech Creek aquifer wells, 03C25 and 03C30, are being monitored to determine if the existing plume in the ABG has moved beyond the point of compliance. Monitoring well 0C03, located in the Beaver Bend aquifer, is

being monitored to determine if there is any contamination in the Beaver Bend aquifer. The Beaver Bend aquifer is considered to be hydraulically separated from the upper Golconda Haney/Beech Creek Aquifer system. NSWC will evaluate results from these wells every sampling event. If it is determined that the existing plume of contamination has moved beyond the compliance point in the Beech Creek aquifer system or if contamination is found in the Beaver Bend aquifer in excess of the ground water protection standard, NSWC Crane will submit to the Regional Administrator an application for a permit modification to establish a Corrective Action Program meeting the requirements of 40 CFR 264.100. This application will be made within 180 days of the date that the determination is made. The application will include, at a minimum, the following information:

- A detailed description of corrective actions that will achieve compliance with the ground water protection standard specified in the permit.

- A plan for a ground water monitoring program that will demonstrate the effectiveness of corrective action.

7.4 NATURAL ATTENUATION MONITORING

Ground water in the Beech Creek aquifer has been contaminated with chlorinated solvents, explosives, and metals. A preliminary evaluation of the existing data indicates that the ABG site is a good candidate for remediation by natural and/or enhanced attenuation. Natural attenuation monitoring will be conducted to determine if natural attenuation is occurring in the ground water.

A review of the hydrogeolgy at the site shows that the primary ground water flow path from the ABG is down the valley of Little Sulphur Creek, the fractured sandstone of the Big Clifty, and the fractures and solution cavities of the Beech Creek limestone and emerging as surface water in springs and seeps downgradient of the ABG. An area of solution cavities in the Beech Creek Limestone acts as a ground water drain to focus contaminated ground water down the valley of Little Sulphur Creek. Extensive drilling shows that the solution cavities found primarily in the valley of Little Sulphur Creek were not found in the ground water divides along the valley. The dense Elwren shale underlying the Beech Creek limestone restricts downward flow of ground water in the ABG area and focuses the flow of ground water down the Little Sulphur Creek valley. Dye tracer tests provided data indicating that a large portion of the ground water exiting the ABG emerges as surface flow from Springs A and C. Ground water also enters Little Sulphur Creek through seeps in the alluvium. The contaminated ground water is attenuated as it moves through the Big Clifty, Beech Creek, and alluvial materials. As the ground water enters the area of the

solution cavities, dilution occurs as clean ground water flows in from the sides of the valley. As the ground water and surface water move toward the installation boundary, the contaminants are reduced to low concentrations.

Eight monitoring wells (03C25, 03C03, 03C04, 03B02, 03C10, 03C11, 03C12, and 03B04), Springs A and C, and Little Sulphur Creek (near the installation boundary and at Spring A) will be monitored. Parameters that will be monitored include TCE and degradation products, explosives and degradation products, and parameters that are indicative of conditions favorable to natural attentuation of explosives and chlorinated hydrocarbons will be monitored. Table 7-5 contains a listing of parameters to be monitored for natural attenuation and the rationale for their analysis.

Natural attenuation monitoring data will be evaluated to determine if there are clear and meaningful trends of decreasing contaminant mass and/or concentration over time. Graphs showing concentration trends over time will be prepared. Geochemical data will be used to evaluate the types of degradation that may be occurring. The presence of degradation products will be considered evidence that natural attenuation is occurring. The characterization data will be used to quantify the rates of contaminant sorption, dilution, or volatilization or to demonstrate and quantify the rates of biological degradation processes occurring at the ABG.

Natural attenuation monitoring will take place over a period of up to 2 years. If the data indicate that the TCE, explosives, and metals contaminants in the ground water or surface water have not been attenuated below risk-based levels before they reach the installation boundary, remediation activities such as phytoremediation will be considered. Plant enzyme mediated degradation of munitions-contaminated soils, sediments, and surface waters has been shown to reduce the concentration of these contaminants. If contaminants are present in ground water or surface water near the installation boundary above risk-based levels, NSWC Crane will submit a permit modification request to address additional remediation of ground water and/or surface water. NSWC Crane may also submit a permit modification request to modify the natural attentuation monitoring program based on the results of the initial screening.

7.5 KARST MONITORING

Part of the ABG is underlain by a karst system. Several studies of the karst system have been conducted by the United States Army Corps of Engineers Waterways Experiment Station (USACE – WES) and the Indiana University Department of Geological Sciences. Information regarding the karst system and

parameters to be monitored for karst behavior is contained in this section. Information on behavior of the karst system was obtained from a thesis that was prepared by Stephen J. Baedke, a graduate student at Indiana University. Appendix 7-1 contains this thesis.

Three aquifers are present at the ABG. One aquifer is a karst system. Karst systems show both temporal and spatial variation between diffuse-type and conduit-type ground water flow. The locations of the monitoring points are based on the current understanding of the aquifer system present at the ABG.

From highest to lowest, the three aquifer systems present at the ABG are the Golconda-Haney aquifer, the Beech Creek aquifer, and the Beaver Bend aquifer.

The Golconda-Haney aquifer consists of the Golconda and Haney limestones. The prevalent chemical character of ground water from this aquifer is Ca^{2+}-HCO_3. Figure 7-3 is a Piper diagram of water chemistry analysis for the Golconda/Haney aquifer. Underlying the aquifer is the Indian Springs shale, which acts as an aquiclude. Water entering this aquifer moves laterally along its base and eventually exits the aquifer via seeps. Once at the ground surface, water enters the Beech Creek aquifer either by percolation through the Big Clifty sandstone or by entering the headwaters of the Little Sulphur Creek. The Golconda-Haney aquifer is at a higher elevation than the operating area at the ABG; therefore, there is little potential for this aquifer to be contaminated by ABG operations.

The Beech Creek aquifer consists of the Big Clifty sandstone and the Beech Creek limestone. Underlying the aquifer is the Elwren shale, which acts as an aquiclude. The prevalent "natural" chemical character of the ground water is Ca^{2+} + Mg^{2+} -HCO_3, which is expected from a carbonate terraine. The determination of chemical character of the Beech Creek aquifer is complicated by a plume of Mg^{2+} and SO_4^{2-} from past practices and the presence of Na^+, K^+, and Cl^- in wells near roads where salting occurs in the winter. Figure 7-4 is a Piper diagram of water chemistry analysis for the Beech Creek aquifer. Figure 7-5 is a Piper diagram of water chemistry analysis from "uncontaminated" wells in the Beech Creek aquifer. This figure was constructed by removing wells that contained anamously high Mg^{2+}, SO_4^{2-}, Cl^-, and Na^+. The Beech Creek aquifer is partially open to recharge from surface water infiltration during precipitation. Precipitation falling on the ABG drains into the headwaters of Little Sulphur Creek. As surface waters travel down Little Sulphur Creek, the Indian Springs shale pinches out and the Big Clifty sandstone comes to outcrop. Here, surface water percolates into the Big Clifty sandstone.

7.6 CLOSURE MONITORING [40 CFR 264.117]

A waste pile and surface impoundments located within the ABG are currently undergoing closure. These units are located among the active units. The approved closure plan will require post-closure monitoring by the IDEM. The monitoring wells located in the Beech Creek aquifer that are used for the monitoring of the active units will also be used for monitoring of the closed waste pile and surface impoundments. Table 7-1 contains a list of the wells that will be monitored for post-closure monitoring. The monitoring frequencies and analyses are described in Tables 7-2, 7-3, and 7-4.

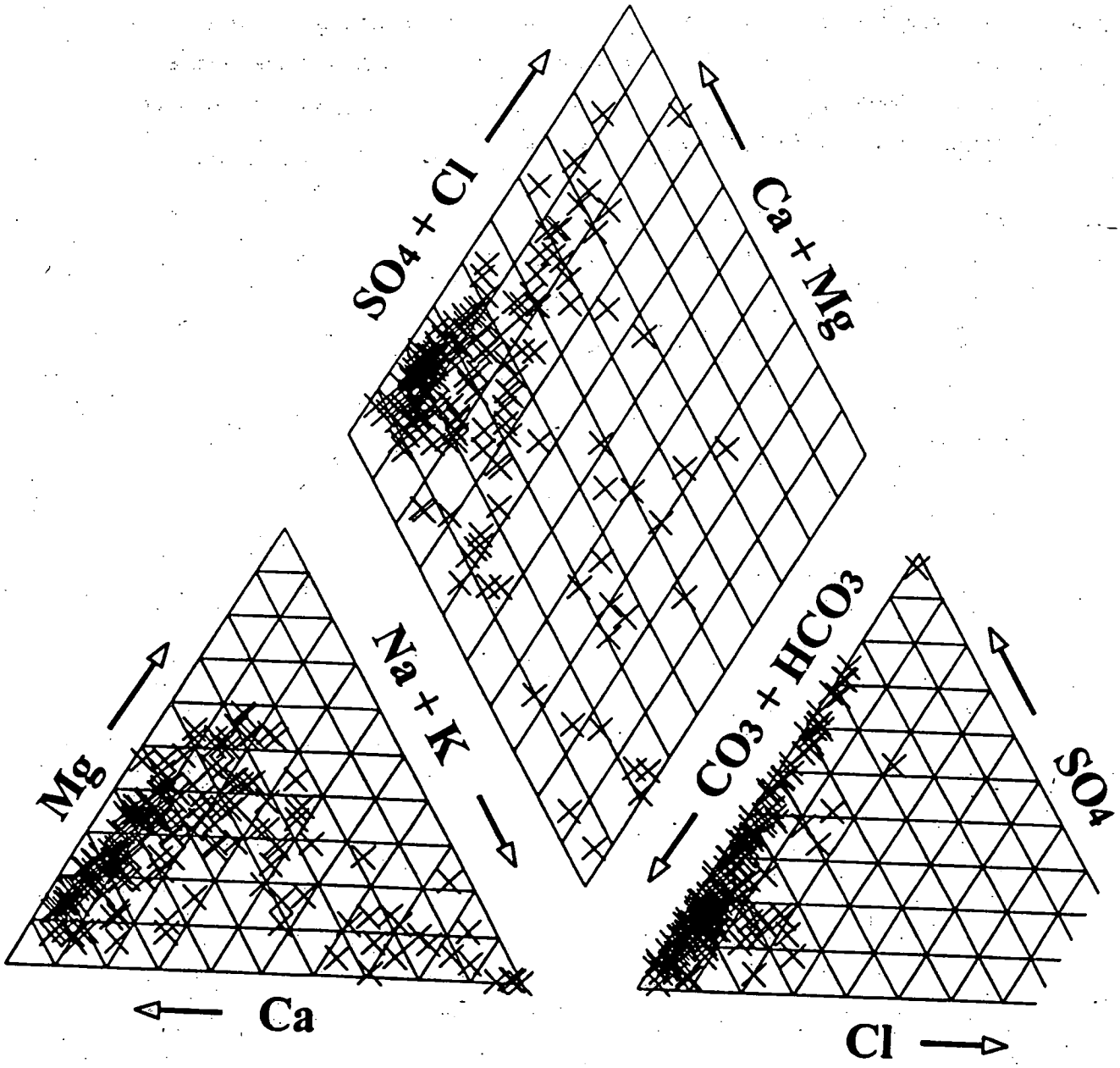


Figure 7-4. Piper diagram of all water chemistry analysis' taken from the Beech Creek aquifer.

TABLE 7-1

MONITORING POINT OBJECTIVES
AMMUNITION BURNING GROUNDS
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

Monitoring Point	Aquifer Monitored	Background Monitoring	Compliance Monitoring	Corrective Action	Closure Monitoring	Natural Attenuation	Karst Monitoring
03B02	Al					X	X
03B04	Al					X	X
03C02P2	BC		X		X		X
03C03	BB		X	X	X	X	X
03C04	BC		X		X	X	X
03C07	BC		X		X		X
03C08P2	BC		X		X		X
03C09P2	BC		X		X		X
03C10	BC					X	X
03C11	BC					X	X
03C12	BC		X		X	X	X
03C15	BC		X		X		X
03C17	BC	X	X	X	X		X
03C20	BC		X		X		X
03C25	BC		X	X	X	X	X
03C26	BC		X		X		X
03C27	BC		X		X		X
03C30	BC		X	X	X		X
Little Sulphur Creek Below Spring C	NA					X	X
Little Sulphur Creek at Boundary	NA		X		X	X	X
Spring A	NA		X		X	X	X
Spring C	NA		X		X	X	X

Al Alluvium
BC Beech Creek Aquifer
BB Beaver Bend Aquifer
NA Not Applicable

TABLE 7-2

AMMUNITION BURNING GROUNDS
QUARTERLY MONITORING - QUARTERS 1 THROUGH 8
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

Monitoring Point	Field[1],	Volatiles[1]	Dissolved Gases[1]	Explosives[1]	Metals[1] (Total)	Metals[1] (Dissolved)	Cyanide	TOX	TOC	Sulfide	Sulfate	Phosphorus (Total and Dissolved)	Chloride
03B02	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•
03B04	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•
03C02P2	A, B	B		A	A, D	A, C, D	•	•	•		•	•	•
03C03	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•
03C04	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•
03C07	A, B	B		A	A, D	A, C, D	•	•	•		•	•	•
03C08P2	A, B	B		A	A, D	A, C, D	•	•	•		•	•	•
03C09P2	A, B	B		A	A, D	A, C, D	•	•	•		•	•	•
03C10	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•
03C11	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•
03C12	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•
03C15	A, B	B		A	A, D	A, C, D	•	•	•		•	•	•
03C17	A, B	B		A	A, D	A, C, D	•	•	•		•	•	•
03C20	A, B	B		A	A, D	A, C, D	•	•	•		•	•	•
03C25	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•
03C26	A, B	B		A	A, D	A, C, D	•	•	•		•	•	•
03C27	A, B	B		A	A, D	A, C, D	•	•	•		•	•	•
03C30	A, B	B		A	A, D	A, C, D	•	•	•		•	•	
Little Sulphur Creek Below Spring A	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•
Little Sulphur Creek at Boundary	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•
Spring A	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•
Spring C	A, B, C	B, C	A	A, B	A, B, D	A, C, D	•	•	•	•	•	•	•

1 The letters A, B, C, etc., indicate subsets of the parameter group shown in the column headings. Specific parameters included in each subset are listed in Appendix D of the approved FSP.

TABLE 7-3

AMMUNITION BURNING GROUNDS
QUARTERLY MONITORING-QUARTERS 9 THROUGH 30
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

Monitoring Point	Field[1]	Volatiles[1]	Explosives[1]	Metals [1] (Total)	Metals [1] (Dissolved)	Cyanide	TOX	TOC	Sulfate	Phosphorus (Total and Dissolved)	Chloride
03C02P2	A, B	B	A	A	A, C	•	•	•	•	•	•
03C03	A, B	B	A	A	A, C	•	•	•	•	•	•
03C04	A, B	B	A	A	A, C	•	•	•	•	•	•
03C07	A, B	B	A	A	A, C	•	•	•	•	•	•
03C08P2	A, B	B	A	A	A, C	•	•	•	•	•	•
03C09P2	A, B	B	A	A	A, C	•	•	•	•	•	•
03C15	A, B	B	A	A	A, C	•	•	•	•	•	•
03C17	A, B	B	A	A	A, C	•	•	•	•	•	•
03C20	A, B	B	A	A	A, C	•	•	•	•	•	•
03C25	A, B	B	A	A	A, C	•	•	•	•	•	•
03C26	A, B	B	A	A	A, C	•	•	•	•	•	•
03C27	A, B	B	A	A	A, C	•	•	•	•	•	•
03C30	A, B	B	A	A	A, C	•	•	•	•	•	•
Spring A	A, B	B	A	A	A, C	•	•	•	•	•	•
Spring C	A, B	B	A	A	A, C	•	•	•	•	•	•

1 The letters A, B, C, etc., indicate subsets of the parameter group shown in the column headings. Specific parameters included in each subset are listed in Appendix D of the approved FSP.

Note: Monitoring for natural attenuation is scheduled only for the first eight quarters. Therefore the analytical scheme has been modified to discontinue analysis of natural attenuation parameters.

TABLE 7-4
AMMUNITION BURNING GROUNDS
ANNUAL APPENDIX IX MONITORING
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

Monitoring Points	Appendix IX Volatile Organic Compounds (1)	Appendix IX Semivolatile Organic Compounds (1)	Appendix IX Pesticides/ PCBs (1)	Appendix IX Herbicides (1)	Appendix IX Dioxins/ Furans (1)	Sulfide
03C02P2	A	A	A	A	A	•
03C03	A	A	A	A	A	•
03C04	A	A	A	A	A	•
03C07	A	A	A	A	A	•
03C08P2	A	A	A	A	A	•
03C09P2	A	A	A	A	A	•
03C15	A	A	A	A	A	•
03C17	A	A	A	A	A	•
03C20	A	A	A	A	A	•
03C25	A	A	A	A	A	•
03C26	A	A	A	A	A	•
03C27	A	A	A	A	A	•
03C30	A	A	A	A	A	•
Spring A	A	A	A	A	A	•
Spring C	A	A	A	A	A	•

1 The letters A, B, C, etc., indicate subsets of the parameter group shown in the column headings. Specific parameters included in each subset are listed in Appendix D of the approved FSP.

Note: Annual Appendix IX monitoring will be performed in conjunction with quarterly monitoring.

TABLE 7-5

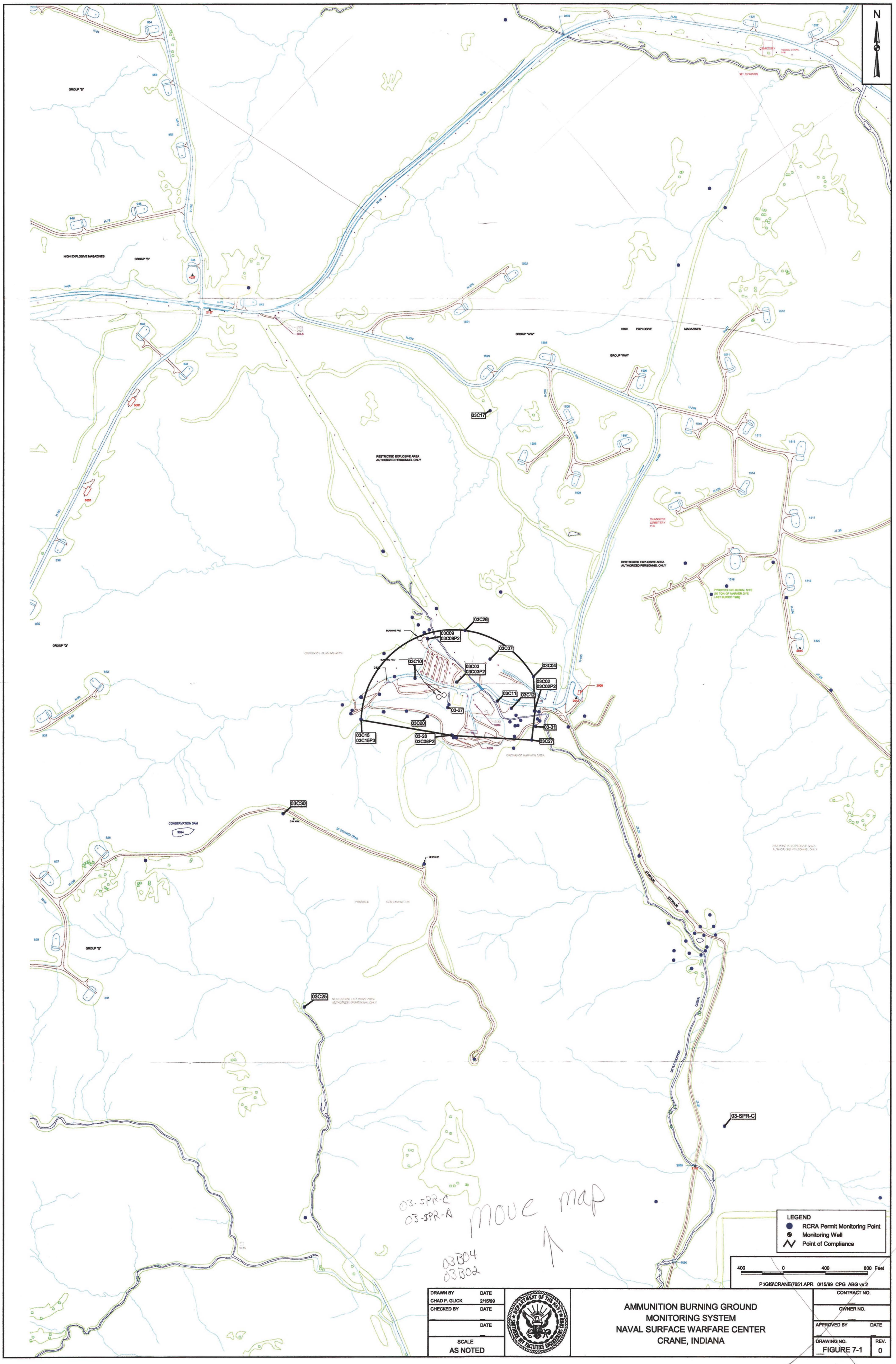
NATURAL ATTENUATION PARAMETERS
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA
PAGE 2 OF 2

ANALYSIS	RATIONALE
(MNX)	
Nitrobenzene (NB)	Explosive degradation product
1,3-dintrobenzene (DNB)	Explosive degradation product
Nitrocellulose (NC)	Explosive contaminant
Nitroglycerine (NG)	Explosive contaminant

After entering the Big Clifty sandstone, ground water moves vertically and horizontally by diffuse and conduit flow. Vertical ground water movement allows recharge into the underlying Beech Creek limestone. Ground water then enters the Beech Creek Limestone and moves through solution features and fractures and along bedding planes. The Elwren Shale inhibits further vertical movement of groundwater and forces subsequent movement to be parallel to the contact between the Elwren Shale and Beech Creek limestone. Several springs emerge from the walls of Little Sulphur Creek at the contact between the Elwren Shale and Beech Creek limestone. Spring A has been shown to be hydraulically connected to the Beech Creek aquifer.

The Beaver Bend aquifer consists of the Beaver Bend limestone. It is a confined aquifer overlaid with 70 ft of Elwren and Sample shales. Hydraulic heads in this aquifer are 50 to 60 ft above the top of the aquifer and 33 to 47 ft below the heads in the overlying Beech Creek aquifer. The extreme differences in head and the presence of a thick shale between these two aquifers show that there is no hydrologic connection between these two aquifers. This is supported by the prevalent chemical character of ground water in this aquifer, which is Na^+ -HCO_3. The chemistry of ground water from the Beaver Bend aquifer is distinctly different from the other aquifers. Figure 7-6 illustrates the prevalent water chemistry of the Beaver Bend aquifer.

Karst parameters will be monitored at all monitoring points to determine if there are any changes in the behavior of the aquifers present at the ABG. The parameters that will be monitored include pH, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, SO_4^{2-}, and Cl^-. Piper diagrams of water chemistry will be constructed for each aquifer. Information from the Piper diagrams will be used to determine if the behavior of the aquifers present at the ABG has changed. If the behavior of the aquifer system changes, evaluations will be conducted of the necessity for changes in the current monitoring system. A permit modification request will be made to the U.S. EPA in the event it is determined that changes to the current monitoring system are necessary to meet 40 CFR requirements.



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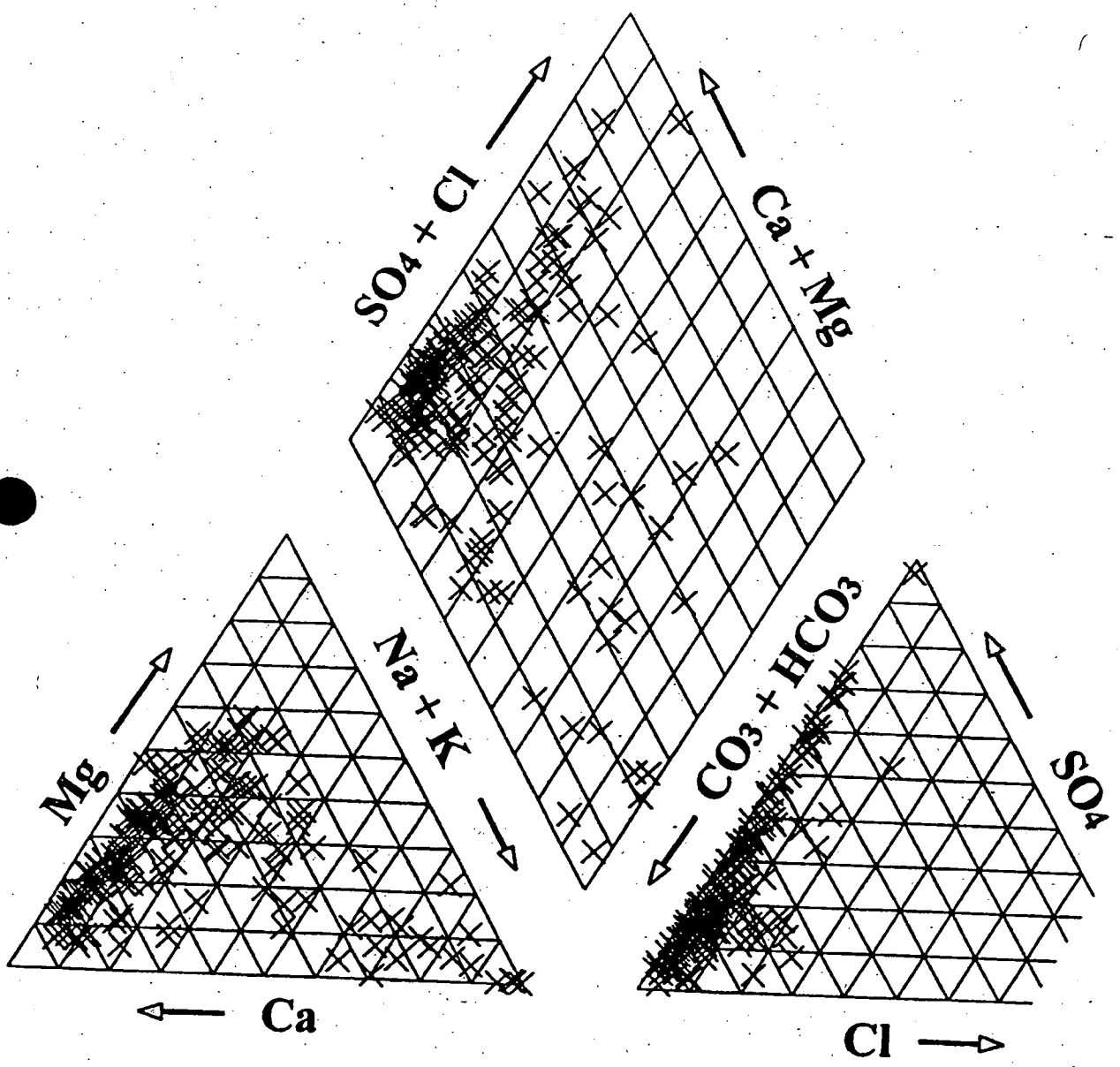


Figure 7-4. Piper diagram of all water chemistry analysis' taken from the Beech Creek aquifer.

7.6 CLOSURE MONITORING [40 CFR 264.117]

A waste pile and surface impoundments located within the ABG are currently undergoing closure. These units are located among the active units. The approved closure plan will require post-closure monitoring by the IDEM. The monitoring wells located in the Beech Creek aquifer that are used for the monitoring of the active units will also be used for monitoring of the closed waste pile and surface impoundments. Table 7-1 contains a list of the wells that will be monitored for post-closure monitoring. The monitoring frequencies and analyses are described in Tables 7-2, 7-3, and 7-4.

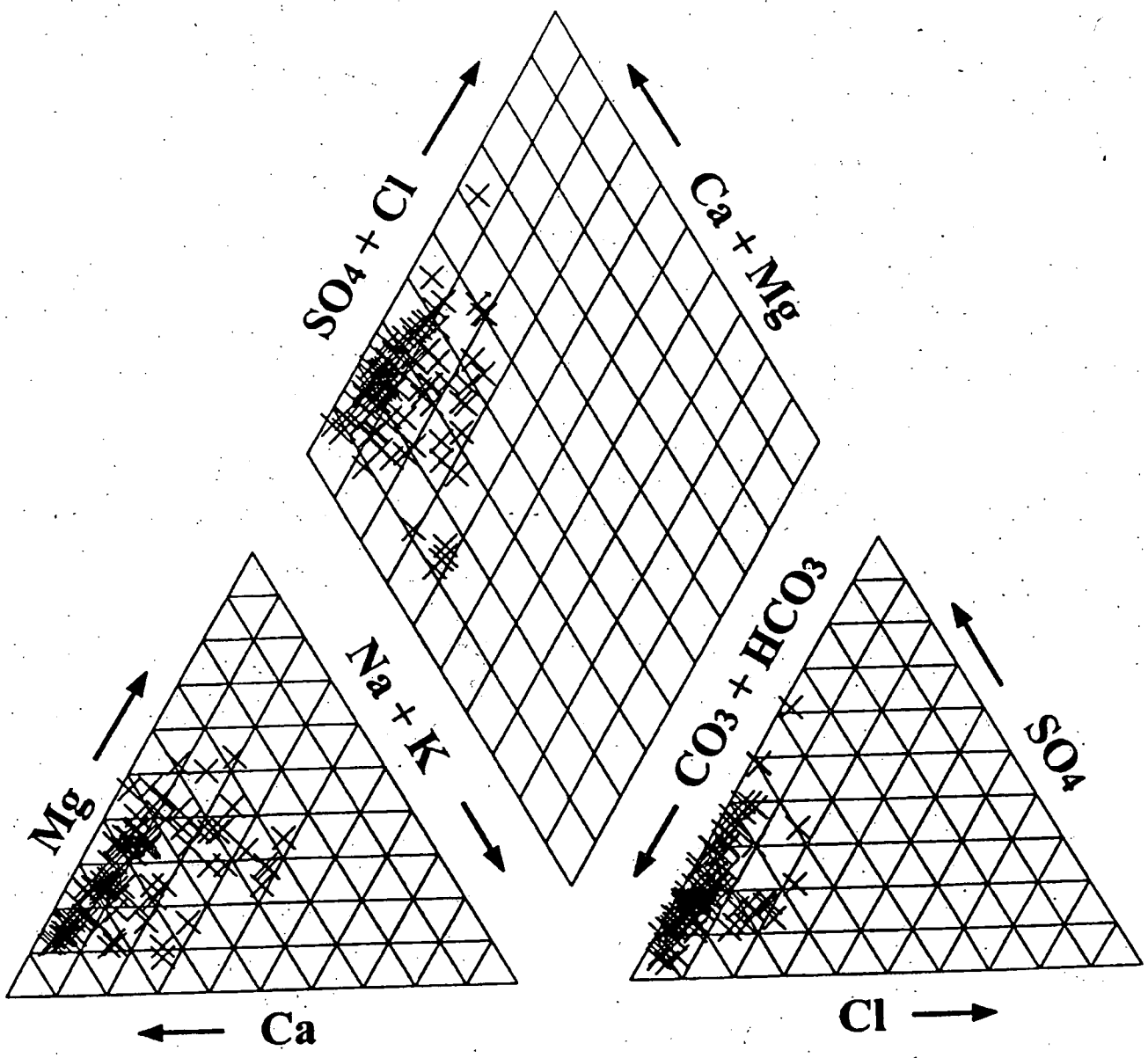


Figure 7-5. Piper diagram of water chemistry analysis' taken from "uncontaminated" wells in the Beech Creek aquifer.

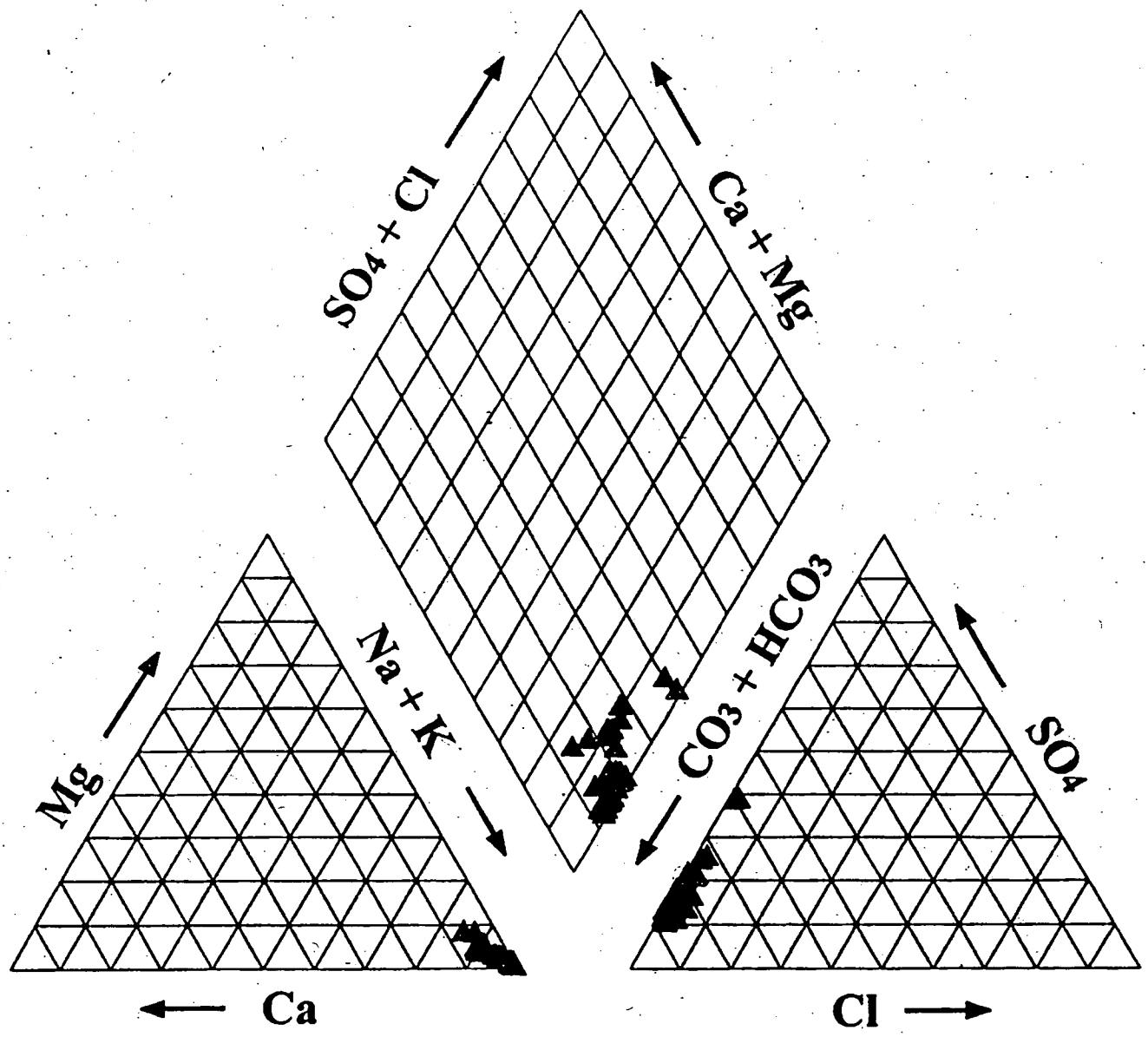


Figure 7-6. Piper diagram of water chemistry analysis' from wells in the Beaver Bend aquifer.

8.0 OLD RIFLE RANGE GROUND WATER MONITORING

This section contains a description of the ground water monitoring programs at the NSWC Crane ORR. Ground water monitoring is being conducted at the ORR to meet the requirements of 40 CFR 264 Subpart F.

8.1 GROUND WATER MONITORING AT THE OLD RIFLE RANGE [40 CFR 264 SUBPART F]

Compliance Monitoring [40 CFR 264.99]

Interim status ground water monitoring results show that hazardous constituents have entered the ground water. Therefore, in compliance with 40 CFR 264.99, a compliance-monitoring program is being implemented at the ORR to determine whether the ORR is in compliance with the ground water protection standard established under 40 CFR 264.92.

Table 8-1 lists each of the monitoring points at the ORR and the purposes for which each point is being monitored. Table 8-2 lists the analyses conducted at each monitoring point each quarter. Table 8-3 lists the analyses conducted during the annual Appendix IX monitoring. Figure 8-1 shows the locations of the ground water monitoring points at the ORR. The upgradient well for the ORR screened in the Big Clifty/Beech Creek aquifer, 06C08, is also the upgradient well for the DR. Figure 9-1 shows the location of this well in relation to the DR and ORR.

8.2 COMPLIANCE MONITORING [40 CFR 264.99]

Compliance-monitoring programs at the ORR must meet the requirements of 40 CFR 264.99.

40 CFR 264.99(a) requires that ground water be monitored to determine whether regulated units are in compliance with ground water protection standards under 264.92. The permit must specify the following:

- A list of hazardous constituents identified under 264.93.
- Concentration limits under 264.94 for each hazardous constituent. Concentration limits must not exceed background at the time that limit is specified in the permit, or the specified concentrations for constituents listed in Table 1 of 264.94, or alternate limits established by the regional administrator.

TABLE 8-1

OLD RIFLE RANGE
MONITORING WELL SUMMARY
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

Wells	Screened Formation	Objective
06C08	BC/BC	Upgradient
06C11	BC/BC	Downgradient (POC)
06C11P2	BCU	Downgradient (POC)
06C12	BC/BC	Downgradient (POC)
06C13	BC/BC	Downgradient (POC)
06C13P2	BCU	Downgradient (POC)
06C14	BC/BC	Downgradient (POC)
06C14P2	BCU	Upgradient
06C15	BC/BC	Downgradient (POC)
06C16	BC/BC	Downgradient (POC)
06C18	BC/BC	Downgradient (POC)
06C18P2	BCU	Downgradient (POC)
06C19	BC/BC	Downgradient
06C19P2	BCU	Downgradient

Notes:

BCU - Big Clifty Upper
BC/BC - Big Clifty/Beech Creek
POC - Point-of-Compliance

TABLE 8-2

OLD RIFLE RANGE
QUARTERLY MONITORING
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

Wells	Field[1]	Explosives[1]	Ammonia	Appendix IX Metals[1] (Total)	Appendix IX Metals[1] (Dissolved)	Cyanide	TOX	TOC
06C08[2]	A	A, C	•	A, D	A, D	•	•	•
06C11	A	A, C	•	A, D	A, D	•	•	•
06C11P2	A	A, C	•	A, D	A, D	•	•	•
06C12	A	A, C	•	A, D	A, D	•	•	•
06C13	A	A, C	•	A, D	A, D	•	•	•
06C13P2	A	A, C	•	A, D	A, D	•	•	•
06C14	A	A, C	•	A, D	A, D	•	•	•
06C14P2	A	A, C	•	A, D	A, D	•	•	•
06C15	A	A, C	•	A, D	A, D	•	•	•
06C16	A	A, C	•	A, D	A, D	•	•	•
06C18	A	A, C	•	A, D	A, D	•	•	•
06C18P2	A	A, C	•	A, D	A, D	•	•	•
06C19	A	A, C	•	A, D	A, D	•	•	•
06C19P2	A	A, C	•	A, D	A, D	•	•	•

1 The letters A, B, C, etc. indicate subsets of the parameter group shown in the column headings. Specific parameters included in each subset are listed in Appendix D of the approved FSP.

2 Monitoring well 06C08 is also an upgradient well for the DR. Analyses are also listed in Table 9-2.

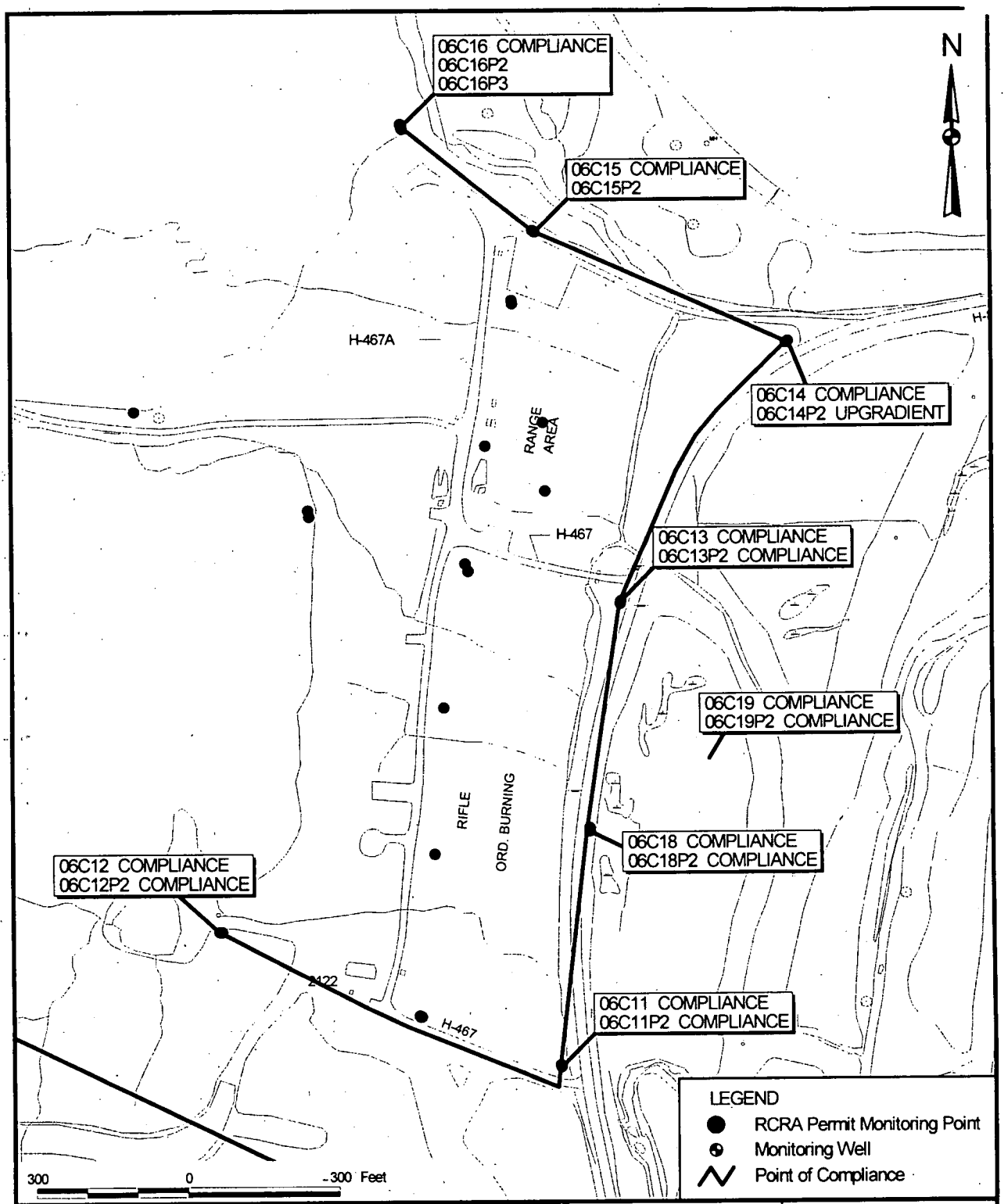
TABLE 8-3

OLD RIFLE RANGE
ANNUAL APPENDIX IX GROUND WATER MONITORING
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

Wells	Appendix IX Volatile Organic Compounds (1)	Appendix IX Semivolatile Organic Compounds (1)	Appendix IX Pesticides/ PCBs (1)	Appendix IX Herbicides (1)	Dioxins/ Furans (1)	Sulfide
06C08	A	A	A	A	A	•
06C11	A	A	A	A	A	•
06C11P 2	A	A	A	A	A	•
06C12	A	A	A	A	A	•
06C13	A	A	A	A	A	•
06C13P 2	A	A	A	A	A	•
06C14	A	A	A	A	A	•
06C14P 2	A	A	A	A	A	•
06C15	A	A	A	A	A	•
06C16	A	A	A	A	A	•
06C18	A	A	A	A	A	•
06C18P 2	A	A	A	A	A	•
06C19	A	A	A	A	A	•
06C19P 2	A	A	A	A	A	•

1 The letters A, B, C, etc. indicate subsets of the parameter group shown in the column headings. Specific parameters included in each subset are listed in Appendix D of the approved FSP.

Note: Annual Appendix IX monitoring will be performed in conjunction with quarterly monitoring.



DRAWN BY S. TABLER	DATE 10/30/98	OLD RIFLE RANGE POINT OF COMPLIANCE WELLS & UNIT BOUNDARY NAVAL SURFACE WARFARE CENTER CRANE, INDIANA	CONTRACT NUMBER —
CHECKED BY	DATE		APPROVED BY — DATE —
COST/SCHEDULE-AREA			APPROVED BY — DATE —
SCALE AS NOTED			DRAWING NO. FIGURE 8-1 REV 0

P:\GIS\CRANE\7651.APR 10/30/98 SMT

- The compliance point under 264.95.

- The compliance period under 264.96:

NSWC Crane meets these requirements for compliance monitoring at the ORR. Hazardous constituents identified under 40 CFR 264.93 that will be monitored include metals. In addition to metals, explosives will be monitored. A detailed listing of constituents, including hazardous constituents, in each of these categories is included in Table 1-2. Alternate concentration limits (risk-based target levels), established under 40 CFR 264.94(a)(3), are also listed in Table 1-2. The compliance point at which the ground water protection standard applies is the vertical surface located at the hydraulically downgradient limit of the waste management area. Figure 8-1 shows the compliance point. The period of compliance will include the entire active life of the ORR and the closure period. The compliance period will be extended if corrective action is occurring at the ORR until it is demonstrated for a period of 3 years that the ground water protection levels (risk-based target levels listed in Table 1-2) are attained.

40 CFR 264.99(b) requires the installation of a ground water monitoring system at the compliance point. The ground water monitoring system must represent the quality of ground water passing the point of compliance [264.97(a)(2)]. Where the facility contains more than one regulated unit, separate ground water monitoring systems are not required for each regulated unit if the provisions for sampling will enable detection and measurement of hazardous constituents that have entered the ground water. The waste management area is described by an imaginary line circumscribing the several regulated units (40 CFR 264.95(b)(2). Monitoring wells must meet the casing, screening, and annual space sealing requirements in 40 CFR 264.97(c). NSWC Crane meets these requirements. Compliance ground water monitoring wells at the ORR are placed at the edge of the waste management area and monitor ground water in the uppermost aquifer system. Table 8-1 lists the ORR compliance wells. Figure 8-1 shows the locations of these wells at the compliance point. The ORR contains several waste management units. Figure 8-1 shows that a line circumscribing the regulated units describes the waste management area. The ORR monitoring wells meet the construction requirements of 40 CFR 264.97(c). ORR monitoring well construction diagrams are shown in Figure 6-5.

40 CFR 264.99(c) requires the specification of sampling procedures and statistical methods appropriate for the constituents and the facility, consistent with 264.97(g) and (h). 40 CFR 264.97(g) requires that data be collected on each hazardous constituent specified in the permit at background and compliance point wells. The numbers and kinds of samples collected to establish background will be appropriate for

the form of statistical test employed. The sampling procedure must consist of a sequence of at least four samples taken at intervals sufficient to assure that an independent sample is obtained that considers the aquifer's characteristics and the fate and transport characteristics of the potential contaminants. 40 CFR 26497(h) contains requirements for statistical evaluations. NSWC Crane will collect data each quarter at the ORR background and compliance point wells listed in Table 7-1. After four rounds of data are available, background will be re-established and statistical comparisons will be made to downgradient wells. Statistical procedures are described in Section 10.

40 CFR 264.99(d) requires the determination at the frequency specified in the permit, of whether there is statistically significance evidence of increased contamination for chemical parameters or hazardous constituents specified in the permit. The statistical method must meet 40 CFR 264.97(h) requirements. A time period for completion of statistical evaluations must be included in the permit. NSWC Crane will conduct four rounds of ground water sampling and re-establish background concentrations for the ORR. After background is re-established, statistical evaluations will be conducted each quarter. The statistical evaluation procedure contained in Section 10 meets the requirements of 40 CFR 264.97(h). Results of the statistical evaluations will be submitted to the Regional Administrator within 45 days of the date that the complete analytical results are available from the laboratory.

40 CFR 264.99(e) requires annual determination of ground water flow rate and direction in the uppermost aquifer. NSWC Crane will prepare an annual ground water monitoring report, as described in Section 1.3.4. This report will include maps showing ground water flow rate and direction for the Big Clifty Upper and Big Clifty/Beech Creek aquifers. Appendix 6-1 describes how the ground water flow rates and direction will be determined.

40 CFR 264.99(f) requires specification in the permit of the frequencies for collecting samples and conducting statistical tests in accordance with 264.97(g). NSWC Crane will collect data each quarter at the ORR background and compliance point wells listed in Table 7-1. After four rounds of data are available, background will be re-established and statistical comparisons will be made to downgradient wells. Once background is re-established, statistical evaluations will be conducted every quarter.

40 CFR 264.99(g) requires analysis of samples, at least annually, from all wells at the compliance point for all constituents contained in Appendix IX, part 264, to determine whether additional hazardous constituents have entered the ground water. Requirements for confirmation analysis, reports to the regional administrator, and additions of new hazardous constituents to the monitoring list are included.

NSWC will annually monitor wells at the ORR compliance point for Appendix IX constituents. If these analyses show the presence of hazardous constituents in the ground water that are not already identified in the permit as monitoring requirements, the wells may be resampled within 1 month to confirm the presence of the hazardous constituents. If this is confirmed, NSWC Crane will report the concentrations of these additional hazardous constituents to the regional administrator within 7 days and add them to the compliance-monitoring list. If NSWC Crane chooses not to resample the wells, the concentrations will be reported to the regional administrator within 7 days and added to the monitoring list.

40 CFR 264.99(h) contains requirements for notification and submission of a permit modification for establishment of a Corrective Action Program where concentration limits established under 264.94 are being exceeded. NSWC will implement the procedures described in Section 1.3.2.3 if it is determined that the alternate concentration limits (risk-based target levels) listed in Table 1-2 are exceeded for any compliance well at the ORR.

40 CFR 264.99(i) contains procedures for demonstrations that sources other than the regulated unit caused the exceedence at the compliance point. NSWC Crane will notify the regional administrator that a demonstration will be made that the contamination is not due to the regulated unit if contamination resulting in exceedence(s) of the ground water protection standard at the compliance point are not due to the regulated unit (ORR). This notification will be made within 7 days after the completion of the analysis.

If it is determined that the compliance monitoring program no longer meets the requirements of Subpart F, 40 CFR 264(99)(j), within 90 days, a permit application will be submitted for a permit modification for appropriate changes. NSWC Crane will evaluate the compliance-monitoring program at the ORR each quarter. If it is determined that the ORR compliance monitoring program no longer meets 40 CFR 264 Subpart F requirements, NSWC Crane will submit a permit application to modify the ORR ground water monitoring program to meet the requirements of 264 Subpart F.

The ORR compliance-monitoring program must also meet the general ground water monitoring requirements described in 40 CFR 264.97. Compliance with general ground water monitoring requirements is described in Section 6.

9.0 DEMOLITION RANGE GROUND WATER MONITORING PROGRAM [40 CFR SUBPART F]

This section contains a description of the DR ground water monitoring program. The monitoring program meets the requirements of 40 CFR 264 Subpart F for ground water monitoring programs. Descriptions of the applicable 40 CFR Subpart F requirements and discussions of how each requirement is met are provided in this section.

Table 9-1 lists each of the monitoring points at the DR and the purposes for which each point is being monitored. Table 9-2 lists the analyses conducted semi-annually at each monitoring point. Figure 9-1 shows the location of each ground water DR monitoring point, including the compliance point.

9.1 DETECTION MONITORING AT DEMOLITION RANGE [40CFR 264.98]

Interim status ground water monitoring results show contamination from metals in the active range area. No contamination was found from explosives or from other constituents. However, contamination was not found at the point-of-compliance groundwater monitoring wells. Therefore, detection monitoring is warranted. Section 5.2 contains information on interim status ground water monitoring data.

40 CFR 264.98 contains the requirements for detection monitoring programs:

40 CFR 264.98(a) requires monitoring of indicator parameters that provide a reliable indication of the presence of hazardous constituents in ground water considering waste composition, mobility in the environment, detectability, and background variations. The hazardous constituents that will be monitored at the DR include explosives, metals, cyanide, total organic carbon (TOC), and total organic halogens (TOX). The munitions/explosives detonated in the DR are composed of metals and explosives. Cyanide is a potential degradation product from the detonation of explosives. TOC and TOX are indicator parameters that indicate the potential for ground water contamination.

40 CFR 264.98(b) requires installation of a ground water monitoring system at the compliance point specified under 264.95 and in the general ground water monitoring requirements in 264.97(a)(2), (b), and (c). 40 CFR 264.95 defines the compliance point as a vertical surface located at the hydraulically downgradient limit of the waste management area that extends down into the uppermost aquifer underlying the regulated units. 40 CFR 264.97(a)(2) requires that the ground water monitoring system represent the quality of ground water passing the point of compliance. NSWC Crane has located the DR

ground water monitoring system at the compliance point. Samples from the downgradient wells represent the quality of ground water passing the point of compliance. Three aquifers are monitored at the DR. Monitoring wells 06C08P2 (upgradient) and 06C06P2 (compliance point) monitor the Pennsylvanian aquifer. Monitoring wells 06C03P2 and 06C04P2, both located at the compliance point, monitor the Golconda/Haney aquifer. The major aquifer system underlying the DR is the Big Clifty/Beech Creek (BC/BC) aquifer system. These two aquifers are treated as one aquifer system. The upgradient well is 06C08, and the compliance point wells are 06C02, 06C03, 06C04, 06C05, 06C06, and 06C07.

40 CFR 264.97(c) contains construction requirements for monitoring wells. NSWC Crane has constructed the monitoring wells to meet the requirements of 40 CFR 264.97(c). Details of monitoring well construction are provided in Section 6.2.

40 CFR 264.98(c) requires collection of samples at background wells and wells at the compliance points. The numbers and kinds of samples collected to establish background will be appropriate for the form of statistical test employed, and the sample size will be as large as necessary to ensure with reasonable confidence that a contaminant release to ground water from a facility will be detected. A record of ground water analytical data as measured must be maintained in a form necessary for determination of statistical significance under 264.97(h). NSWC Crane will collect groundwater samples semi-annually at background and compliance-point wells at the DR. Background concentrations will be established after four rounds of sampling and compared to concentrations in downgradient compliance-point wells. The laboratory will supply analytical data in a form suitable for statistical evaluations. All analytical data will be maintained in the recordkeeping repository located at NSWC Crane.

40 CFR 264.98(d) requires the collection of a sequence of at least four samples from each well (background and compliance) collected at least semi-annually. 40 CFR 264.97(g) requirements are also referenced. The samples must be taken at an interval that assures to the greatest extent technically feasible that an independent sample is obtained. NSWC Crane will collect samples semi-annually and will conduct statistical evaluation when four rounds of analytical data are available.

40 CFR 264.98(e) requires annual determinations of ground water flow rate and direction in the uppermost aquifer. NSWC Crane will obtain ground water elevation data at each monitoring well every sampling event. The elevation data will be used along with hydraulic conductivity data in the annual determination of ground water flow rate and direction. This information will be included in the annual report, described in Section 1.3.4.

40 CFR 264.98(f) requires determination of whether there is a statistically significant evidence of contamination for indicator parameters. Data collected at compliance points must be compared to background water-quality data. Results of the statistical evaluation must be reported in writing within a reasonable period of time. NSWC Crane will collect four rounds of samples at the DR and re-establish background. When the fourth round is collected, statistical evaluations will be conducted. Analysis of ground water samples will be completed within 45 days, after the completion of each semi-annual sampling at the DR. Within 45 days, the data will be statistically evaluated and the results made available to the regional administrator.

40 CFR 264.98(g) contains requirements for various reports and actions that must occur if there is statistically significant evidence of contamination at any well at the compliance point. NSWC will implement the procedures in Section 1.3.1. Section 1.3.1 describes the reports to be submitted and actions to be undertaken if statistically significant evidence of contamination is found at any well at the DR compliance point.

40 CFR 264.98(h) requires submission of an application for a permit modification if it is determined that the detection monitoring program no longer satisfies the requirements of 264 Subpart F. NSWC Crane will evaluate the detection-monitoring program semi-annually. If it is determined that the DR detection monitoring program no longer meets 40 CFR 264 Subpart F requirements, NSWC Crane will submit a permit application to modify the DR ground water monitoring program, within 90 days to meet the requirements of 264 Subpart F.

The DR detection-monitoring program must also meet the general ground water monitoring requirements described in 40 CFR 264.97. Compliance with the general ground water monitoring requirements is addressed in Section 6.

TABLE 9-1

DEMOLITION RANGE
MONITORING WELL SUMMARY
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

Wells	Screened Formation	Objective
06C02	BC/BC	Downgradient (POC)
06C03	BC/BC	Downgradient (POC)
06C03P2	G/H	Downgradient (POC)
06C04	BC/BC	Downgradient (POC)
06C04P2	G/H	Downgradient (POC)
06C05	BC/BC	Downgradient (POC)
06C06	LP/BC	Downgradient (POC)
06C06P2	P	Downgradient (POC)
06C07	BC	Downgradient (POC)
06C08	BC/BC	Upgradient
06C08P2	P	Upgradient

Notes:

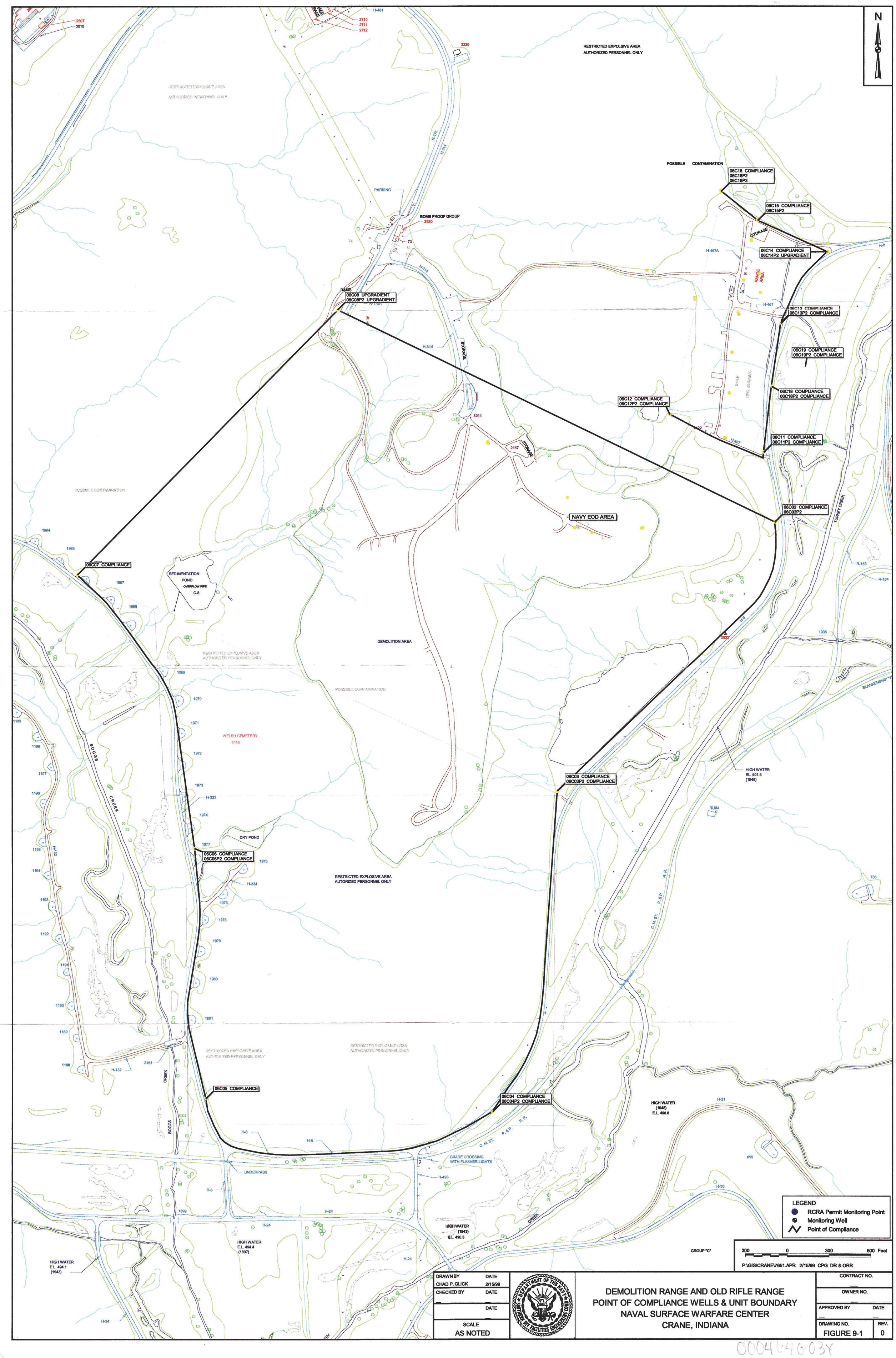
BC = Beech Creek
BC/BC = Big Clifty/Beech Creek
G/H = Golconda/Haney LS
LP/BC = Lower Pennsylvanian/Beech Creek
P = Pennsylvanian
POC = Point of Compliance

TABLE 9-2

DEMOLITION RANGE
SEMIANNUAL MONITORING
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

Wells	Field[1]	Explosives[1]	Appendix IX Metals[1] Total	Appendix IX Metals[1] Dissolved	Cyanide	TOC	TOX
06C02	A	A	A, D	A, D	•	•	•
06C03	A	A	A, D	A, D	•	•	•
06C03P2	A	A	A, D	A, D	•	•	•
06C04	A	A	A, D	A, D	•	•	•
06C04P2	A	A	A, D	A, D	•	•	•
06C05	A	A	A, D	A, D	•	•	•
06C06	A	A	A, D	A, D	•	•	•
06C06P2	A	A	A, D	A, D	•	•	•
06C07	A	A	A, D	A, D	•	•	•
06C08[2]	A	A	A, D	A, D	•	•	•
06C08P2	A	A	A, D	A, D	•	•	•

1 The letters A, B, C, etc. indicate subsets of the parameter group shown in the column headings. Specific parameters included in each subset are listed in Appendix D of the approved FSP.
2 Monitoring well 06C08 is also an upgradient well for the ORR. Analyses are also included in Table 8-2.



DRAWN BY	DATE
CHAD P. GLICK	2/15/99
CHECKED BY	DATE
	DATE
SCALE	
AS NOTED	

DEMOLITION RANGE AND OLD RIFLE RANGE
POINT OF COMPLIANCE WELLS & UNIT BOUNDARY
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

CONTRACT NO.	
OWNER NO.	
APPROVED BY	DATE
DRAWING NO.	REV.
FIGURE 9-1	0

000446 03Y

10.0 PROCEDURE FOR DETERMINING STATISTICALLY SIGNIFICANT INCREASES FOR MONITORED PARAMETERS [40 CFR 264.97 AND 264.98]

For purposes of determining compliance with RCRA 40 CFR Subpart F ground water requirements, it is necessary to differentiate between downgradient concentrations potentially attributable to waste treatment at the NSWC Crane sites (ABG, ORR, and DR) and those present in the upgradient wells at these sites.

The statistical methods proposed to evaluate the ground water data for the NSWC Crane are employed to

- Develop summary statistics (e.g., range, mean, standard deviation) that describe environmental contaminant concentrations at the NSWC Crane sites.

- Allow comparisons of upgradient concentrations to those detected in site environmental samples (i.e., samples collected in areas potentially contaminated by waste treatment) at the NSWC Crane site.

The statistical methods presented are based on the following references

- Snedecor, George W. and William G Cochran, 1980. Statistical Methods. The Iowa State University Press (Snedecor and Cochran, 1980).

- Gilbert, Richard O., 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold Company. New York, New York (Gilbert, 1987).

- U.S. EPA, 1989. Guidance Document on the Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities. EPA 530/SW-89-026 (EPA, 1989).

- U.S. EPA, July 1992. Statistical Training Course for Ground-Water Monitoring Data Analysis. EPA 530/R-93-003 (EPA, 1992).

10.1 BASIC APPROACH OF THE COMPARISON OF DOWNGRADIENT WELLS TO THE UPGRADIENT WELLS

Downgradient data will be compared to upgradient data using either parametric or nonparametric analysis, as defined below. No correction for seasonal variability is required, since all wells at the facility

should be affected similarly. The statistical methods described in the following paragraphs will be used to determine whether parameter concentrations detected in downgradient wells are significantly different, statistically speaking, from those detected in samples from the upgradient wells.

The Analysis of Variance (ANOVA) technique will be the basic approach used to compare data from upgradient and downgradient monitoring well locations. The ANOVA technique is used to test whether there is statistically significant evidence of contamination. The two types of ANOVA are parametric and nonparametric. Parametric ANOVA methods make two important assumptions: the data residuals are normally (or lognormally) distributed, and the group variances are homogeneous.

If the analysis of the data demonstrates that these assumptions, critical to the parametric ANOVA, are violated, nonparametric ANOVA techniques will be conducted using the ranks of the observations rather than the observations themselves (U.S. EPA, 1989). The Kruskal-Wallis test will be employed as the nonparametric ANOVA for comparing the downgradient wells to the upgradient wells.

10.2 ASSESSMENT OF DATA FOR USE IN STATISTICAL ANALYSIS

As discussed in Section 9.2.2 of the QAPP, qualification of analytical data during the validation process (i.e., the application of U, BU, J, BJ, JN, UJ, UR, and R qualifiers) will be conducted as required by Region 5 data validation SOPs. The addition of the data qualifiers to analytical results signifies the occurrence of QC noncompliances that have been noted during the course of data validation. The various data qualifiers are defined as follows:

- U - Indicates that the chemical was not detected at the sample quantitation limit (SQL) noted. The laboratory reports the SQL for an analyte followed by this qualifier code if the analyte was not detected at a concentration greater than or equal to the SQL. This qualifier is added to a positive result (reported by the laboratory) during data validation if the detected concentration is determined to be attributable to contamination introduced during field sampling.

- BU - Indicates that the chemical was not detected at the SQL noted. This qualifier is added to a positive result (reported by the laboratory) during data validation if the detected concentration is determined to be attributable to contamination introduced during laboratory analysis.

- UJ - Indicates that the chemical was not detected at the SQL noted. However, the SQL is considered to be an estimate based on technical problems identified during data validation.

- J - Indicates that the chemical was detected. However, the laboratory-reported quantity is considered to be an estimate of the concentration that is actually present in the sample.

- BJ - Indicates that the chemical was detected in the sample as well as in an associated laboratory blank. The detected concentration was not determined during data validation to be wholly attributable to contamination introduced during laboratory analysis. However, the laboratory-reported quantity is considered to be an estimate of the concentration that is actually present in the sample.

- JN - Indicates that the qualitative presence of the chemical cannot be definitely confirmed, but that the chemical is presumed to be present. The laboratory-reported quantity is considered to be an estimated concentration. This qualifier is added to a positive result during data validation whenever qualitative and quantitative confirmation is not definitive.

- UR - Indicates that the nondetected analytical result (i.e., the SQL) reported by the laboratory is considered to be unreliable or unusable and has been rejected. The chemical may or may not be present. This qualifier is applied in cases of gross technical deficiencies (e.g., holding times missed by a factor of two times the specified limit, severe calibration noncompliance, and extremely low QC recoveries).

- R - Indicates that the positive analytical result reported by the laboratory is considered to be unreliable and unusable and has been rejected. The chemical may or may not be present. This qualifier is applied in cases of gross technical deficiencies.

Analytical results that are qualified as rejected (R or UR) are considered to be invalid will not be used for statistical analysis or decision making. Analytical results that are qualified as estimated (J, BJ, JN, or UJ) are considered to be suitable for statistical analysis and decision making purposes. In cases where a chemical is not detected by the laboratory or is qualified as not detected during data validation (i.e., qualified with U, BU, or UJ), half the value of the reported SQL will be used for statistical analysis. Clearly, if all the results are nondetects, no statistical analysis is warranted. In addition, field duplicate results will be averaged and counted as one sample for use in statistical analysis.

10.3 PARAMETRIC AND NONPARAMETRIC ANALYSIS OF VARIANCE (ANOVA)

10.3.1 Parametric ANOVA

ANOVA is widely used in the examination of environmental data sets. A one-way classification ANOVA is used to determine whether or not the difference between average concentrations of a parameter detected in downgradient wells and upgradient concentrations is statistically significant. The data residuals are the values resulting from subtracting each measured value from the arithmetic mean. The assumptions that the residuals are drawn from an underlying normal (or lognormal) distribution and that the upgradient and downgradient data sets have homogeneous variances must be examined before a parametric ANOVA is employed.

As stated above, the data residuals must be analyzed to determine whether they were drawn from an underlying normal, lognormal, or undetermined distribution. A number of statistical evaluations may be used to determine which, if either, of the distributions are exhibited by a given data set. As recommended by the U.S. EPA, the Shapiro and Wilk "W-test" (for sample sets ≤50) and the Shapiro-Francia "W-test" (for sample sets >50) will be used to determine whether the data are normally or lognormally distributed (U.S. EPA, 1992).

10.3.1.1 The Shapiro and Wilk "W-test" of Normality (n≤50)

The Shapiro and Wilk W-test (Gilbert, 1987) is an effective method for determining whether a data set has been drawn from an underlying normal (or lognormal) distribution. In addition, when the Shapiro and Wilk W-test is conducted on the log-transformed data, the test may be used to determine whether the data have been drawn from an underlying lognormal distribution. The null hypothesis (H_0) that is tested is

H_0: *The population has a normal (or lognormal when the data are log-transformed) distribution.*

The alternate hypothesis (H_A) is

H_A *The population does not have a normal (or lognormal when the data are log-transformed) distribution.*

If H_0 is rejected, then H_A is accepted. If H_0 is not rejected, the data set is consistent with the H_0 distribution.

A "W" statistic (W_{calc}) is computed for a data set (or a log transformed data set) and compared to a test statistic (W_{test}). If $W_{calc} \geq W_{test}$, then the null hypothesis is not rejected [i.e., the data are assumed to be normally distributed (or lognormally distributed if log transformed data are tested)]. If $W_{calc} < W_{test}$, then the null hypothesis is rejected and the alternative hypothesis is accepted [i.e., the data are not assumed to be normally distributed (or not lognormally distributed if log transformed data are tested)].

The following equations present a step-by-step procedure for conducting the W-test on the residuals:

- Step 1. Group all the data from each of the individual wells.

- Step 2. Calculate the mean for each of the *k* wells $\overline{x_j}$ by the equation

$$\overline{x_j} = \frac{\sum_{i=1}^{n} x_i}{n}$$

where n is the total number of samples in each well.

- Step 3. Calculate the residuals for each ith well and j^{th} sampling round by

$$R_{ij} = x_{ij} - \overline{x_i}$$

The equation for conducting the W-Test is

$$W_{calc} = \left[\frac{b}{S_R\sqrt{n-1}}\right]^2$$

where

$$b = \sum_{i=1}^{k} a_i \left(R_{[n-i+1]} - R_i\right) = \sum_{i=1}^{k} b_i$$

and *n* is the total number of sampling rounds.

- Step 4. Order the *n* residuals from smallest to largest to obtain the sample order statistics:

$$x_1 \leq x_2 \leq x_3 \leq \ldots \leq x_n$$

- Step 5. Compute the standard deviation by

$$S_R = \sqrt{\sum_{i=1}^{n} \frac{\left(R_{ij} - \overline{R}\right)^2}{(n-1)}}$$

- Step 6. Determine the coefficients $a_1, a_2, a_3, .., a_k$ for the sample size n using Table 10-1 where

$$k = \frac{n}{2} \quad if\, n\ is\ even\text{; and}$$

$$k = \frac{n-1}{2} \quad if\, n\ is\ odd$$

- Step 7. Determine b by the formula

$$b = \sum_{i=1}^{k} a_i \left(R_{[n-i+1]} - R_i\right) = \sum_{i=1}^{k} b_i$$

- Step 8. Calculate W_{calc} using b from above

$$W_{calc} = \left[\frac{b}{S_R\sqrt{n-1}}\right]^2$$

- Step 9. Determine W_{test} at the 5 percent significance level from Table 10-2.

- Step 10. Reject H_O at the 5 percent significance level if W_{calc} is less than W_{test}.

To test the null hypothesis that the data set has been drawn from an underlying lognormal distribution, transform the data to $y_{1j}, y_{2j}, y_{3j}, \ldots, y_{km}$ where $y_{ij} = ln\ R_{ij}$. Repeat steps 1 through 10 as described in the preceding paragraphs.

TABLE 10-1

COEFFICIENTS A_1 FOR W TEST OF NORMALITY FOR N=2 to 50
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

i/n	2	3	4	5	6	7	8	9	10
1	0.7071	0.7071	0.6872	0.6646	0.6431	0.6233	0.6052	0.5888	0.5739
2			0.1677	0.2413	0.2806	0.3031	0.3164	0.3244	0.3291
3					0.0875	0.1401	0.1743	0.1976	0.2141
4							0.0561	0.0947	0.1224
5									0.0399

i/n	11	12	13	14	15	16	17	18	19	20
1	0.5601	0.5475	0.5359	0.5251	0.5150	0.5056	0.4968	0.4886	0.4808	0.4734
2	0.3315	0.3325	0.3325	0.3318	0.3306	0.3290	0.3273	0.3253	0.3232	0.3211
3	0.2260	0.2347	0.2412	0.2460	0.2495	0.2521	0.2540	0.2553	0.2561	0.2565
4	0.1429	0.1586	0.1707	0.1802	0.1878	0.1939	0.1988	0.2027	0.2059	0.2085
5	0.0695	0.0922	0.1099	0.1240	0.1353	0.1447	0.1524	0.1587	0.1641	0.1686
6		0.0303	0.0539	0.0727	0.0880	0.1005	0.1109	0.1197	0.1271	0.1334
7				0.0240	0.0433	0.0593	0.0725	0.0837	0.0932	0.1013
8						0.0196	0.0359	0.0496	0.0612	0.0711
9								0.0163	0.0303	0.0422
10										0.0140

i/n	21	22	23	24	25	26	27	28	29	30
1	0.4643	0.4590	0.4542	0.4493	0.4450	0.4407	0.4366	0.4328	0.4291	0.4254
2	0.3185	0.3156	0.3126	0.3098	0.3069	0.3043	0.3018	0.2992	0.2968	0.2944
3	0.2578	0.2571	0.2563	0.2554	0.2543	0.2533	0.2522	0.2510	0.2499	0.2487
4	0.2119	0.2131	0.2139	0.2145	0.2148	0.2151	0.2152	0.2151	0.2150	0.2148
5	0.1736	0.1764	0.1787	0.1807	0.1822	0.1836	0.1848	0.1857	0.1864	0.1870
6	0.1399	0.1443	0.1480	0.1512	0.1539	0.1563	0.1584	0.1601	0.1616	0.1630
7	0.1092	0.1150	0.1201	0.1245	0.1283	0.1316	0.1346	0.1372	0.1395	0.1415
8	0.0804	0.0878	0.0941	0.0997	0.1046	0.1089	0.1128	0.1162	0.1192	0.1219
9	0.0530	0.0618	0.0696	0.0764	0.0823	0.0876	0.0923	0.0965	0.1002	0.1036
10	0.0263	0.0368	0.0459	0.0539	0.0610	0.0672	0.0728	0.0778	0.0822	0.0862
11		0.0122	0.0228	0.0321	0.0403	0.0476	0.0540	0.0598	0.0650	0.0697
12				0.0107	0.0200	0.0284	0.0358	0.0424	0.0483	0.0537
13						0.0094	0.0178	0.0253	0.0320	0.0381
14								0.0084	0.0159	0.0227
15										0.0076

i/n	31	32	33	34	35	36	37	38	39	40
1	0.4220	0.4188	0.4156	0.4127	0.4096	0.4068	0.4040	0.4015	0.9689	0.3964
2	0.2921	0.2898	0.2876	0.2854	0.2834	0.2813	0.2794	0.2774	0.2755	0.2737
3	0.2475	0.2463	0.2451	0.2439	0.2427	0.2415	0.2403	0.2391	0.2380	0.2368
4	0.2145	0.2141	0.2137	0.2132	0.2127	0.2121	0.2116	0.2110	0.2104	0.2098
5	0.1874	0.1878	0.1880	0.1882	0.1883	0.1883	0.1883	0.1881	0.1880	0.1878
6	0.1641	0.1651	0.1660	0.1667	0.1673	0.1678	0.1683	0.1686	0.1689	0.1691
7	0.1433	0.1449	0.1463	0.1475	0.1487	0.1496	0.1503	0.1513	0.1520	0.1526
8	0.1243	0.1265	0.1284	0.1301	0.1317	0.1331	0.1344	0.1356	0.1366	0.1376
9	0.1066	0.1093	0.1118	0.1140	0.1160	0.1179	0.1196	0.1211	0.1225	0.1237
10	0.0899	0.0931	0.0961	0.0988	0.1013	0.1036	0.1056	0.1075	0.1092	0.1108
11	0.0739	0.0777	0.0821	0.0844	0.0873	0.0900	0.0924	0.0947	0.0967	0.0986
12	0.0585	0.0629	0.0669	0.0706	0.0739	0.0770	0.0798	0.0824	0.0848	0.0870
13	0.0435	0.0485	0.0530	0.0572	0.0610	0.0645	0.0677	0.0706	0.0733	0.0759
14	0.0289	0.0344	0.0395	0.0441	0.0484	0.0523	0.0559	0.0592	0.0622	0.0651
15	0.0144	0.0206	0.0262	0.0314	0.0361	0.0404	0.0444	0.0481	0.0515	0.0546
16		0.0068	0.0131	0.0187	0.0239	0.0287	0.0331	0.0372	0.0409	0.0444
17				0.0062	0.0119	0.0172	0.0220	0.0264	0.0305	0.0343
18						0.0057	0.0110	0.0158	0.0203	0.0244
19								0.0053	0.0101	0.0146
20										0.0049

i/n	41	42	43	44	45	46	47	48	49	50
1	0.3940	0.3917	0.3894	0.3872	0.3850	0.3830	0.3808	0.3789	0.3770	0.3751
2	0.2719	0.2701	0.2684	0.2667	0.2651	0.2635	0.2620	0.2604	0.2589	0.2574
3	0.2357	0.2345	0.2334	0.2323	0.2313	0.2302	0.2291	0.2281	0.2271	0.2260
4	0.2091	0.2085	0.2078	0.2072	0.2065	0.2058	0.2052	0.2045	0.2038	0.2032
5	0.1876	0.1874	0.1871	0.1868	0.1865	0.1862	0.1859	0.1855	0.1851	0.1847
6	0.1693	0.1694	0.1695	0.1695	0.1695	0.1695	0.1695	0.1693	0.1692	0.1691
7	0.1531	0.1535	0.1539	0.1542	0.1545	0.1548	0.1550	0.1551	0.1553	0.1554
8	0.1384	0.1392	0.1398	0.1405	0.1410	0.1415	0.1420	0.1423	0.1427	0.1430
9	0.1249	0.1259	0.1269	0.1278	0.1286	0.1293	0.1300	0.1306	0.1312	0.1317
10	0.1123	0.1136	0.1149	0.1160	0.1170	0.1180	0.1189	0.1197	0.1205	0.1212
11	0.1004	0.1020	0.1035	0.1049	0.1062	0.1073	0.1085	0.1095	0.1105	0.1113
12	0.0891	0.0909	0.0927	0.0943	0.0959	0.0972	0.0986	0.0998	0.1010	0.1020
13	0.0782	0.0804	0.0824	0.0842	0.0860	0.0876	0.0892	0.0906	0.0919	0.0932
14	0.0677	0.0701	0.0724	0.0745	0.0775	0.0785	0.0801	0.0817	0.0832	0.0846
15	0.0575	0.0602	0.0628	0.0651	0.0673	0.0694	0.0713	0.0731	0.0748	0.0764
16	0.0476	0.0506	0.0534	0.0560	0.0584	0.0607	0.0628	0.0648	0.0667	0.0685
17	0.0379	0.0411	0.0442	0.0471	0.0497	0.0522	0.0546	0.0568	0.0588	0.0608
18	0.0283	0.0318	0.0352	0.0383	0.0412	0.0439	0.0465	0.0489	0.0511	0.0532
19	0.0188	0.0227	0.0263	0.0296	0.0328	0.0357	0.0385	0.0411	0.0436	0.0459
20	0.0094	0.0136	0.0175	0.0211	0.0245	0.0277	0.0307	0.0335	0.0361	0.0386
21		0.0045	0.0087	0.0126	0.0163	0.0197	0.0229	0.0259	0.0288	0.0314
22				0.0042	0.0081	0.0188	0.0153	0.0185	0.0215	0.0244
23						0.0039	0.0076	0.0111	0.0143	0.0174
24								0.0037	0.0071	0.0104
25										0.0350

TABLE 10-2

PERCENTAGE POINTS OF THE W TEST FOR N=3 to 50
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

n	0.01	0.05
3	0.753	0.767
4	0.687	0.748
5	0.686	0.762
6	0.713	0.788
7	0.730	0.803
8	0.749	0.818
9	0.764	0.829
10	0.781	0.842
11	0.792	0.850
12	0.805	0.859
13	0.814	0.866
14	0.825	0.874
15	0.835	0.881
16	0.844	0.887
17	0.851	0.892
18	0.858	0.897
19	0.863	0.901
20	0.868	0.905
21	0.873	0.908
22	0.878	0.911
23	0.881	0.914
24	0.884	0.916
25	0.888	0.918
26	0.891	0.920
27	0.894	0.923
28	0.896	0.924
29	0.898	0.926
30	0.900	0.927

n	0.01	0.05
31	0.902	0.929
32	0.904	0.930
33	0.906	0.931
34	0.908	0.933
35	0.910	0.934
36	0.912	0.935
37	0.914	0.936
38	0.916	0.938
39	0.917	0.939
40	0.919	0.940
41	0.920	0.941
42	0.922	0.942
43	0.923	0.943
44	0.924	0.944
45	0.926	0.945
46	0.927	0.945
47	0.928	0.946
48	0.929	0.947
49	0.929	0.947
50	0.930	0.947

10.3.1.2 Shapiro-Francia Test of Normality (n>50)

The Shapiro-Wilk test of Normality can be used for sample sizes up to 50. When the sample size is larger than 50, a slight modification of the procedure, known as the Shapiro-Francia test (U.S. EPA, 1992), can be used instead.

Like the Shapiro-Wilk test, the Shapiro-Francia test statistic (W') will tend to be large when a probability plot of the data indicates a nearly straight line. Only when the plotted data show significant bends or curves will the test statistic be small.

To calculate the test statistic W', one can use the following formula:

$$W' = \frac{\left[\sum_i m_i x_i\right]^2}{(n-1)\sigma^2 \sum_i m_i^2}$$

where x_i represents the ith ordered value of the sample and m_i denotes the approximate expected value of the ith ordered normal quantile. The values of m_i can be approximately computed as

$$m_i = \Phi^{-1}\left(\frac{i}{n+1}\right)$$

where Φ^{-1} denotes the inverse of the standard normal distribution with zero mean and unit variance.

Normality of the data should be rejected if the Shapiro-Francia statistic is too low when compared to the critical values provide in Table 10-3. Otherwise, one can assume the data are approximately normal for purposes of further statistical analysis

TABLE 10-3

PERCENTAGE POINTS OF THE W' TEST FOR N>50 (SHAPIRO-FRANCIA TEST) NAVAL SURFACE WARFARE CENTER CRANE, INDIANA

n	0.01	0.05
51	0.935	0.954
53	0.938	0.957
55	0.940	0.958
57	0.944	0.961
59	0.945	0.962
61	0.947	0.963
63	0.947	0.964
65	0.948	0.965
67	0.950	0.966
69	0.951	0.966
71	0.953	0.967
73	0.956	0.968
75	0.956	0.969
77	0.957	0.969
79	0.957	0.970
81	0.958	0.970
83	0.960	0.971
85	0.961	0.972
87	0.961	0.972
89	0.961	0.972
91	0.962	0.973
93	0.963	0.973
95	0.965	0.974
97	0.965	0.975
99	0.967	0.976

10.3.1.3 Homogeneity of Variance

An important assumption in ANOVA is that the variances in the different groups are equal (homogeneous). A powerful and commonly used test of this assumption is the Levene test. This test has practically replaced the older and less robust Bartlett's test and Chi-square test.

Levene's test (homogeneity of variances) is as follows: For each dependent variable, an analysis of variance is performed on the absolute deviations of values from the respective group means. If the Levene test is statistically significant, then the hypothesis of homogeneous variances should be rejected

To conduct Levene's test, first compute the absolute value of the residuals:

$$Zij = |Xij - Xi|$$

where Xij represents the jth value from the ith well. Then perform a standard one-way analysis of variation (ANOVA) on the variable Zij (see Section 10.3.1.4). If the F test is significant, reject the hypothesis of equal group variances. Otherwise, proceed with the analysis of Xij's as planned.

10.3.1.4 Parametric ANOVA Procedure

Assume that a site has k wells and that n_i data points (analyte concentrations) are available for the ith well. The following equations present a step-by-step procedure for conducting the parametric ANOVA.

- Step 1. Compute the sums and means of each well (i) as follows:

- Step 2. Compute the sum of squares of differences between the individual well means and the grand mean:

$$SS_{sample} = \sum_{i=1}^{k} n_i\left(\overline{X}_i - \overline{X}\right)^2 = \sum_{i=1}^{k}\left[\frac{X_i^2}{n_i}\right] - \frac{X^2}{N}$$

This sum of squares has (k-1) degrees of freedom associated with it and is a measure of the variability between wells.

- Step 3. Compute the corrected total sum of squares

$$SS_{total} = \sum_{i=1}^{k}\sum_{j=1}^{n_i}\left(X_{ij} - \overline{X}\right)^2 = \sum_{i=1}^{k}\sum_{j=1}^{n_i}\left[\left(X_{ij}\right)^2\right] - \frac{X^2}{N}$$

This sum of squares has (*N-1*) degrees of freedom associated with it and is a measure of variability in the whole data set.

- Step 4. Compute the sum of squares of differences of observations within wells from the well means. This value is the sum of squares due to error and is obtained by simple subtraction:

$$SS_{Error} = SS_{Total} - SS_{Sample}$$

The sum of squares due to error has associated with it (*N-k*) degrees of freedom and is a measure of the variability within wells.

- Step 5. Set up the ANOVA table. The sums of squares and their degree of freedom were obtained from Steps 2 through 4. The mean square quantities are simply obtained by dividing each sum of squares by its corresponding degrees of freedom.

ONE-WAY PARAMETRIC ANOVA TABLE

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F
Between Locations	$S_{Ssample}$	MS_{Sample}=k-1	SS_{Sample}/(k-1)	F=$MS_{samples}/MS_{Error}$
Error (within locations)	SS_{Error}	MS_{Error}=N-k	SS_{Error}/(N-k)	
Total	SS_{Total}	N-1		

Step 6. To test the hypothesis of equal means for all *k* wells, compute $F = MS_{Sample}/MS_{Error}$ (last column in above table). Compare this statistic to the tabulated F statistic with (*k-1*) and (*N-k*) degrees of freedom (Table 10-4) at the 5 percent significance level. If the calculated *F* value exceeds the tabulated value, reject the hypothesis of equal well means. Otherwise, conclude that there is no

TABLE 10-4

95TH PERCENTILES OF F-DISTRIBUTION WITH v_1 and v_2 DEGREES OF FREEDOM
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

v_1/v_2	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120
1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5	241.9	243.9	245.9	248.0	249.1	250.1	251.1	252.2	253.3
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.72
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35

NOTE: v1: Degrees of Freedom for Numerator
v2: Degrees of Freedom for denominator

significant difference between the concentrations of the *k* wells and thus no evidence of contamination.

In the case where the downgradient well data exhibit a statistically significant difference from the upgradient well data, the following steps may be followed to determine which areas are contaminated. This is done by comparing each individual well to the upgradient well separately using the Bonferroni *t-statistic*.

- Step 7. Determine whether the significant *F* is due to differences between upgradient concentrations and downgradient well concentrations (computation of Bonferroni *t-statistics*).

  Assume that, of the *k* wells, *u* are from the upgradient well and *m* are from downgradient wells (i.e., $u + m = k$). Then *m* differences need to be computed and tested for statistical significance. If there are more than five downgradient wells, the individual comparisons are done at the significance level of 1 percent, which may make the experiment's significance level greater than 5 percent (U.S. EPA, 1989).

- Step 8. Obtain the total sample size of all upgradient concentrations.

$$n_b = \sum_{i=1}^{u} n_i$$

- Step 9. Compute the average concentration from the upgradient well.

$$\overline{X_b} = \frac{1}{n_b} \sum_{i=1}^{u} \overline{X_i}$$

- Step 10. Compute the *m* differences between the average concentrations from each downgradient well and the upgradient well.

$$\overline{X_i} - \overline{X_b}, \quad i = 1,\ldots,m$$

- Step 11. Compute the standard error of each difference as

$$SE_i = \sqrt{MS_{Error}\left(\frac{1}{n_b} + \frac{1}{n_i}\right)}$$

where MS_{Error} is determined from the ANOVA table from Step 5 and n_i is the number of observations at downgradient well i.

- Step 12. Obtain the t-statistic $t = t_{(N-k),(1-a/m)}$ from Bonferroni's t-table (Table 10-5) with a =0.05 and (N-k) degrees of freedom.

- Step 13. Compute the m quantities $D_i = (SE_i)(t)$ for each downgradient well i. If $m > 5$, use the entry for $t_{(N-k),(1-0.01)}$. That is, use the entry at $m = 5$.

Interpretation of Bonferroni's Statistic:

If the difference

$$\overline{X_i} - \overline{X_b}$$

exceeds the value D_i, conclude that the downgradient well has significantly higher concentrations than the average upgradient concentrations. Otherwise conclude that the downgradient well is not contaminated. This exercise may be performed for each of the m downgradient wells individually. The test is designed so that the overall experimental error is 5 percent if there are no more than five wells.

If the number of wells is greater than five, the experimental error will be greater than 5 percent. In this case, the Bonferroni *t-test* should be modified by doing the individual comparisons at the 1 percent level.

10.3.2 Nonparametric ANOVA

The parametric ANOVA technique is the preferred approach for comparing environmental measurements from downgradient monitoring wells to upgradient well data. However, parametric ANOVA methods make

TABLE 10-5

95TH PERCENTILES OF THE BONFERRIONI t-STATISTIC WITH DEGREES OF FREEDOM, $t_{va/m}$
NAVAL SURFACE WARFARE CENTER
CRANE, INDIANA

	m	1	2	3	4	5
v	**α/m**	**0.05**	**0.025**	**0.0167**	**0.0125**	**0.01**
4		2.13	2.78	3.20	3.51	3.75
5		2.02	2.57	2.90	3.17	3.37
6		1.94	2.45	2.74	2.97	3.14
7		1.90	2.37	2.63	2.83	3.00
8		1.86	2.31	2.55	2.74	2.90
9		1.83	2.26	2.50	2.67	2.82
10		1.81	2.23	2.45	2.61	2.76
15		1.75	2.13	2.32	2.47	2.60
20		1.73	2.09	2.27	2.40	2.53
30		1.70	2.04	2.21	2.34	2.46

v = degrees of freedom associated with mean squares error
m = # of comparisons
α = 0.05, the experimentwise error level

two key assumptions: the inter-well residuals are normally (or lognormally) distributed and the group variances are approximately equal. If either of these assumptions is violated, non-parametric tests (i.e., Kruskal-Wallis or Wilcoxon Rank-Sum tests) may be used to determine whether constituent concentrations present in the downgradient areas significantly exceed those present in the upgradient well.

Nonparametric tests are conducted using the ranks of the analytical results rather than the analytical results themselves. Therefore, the data sets are inspected for extremely high values that may have been underestimated as a result of the ranking process.

The Kruskal-Wallis (U.S. EPA, 1989) test should be employed when comparing three or more data sets. However, it is not amenable to two-well comparisons (e.g., one downgradient well to one upgradient well). In these situations, the Wilcoxon Rank-Sum test (U.S. EPA, 1992) should be employed.

10.3.2.1 The Wilcoxon Rank-Sum Test

When data from multiple downgradient wells are being compared to a single upgradient well and a non-parametric test is needed (i.e., the population is not normally or lognormally distributed), the Wilcoxon Rank-Sum test (also known as the Mann-Whitney U test) should be employed (EPA, 1992). In general, the Wilcoxon Rank-Sum test should be employed whenever the proportion of nondetects is greater than 15 percent (but less than 90 percent). However, to provide valid results, the Wilcoxon Rank-Sum test should not be used unless the downgradient and upgradient wells have been sampled at least four times. The following equations present a step-by-step procedure for conducting the Wilcoxon Rank-Sum test.

- Step 1. Combine the upgradient and downgradient data and rank the ordered values from 1 to N. Assume there are n downgradient samples and m upgradient samples so that $N = m + n$.

$$W = \sum_{i=1}^{n} E_i - \frac{1}{2}n(n+1)$$

- Step 2. Compute the Wilcoxon statistic W:

  where E_i are the ranks of the downgradient samples (Large values of the statistic W give evidence of contamination in downgradient wells).

- Step 3. Compute an approximate *Z-score*. To find the critical value of *W*, a normal approximation to its distribution is used. The expected value and standard deviation of *W* under the null hypothesis (i.e., no contamination exists) are given by the formulas

$$E(W) = \frac{1}{2}mn; \qquad SD(W) = \sqrt{\frac{1}{12}mn(N+1)}$$

An approximate *Z-score* for the Wilcoxon Rank-Sum test may be calculated by the following equations:

$$Z = \frac{W - E(W) - \frac{1}{2}}{SD(W)}$$

The factor of 1/2 in the numerator serves as a continuity correction, since the discrete distribution of the statistic W is being approximated by the continuous normal distribution. If $n,m > 10$ and ties are present, an adjustment to the approximate *Z-score* must be made:

$$Z_{RS} = \frac{W - E(W) - \frac{1}{2}}{SD'(W)}$$

where: $$SD'(W) = \left(\frac{mn}{12} \left[N + 1 - \frac{\sum_{j=1}^{g} t_j(t_j^2 - 1)}{N(N-1)} \right] \right)^{\frac{1}{2}}$$

g = the number of tied groups and t_j is the number of tied data in the jth group.

- Step 4. For a one-tailed, 0.05 significance level test for H_0 versus the H_A (i.e., the measurements from population 1 tend to exceed those from population 2), reject H_0 and accept H_A if $Z_{rs} > Z_{0.95} = 1.645$. For a one-tailed a significance level test for H_0 versus the H_A that the measurements from population 2 tend to exceed those from population 1, reject H_0 and accept H_A if $-Z_{rs} < -Z_{0.95} = -1.645$.

10.4 DISCUSSION

Summaries of the analytical data and statistical analyses performed will be presented in the quarterly and semiannual reports and will include the following

- Summary of concentrations of each constituent for which analysis was performed at each downgradient and upgradient well for the most recent quarter and the detection limit for each constituent.

- Summary of the most recent quarter's statistical results including

  - Concentration of each chemical at each well for that quarter.

  - Results from tests of normality (Shapiro-Wilk or Shapiro-Francia, where appropriate); tests of homogeneity of variance (Levene's test); one-way analysis of variance [parametric ANOVA (F test) or nonparametric ANOVA (Kruskal-Wallis test), where appropriate] for each chemical at each well for that quarter.

  - Tables showing frequency of detection, range of detections, arithmetic mean, location of maximum detection, 95 percent upper confidence limit at the upgradient well, and the appropriate data quality level.

  - Identification of downgradient wells with concentrations statistically higher than the upgradient concentration. Those parameters found statistically to be exceeding upgradient will be in **boldface** for clarity.

  - Sample calculations for all statistical tests performed that quarter.

Annual reports will also include a trend analysis showing mean concentrations of each chemical for the upgradient and downgradient wells for the four most recent quarters (e.g., quarters 2, 3, 4, and 5 in fifth quarter). These moving averages will be compared to the moving averages from the previous quarters (e.g., quarters 1, 2, 3, and 4 from the fourth quarter). Graphical representations of these trends comparing upgradient versus downgradient concentrations for constituents that have been shown to be statistically higher than the upgradient concentration will be presented.

11.0 CORRECTIVE ACTION PROGRAM [40 CFR 270.14(c)(8)]

Corrective action for Solid Waste Management Units (SWMUs) is discussed in the RCRA Part B permit application submitted by NSWC Crane in November 1997, and is included in the operating permit for the Central Storage Facility and Incinerator.

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