STUDY APPROACH FOR THE HYDROGEOLOGIC ASSESSMENT OF CARROLL ISLAND AND GRACES QUARTERS, ABERDEEN PROVING GROUND, MARYLAND

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CONVERSION FACTORS AND ABBREVIATIONS

For those readers who prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted using the following factors:

Multiply inch-pound units	By	To obtain metric units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
yard (yd)	0.9144	meter (m)
mile (mi)	1.609	kilometer (km)
acre	4,047.0	square meter (m^2)
acre	0.4047	hectare
gallon (gal)	3.785	liter (L)
gallon (gal)	.003785	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
pound, avoirdupois (lb)	0.4536	kilogram (k)

Chemical concentration is expressed in micrograms per liter (µg/L) and micrograms per kilogram (µg/g). Water temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the following equation:

$$°F = 1.8\,(°C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "*Sea Level Datum of 1929.*"

ACRONYMS AND ABBREVIATIONS

AEHA:	U.S. Army Environmental Hygiene Agency
APG:	Aberdeen Proving Ground
BBC:	An irritant (bromobenzyl cyanide) [1]
Bis:	A simulant (bis-2-ethylhexyl hydrogen phosphite)
BHC:	Benzenehexachloride
BOD:	Biological oxygen demand
BZ:	An incapacitating agent (3-quinuclidinyl benzilate)
CN:	Tear gas, a riot control agent (chloroacetophenone)
COD:	Chemical oxygen demand
COE:	U.S. Army Corps of Engineers
CS:	Tear gas, a riot control agent (o-chlorobenzylidene malononitrile)
CS-1:	CS blended with 5-percent silica aerogel
CS-2:	CS blended with a hydrophoric compound

[1] Common and chemical names for chemical agents were obtained from the Field Manual listed in the reference section under U.S. Departments of the Army and Air Force (1975), and from Nemeth and others (1983, Table 3-1).

DANC:	Decontaminating agent, noncorrosive; an organic-based decontaminant
DBHP:	A simulant (dibutyl hydrogen phosphite)
DDD:	Dichloro-diphenyl-dichloroethane
DDE:	Dichloro-diphenyl-dichloroethylene
DEHP:	A simulant (chemical name not available; possibly diethyl hydrogen phosphite)
DM:	Adamsite, a vomiting agent (diphenylamino-chloroarsine)
DMHP:	A simulant (dimethyl hydrogen phosphite)
DS-2:	An organic-based decontaminant
EA 1356:	An organophosphorus nerve agent
EA 3834:	An incapacitating agent (no common or chemical name available)
EA 3528:	An incapacitating agent (no common or chemical name available)
EA 3990:	A nerve agent (no common or chemical name available)
EDA:	A simulant (ethylenediamine)
EM:	Electromagnetic induction, a surface geophysical method
EPG:	Edgewood Proving Ground, an organization which operated for a period in the 1940's or 1950's and was later incorporated into Edgewood Arsenal
FEMA:	U.S. Federal Emergency Management Agency
FS:	A screening smoke (sulfur trioxide and chlorosulfonic acid)
GA:	The nerve agent tabun (ethyl N,N-dimethyl phosphoroamidocyanidate)
GB:	The nerve agent sarin (isopropyl methyl phosphonofluoridate)
GD:	The nerve agent soman (pinacolyl methyl phosphonofluoridate)
HCN:	Hydrogen cyanide, a hydrolysis product of G-type agents
HD:	Distilled mustard, a blister agent (bis (2-chloroethyl) sulfide)
HE:	High explosive
HEA:	Health and Environmental Assessment
HF:	Hydrogen fluoride, a hydrolysis product of G-type agents
HGA:	Hydrogeologic Assessment
HTH:	Calcium hypochlorite, used as a chemical decontaminant
IMPA:	Isopropylmethyl phosphonic acid
MCL:	Maximum Contaminant Level
PCB:	Polychlorinated biphenyls
PVC:	Polyvinyl chloride, a plastic
RCRA:	Resource Conservation and Recovery Act
RFA:	RCRA Facility Assessment
RFI:	RCRA Facility Investigation
RSD:	Risk-specific dose
SP:	Spontaneous potential, a borehole geophysical method
STB:	Supertropical bleach, a chemical decontaminant
SWMU:	Solid Waste Management Unit
TEA:	A simulant (triethyl aluminum)
TEU:	U.S. Army Technical Escort Unit, also called Tech Escort in this report
TOC:	Total organic carbon
TOF:	A simulant (tri(2-ethylhexyl) phosphate)
TOX:	Total organic halogen
USATHAMA:	U.S. Army Toxic and Hazardous Materials Agency
USEPA:	U.S. Environmental Protection Agency
VX:	A nerve agent (b-diisopropylaminoethyl-mercapto-O-ethyl methylphosphonothioate)
WP:	White phosphorus, a screening smoke or incendiary

STUDY APPROACH FOR THE HYDROGEOLOGIC ASSESSMENT OF CARROLL ISLAND AND GRACES QUARTERS, ABERDEEN PROVING GROUND, MARYLAND

By Frederick J. Tenbus and Scott W. Phillips

ABSTRACT

The Carroll Island and Graces Quarters areas of Aberdeen Proving Ground, Maryland, were used as open-air test facilities for chemical-warfare agents from the late 1940's through 1971. Test activities were conducted at several locations in each area, and test-related equipment and material were disposed of at both sites. In 1986, the U.S. Environmental Protection Agency issued a Resource Conservation and Recovery Act permit to address solid waste management units (SWMU's) in the Edgewood Area of Aberdeen Proving Ground. One of the requirements of the permit was to perform a hydrogeologic assessment of any area that contained SWMU's. There are at least seven SWMU's on Carroll Island and four on Graces Quarters. In October 1986, the U.S. Geological Survey, in cooperation with the U.S. Army, began hydrogeologic assessments of Carroll Island and Graces Quarters.

This report presents background information, study approaches, and methods of data collection for the hydrogeologic assessment. Background information includes current physiographic features and historical testing and disposal practices for each SWMU and chemical-agent test area. The study approach sections present the objectives and tasks to complete the hydrogeologic assessment. A general study approach for the sampling and analysis of ground water, surface water, soil, and bottom sediment on Carroll Island and Graces Quarters is presented. Also presented are study approaches for each individual SWMU and test area, which include identification of the migration pathway and the number of samples to be collected from each medium. Methods of data collection are discussed for geophysical surveys, drilling and well installation, hydrologic testing, sampling, and quality control of samples.

INTRODUCTION

The Edgewood area of Aberdeen Proving Ground (APG), Maryland, has been used to develop, manufacture, and test chemical agents and munitions since World War I. Some of the munitions and chemical agents include smoke munitions such as WP (white phosphorus), nerve agents such as GB (Isopropylmethylphosphonofluoridate), VX (B-diisopropylaminoethyl-mercapto-O-ethylmethylphosphonothioate), blister or vesicant agents such as HD (distilled mustard) and lewisite, and vomiting agents such as DM (adamsite). Other agents that were tested or manufactured include riot control or tear agents such as CS (O-chlorobenzylidene malononitrile) and CN (chloroacetophenone), and incapacitating agents such as BZ (3-quinuclidinyl benzilate).

An environmental survey of the Edgewood area was conducted by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) during 1977 and 1978 to determine the effect of past manufacturing and testing operations on the environment (Nemeth and others, 1983). The report from this environmental survey identified several areas that were contaminated to some degree, including Canal Creek, O-Field, J-Field, and Carroll Island and Graces Quarters.

In 1986, the U.S. Environmental Protection Agency (USEPA) issued a Resource Conservation and Recovery Act (RCRA) permit (MD3-21-002-1355) to address solid waste management units (SWMU's) in the Edgewood and Aberdeen areas of APG. Solid waste management units are those sites that contain hazardous materials and thus have a potential effect on the environment. The RCRA permit identified several areas that contain SWMU's, including Canal Creek, O-Field, J-Field, Phillips Landfill, Michaelsville Landfill, and Carroll Island and Graces Quarters. The permit required that a hydrogeologic assessment (HGA) be performed at each of the identified areas.

Carroll Island and Graces Quarters (fig. 1) occupy about 1,500 acres in the Edgewood area of APG. In October of 1986, at the request of the Environmental Management Office of APG, U.S. Department of Defense, the U.S. Geological Survey began a study to collect the data needed for an HGA of Carroll Island and Graces Quarters. The purpose of the HGA is to collect hydrologic data in the vicinity of SWMU's in order to provide a framework for characterizing any release and movement of contaminants. The data collection includes establishing an observation-well network capable of determining (1) directions and rates of ground-water movement, and (2) concentrations and spatial distributions of various constituents in the ground water. These data are needed to develop predictive systems used to select the best method of remediation. Data collection also includes a sediment and surface-water sampling network, which can provide information on the concentrations and spatial distributions of constituents in these media. At the chemical-agent test sites, the HGA requires information on the type of chemical agent that was tested and the period in which testing took place.

Problem

Nineteen observation wells were installed in the surficial aquifers of Carroll Island and Graces Quarters in 1977 and 1978. Analysis of ground-water samples revealed low-level concentrations of various compounds related to the testing and disposal of munitions and chemical agents (Nemeth and others, 1983, p. 3-81 through 3-105). Some of the compounds detected include methylene chloride, chloroform, and trichloroethylene. Concentrations ranged from trace levels (about 1 microgram per liter) to milligrams per liter.

It is likely that ground water from Carroll Island and Graces Quarters discharges into adjacent surface-water bodies, principally the Gunpowder River and Seneca and Saltpeter Creeks, which are tributaries of the Chesapeake Bay. If there is significant discharge of contaminated ground water to these surface-water bodies, the potential exists for adverse effects on wildlife and aquatic populations in the area. In addition, some domestic and commercial water-supply wells are located near Carroll Island and Graces Quarters. Transport of contaminated water to these wells is undesirable because of potential human exposure to contamination. Therefore, it is important to define the ground-water flow system and extent of contamination on Carroll Island and Graces Quarters in order to characterize the potential migration of releases into water-supply areas or the surface-water bodies.

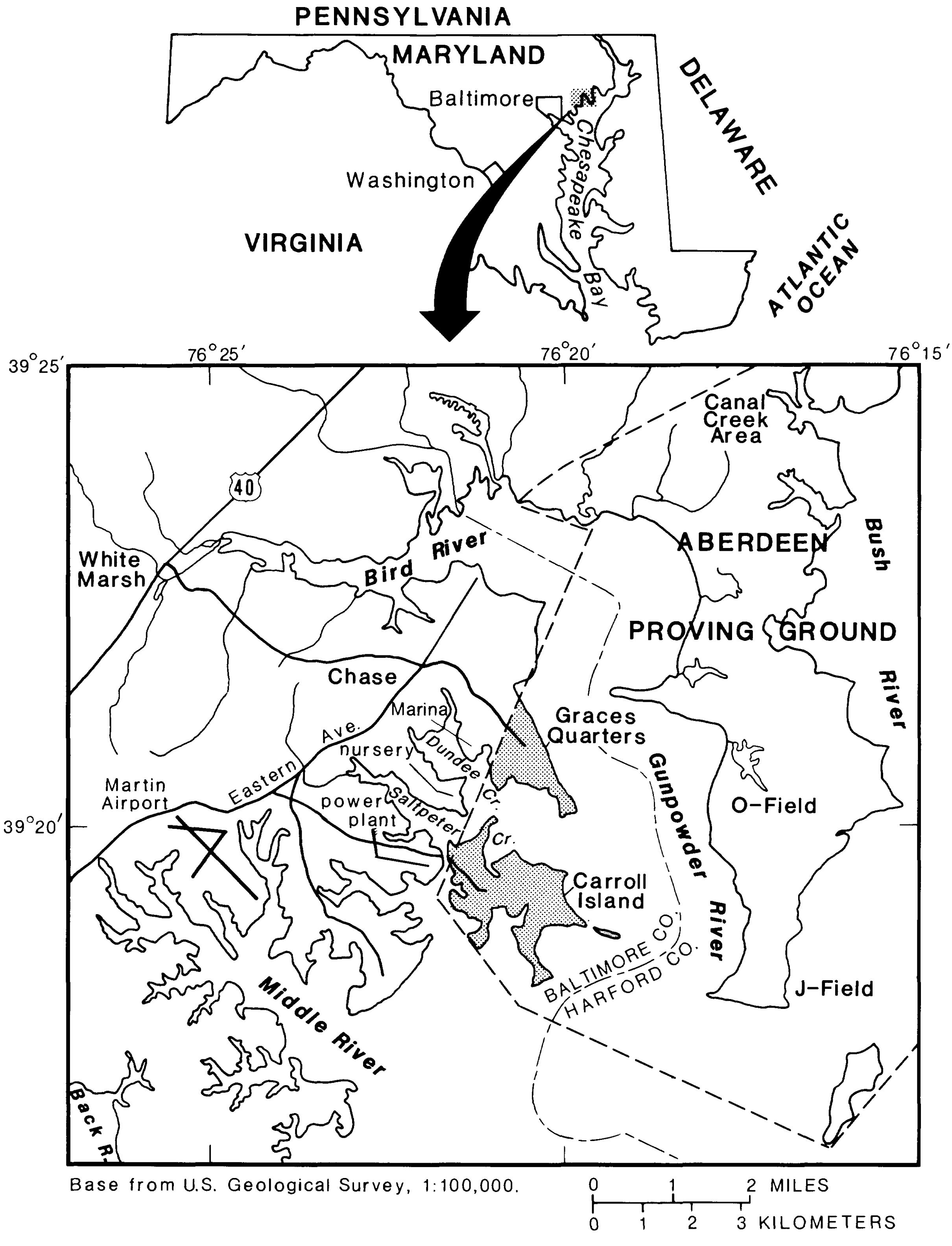

Figure 1.--Location of study area.

Purpose and Scope

The purpose of this report is to present a sampling and analysis plan for the hydrogeologic assessment part of the RCRA Facility Investigation (RFI) for Carroll Island and Graces Quarters. The report contains the following:

1) The objectives of the study.
2) Background information on the study areas.
3) Study approaches for meeting the objectives of the hydrogeologic assessment.
4) The methods used in the hydrogeologic assessment.

The approach of the hydrogeologic assessment is two-phased. This report presents the methods and rationale for phase I of the study, along with the decision criteria for expansion of the study into phase II.

The objectives of phase I of the hydrogeologic assessment are--

1) To identify the locations and dimensions of SWMU's and chemical-agent test sites.
2) To define the hydrogeologic system.
3) To verify whether SWMU's in the study area have released or are still releasing chemicals into the environment, and whether there is residual contamination from chemical-agent testing activities in the study areas.

Whether or not phase II of the hydrogeologic assessment will be implemented is contingent upon the results from phase I. The objectives of phase II of the hydrogeologic assessment are--

1) To characterize further the extent of contamination.
2) To identify possible remedial-action alternatives.
3) To evaluate the hydrogeologic effects of various remedial-action scenarios.

To fulfill the phase I objectives, adequate background information on the study areas had to be provided. This report provides background information for both Carroll Island and Graces Quarters. A physiographic description of the study areas is provided, along with the following:

1) A summary of all available historical information on the types and quantities of chemicals used during chemical-agent testing on Carroll Island and Graces Quarters.
2) A description of the types of chemical-agent tests that were performed, and the ways in which these tests dispersed chemicals into the environment.
3) Location maps that show the areas in which testing and disposal took place.
4) Descriptions of all the SWMU's and test areas, including construction information, testing or disposal that was done at each site, location and size of each site, and current conditions such as topographic features, remaining surface debris and structures, proximity of the site to surface water, and manmade influences on the hydrogeology.

The study approaches for the phase I objectives are provided in this report. These study approaches include a general study approach that provides the technical rationale and methods of fulfilling the objectives of the hydrogeologic assessment, and individual study approaches for each SWMU and test area on Carroll Island and Graces Quarters. The general study approach section reiterates the objectives of the study, and explains the sources of information, data-collection tasks, analyses, and interpretations necessary to complete each objective. It also provides the technical rationale for the data collection and analyses, and the criteria for the implementation of phase II. The study approaches for individual SWMU's and chemical-agent test areas include the location of each sampling site and the rationale behind the sampling-site locations.

The methods of investigation for the hydrogeologic assessment are given in the appendixes to this report. The surface and borehole geophysical methods for the study are explained in Appendix I. These methods include surface geophysics such as the electromagnetic induction and magnetometer surveys done on Carroll Island and Graces Quarters, and the borehole geophysics such as the gamma and electric logs done during the well and test-hole drilling.

The well and test-hole drilling and installation methods are provided in Appendix II. This appendix describes the two drilling methods (hollow-stem auger and mud-rotary), and the safety precautions used during drilling. It also provides information on well construction and test-hole closure. Appendix III provides an explanation of the data-collection methods and data analyses for the slug test, which was the method used to determine hydraulic conductivity of the material in the aquifers at Carroll Island and Graces Quarters.

The sampling methods and quality control for ground water, surface water, soil and bottom sediments are provided in Appendix IV. This appendix includes discussions of sampling equipment, sample withdrawal and preservation techniques, and equipment decontamination for each medium. Components of the quality-control program that are discussed include the data-management procedures.

To fulfill the requirements of this report, certain conclusions had to be drawn about geological features, hydraulic gradients, and other aspects of the study areas. This information is preliminary and is subject to change. For purposes of clarity, some of the information that is included in the early sections of this report is described before the methods of obtaining the information are presented.

This report was intended to be both a planning document and an explanation of the work that had already been completed during the phase I field investigations; verb usage in the report reflects this accordingly. The field work and data analysis indicated as "in progress" or "will be done" represent the state of the project in early 1990, and may have been modified in response to the changing requirements of the U.S. Army and USEPA.

Acknowledgments

The authors wish to thank the following people for their assistance with various aspects of this report. Gary Nemeth of the U.S. Army Environmental Hygiene Agency provided much of the background information for this report. The U.S. Army Technical Escort Unit provided manpower and equipment for magnetometer surveys, visual searches of the study areas for unexploded ordnance, air sampling, logistical support, and chemical-agent field testing during the remote drilling activities. The U.S. Army Corps of Engineers was responsible for drilling of wells and test holes, borehole geophysics, and installation of observation wells. The U.S. Army Combat System and Testing Activity provided manpower and equipment for some of the magnetometer surveys in this study.

Administrative assistance was provided by Cynthia Couch of the U.S. Army Directorate of Safety, Health and the Environment. Douglas Stevenson and Ann Ryan of the U.S. Army Toxic and Hazardous Materials Agency provided assistance in securing laboratory contracts for chemical analysis of various samples. Eric Kauffman and Ira May of USATHAMA provided assistance with water-quality data management.

DESCRIPTION OF CARROLL ISLAND STUDY AREA

Physiographic Setting

Carroll Island is a low-lying, flat island located approximately 1 mile from the community of Bowley's Quarters in the Middle River area of eastern Baltimore County (fig. 1). The land area of Carroll Island (fig. 2) consists of tidal marsh, open field, and wooded areas. Carroll Island is surrounded by estuaries, including Saltpeter Creek to the north, Gunpowder River to the east, Chesapeake Bay to the southeast, and Seneca Creek to the southwest. Seneca and Saltpeter Creeks connect to separate Carroll Island from the mainland to the west.

Surface water on Carroll Island is mostly confined to tidal marshes and ponds that form in land-surface depressions. The island is very flat, with a relief of less than 15 ft (feet). Surface-water runoff only occurs in limited areas and is usually tidally influenced. Much of the ponding on Carroll Island is seasonal, and generally appears in poorly drained soils.

The mainland near Carroll Island is not heavily populated. There are several small communities and some scattered houses nearby, but development in the immediate area has not been extensive. Most of the houses in the area obtain drinking water from wells. There are two commercial ground-water users in the area. A powerplant is located immediately west of Carroll Island. This plant has an aquaculture facility that draws water from a well at a rate of approximately 150 gal/min (gallon per minute) during the hottest part of the summer (Curry Woods, C.P. Crane Aquaculture Facility, written commun., 1988). The water is added to the estuary water in the fish tanks of the aquaculture facility for cooling purposes. Northwest of Carroll Island is a nursery that uses ground water during the growing season to water plants and trees.

There are currently no military activities on Carroll Island. Access to Carroll Island is restricted, but some hunting and fur trapping is done on the island. Surrounding water bodies are used for recreational purposes such as boating and fishing. The bridge between Carroll Island and the mainland also is used for recreational fishing.

Background

Carroll Island was used as a test area for military chemicals and chemical agents for a period beginning in the late 1940's or early 1950's and ending about 1971 (Nemeth, 1989, p. 141). Testing activities on Carroll Island included open-air and contained release of chemical agents and simulants, chemical decontamination of surfaces and equipment, and disposal of certain materials related to tests. Related activities included construction and maintenance of test areas and insect and vegetation control using chemicals.

Although testing activities began on Carroll Island and Graces Quarters during the late 1940's or early 1950's, detailed records of testing activities are only available for the period between July 1964 and December 1971 (Nemeth, 1989, p. 146). A summary of the total quantities of chemicals released on Carroll Island during July 1964–December 1971 is provided in table 1.

Nemeth (1989) presents much of the available information on the Carroll Island test activities. Appendix H of the RFA (Nemeth, 1989) provides a tabular listing of known chemical tests from selected technical reports, which are the only available sources of information on tests prior to 1964. Although this listing is not complete, it indicates the type of testing done at various sites before the early 1960's (Nemeth, 1989, p. 146).

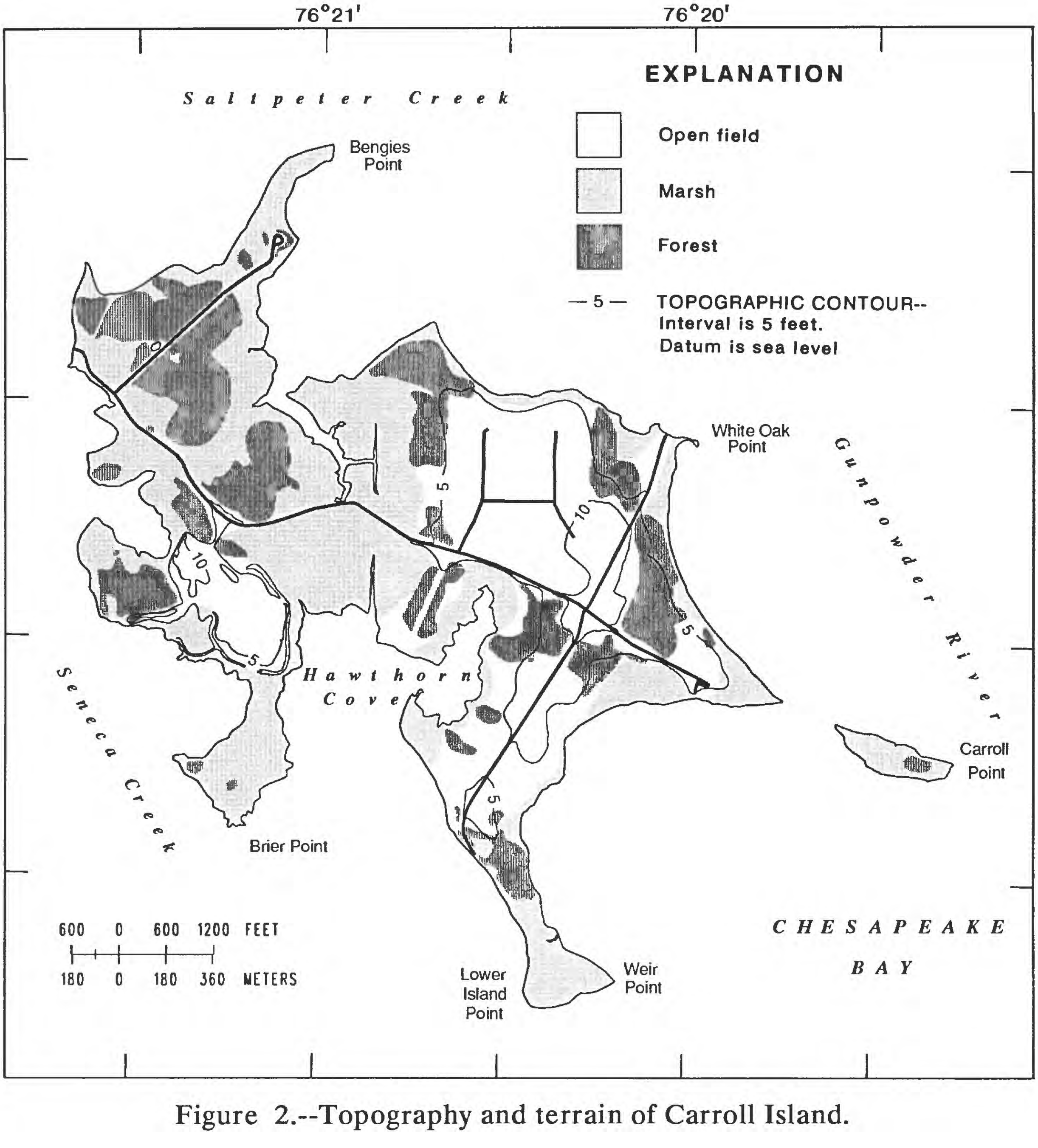

Figure 2.--Topography and terrain of Carroll Island.

Table 1.--Quantities of chemicals released on Carroll Island from July 1964 through December 1971

[See the Glossary of Acronyms and Abbreviations for chemical names]

Material released	*Type*	*Pounds released*
Talcum powder	simulant	5,438.5
CS-1	irritant	3,608.7
CS-2	irritant	664.3
VX	anticholinesterase	422.4
DBHP	simulant	403.8
Telvar	herbicide	350.0
Furfural	simulant	264.0
BZ	incapacitant	260.4
TEA	incendiary	221.0
Chloroform and dye	simulant	208.0
CN/DM	irritant	181.2
NaOH	decontaminant	180.0
GB	anticholinesterase	148.1
WP	screening smoke	147.5
CS/DM	irritant	134.2
DMHP	simulant	48.4
Isopropyl alcohol	simulant	48.0
Combined nerve agents [1]	anticholinesterase	40.0
EDA	simulant	33.8
GA	anticholinesterase	31.5
TOF	simulant	27.2
Signaling smokes	smokes	26.4
DM	irritant	15.8
FS	screening smoke	12.0
1,2,3-Trichloropropane	simulant	11.2
Methylacetoacetate	simulant	11.2
EA 1356	anticholinesterase	10.0
Bis	simulant	9.8
HD	vesicant agent	7.6
BBC	irritant	5.7
CN	irritant	4.0
GD	anticholinesterase	3.0
EA 3834	incapacitant	2.3
EA 3528	incapacitant	1.0
EA 3990	anticholinesterase	.7
DEHP	simulant	.04
	Total pounds	12,981.74

[1] Old stocks of agents taken to field, dumped, and detoxified on the ground with sodium hydroxide (NaOH). From Ward and Pinkham (1973, p. 10).

Information on testing during 1964 and 1971 on Carroll Island and Graces Quarters was reviewed and compiled by F.P. Ward, and is now available in several sources, including Ward (1971), Ward and Pinkham (1973), Ward (1979), and Nemeth (1989). Some of the information is also available in Nemeth and others (1983). Information on pesticide applications on Carroll Island from 1959 to 1969 is available in Ward (1971, p. 24).

Agents were dispersed on Carroll Island in many ways, including the following (Nemeth, 1989, p. 480-489):

1) Static munition bursts at or above the ground surface.
2) Bursts from munitions that were fired from towers toward the ground at a steep angle.
3) Spray applications of chemicals, either at ground surface or from aircraft.
4) Discharge of agent into the atmosphere through an exhaust stack.
5) Applications by various means to structures and equipment.
6) Washdown from decontamination activities.
7) Dispersal from pit burning.

Different testing methods affected the behavior of the chemicals in the environment in different ways. Some of the testing methods involved immediate decontamination, while others were designed to measure the persistence of a chemical agent in the environment. The likely environmental effects from the different tests, the locations in which the tests were performed, and the size of the potentially impacted areas are discussed in later sections of this report. The information in this section is from Gary Nemeth (1989, p. 140-150, 470-489; Nemeth, U.S. Army Environmental Hygiene Agency, oral commun., 1989).

Some of the types of tests that were done on Carroll Island are (1) ground-contamination studies; (2) shock tests; (3) decontamination tests; (4) surveillance tests; and (5) chemical-munitions tests. Ground-contamination studies involved applying chemical agent to the soil surface or vegetation, and studying terrain denial and agent persistence. Application of chemical agent was by spraying, pouring, or functioning of a chemical-filled munition. The tests were designed to determine the length of time in which an unprotected enemy would be denied access to a land area after agents were applied. Test areas were probably not decontaminated after studies of this type were completed.

Shock tests were done to determine the capability of munitions to withstand shocks. These tests were generally done from drop towers. Agents were not dispersed during these tests unless the munition that was being tested failed to withstand the shock.

Decontamination tests were done to test the effectiveness of particular decontamination materials and mixtures, to evaluate and determine procedures for equipment decontamination, and to evaluate the reaction of chemical agents to decontamination procedures. Much of this testing involved contaminating and decontaminating equipment, structures, and test surfaces, but some of it involved decontamination of contaminated soils. Decontamination also was involved in cleanup after some of the chemical agent and munitions tests. Decontamination tests and activities could result in the introduction of chemical agents, decontamination materials, and degradation products into the environment.

Surveillance tests involved submitting a chemical agent or agent-filled munition to different environmental stresses in order to simulate possible storage conditions. The purpose of these tests was to determine if the combination of munition and filler was compatible, or if the munition would corrode, leak, or explode under storage conditions. The testing was done both in temperature-controlled chambers and out in the open, depending on the properties being examined. As with shock testing, hazardous materials were not released to the environment unless the munitions failed the test.

Chemical-munitions tests involved dissemination of agent from munitions, generally by the explosion of a bursting charge in the munition. The method in which this was done differed depending on the type of munition and the constraints of the test. Some of the tests involved live firing at a steep angle from a tower toward the ground surface. Other tests involved static functioning at ground surface or at various heights above ground. A lot of this testing was done in open air and was likely to have caused the release of chemical agent into the environment.

Waste disposal on Carroll Island was directly related to testing activities. Materials that were disposed include spent munitions, unusable testing and personnel protective equipment, and materials on which testing took place, such as demolished structures. No large-scale disposal of chemicals was reported on Carroll Island (Nemeth and others, 1983, p. 3-6), and materials that were contaminated with lethal chemical agents were chemically decontaminated before disposal (Nemeth, 1989, p. 144).

Location and Historical Use of Solid Waste Management Units and Chemical-Agent Test Areas

Testing and disposal activities were done at several sites on Carroll Island (fig. 3). Areas in which potentially hazardous solid waste was disposed or managed are considered to be SWMU's; however, most of the test areas are not. Test areas do, however, represent areas of previous releases and are therefore addressed in this study.

Most of the chemical-agent testing on Carroll Island was done on the eastern half of the island at four major test areas (Ward, 1971): Test grid 1, test grid 2, the aerial spray grid, and the wind tunnel. During the history of testing at Carroll Island, however, testing was done in at least five other areas. Each of the test areas is discussed below.

Disposal from test activities also was done in many areas. Disposal sites include the Lower Island disposal site, Bengies Point Road dump site, the Edgewood Proving Ground (EPG) dump site, the BZ test burn pit, and at an area designated as the decontamination pits. Each of the disposal sites also is discussed below. Two areas in which support activity took place on Carroll Island also are addressed and are discussed below. A list of solid waste management units and test areas on Carroll Island is provided in table 2. Detailed maps showing the SWMU's and test areas are provided in subsequent sections of the report.

Lower Island Disposal Site

The Lower Island disposal site is located at the southern end of the eastern half of Carroll Island northwest of Lower Island Point (fig. 3). Historical information on the unit is from Nemeth (1989, p. 474-477), and was derived from visual inspections, sampling, and interviews by Nemeth. Information on current conditions was from observations by Survey personnel, magnetic surveys and observations by the U.S. Army Technical Escort Unit (TEU), and from Nemeth (1989, p. 474-477).

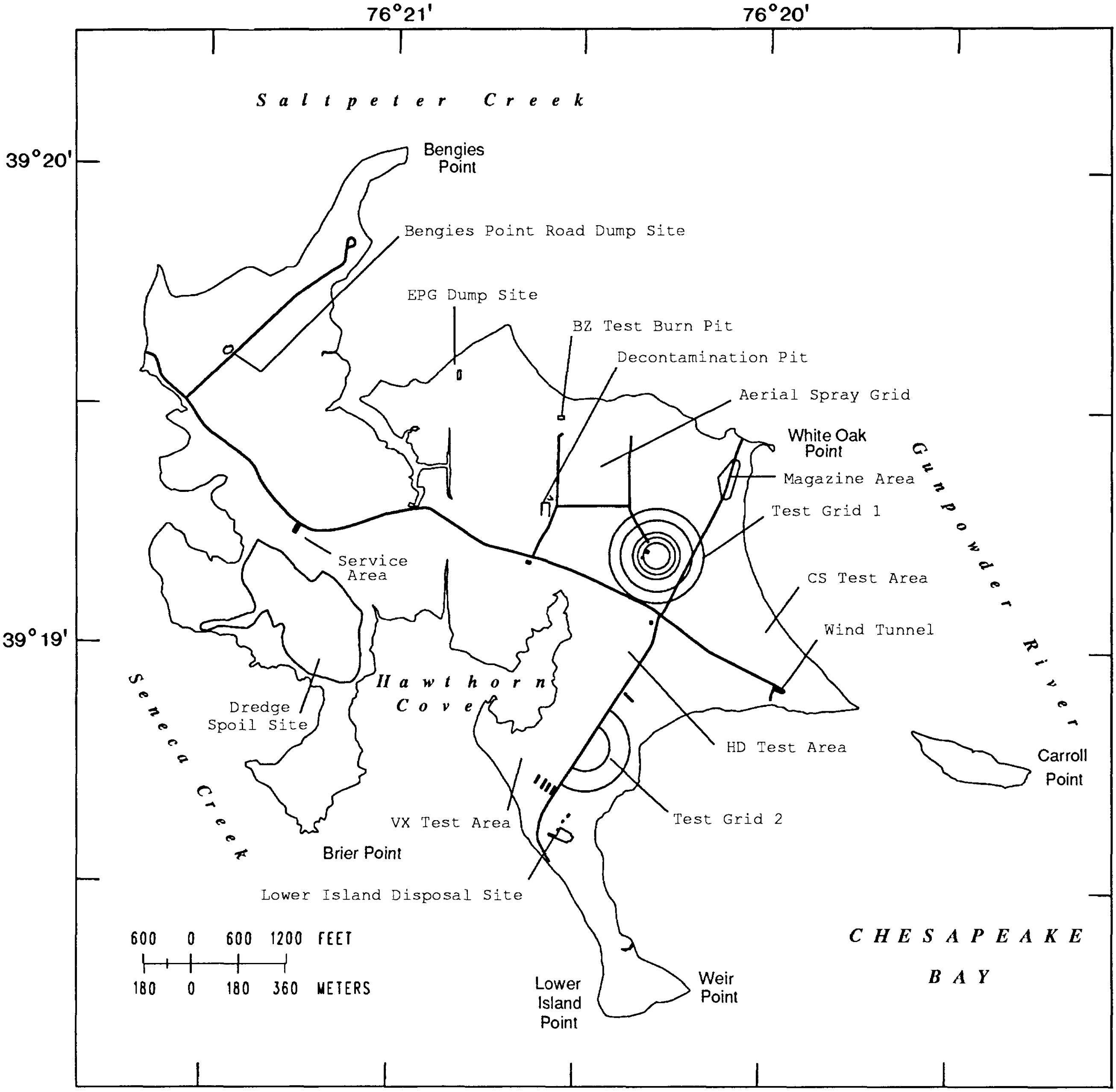

Figure 3.--Location of solid waste management units, test areas, and support facilities on Carroll Island.

Table 2.--Solid waste management units, test areas, and support facilities on Carroll Island

[SWMU, solid waste management unit. See the Glossary of Acronyms and Abbreviations for chemical names]

Site name	*Classification*
Lower Island disposal site	SWMU
Bengies Point Road dump site	SWMU
Edgewood Proving Ground dump site	SWMU
BZ test burn pit	SWMU
Decontamination pits	SWMU
Test grid 1	test area
Aerial spray grid	test area
Wind tunnel	test area (drain ditch is a SWMU)
Test grid 2	test area
HD test area	test area
Dredge-spoil site	test area, SWMU
Service area	support facility
Magazine area	support facility
CS test area	test area
VX test area	test area
Area across from HD test site	test area

The Lower Island disposal site is a unit that was used for solid waste disposal and is considered to be a SWMU. The unit consists of approximately 10 burial pits and a marsh dump site. The pits are located in an area approximately 4 acres in size, but only occupy a small part of this total area. The disposal site was used from the early 1940's until testing operations ceased in the early 1970's.

Early disposal in the unit consisted of dumping without burial in the marsh along the road that crossed the marsh area near the shoreline. Sometime during the 1950's, disposal was moved to the area immediately north of the tree line north of the marsh. This area was used for a number of years, with disposal taking place in five to seven burial pits. Each of the pits was from 20 to 50 ft in length and as wide as the blade of a bulldozer or front-end loader. After these pits were filled, a larger pit was dug farther east along the edge of the marsh, about 400 ft east of the road. This pit was about 20 by 40 ft in size. After this pit was filled, solid-waste disposal was continued in two pits to the north of the earlier pits and immediately west of a group of trees in the area. The last pit that was used in this area is still open as of 1989. All of the other disposal pits were covered with soil when they were full. The thickness of the soil cover and the exact depth of the pits is unknown, but they were probably dug to the water table, which is only a few feet below land surface in this area.

Another disposal site which may be in this unit was a bomb crater approximately 12 to 15 ft in diameter and 6 to 8 ft deep. This crater was operated in the same manner as the pits; waste was dumped in the pit until it was nearly full, and then it was covered with soil. This disposal site was used during the early years of testing.

In the late 1960's the area was used for testing (primarily CS). Huts were constructed for this purpose; these huts no longer exist.

The solid waste that was placed in this unit was from test activities conducted on Carroll Island (Nemeth, 1989, p. 476). This waste most likely consisted of fragments and remains of munitions items tested, sampling equipment and protective clothing items which were no longer usable, and other solid wastes generated during testing activities. No items containing lethal agents were to be placed in the pits. Items contaminated with persistent lethal agents were chemically decontaminated prior to disposal; items contaminated with CS or BZ were not decontaminated. Procedures specified that explosive items were not to be placed in the pits. Very little actual chemical waste was disposed of in this SWMU.

Current conditions at the site show limited surficial evidence of disposal. The open disposal pit contains material such as discarded personal protective equipment and various metal fragments. Also near this pit were blocks of a paraffin-like material and some styrofoam. To the west of the open pit are two underground bunkers; these fill with water during the winter and dry out in the summer.

There is little surficial evidence of the other burial pits in the unit. In the wooded area to the south of the burial pits, there are miscellaneous items at the surface such as steel sheets, some pipes, plastic tubing, mask filters, supertropical bleach (STB), and decontaminating agent noncorrosive containers (DANC). There are also metal items just offshore in Seneca Creek to the south. These items were probably washed out of the marsh dumping area by beach erosion.

Topography of the area is flat; elevation is approximately 5 ft above sea level (fig. 2). Soil types include Woodstown sandy loam, tidal marsh, and made land (Reybold and Matthews, 1976). The manmade features that could potentially affect the hydrogeology are the SWMU's themselves. The disturbed land probably has affected infiltration rates, and the solid waste in these pits is likely to be in direct hydrologic contact with ground water.

Magnetometer surveys in the area confirm most of the historical information presented above. The surveys indicated the presence of a significant amount of metal in most of the burial pits. However, relatively small amounts of metal were identified in the area along the marsh originally used for dumping, and the bomb-crater disposal site was not located in the surveys.

Bengies Point Road Dump Site

The Bengies Point Road dump site is located on Bengies Point Road (which is unpaved) on the western half of Carroll Island near the entrance to the island (fig. 3). It is considered to be a SWMU. Historical information on this unit is from Nemeth (1989, p. 477-478). Information on current conditions for the site is from observations by Survey personnel.

This unit was used to manage solid waste by dumping into a low-lying marshy area near the road. No burial pits were maintained; the area was simply a dump site. The period of operation was from the early 1950's to the early 1970's. The dump site was closed when activities ceased on Carroll Island, with no specific closure steps taken.

The material that was placed in this dump included all the solid waste generated by the test activities on Carroll Island that was not contaminated with chemical agent. Paper, wood, and empty reagent containers are examples of waste that was disposed in this unit.

Currently, the area appears as a marshy depression on the western side of the road to Bengies Point. The water table is close to the land surface, and fluctuations in water level result in seasonal submergence. The dump site is partially overgrown with vegetation, and during the dry season some of the material that was dumped here is visible. The material that was observed included discarded personal protective equipment and metal fragments, along with concrete and other building materials.

Topographic features (fig. 2) include a small pond to the east of the road across from the dump area, and marshes to the west and south of the dump site. To the north is a wooded area and more marshes. Soil types include Woodstown sandy loam and tidal marsh (Reybold and Matthews, 1976). The roadbed appears to have been built up with fill material in some places because it is surrounded by marshes. A small area was built between the road and the dump area for vehicles to unload or turn. The dump area represents some concern because it is located within about 1,500 ft of an off-site production well at a nearby powerplant. Pumping from this production well affects the hydraulic gradient of the confined aquifer beneath this SWMU; the effect of the pumping is being investigated in this study with observation-well clusters and continuous water-level recorders. The only other manmade feature that might affect the hydrogeology is the SWMU itself; because the area is seasonally submerged, the solid waste is often in direct contact with surface and ground water.

Edgewood Proving Ground Dump Site

The Edgewood Proving Ground dump site is located in the north-central part of Carroll Island near the shoreline (fig. 3). Historical information on this site is from Nemeth (1989, p. 471-473); information on current conditions is from observations by Survey personnel and from Nemeth (1989, p. 471-473).

The site is at the northern end of a linear drainage ditch that extends north-south across the center of the island. The unit appears to be a simple dump site, with no historical burning and only limited burial. The site was used sometime between 1943 and the early 1950's. Waste was dumped along the eastern edge or berm of the ditch and also into the bottom of the ditch.

Visible evidence shows the dump area to be approximately 30 ft in length; this is supported by a magnetometer survey, which revealed very little material that was not visible. Surficial debris includes construction material and drums of STB. Two buried metallic objects were indicated within the mound during the magnetometer surveys; these objects were drum-sized, and probably only a few feet below the surface. The objects were located approximately 20 ft from the southern edge of the visible debris. No other buried metal was found south of these objects.

Topographically, the major features are the drainage ditch and berm and the proximity of the unit to Saltpeter Creek. The ditch periodically contains water, which could result in the SWMU being in direct surface-water contact with the river. The area is low-lying and flat; there are woods to the southeast, a marsh to the southwest and the estuary to the north and west. Soil types include Woodstown loam and tidal marsh (Reybold and Matthews, 1976). Manmade features other than the SWMU itself are unlikely to affect the hydrogeology of the area.

BZ Test Burn Pit

The BZ test burn pit is located in the northern part of Carroll Island east of the EPG dump site, within the test area known as the aerial spray grid (fig. 3). Historical information on the site is from Nemeth (1989, p. 480-481); information on current conditions is from observations by Survey personnel and from Nemeth (1989, p. 480-481).

The unit is a test burn pit approximately 10 ft in diameter that was used briefly during the 1960's. The site was used to study the effectiveness of disposal by open-pit burning of munitions containing BZ. The burning pit was used for testing and never used for routine disposal operations; therefore, it may not actually be a SWMU. However, evidence from magnetometer surveys indicates that buried metal is located in two small pits near the burn pit; for this reason the area will be treated as a SWMU.

Historical information suggests the burn pit was only used for a limited time. No historical information is available concerning the metal items buried near the burn pit. The depth of burial is unknown, and it also is not known if chemicals or chemically contaminated items were buried.

Present (1990) site characteristics include the test pit, which is about 5 ft deep; a mound next to the pit that is most likely the excavated material from the pit (no magnetic evidence of buried metal); the two small burial pits southeast of the burn pit; and a small (approximately 20 ft) test tower north of the burn pit. The area is topographically flat at an elevation of about 5 ft above sea level (fig. 2). Soil types include Mattapex silt loam and Sassafras sandy loam (Reybold and Matthews, 1976). Manmade features are unlikely to significantly affect the hydrogeology of the area.

Decontamination Pits

The decontamination pits are located in the central part of Carroll Island south of the BZ test burn pit, within the aerial spray grid (fig. 3). Historical information on the decontamination pits is from Nemeth (1989, p. 478-480); information on current conditions is from observations by Survey personnel. The unit consists of two pits that were used for burning; the pits were constructed, used, and closed during 1975. One of the pits was used for burning, and the other was used for reburning the same material. The pits are located in a rectangular area approximately 100 by 180 ft, and are about 1 to 2 ft deep.

The decontamination pits were used to burn items from facilities that had been used in chemical agent testing at Carroll Island. Both combustible and non-combustible items were burned in the pits. Items that were burned included buildings that had been used in testing operations, above-ground items from the test grids, small wind tunnels that were used on Carroll Island, and meteorological equipment. Several burns were made, with wood dunnage and fuel oil being used for each burn. No chemicals were disposed of in this unit and the items placed into the burn pits were not contaminated with detectable levels of toxic chemical agents (Nemeth, 1989, p. 478). Some of the materials from certain buildings used in testing were probably contaminated with small amounts of CS. The principal introduction of chemicals into the environment as part of the operation of this unit was the fuel oil used in conducting the burns. Larger scrap-metal items were removed from the reburn pit and disposed of as scrap by APG. The pits were closed by filling them with the soil that had been removed in their construction. Small metal items were not recovered for salvage but were buried when the pits were filled.

Current conditions at the unit show vegetation changes in the shape of a "U" and a "V", which are at the locations of the two main burn pits. The unit was discovered by observations of these vegetation changes during an air reconnaissance performed early in the study. The area is in an open field, is flat, and is basically dry year round. The elevation at the site is between 5 and 10 ft above sea level (fig. 2). The soil type is Woodstown loam (Reybold and Matthews, 1976). Magnetometer surveys showed buried metal within and just outside the two main pits; there also is buried metal scattered around the pit area. Manmade features that are likely to affect the hydrogeology are not present.

Test Grid 1

Test grid 1 is located in the center of the eastern half of Carroll Island (fig. 3) in an open, level field. Much of the historical information on the testing and features of test grid 1 is from Nemeth (1989, p. 481-483). Other historical information is from Ward (1971) and is cited as such in the text below. Information on current features of the test grid area is from observations by Survey personnel.

This area was used for chemical agent testing from the late 1940's (before the grid was constructed) to about 1971. The test grid was constructed in the early 1950's and was later upgraded and rebuilt in 1963. The grid consisted of a central testing area surrounded by sampling apparatus located in concentric circles with radii of 20, 30, 40, 50, 75, 100, 150, and 200 yd (yards).

During the testing history of test grid 1, various methods were used to release chemical agents and simulants. The methods of release included static functioning of munitions at or near the ground surface, firing munitions into the grid from towers, and releasing chemicals using a spray system. A 60-ft tall metal frame tower located in the grid west of the center was used both as a platform for firing munitions into the grid and also as a drop tower for testing the ability of the munitions to withstand shocks. Other features of the test grid included another taller tower that also was used as a firing platform for munitions testing; a 200-ft tall meteorological tower located in the grid west of center; a 40-ft tall A-frame tower that was used to suspend munitions at various heights for testing; and short wind-profile stations that were located on the 20-, 30-, and 100-yd circles on the grid.

The sampling system for the grid (circa 1970) is described by Ward (1971, p. 38). An inner sampling system covered the surface area between the grid center and 20-yd circle with 172 individual ground-level samplers. A vertical sampling system that consisted of 64 masts located on the 20- and 30-yd circles was used to measure agent densities at heights of 1.6, 3.3, 6.6, 9.8, 16.4, and 26.2 ft. A horizontal sampling system consisted of 512 sampling positions equally spaced along the circumferences of the eight sampling circles. Motion-picture cameras and high-speed cameras were used to record movement of agent clouds and to photograph the bursting characteristics of munitions.

Portions of the sampling vacuum systems, control systems, and electric power lines for the grid were located underground (Nemeth, 1989, p. 482). In order to prevent flooding of the underground elements of the inner sampling system, a drainage system with a sump pump was installed near the center of the grid. The subsurface drainage system was 5 to 6 ft deep. The sump and pump for the system were located in the grid southwest of center, and an underground drainage pipe carried the wastewater southwest. The drainage pipe discharged the water underground about 350 yds west-southwest of the center of the grid; there, it presumably percolated to the surface, and out the culvert to Hawthorn Cove (Ward, 1971, p. 47).

Because test grid 1 was not used to manage solid waste, it is not considered to be a SWMU for the purposes of this study. However, toxic materials were introduced into the environment in this area, so test grid 1 is addressed as an area of previous release.

Currently, the test grid's most outstanding feature is the 60-ft tower that remains near the center of the grid (fig. 4). Grass has overgrown the grid, and some of the wetter areas contain marsh grasses. The sump area for the drainage system remains intact, and the surface-water ditch into which it drained can be located. The sluice pipe that carries the surface water under the road also remains. The exact location and size of the drainage pipe is not known, but its approximate location is given in Ward (1971, p. 37) and shown in figure 4. This underground sump system might have an effect on the hydraulic gradient in the test grid 1 area; it would have affected the gradient when it was in use during testing periods. Any effects that might be caused by the sump and drainage system are being addressed in this study through water-level monitoring and water-quality sampling.

Close inspection of the grid area reveals the locations of the sampling points used during the chemical-agent testing; these are arranged in concentric circles and are visible as partially buried concrete blocks of about 1 ft^2 with short lengths of pipe imbedded in them. A paved road just outside the 200-yd circle to the south of the grid and one that crosses within the grid to the east still remain. A small trailer that was probably used for meteorological observations and for firing control is still located about 1,500 yds west of the tower near the road. One building (Building E7987) remains southeast of the grid at the crossroad. None of the manmade features, except for the sump and drainage system, are likely to have much of an effect on the hydrogeology of the test grid.

The topography of the area (fig. 2) is flat, with a maximum relief of 4 to 5 ft and a maximum elevation of about 11 ft. The high point in the test grid is near the center, and, during wet seasons, some ponding occurs over much of the southern part of the grid. Soil types include Woodstown loam, Sassafras sandy loam, Woodstown sandy loam and Fallsington loam (Reybold and Matthews, 1976). A core sample from one of the wells drilled in the test grid indicates that at least part of the grid is covered with a few inches of gravelly fill material.

Aerial Spray Grid

The aerial spray grid is located in the north-central part of the eastern half of Carroll Island (fig. 3). Historical information on the spray grid is from Nemeth (1989, p. 484); description of current conditions is from observations by Survey personnel.

The aerial spray grid was the location of chemical-agent testing from the late 1940's or early 1950's until the early 1970's. The grid had no permanent facilities, such as sampling equipment, associated with it. The testing area was apparently not limited to the open field, but also included some of the adjacent wooded areas.

The spray grid was not used to manage solid waste and is not a SWMU. Solid wastes generated during testing operations were disposed in the Lower Island disposal pits. Two SWMU's are located within the perimeter of the spray grid; these are the BZ test burn pit and the decontamination pits.

Most of the chemical release in the spray grid was by aerial spraying, but ground-contamination studies involving other means of chemical release also were conducted within the spray grid area.

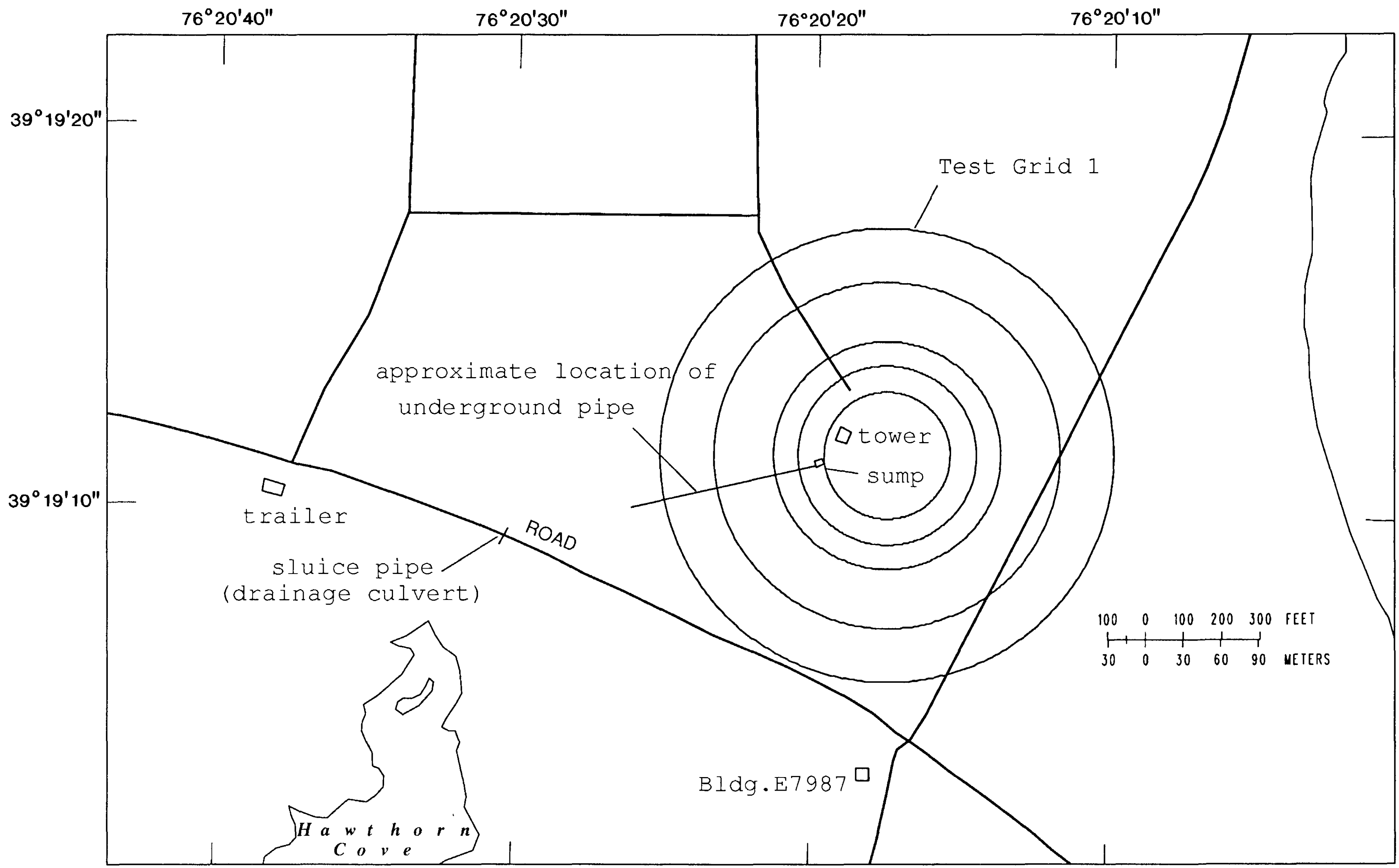

Figure 4.--Current features of the test grid 1 area of Carroll Island.

Currently, the area is probably much the same as it was during testing. The grass in the open field is no longer mowed, but only a few small trees have grown in the field. There is an unpaved road that leads from the paved road near the control trailer for test grid 1 to the BZ test burn pit; this road was visible in airphotos taken during the testing period. Other roads also were visible in the photos, but they have since been overgrown with vegetation and can no longer be located. There are remnants of a fence with warning signs of chemical-agent testing between the wooded area to the west of the spray grid and the open field. Some fencing also is present near the shoreline north of the field.

The topography of the area is flat; elevations are from about 4 to 10 ft above sea level (fig. 2). Some ponding is present in wet seasons, generally in the northeastern and far westernpart of the field. Soil types include Fallsington loam, Mattapex silt loam, Sassafras sandy loam, Woodstown loam, and some Woodstown sandy loam and tidal marsh (Reybold and Matthews, 1976).

The only manmade features in the area are the unpaved road, the SWMU's mentioned above, and the features that were mentioned in association with the SWMU's. These are unlikely to have a significant effect on the hydrogeology of the area.

Wind Tunnel

The wind tunnel (Building E7995) is located near Carroll Point on the eastern end of Carroll Island (fig. 3). Historical information on the wind tunnel is from Nemeth (1989, p. 485-486) and from Ward (1971). Information on current characteristics of the site is from observation by Survey personnel.

The wind tunnel was used as a facility for testing chemical agents. It was constructed of corrugated metal during the early 1960's, possibly 1963, and was used until 1971. Agent was released in the tunnel and was discharged to the atmosphere. During nearly all of the operational period there was no scrubbing of the tunnel exhaust to remove chemical agents. Near the end of the operational period a scrubber was installed on the wind tunnel, but it was used only briefly prior to cessation of testing activities. A nonlethal tear agent, CS, was the material being tested at the time.

Test operations in the wind tunnel were conducted when the wind direction was such that released agent would not be carried westward. Therefore, it is likely that nearly all of the chemicals discharged from the wind tunnel stack were carried out over the Gunpowder River. Throughout its operational period, the wind tunnel was chemically decontaminated after tests and the wastewater from decontamination was discharged to a ditch that led to a marsh east of the wind tunnel. The chemical decontaminants used included chlorinating agents such as STB, and other inorganic decontaminants such as sodium bicarbonate. Organic-based decontaminants such as DS-2 (no common name available) and DANC were not used to decontaminate the wind tunnel after tests with lethal agents. The ditch into which wastewater was discharged is considered to be a SWMU.

Uses of the wind tunnel (Ward, 1971, p. 38-40) included studies to determine the behavior of aerosols, the efficiency of thermogenerating devices, and the vaporization efficiency of agents, and to calibrate new sampling equipment. The tunnel also was used as a static diffusion chamber, for protective mask studies, and for controlled agent exposures of animals and humans. Wind speeds could be set from 2 to 20 mi/h (miles per hour). The tunnel was divided into three sections, described as (1) the mixing section, where munitions were exploded and the products mixed with the incoming air; (2) the test section, where samples of air were collected by vacuum sampling devices; and (3) the exhaust section, consisting of blower and exhaust stack.

Currently, the wind tunnel building remains, but it is in disrepair. Dimensions of the building are approximately 20 by 90 ft. The scrubber is still standing on the northern side of the building, and a paved road leads from the western part of the island up to the wind tunnel and then south to the bay. To the north of the wind tunnel is open field; to the east is about 50 ft of open field and then a marsh (fig. 2). The tunnel is approximately 100 ft from the bay to the south. Soil types adjacent to the wind tunnel include Woodstown loam and tidal marsh (Reybold and Matthews, 1976). Manmade features in the area include the wind tunnel building, the scrubber, and the paved road to the west and south of the tunnel. These are unlikely to significantly affect the hydrogeology.

The topography of the area is flat and at an elevation of about 5 ft above sea level. The area has a few shallow ditches and depressions and, during the wet season, much of the adjacent field to the north contains ponded water. There is a shallow ditch to the east of the tunnel leading to the marsh; this is thought to be the ditch that was the effluent path for the decontaminated waste.

Test Grid 2

Test grid 2 is located on the southern part of the eastern half of Carroll Island (fig. 3). Historical information on the test grid is from Nemeth (1989, p. 487); information on current conditions is from observations by Survey personnel. The test grid was not used to manage solid waste; therefore, it is not considered to be a SWMU.

The features of test grid 2 were similar to test grid 1, only the grid was smaller and had no underground drainage, sampling, or control systems. The grid was semicircular, with air samplers arranged mainly to the east of the release point.

Testing in the area began before the test grid was constructed. The area was first used in the mid-1940's as an impact area for 4.2-in. (inch) chemical mortar filled with high explosive (HE), white phosphorus (WP), and possibly other smoke materials. The area was used to test chemical agents from the late 1940's or early 1950's to the early 1970's. Probably the greatest use of the area was in the early 1960's when test grid 1 was being renovated.

The test grid 2 area does not show much current evidence of testing activities at the site. The field is still open and overgrown with grass; there is a gravel road to the west adjacent to the old test grid, and a sluice pipe near what might have been the center of the grid allows vehicular access to the field. Close inspection of the ground surface reveals pipes oriented in a semicircular manner, indicating the probable location of the grid annuli. The topography is flat; elevation is 3 to 5 ft above sea level (fig. 2), and the areas to the east and to the west of the grid exhibit seasonal ponding. Core samples from well drilling indicate that at least part of the test grid is covered with a few inches of gravelly fill material. Soil types include Fallsington loam, Woodstown sandy loam, Othello silt loam, and Barclay silt loam (Reybold and Matthews, 1976). There are no manmade features in the area that are likely to affect the hydrogeology.

HD Test Area

The HD test area is located west of the road to Lower Island Point, north of test grid 2 (fig. 3). Historical information on this area is from Nemeth (1989, p. 488); information on current features is from observations by Survey personnel.

This test area was used for ground-contamination studies with chemical agents, including HD and VX. The studies were conducted by contaminating an area and then measuring the persistence of the agent. The area was decontaminated using STB or chlorine bleach (HTH) after mustard was used. The area was not used to manage solid wastes and, therefore, is not considered a SWMU.

This area, like the aerial spray grid, was an open field and had no permanent facilities associated with it. The exact extent of the test area is unknown, but was probably limited to the area that was cleared during the testing period.

Current conditions at the test area show an open field with a growth of small trees in an area that was once clear (fig. 2). Topography is flat; the elevation is about 6 ft. A small amount of ponding is present in various spots on the field during wet seasons. Soil types include Mattapex silt loam and Woodstown sandy loam (Reybold and Matthews, 1976). There are no manmade features in the area that are likely to influence the hydrogeology of the test area.

Dredge-Spoil Site

The dredge-spoil site is located on the southern part of the western half of Carroll Island (fig. 3). Historical information on the site is from Nemeth (1989, p. 486-487); description of current conditions is from observation by Survey personnel.

This site is a unit in which dredge spoil from the channel between Carroll Island and the powerplant to the west was deposited on two occasions. The first occasion was during the 1950's or 1960; the second was in May and June of 1972. The area has not been used since. The dredge spoil was placed in a large bermed area. Pearson and Bender (1975, p. 7) report that the volume of spoil deposited in this area in 1972 was 88,030 yd^3 (cubic yards); the volume deposited during the earlier dredging is unknown. The channel from which this material was dredged is not considered to contain contaminated sediments, and the dredge-spoil site was not used for disposal of other solid wastes. However, it was still classified as a SWMU by Nemeth (1989, p. 486).

A limited amount of chemical testing was performed on the northern part of this site. The testing involved ground-contamination studies using VX, CS, and GB.

Current conditions at the dredge-spoil site show a sandy area covered with grass and a few small trees. Topographically, the site is one of the highest on the island, with elevations up to 13 ft (fig. 2). The topographic relief is all manmade; the mound was deposited in an area that appears to have been marshland. Deposition of fill on the marsh might have affected the hydrogeology of the area; certain natural processes, such as evapotranspiration from the marsh, are probably reduced by the dredge spoils. Soils are classified as made land (Reybold and Matthews, 1976). Since the dredge spoils are sand, ponding or runoff on the mound is unlikely. No evidence of ponding or runoff has been observed.

No visible evidence of chemical testing at the site remains. There are remnants of a fence at the northern border of the site, and also remnants of what appears to be a holding pen for animals. There is no surficial evidence of solid-waste disposal in this area.

Service Area

The Carroll Island service area was located on the western half of the island, north of the dredge-spoil site (fig. 3). Historical information on this site is from Nemeth (1989, p. 490-491); information on current site characteristics is from observations by Survey personnel.

The service area consisted of two Quonset huts and several small support facilities for water supply and wastewater handling. The service area supported testing operations on Carroll Island and housed various activities such as minor laboratory work and equipment maintenance. The water supply for the service area was provided by a drilled well located immediately west of the Quonset huts. The well water was considered potable, but, because it tasted bad, most of the potable water for Carroll Island was transported in from the main part of the army base. Well water was used for nonpotable uses such as showering. Wastewater generated in the service area was treated in a small package treatment plant located 30 ft east of the Quonset huts, and then was discharged to the marsh area southeast of the service area.

Solid wastes generated in the service area were disposed in the Bengies Point Road dump, or if potentially agent contaminated, in the Lower Island Point disposal pits. The wastewater treatment unit is considered to be a SWMU.

Current conditions at the service area show two concrete pads where the Quonset huts were located. A gravel parking area surrounds the concrete pads, and there is an unpaved road leading from this area to the dredge-spoil site. The wastewater-treatment plant remains. It is a small metal unit located on a grate over a concrete sump. Some trash was disposed in the area southeast of the pads. The trash includes empty glass containers, empty cans, and a few items such as gas-mask filter canisters.

The area exhibits some topographic relief. Generally, it is flat near the concrete pads. This area was probably constructed from fill material or graded in some way. There is a marsh east of the parking area, and woods to the west. Carroll Island Road (paved) is immediately north of the service area, and to the south is the marsh which is adjacent to the dredge-spoil mound. Elevation at the concrete pad is approximately 5 ft (fig. 2); elevations at the nearby dredge-spoil site are 10 ft or more above sea level. Soils are classified as Fallsington loam, Woodstown sandy loam, and tidal marsh (Reybold and Matthews, 1976). One manmade feature might affect the hydrogeology; there is evidence that the production well at the powerplant influences the heads in the confined aquifer at this site. The other features are unlikely to have much of an effect; the paved areas might inhibit infiltration, but it is unlikely that this would significantly affect the hydrogeology of the area.

Other Areas

This section describes the location and known activities for some of the areas in which small amounts of testing or some support activity took place. Information in this section comes from Nemeth (1989, p. 488-489) and from observations by Survey personnel. None of the sites are SWMU's because they were not used to manage solid wastes; many of the sites are adjacent to other test areas or SWMU's described above. The potential for significant residual contamination in these areas is low in comparison to the SWMU's and primary test areas because of factors such as limited periods of operation, methods of release, or small quantities of materials released. The areas addressed in this section (fig. 3) include the magazine area, a CS test area near the wind tunnel, a VX test area near test grid 2, and an area near the HD test area.

The magazine area is located on the northeastern part of Carroll Island near the former dock (fig. 3). The area was used for temporary storage of chemical agents prior to use in test programs. The filling of munitions with chemical agent also was performed in this area. The magazine area was used for these purposes for most of the period of testing activities on Carroll Island. The site was not used for managing solid wastes; any spillage or leakage of chemicals was not routine, systematic, or deliberate (Nemeth, 1989, p. 490).

Present conditions in the magazine area include the paved road from the central part of the island to the dock; a chain-link fence in good condition still surrounds the area, and all that is left of the dock is pilings. The area is topographically flat with an elevation of less than 5 ft (fig. 2); a small amount of ponding is present within the fenced area during wet seasons, and there is marsh to the east and west. Soils are classified as tidal marsh and Fallsington loam (Reybold and Matthews, 1976). Manmade features are unlikely to significantly affect the hydrogeology of the magazine area.

Near the wind tunnel was an area that was used for ground contamination studies involving CS (fig. 3). The area is northwest of the wind tunnel in an open field. There is no current evidence of testing in the field. The field is flat, low-lying, and exhibits some ponding during wet seasons. Soil types include Woodstown loam and Barclay silt loam (Reybold and Matthews, 1976). There are no manmade features in the area except for a paved road on the southern border of the field; this is unlikely to affect the hydrogeology.

The area to the southwest of test grid 2 was used for testing that involved above-ground release of VX (fig. 3). Other testing in the area involved contamination and decontamination of four rectangular pads made of asphalt and concrete. These pads still exist; generally the area is open field with bushes and other growth encroaching on the field. Soils in this area include Barclay silt loam, Woodstown sandy loam, and Othello silt loam (Reybold and Matthews 1976). Some ponding is present during wet seasons; manmade features are unlikely to have an effect on the hydrogeology.

Another area in which some testing took place is east of the HD test area. Testing in this area included operations with small wind tunnels, shock testing of chemical-filled items, and tests of agent penetration of a small portable bunker. Present conditions in the area show a small concrete pad at the site of one of the wind tunnels (fig. 3), and another small concrete pad nearby that looks as if it were used for the shock tests. The area is flat, open, and does not exhibit much ponding of surface water, even during wet seasons. The soil types in this area are Mattapex silt loam and Woodstown sandy loam (Reybold and Matthews, 1976). Manmade features are unlikely to affect the hydrogeology of this area.

DESCRIPTION OF GRACES QUARTERS STUDY AREA

Physiographic Setting

Graces Quarters is a peninsula located north of Carroll Island (fig. 1). The Gunpowder River is east of Graces Quarters, Saltpeter Creek is to the south, and Dundee Creek is to the west. To the north of the peninsula is the Hammerman area of the Gunpowder State Park.

The topography of Graces Quarters (fig. 5) differs from that of Carroll Island. Graces Quarters slopes from a high point of about 40 ft above sea level to low-lying marshy areas to the south. There is a cliff over 30 ft high on one section of the eastern shore of the peninsula. Much of Graces Quarters is wooded, although there is one large open field, a smaller open field, and some marshy areas. Surface-water runoff has been observed on Graces Quarters during storm events. The peninsula also exhibits ponding during wet seasons and after storms.

Graces Quarters is located approximately 1 mile from the community of Chase, Maryland (fig. 1); there are only a few scattered houses between Chase and Graces Quarters. The nearest ground-water users are a marina to the west, and the nursery that was mentioned in the physiographic description of Carroll Island.

Graces Quarters has no current military activity. The area was leased by the U.S. Federal Emergency Management Agency (FEMA) from 1970 to 1988 for an emergency radio transmitter. This lease has terminated, and the area has been leased by the U.S. Air Force for use as a radio receiving station. Initial surveys and test drilling have been done for construction of this station on the peninsula. Construction plans are not known at this time.

As with Carroll Island, the estuaries surrounding Graces Quarters are used for recreational purposes such as fishing and boating. The State Park adjacent to Graces Quarters is used for many recreational purposes, including picnicking, swimming, and target shooting with longbows.

Background

Testing activities were performed on Graces Quarters in much the same way as on Carroll Island, and during the same time period (late 1940's to 1971). The major difference was that the amount of testing on Graces Quarters was much less than on Carroll Island. Testing facilities also were not as permanent or as extensive on Graces Quarters. A summary of testing activities for July 1964 through December 1971 on Graces Quarters is given in table 3.

Table 3.--Quantities of chemicals released on Graces Quarters from July 1964 through December 1971

[See the Glossary of Acronyms and Abbreviations for chemical names]

Material released	*Type*	*Pounds released*
VX	anticholinesterase	199.5
Telvar	herbicide	50.0
GB [1]	anticholinesterase	9.2
GD	anticholinesterase	1.2
EA 3990	anticholinesterase	.5
CS-1	irritant	.3
	Total pounds	260.7

[1] Includes 6.6 pounds destroyed in a caustic bath. (From Nemeth, 1989, p. 150.)

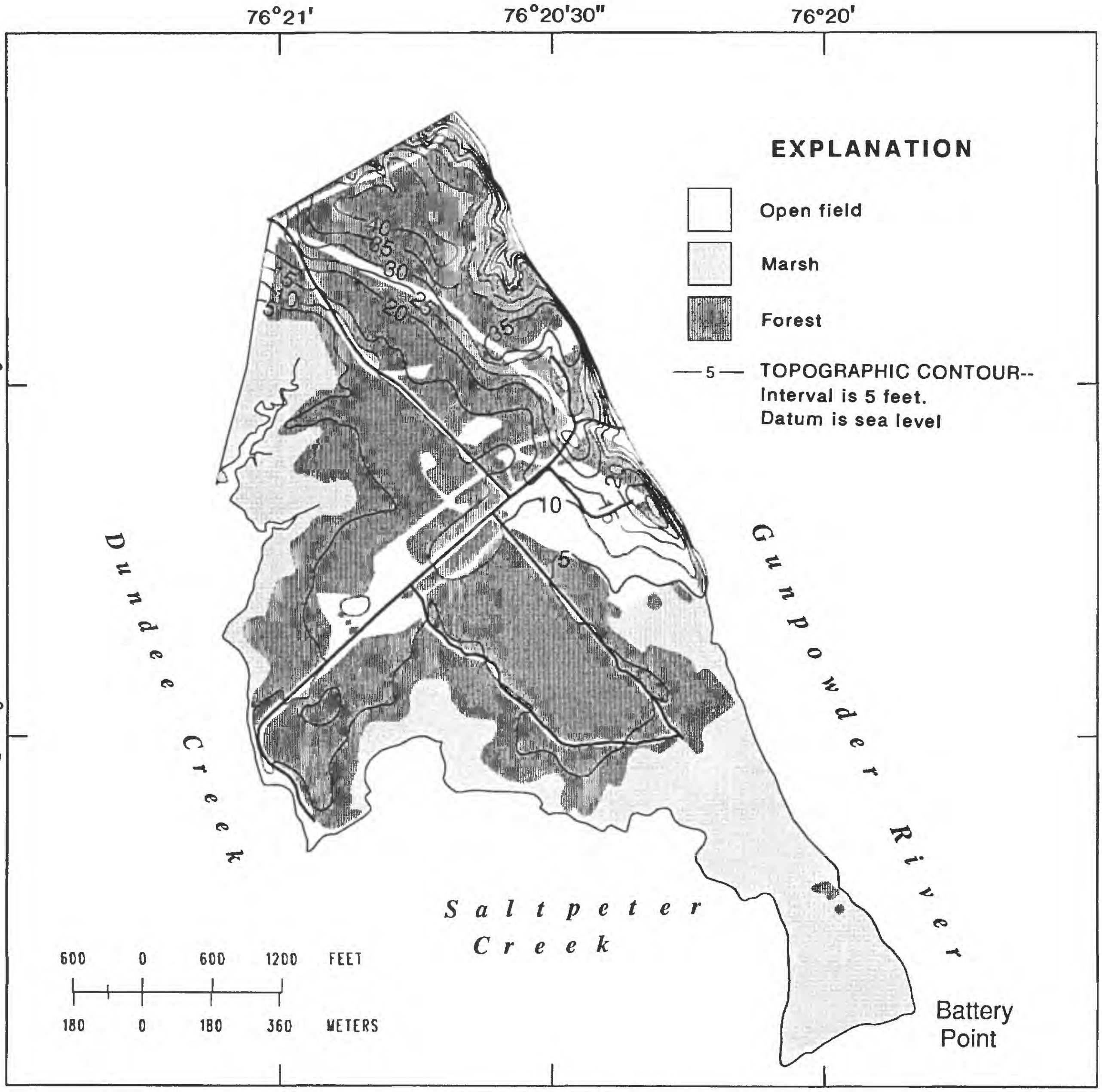

Figure 5.--Topography and terrain of Graces Quarters.

Testing and disposal activity on Graces Quarters was generally on the eastern part of the peninsula (fig. 6). Testing activities were not as extensive as on Carroll Island; most of the testing was confined to one field, designated as the primary test area. Smaller amounts of testing were done at a secondary test area and at three concrete rings known as the HD test annuli.

Disposal occurred in several areas, but it is not thought to have been as extensive as on Carroll Island (Gary Nemeth, U.S. Army Environmental Hygiene Agency, oral commun., 1988). Solid waste management units on Graces Quarters are limited to areas in which disposal took place; the test areas were not designed to manage solid waste and are not classified as SWMU's unless actual disposal occurred. Solid waste was buried at an area designated as the disposal area. Some waste was dumped at three other sites, two of which were located in the primary test area. These two sites were designated as the northern and the southern dumps. The third dump site was designated as the Graces Quarters dump.

Table 4 provides a listing of the SWMU's and test areas on Graces Quarters. The following sections provide information on individual SWMU's and test areas, along with two other areas (the service area and bunker) that were related to activity on Graces Quarters during its testing history.

Table 4.--Solid waste management units, test areas, and support facilities on Graces Quarters

[*SWMU, solid waste management unit*]

Site name	*Classification*
Disposal area	SWMU
Primary test area	test area
Test site, northern dump	SWMU
Test site, southern dump	SWMU
Graces Quarters dump	SWMU
Secondary test area	test area
HD test annuli [1]	test area
Service area	support facility
Bunker	support facility

[1] HD is an abbreviation for distilled mustard.

Disposal Area

The disposal area at Graces Quarters is located on the eastern side of the peninsula north of the primary test area (fig. 6). Most of the historical information about the disposal area is from Nemeth (1989, p. 492-494); information on current conditions at the site was from observations by Survey personnel.

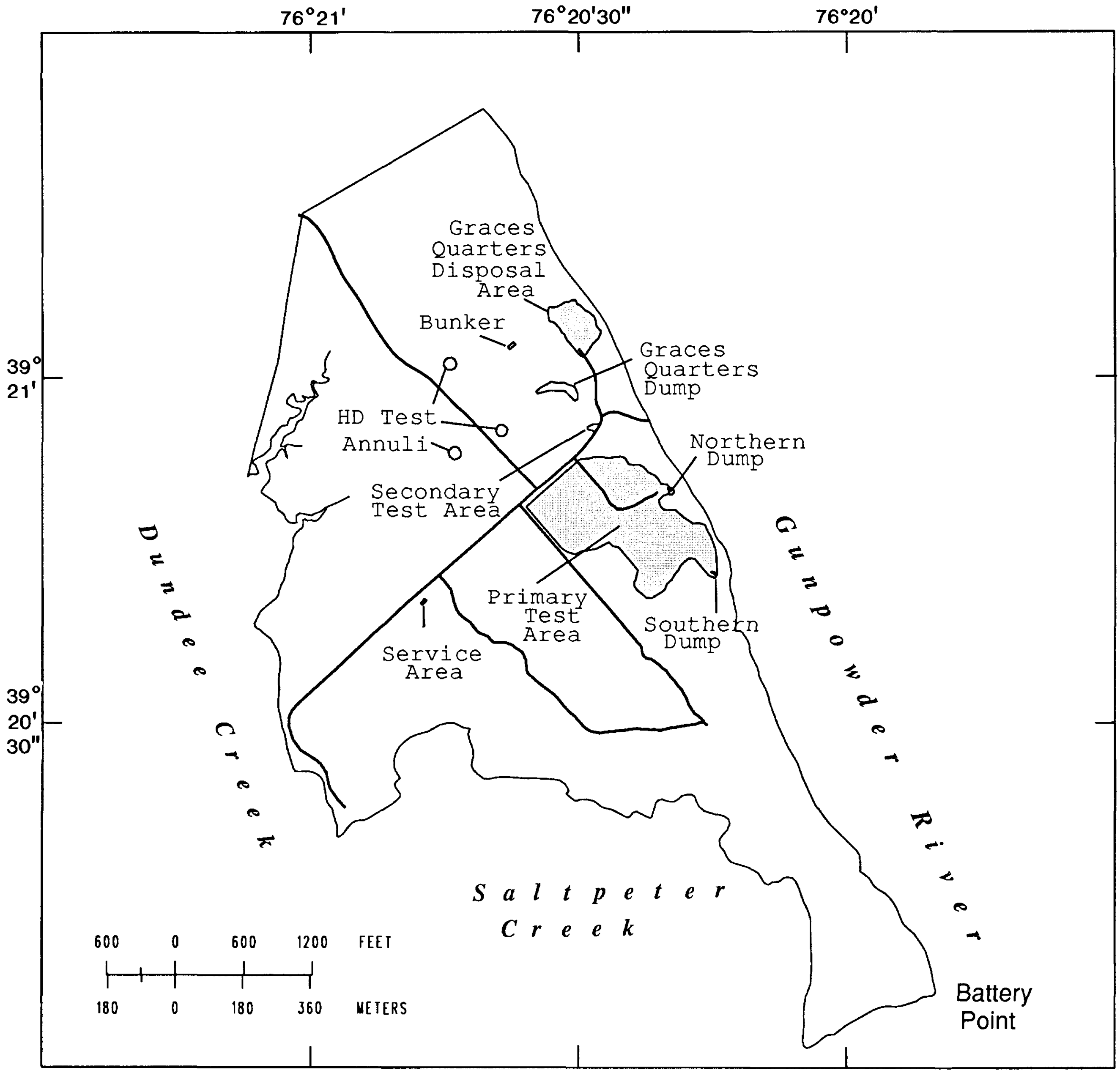

Figure 6.--Location of solid waste management units, test areas, and other selected areas on Graces Quarters.

The disposal area is a site in which solid wastes from chemical agent test operations were buried during the period from the mid-1940's until the early 1970's. The unit is considered to be a SWMU. The pits were constructed in a manner similar to the Lower Island disposal pits on Carroll Island. A pit was dug, filled almost to the top with solid waste, and covered with soil. The exact depth of the pits is not known, but they might be deeper than those on Carroll Island, because a near-surface water table is not a limiting factor here. The depth of the pits is more likely to have been limited by the available digging equipment than by the depth to water table.

There is little historical information on the exact location and number of burial pits in this area. Nemeth (1989, p. 252-271) used aerial photos to try to determine the locations and number of pits. However, information that can be derived from these airphotos is limited in two ways. The first is that the photos do not represent a continuous record of activity at the disposal area. Activity at times other than when the photos were taken would be missed. The second problem is that the photos were taken at a high altitude, which limits the amount of detail that can be perceived. This means that ground scars and other features that are apparent in the airphotos and thought to be burial pits might have been something else.

The wastes that were disposed in the burial pits were items generated during testing operations, such as munitions fragments, unusable sampling equipment, empty containers, and other similar solid wastes. There is no information to indicate that bulk chemicals were disposed of in the burial pits, and such disposal is considered unlikely because of the remote location of Graces Quarters from the Edgewood area of APG (Nemeth, 1989, p. 492). During the period from the late 1950's until the early 1970's, the disposal operations were conducted such that items contaminated with lethal chemical agents were chemically decontaminated prior to placement in the pits. Items contaminated with nonlethal chemical materials such as CS and BZ might have been placed in the pits. The disposal pits were operated during the period from the mid-1940's to the early 1950's by the Edgewood Proving Ground. Only limited information concerning EPG testing and disposal operations is available. It is believed that the earliest disposal was in a pit oriented parallel to the shoreline cliff which was 50 or 60 yds in length and 8 to 10 ft deep. Later disposal was in other pits, which are believed to have been smaller.

Currently, the site still (1990) shows some evidence of disposal activities. Trees have encroached the site, but the southeastern part of the area (where most disposal activities took place) was cleared of trees in 1987 to facilitate magnetometer surveys and drilling activities.

Surficial evidence of disposal activities includes depressions in the ground where burial took place, several empty drums scattered about the area, and small (about 8-in. diameter) filter plates on the surface among some wooden planks near the cliff at the shoreline of the Gunpowder River. Other manmade features in the area include a barbed-wire fence at the edge of the cliff, the ruins of a farmhouse that existed before the testing period, an open dug well that was probably the water supply for the farmhouse, and a mounded area in the northern part of the disposal site. None of these features are likely to affect the hydrogeology.

A magnetometer survey of the area was done to determine the exact locations and dimensions of burial pits. The survey revealed buried metal in three sites in the disposal area (fig. 7). Two of the sites had shown up as ground scars in a 1958 airphoto (Nemeth, 1989, p. 259-261), but one site did not coincide with the scarring in the photo. Magnetometer surveys also failed to locate the pit that was oriented parallel to the shoreline and described

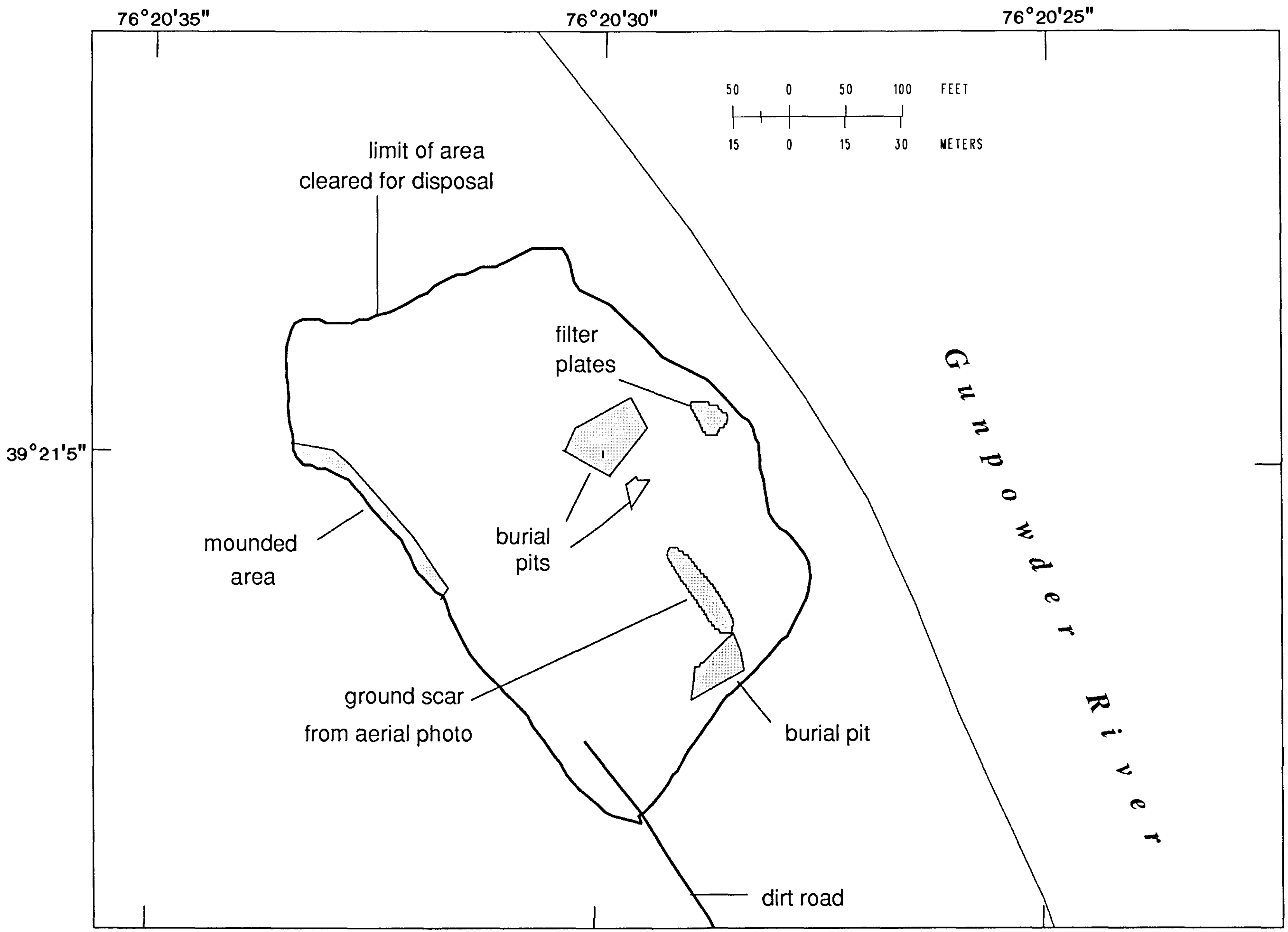

Figure 7.--Burial pits and other features of the Graces Quarters disposal area.

above as the site of earliest disposal. The mounded area in the northern part of the disposal site contained no metal other than that which could be seen partially or completely at the surface. The visible metal in this site consisted of a small amount of sheet steel and concrete-reinforcement barring. The mounding probably resulted from improvement activities that were initiated before testing began at Graces Quarters (Gary Nemeth, U.S. Army Environmental Hygiene Agency, oral commun., 1988).

The disposal area is located on a topographic high area of Graces Quarters (fig. 5). To the east of the area is a cliff that leads to the shore of the Gunpowder River; the land slopes away gradually to the north, west, and south from the disposal area. Elevation of the disposal area is about 35 ft above sea level. Soil types are classified as Mattapex silt loam, Matapeake silt loam, and moderately eroded Sassafras loam (Reybold and Matthews, 1976). Surface-water characteristics in the area include ponding and storm-water runoff. Ponding occurs after storms and during wet seasons in wheel ruts on the dirt road leading to the disposal area. There also is evidence of runoff down the cliff face (there are many rills in the cliff); storm-water runoff to the southwest from the disposal site area was observed by U.S. Geological Survey personnel during the winter of 1987-88. The receptor of runoff from the cliff face is the Gunpowder River; runoff to the southwest of the disposal area probably collects in wooded areas and fields where it most likely infiltrates or evaporates.

Primary Test Area

The primary test area on Graces Quarters was located on the eastern side of the peninsula, southeast of the road that crosses the peninsula (fig. 6). The area was used as a test site from the late 1940's until the early 1970's. Because the area was not used to manage solid waste, it is not considered to be a SWMU; however, the northern and southern dumps on the perimeter of the area are SWMU's.

Much of the testing history for this area of Graces Quarters was inferred from observation of aerial photos by Nemeth (1989, p. 252-271) and by Survey personnel. Information on current conditions in the area is from field observations by Survey personnel.

The amount of testing was reported to be much less than on Carroll Island. In the early 1950's, approximately 10 annular test rings were used for testing. These rings were visible on the aerial photos as ground scars; they might have simply been cleared of vegetation or they might have been covered with gravel. There also were several small structures in the area at this time. By the late 1950's and early 1960's, two airplanes were parked in the test area; these were used for decontamination studies (Nemeth, 1989, p. 261). Various small structures and ground scars were evident in the photos. In the 1970 photo, only one plane is visible, and a small, semicircular test grid can be seen. There also was a trench filled with water on the eastern part of the test area; this trench was reportedly used in vehicle decontamination studies. Some small structures are still visible in the 1970 photo.

Throughout its testing history, much of the area was cleared of trees. Currently, some of the test area has been overgrown by trees, but much of the northern part is still open field with only a few small trees. There are vegetation changes that appear in circular patches in the grassy part of the field; these are almost certainly areas where testing has taken place. In the area where the small test grid appeared in the 1970 photo, there are the remains of a small building, a cement anchor for a cable, and signs warning of chemical testing in the area.

In the northeastern corner of the test area is the northern dump site mentioned above; in the southeastern corner is the southern dump site. Near the southern dump site is the decontamination trench that was visible in the 1970 photo; this trench fills with water during wet seasons.

The topography of the area (fig. 5) varies. The area slopes gently west and south from the hill at the top of the cliff on the northeastern corner of the test area to the relatively flat field on the western part, and to the marshy area south of the test site. North of the primary test area there is a chain-link fence at the road that crosses the peninsula; the area west of the field in the test area is wooded. Elevations in the area range from about 2 to 35 ft above sea level.

Ponding in the area is present mainly in the decontamination trench; the only other ponding that has been observed is in ruts left by vehicles. Rills on the cliff in the northeastern part of the test area indicate that there is intermittent surface-water runoff there. No other evidence of runoff has been observed, although storm-water runoff from the northeastern corner toward the southwest is possible because conditions are much like those at the disposal site. Soil types include Mattapex silt loam, Sassafras sandy loam, Sassafras loam, moderately eroded Sassafras sandy loam, Woodstown sandy loam, and Fallsington loam (Reybold and Matthews, 1976). It is unlikely that any manmade structures in the test area affect the hydrogeology.

Test Site, Northern Dump

The northern dump in the test area was located on the southeastern side of the peninsula on the northeastern end of the Graces Quarters primary test area (fig. 6). No historical information on this site could be found; the dump site was discovered during a Survey field reconnaissance. All information in this section is derived from observations by Survey personnel, and visual inspections by TEU.

The dump is in a wooded area (fig. 5) on the top of a hill, which slopes rapidly off to the north, gently off to the south and west, and down a cliff to the shoreline on the east. There is some linear mounding in the area (that shows no evidence of waste burial), and trees were cleared along an old powerline. Land-surface elevation is approximately 25 to 35 ft above sea level.

There appears to have been no burial of waste in the area; it looks like a dump site, a common area for testing personnel, or a surveillance testing site. The site is considered to be a SWMU. Debris that was found includes seven empty 55-gal (gallon) drums, several small empty decontamination tanks (identified by TEU as M-1 decontamination tanks, which contained DS-2), empty STB containers, some discarded personal protective equipment, the remains of a latrine and a small cinder-block structure, downed power poles, and various unidentified field equipment. There also is a barbed-wire fence at the top of the cliff near the shoreline.

No ponding has been observed in this area; however, rills from surface-water runoff have been observed on the cliff face. Soil types have been classified as Sassafras sandy loam and moderately eroded Sassafras sandy loam (Reybold and Matthews, 1976). Manmade features are not likely to affect the hydrogeology of this area.

Test Site, Southern Dump

The southern dump is a SWMU that is located at the southeastern end of the Graces Quarters primary test area (fig. 6). The site is located in a wooded area adjacent to a marsh (fig. 5) and is about 200 ft from the shoreline of the Gunpowder River to the east. It is low-lying (approximately 5 ft above sea level), and gently slopes to the south.

There is no historical information on this site. The information in this section is from observations by Nemeth (1989, p. 496) and by Survey personnel. It appears that the area was used for disposal of unusable STB and empty STB containers; also it appears that a small amount of what may have been building debris had been pushed by bulldozer into the area. Soil types in the area include Sassafras sandy loam and the adjacent tidal marsh (Reybold and Matthews, 1976). Manmade features are unlikely to affect the hydrogeology.

Graces Quarters Dump

The Graces Quarters dump is a small site located south-southwest of the disposal area (fig. 6). Historical information on use or disposal at this site is limited; information in this section is from Nemeth (1989, p. 495) and from observations by Survey personnel. Visual examination reveals only empty bleach cans that were dumped at the site. The area is considered to be a SWMU. The dump site is on a slope in a wooded area southwest of a clearing, and is 20 to 25 ft above sea level (fig. 5). The soil type in the area is Mattapex silt loam (Reybold and Matthews, 1976). The area to the southwest of the dump site appears to have been used for disposal of trees from other areas of Graces Quarters. There also is some mounding, which looks like it was mainly from construction work. The mounding might be affecting the hydrogeology of the area by producing localized changes in drainage or infiltration. Magnetometer surveys indicated that some buried material was located here. Some areas near this dump site (mainly to the west) contain ponded water during wet seasons.

Secondary Test Area

The secondary test area is a small site south of the Graces Quarters disposal area (fig. 6). Surveillance testing was supposedly performed there (Gary Nemeth, U.S. Army Environmental Hygiene Agency, written commun., 1988). The site is not considered to be a SWMU. The site is on a gently sloping area near the Graces Quarters dump site. There is little current surficial evidence that testing was performed there (except a few scattered STB cans), and very little historical data are available. It is unlikely that the area was used extensively. There are no manmade features in this area. Elevation of the area is approximately 20 ft (fig. 5). The soil type in the area is Mattapex silt loam (Reybold and Matthews, 1976). No ponding or surface-water runoff has been observed.

HD Test Annuli

The HD test annuli were three concrete rings located north of the road that crosses the Graces Quarters peninsula (fig. 6). The information in this section is from Nemeth (1989, p. 495), aerial photo interpretation by Survey personnel, and field observations by Survey personnel.

The test annuli were probably constructed in 1951 or 1952. Each concrete ring had an outside diameter of about 120 ft; the inside of the ring was bare ground, with a diameter of 60 ft. The annuli were used in decontamination studies involving HD, VX, and fuming nitric acid. As with Carroll Island, the testing before 1964 was poorly documented; this is probably the time of the most testing activity (at least with HD) on the test annuli. Since the annuli were not used to manage solid waste, they are not considered to be SWMU's.

About 1971, the northernmost annulus was removed for construction of the FEMA radio tower. The other two annuli remain today. One annulus is east of the gravel road that leads from the entrance gate to the crossroad, and the other ring is to the west. Both remaining annuli are on flat ground between open field and wooded areas. The center of each annulus is overgrown with trees. The elevations of the annuli are about 7 and 13 ft above sea level (fig. 5); ponding or surface-water runoff has not been observed. The soil types are Mattapex silt loam around the eastern annulus and in the area that the northernmost annulus occupied, and Matapeake silt loam around the annulus west of the road (Reybold and Matthews, 1976). Manmade features in the area include the annuli themselves, Graces Quarters road, and a concrete anchor from the FEMA radio tower that is located close to the westernmost annulus. These features are unlikely to influence the hydrogeology.

Other Areas

Two other areas on Graces Quarters that warrant mention are the bunker and the service area. The areas are included for completeness; they are not thought to be a likely source of contamination. Information on this section is from Nemeth (1989, p. 495 and 497) and from field observations by Survey personnel.

The bunker site is a small, water-filled depression about 30 by 75 ft in size, and is located 400 ft west of the Graces Quarters disposal area (fig. 6). The bunker was constructed with timber and sandbags during the late 1940's or early 1950's, when Graces Quarters was used as an impact area, and was destroyed by the late 1950's. The depression that remained was never designated as a disposal site, and there is no information to suggest that it was used for disposal. Metal detection equipment did not detect metal in the depression. This site is not considered to be a SWMU.

Currently, the site is a depression that is always filled with water. There is a thin line of young trees surrounding the depression; otherwise it is in open field. The soil type is Mattapex silt loam (Reybold and Matthews, 1976). The site is on a small grassy knoll, at an elevation of about 30 ft above sea level (fig. 5). The northern side of the knoll is almost level, with a gentle slope to the west and steeper slopes to the east and south. Geologic cores from a well drilled on the knoll show no indication that it was built up for construction of the bunker; the material appears to have been undisturbed sediment.

The Graces Quarters service area is located southwest of the main test area near the road that crosses the peninsula (fig. 3). There is no substantial historical information about this site; it was probably used in much the same manner as the Carroll Island service area.

Currently, the site consists of an abandoned Quonset hut (Building E7825), with a holding tank by the hut. The sign at the hut says that it was a repair facility. There is some assorted junk that was dumped in the area; this included discarded personal protective equipment and empty STB cans. The site is not considered to be a SWMU.

The sight is on flat land, in an area that is now wooded (fig. 5). The elevation is about 8 ft above sea level. The soil type in the area is Mattapex silt loam (Reybold and Matthews, 1976). Manmade features include the Quonset hut, the nearby unpaved road, and the chain-link fence between the road and the Quonset hut. These features are unlikely to affect the hydrogeology.

STUDY APPROACH FOR THE HYDROGEOLOGIC ASSESSMENT

A phased approach is being used for the Carroll Island and Graces Quarters HGA investigations. The purpose of phase I of each investigation is to gather information on the sites of suspected releases and verify if chemicals have been or are still being released. Phase II of each investigation will involve further characterization of any releases that are detected during phase I. Data collected for the HGA's will be used to evaluate remedial measures.

Discussion of the technical approach and rationale of the HGA investigations is divided into (1) a general study approach for both study areas and (2) specific study approaches for individual sites on Carroll Island and Graces Quarters. The chronology of work for phase I at Carroll Island and Graces Quarters is presented in figures 8 and 9, respectively. Because data collection has already begun, the work completed thus far for each task is discussed. The methods and procedures for data collection are presented in Appendixes I-IV.

General Study Approach

Phase I

The objectives of phase I are to: (1) identify the locations and dimensions of SWMU's and chemical-agent test sites, (2) define the hydrogeologic system, and (3) verify suspected releases from SWMU's and chemical-agent test sites. The objectives and associated tasks are discussed below.

The first objective is to identify the locations and dimensions of SWMU's and chemical-agent test sites. This objective involves collecting information on the location, dimension, type of material disposed or tested, and period of operation of SWMU's and chemical-agent test sites on Carroll Island and Graces Quarters. Sources for this information include (a) previous investigations, (b) air photographs, (c) field and air reconnaissance, and (d) magnetometer surveys.

Previous investigations of the study areas include ecological investigations and an environmental survey conducted by USATHAMA (Nemeth and others, 1983). Additionally, a RCRA Facility Assessment has been prepared by the AEHA (Nemeth, 1989). The ecological studies were only performed at Carroll Island; the environmental survey and the RFA included both areas.

A series of ecological investigations were performed by the Department of the Army during the 1970's to determine the effects of chemical-agent testing on Carroll Island. The objectives and methodology of the studies are outlined by Ward (1971). The ecological investigations included concurrent studies of the ecology, toxicology, botany, and analytical techniques. Ecological studies of various organisms are reported in Smrchek (1971a, 1971b), which included investigations of invertebrates and soil-litter invertebrate populations; Slack and others (1972) studied populations of reptiles and amphibians on Carroll Island; Roelle and Slack (1972) studied the bird population; and Speir (1972) inventoried the fish diversity. Pinkham and others (1976) compared the mammals on the eastern and western sections of Carroll Island. Weimer and others (1970) studied the acute toxicity of VX and GD to three estuarine species taken from the waters of the Gunpowder River near Carroll Island.

An environmental survey of Carroll Island and Graces Quarters was conducted during 1977 and 1978 by USATHAMA (Nemeth and others, 1983). The study involved conducting a records search, collecting hydrogeologic data, and sampling for chemical analyses of soil, sediment, ground water, and surface water. The records search identified six potential contaminant sources on Carroll Island and four on Graces Quarters.

Aerial photographs of Carroll Island and Graces Quarters are available for 1952, 1957, 1958, 1960, 1970, and 1971. The photographs were reviewed to provide information on the historical use and locations of SWMU's and chemical-agent test areas. The review was performed by AEHA as part of the RFA and by the U.S. Geological Survey. All information obtained from the aerial photographs is presented in the study area descriptions of this report.

Field and air reconnaissance provided information on the current condition of sites. The information from the previous reports and aerial photography was used to plan the field and air reconnaissance. The field reconnaissance involved visiting every site listed in the RCRA permit and other potential sites discovered from previous investigations and aerial photos. The initial field survey was conducted with the TEU in order to locate any unexploded munitions that might have been on the ground surface. The air reconnaissance was conducted in February 1987 with the U.S. Army providing a helicopter. Observations were recorded in field notebooks and are summarized in the study-area descriptions of this report.

Magnetometer surveys were performed by TEU to better determine the dimensions of buried materials in the SWMU's. The magnetometer readings were interpreted by the operator and recorded in field notebooks by Survey personnel. The location of buried material was marked with stakes and flagging tape. The dimensions were measured and the coordinates were located using points that had a known longitude and latitude. The magnetometer data are presented in the study area descriptions of this report.

The second objective is to define the hydrogeologic system. This objective is important for the identification of potential pathways for contaminant migration. The investigation focuses on the geology and ground-water flow direction in the surficial (uppermost) aquifer because it is the primary migration pathway. Additionally, a summary of the regional geology, climate, soils, and surface water will be provided in the HGA reports.

The hydrogeologic system is being defined by (a) reviewing existing data and reports, (b) conducting field investigations, (c) drilling test holes and observation wells, (d) collecting water-level data, and (e) performing hydrologic testing. All data collected from these tasks will be included in the HGA reports.

Existing data include well records, lithologic logs, geophysical logs, water-level and water-use information, and published reports. With one exception, all these data are on a regional scale and are not site specific to Carroll Island and Graces Quarters. The regional data provide insight into the geologic framework, ground-water flow, water use, climate, and surface water in the vicinity of both areas. Compilation of the existing data included an inventory of all existing wells within a 3-mile radius of the study areas. This information was collected from well permits and completion reports on file at the Maryland Geological Survey and the U.S. Geological Survey. The well locations were plotted on maps having the Maryland grid coordinate system. Water-use data were obtained from the Maryland Department of Natural Resources. These data provide information on potential manmade influences on the ground-water flow system. Existing published reports include water-resource appraisals of Baltimore and Harford Counties that provide summaries of area ground-water, climatic, and surface-water conditions.

PROJECT DATES

Phase 1 of Carroll Island Project

BEGIN 10/01/1986

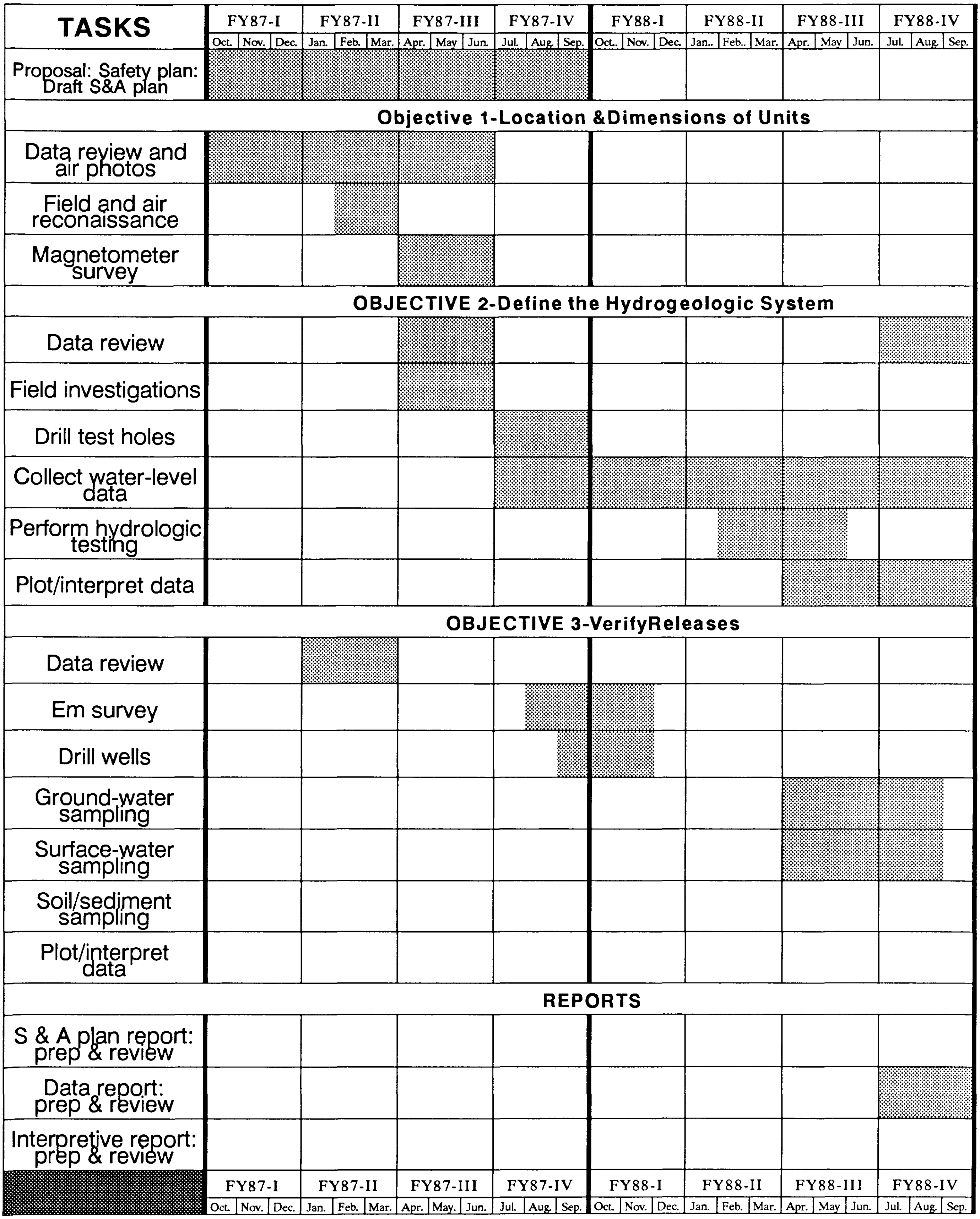

Figure 8.--Chronology of objectives and tasks for Phase I of the study at Carroll Island.

END: 12/31/1990

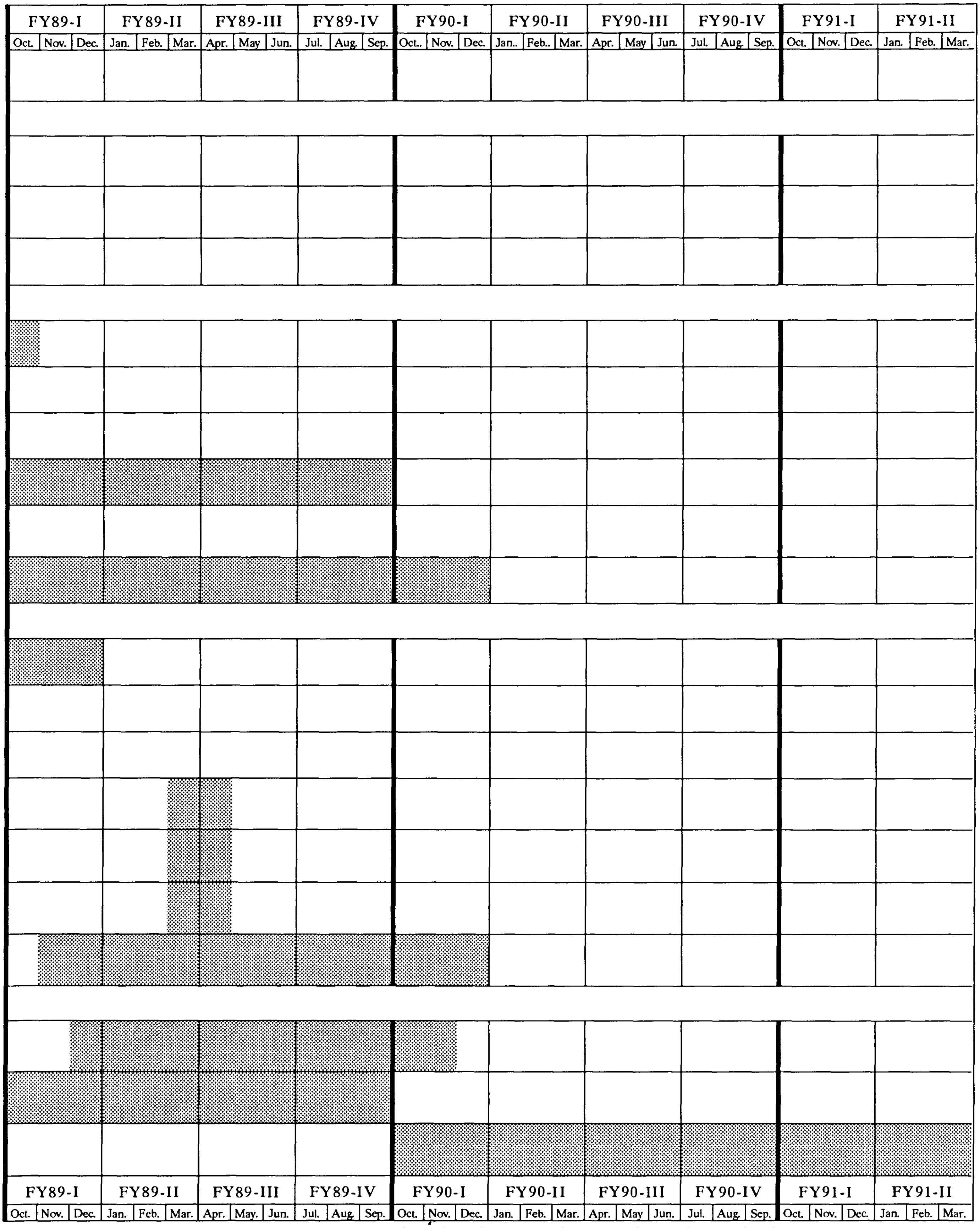

Figure 8.--Chronology of objectives and tasks for Phase I of the study at Carroll Island --Continued.

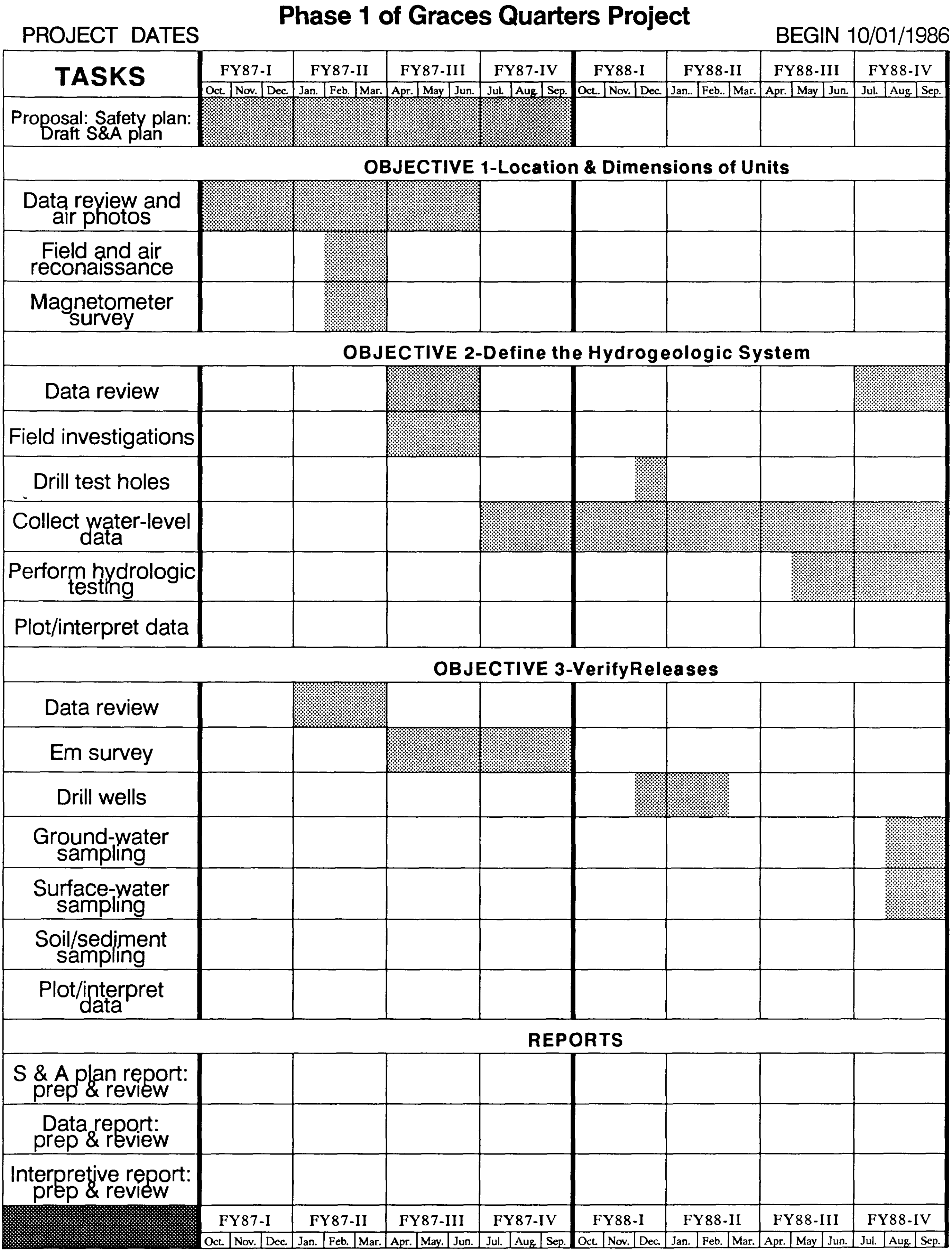

Figure 9.--Chronology of objectives and tasks for Phase I of the study at Graces Quarters.

END: 3/31/1991

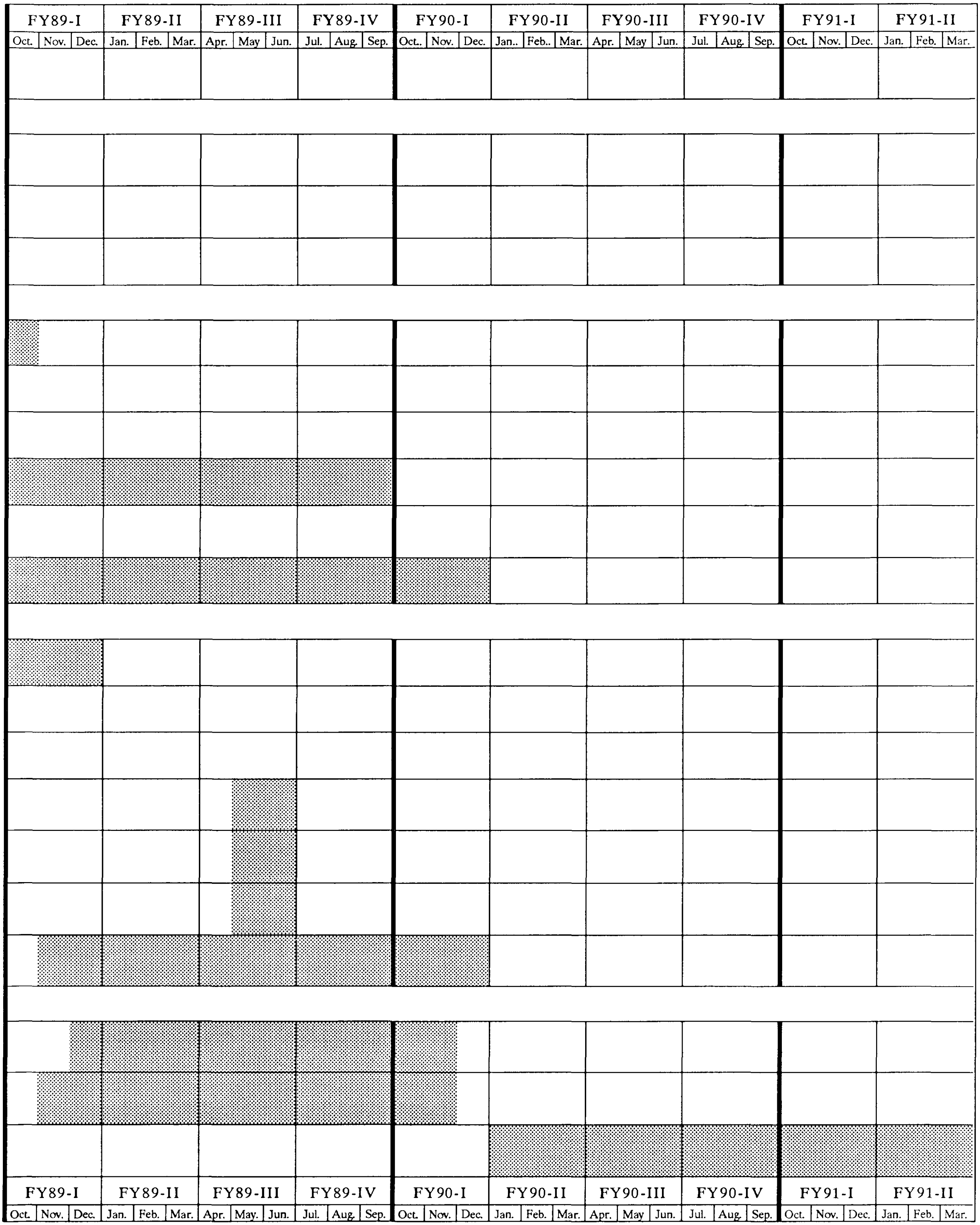

Figure 9.--Chronology of objectives and tasks for Phase I of the study at Graces Quarters --Continued.

Site-specific hydrogeologic data collected from Carroll Island and Graces Quarters in 1977 and 1978 are published in Nemeth and others (1983). On Carroll Island, a total of 13 wells were drilled at three potential contaminant sites to collect hydrogeologic data. The wells were drilled to a depth of about 25 ft. Samples were collected from each well to determine the lithology and physical properties of the sediments. One synoptic water-level measurement was taken on January 23, 1978. On Graces Quarters, six wells were drilled at two potential contaminant sites. Water levels were measured once.

Field inspections were conducted to define the topography and surface drainage to obtain an estimate of ground-water movement. Nemeth and others (1983) reported that the water-table altitude reflects the land-surface topography in both study areas. The topography of Carroll Island is fairly flat and characterized by marsh, open fields, and wooded areas. Graces Quarters has the same type of land cover but has more topographic relief.

The regional hydrogeologic framework was investigated by drilling five test holes each on Carroll Island and Graces Quarters. The U.S. Army Corps of Engineers (COE) provided all drilling services for this study. The test hole locations were chosen to provide data on the spatial characteristics of the geologic framework; therefore, four sites were placed along the perimeter and one in the middle of each study area. The depths of the test holes ranged from 150 to 175 ft with split-spoon samples collected from 10-ft intervals at each site. Electric and gamma logs were obtained from each test hole to enhance stratigraphic interpretations.

The hydrogeologic framework underlying the SWMU's and chemical-agent test areas was addressed by collecting lithologic and geophysical data during the drilling for the water-quality observation network. Forty-nine observation wells, ranging in depth from 9 to 71 ft, were drilled and installed on Carroll Island during the fall of 1987. Twenty-six observation wells, ranging in depth from 10 to 160 ft, were drilled and installed on Graces Quarters the following winter. The screen depths and construction information for the Carroll Island and Graces Quarters wells are shown on tables 5 and 6, respectively.

Continuous cores were collected from each well. A U.S. Geological Survey geologist collected representative samples and prepared descriptive logs of sediment lithology for each drill site. Gamma logs also were obtained from each drill site. A detailed description of the drilling and construction methods for the test holes and observation wells is provided in Appendix II.

The hydrogeologic framework will be interpreted through the preparation of cross sections and thickness maps. Data for the regional framework will include lithologic and geophysical logs obtained from the off-site well inventory and the test holes drilled on Carroll Island and Graces Quarters. Lithologic and geophysical logs collected from the observation-well drilling will be used to determine the geologic framework near SWMU's and chemical-agent test areas. The hydrogeologic interpretations will include the depth to top and thickness of the aquifers and confining units in the study area.

Preliminary interpretations of the hydrogeologic framework indicate that the surficial aquifer underlying Carroll Island is generally one continuous unit that consists of interbedded sand, silty sand, and silt. The depth to the top of the aquifer is 2 to 15 ft but changes seasonally because of water-level fluctuations. Thickness of the aquifer ranges from about 5 to 25 ft. The aquifer is underlain by an extensive confining unit that ranges in thickness from 20 to 40 ft. A confined aquifer is present under the confining unit.

The hydrogeologic framework of Graces Quarters is more complex than Carroll Island. The surficial aquifer is a series of perched aquifers due to discontinuous sand and clay lenses that exhibit rapid facies changes. Several small-scale paleochannels also are present. The depth to the top of the surficial aquifer ranges from 5 to 40 ft; however, in some areas the surficial aquifer is nonexistent. Aquifer thickness ranges from 0 to about 20 ft. A dense clay underlies the shallow aquifer system and acts as a confining unit. Underlying confined aquifers are present at about 60 and 100 ft below land surface.

Water levels were measured once a month in each well and continuous water-level recorders were installed on selected wells to determine the direction of ground-water flow. The well network is designed to determine areal flow directions in the surficial aquifer near each SWMU and on an area-wide scale as well as vertical flow direction between the surficial aquifer and underlying aquifers. At least three wells were drilled into the surficial aquifer at each SWMU in order to determine areal flow direction. The monthly synoptic water levels were collected from the 62 wells on Carroll Island and 31 wells on Graces Quarters for at least one year to provide data on seasonal water-level fluctuations. Continuous water-level recorders that were installed on 14 wells at Carroll Island and 11 wells at Graces Quarters provided data on short-term water-level fluctuations due to tides or pumpage. Additionally, a tide gage was installed to help characterize tidal influences in the aquifers and a rain gage was installed to help quantify precipitation recharge to the aquifers. The monthly water-level measurements were recorded in field notebooks and then transferred to a U.S. Geological Survey data base. The continuous water-level data were recorded on paper-punch tapes. These tapes were processed in order to transfer the measurements into another U.S. Geological Survey data base. These data bases are used to present the information in tabular or graphical form.

The direction of ground-water flow will be interpreted through the preparation of water-level contour maps and hydrographs of continuous water-level data. Data from the surficial and confined aquifers will be compared to determine vertical flow gradients.

Aquifer and confining unit properties were determined from laboratory and field testing. Slug tests were performed on selected wells to obtain an estimate of horizontal hydraulic conductivity and storativity at various points in the aquifers. The methods used to conduct the slug tests are presented in Appendix III. Twenty-one sediment samples were analyzed for grain-size distribution to characterize the different lithologies found in the study areas. The vertical hydraulic conductivity of the confining units was determined by laboratory testing of seven undisturbed samples collected in shelby tubes.

The physical properties of the soils in the study area will be determined from laboratory testing and existing soil surveys. Soil permeability, texture, depth, moisture capacity, pH, and cation exchange capacity will be presented in the HGA reports.

Objective three was to verify suspected releases from SWMU's and chemical-agent test areas. Potential sites of contamination include SWMU's and chemical-agent test areas. The SWMU's have the potential for continued release; however, the chemical-agent test areas probably contain only residual contamination from testing conducted prior to 1972. Migration of contaminants from SWMU's and chemical-agent tests areas could potentially occur within the soil, ground water, surface water, or air.

Table 5.--Description of observation wells and test holes on Carroll Island

[Latitude and longitude: degrees (o), minutes ('), and seconds ("). Depths and water levels are below land surface datum. Altitude is elevation of the land surface relative to sea level. gal/min, gallons per minute; ft, feet; in., inches; --, no data. Type of pump: H = hand, S = submersible, A = air lift, J = jagger. Driller: U.S. Army Corps of Engineers. Method of construction: Augered, except of test holes (T) which were drilled using mud rotary]

Well no.	USGS well no.	Latitude (o,',")	Longitude (o,',")	Altitude (ft)	Date of completion	Depth of well (ft)	Depth of hole (ft)	Diameter of screen casing (in.)	Aquifer
I01	BA Fg 74	391928	762031	5.70	1977	19	--	2	surficial
I02	BA Fg 95	391926	762028	5.71	1977	19	--	2	surficial
I03	BA Fg 96	391927	762022	4.54	1977	17.5	--	2	surficial
I04	BA Fg 97	391917	762015	8.25	1977	23	--	2	surficial
I05	BA Fg 98	391913	762010	7.62	1977	19.3	--	2	surficial
I06	BA Fg 75	391910	762014	10.00	1977	23	--	2	surficial
I07	BA Fg 99	391905	762013	7.68	1977	23	--	2	surficial
I08	BA Fg 100	391903	762017	8.40	1977	26	--	2	surficial
I09	BA Fg 76	391909	762027	3.71	1977	23.3	--	2	surficial
I10	BA Fg 102	391911	762023	5.30	1977	20.3	--	2	surficial
I11	BA Fg 103	391837	762035	4.58	1977	21.2	--	2	surficial
I12	BA Fg 104	391838	762029	3.05	1977	23	--	2	surficial
I13	BA Fg 77	391835	762032	4.76	1977	20.2	--	2	surficial
I14	BA Fg 105	391837	762036	3.50	02-12-88	11	32	4	surficial
I15	BA Fg 106	391836	762034	5.23	02-05-88	22	30	4	surficial
I16A	BA Fg 107	391835	762030	4.49	02-03-88	53	61	4	confined
I16B	BA Fg 108	391835	762030	3.47	02-03-88	11	15	4	surficial
I17	BA Fg 109	391837	762031	3.31	02-06-88	18	26.5	4	surficial
I18	BA Fg 110	391838	762031	3.24	02-08-88	10	25	4	surficial
I19	BA Fg 78	391835	762035	3.40	02-18-88	19	27	4	surficial
I20A	BA Fg 111	391840	762034	4.86	02-12-88	19	30	4	surficial
I20T	BA Fg 79	391840	762034	--	08-31-87	--	148.1	--	--
I21	BA Fg 113	391844	762036	3.66	02-11-88	15	20	4	surficial
I22A	BA Fg 80	391846	762029	3.58	10-07-87	65	67	4	confined
I22B	BA Fg 81	391846	762029	3.68	10-08-87	19	27	4	surficial
I22C	BA Fg 82	391846	762029	3.65	10-07-87	10	15	4	surficial
I23	BA Fg 114	391843	762028	2.47	02-10-88	20	31	4	surficial
I24	BA Fg 115	391853	762021	4.67	02-01-88	9	15	4	surficial
I25	BA Fg 116	391847	762030	2.49	02-19-88	18	31	4	surficial
I26A	BA Fg 117	391857	762023	6.29	12-04-87	30	45	4	surficial
I26B	BA Fg 118	391857	762023	6.13	12-03-87	14	15	4	surficial
I27A	BA Fg 83	391855	761959	3.88	11-16-87	62.7	65	4	confined
I27B	BA Fg 84	391855	761959	3.88	11-16-87	8	17	4	surficial
I28	BA Fg 85	391855	761956	3.91	11-18-87	11	17	4	surficial
I29	BA Fg 120	391856	761958	4.59	11-17-87	10	30.4	4	surficial
I30	BA Fg 121	391859	761957	2.67	11-18-87	15	25	4	surficial
I31A	BA Fg 122	391919	762007	3.80	02-22-88	15	27	4	surficial
I31T	BA Fg 86	391919	762007	--	09-03-87	--	151.3	--	--
I32	BA Fg 124	391922	762027	5.68	02-11-88	16	25	4	surficial
I33	BA Fg 87	391912	762035	2.90	02-25-88	24.5	25	4	surficial
I34	BA Fg 125	391917	762035	5.33	02-20-88	26	30	4	surficial
I35	BA Fg 126	391917	762036	4.41	02-20-88	25	25	4	surficial
I36	BA Fg 127	391919	762035	5.28	02-20-88	27	29	4	surficial
I37A	BA Fg 128	391912	762021	7.20	02-20-88	64.5	65	4	confined
I37B	BA Fg 129	391912	762021	7.00	02-22-88	21	27	4	surficial
I38A	BA Fg 130	391928	762033	6.46	02-28-88	19	20	4	surficial
I38T	BA Fg 88	391928	762033	--	09-01-87	--	151	--	--
I39	BA Fg 132	391929	762032	6.29	02-22-88	21	25	4	surficial
I40	BA Fg 133	391929	762033	7.47	02-23-88	19	20	4	surficial
I41	BA Fg 134	391934	762050	2.90	02-23-88	12	15	4	surficial
I42	BA Fg 135	391934	762051	3.26	02-25-88	13	15	4	surficial
I43	BA Fg 136	391934	762051	3.63	02-11-88	10	15	4	surficial
I44	BA Fg 137	391845	762035	3.10	02-11-88	14	15	4	surficial
I45	BA Fg 138	391908	762114	8.00	11-13-87	14	20	4	surficial
I46	BA Fg 139	391910	762118	8.50	11-12-87	17	20	4	surficial
I47A	BA Fg 89	391912	762116	3.14	11-06-87	10	15	4	surficial
I47B	BA Fg 90	391912	762116	3.18	11-05-87	65.6	67	4	confined
I47T	BA Fg 91	391912	762116	--	08-29-87	--	180	--	--
I48	BA Fg 141	391914	762115	4.50	10-29-87	10	15	4	surficial
I49	BA Fg 142	391914	762117	4.10	11-02-87	10	15	4	surficial
I50A	BA Fg 143	391935	762127	3.78	10-28-87	19	20	4	surficial
I50T	BA Fg 92	391935	762127	--	09-03-87	--	143	--	--
I51	BA Fg 145	391937	762129	2.30	10-26-87	9	15	4	surficial
I52	BA Fg 146	391936	762126	4.20	10-20-87	11	25	4	surficial
I53	BA Fg 147	391938	762125	3.35	10-16-87	10	15	4	surficial
I54A	BA Fg 93	391938	762127	3.63	10-22-87	9	15	4	surficial
I54B	BA Fg 94	391938	762127	3.44	10-23-87	59	59	4	confined

Screen (ft)	Sand pack (ft)	Bentonite seal (ft)	Grout (ft)	Pumping rate (gal/min)	Hours pumped	Water level before pumping (ft)	Type of pump	Well no.
4.0-19.0	--	--	--	--	--	--	--	I01
4.0-19.0	--	--	--	--	--	--	--	I02
2.5-17.5	--	--	--	--	--	--	--	I03
8.0-23.0	--	--	--	--	--	--	--	I04
4.3-19.3	--	--	--	--	--	--	--	I05
8.0-23.0	--	--	--	--	--	--	--	I06
8.0-23.0	--	--	--	--	--	--	--	I07
8.3-23.3	--	--	--	--	--	--	--	I08
8.3-23.3	--	--	--	--	--	--	--	I09
5.3-20.3	--	--	--	--	--	--	--	I10
6.2-21.2	--	--	--	--	--	--	--	I11
8.0-23.0	--	--	--	--	--	--	--	I12
5.2-20.2	--	--	--	--	--	--	--	I13
6.0-11.0	5.0-13.0	3.0- 5.0	2.0- 3.0	1	6	0.2	H	I14
17.0-22.0	15.0-30.0	12.0-15.0	3.0-12.0	2	8	3.0	H	I15
43.0-53.0	40.2-61.0	39.1-40.2	2.5-39.1	10	9	2.8	S	I16A
6.0-11.0	5.0-15.0	--	2.5- 5.0	3	10	1.1	H	I16B
8.0-18.0	5.4-26.5	4.3- 5.4	2.5- 4.3	1	7	1.0	H	I17
5.0-10.0	3.5-25.0	0 - 3.0	2.0- 3.0	1.5	4	1.2	H	I18
14.0-19.0	12.5-27.0	9.5-12.5	3.0- 9.5	2	10	1.7	H	I19
14.0-19.0	13.0-30.0	11.0-13.1	2.5-11.0	1	8	1.2	H	I20A
--	--	--	--	--	--	--	--	I20T
10.0-15.0	8.0-20.0	5.0- 8.0	2.5- 5.0	10	6	.5	S	I21
55.0-65.0	52.6-67.0	51.7-52.6	2.5-51.7	5	16	6.2	J	I22A
14.0-19.0	13.0-27.0	11.0-13.0	2.5-11.0	1.5	8	8.0	J	I22B
5.0-10.0	4.0-10.0	10.0-15.0	2.0- 4.0	1	6	4.9	A, H	I22C
15.0-20.0	13.0-30.0	11.0-13.0	2.5-11.0	1	8	.2	H	I23
4.0- 9.0	3.1-15.0	10.5-15.0	2.5- 3.1	.5	6	2.0	H	I24
13.0-18.0	12.0-30.0	10.0-12.0	2.5-10.0	1.5	5	.3	H	I25
25.0-30.0	23.9-45.0	20.0-23.9	2.5-20.0	2	5	4.5	H	I26A
9.0-14.0	8.0-15.0	6.1- 8.0	2.5- 6.1	2	4	4.5	H	I26B
52.7-62.7	50.3-65.0	48.0-50.3	2.0-48.0	2	18	5.3	A, S	I27A
3.0- 8.0	2.5-17.0	--	0 - 2.5	1	8	1.0	H	I27B
6.0-11.0	4.0-17.0	2.5- 4.0	2.0- 2.5	.5	6	2.0	H	I28
5.0-10.0	4.5-10.0	10.6-15.3	2.5- 4.5	1	8	1.3	H	I29
10.0-15.0	8.0-25.0	6.0- 8.0	2.5- 6.0	1	8	.6	H	I30
10.0-15.0	9.0-27.0	7.0- 9.0	2.5- 7.0	1	8	1.5	H	I31A
--	--	--	--	--	--	--	--	I31T
11.0-16.0	9.0-25.0	7.0- 9.0	3.0- 7.0	.5	7	1.5	H	I32
19.5-24.5	17.0-25.0	15.5-17.0	3.0-15.5	5	3.5	1.5	H	I33
21.0-26.0	19.0-30.0	16.0-19.0	3.0-16.0	8	5	1.2	H	I34
20.0-25.0	18.0-25.0	16.5-18.0	3.0-16.5	.25	9	.7	H	I35
22.0-27.0	20.0-29.0	18.0-20.0	3.0-18.0	10+	5	1.0	H	I36
59.5-64.5	57.0-65.0	55.0-57.0	3.0-55.0	9	4	.9	S	I37A
16.0-21.0	14.0-27.0	12.0-14.0	3.0-12.0	5	8	8.3	H	I37B
14.0-19.0	9.0-20.0	4.0- 9.0	2.0- 4.0	.33	5.5	--	H	I38A
--	--	--	--	--	--	--	--	I38T
11.0-21.0	9.0-25.0	7.0- 9.0	3.0- 7.0	1.5	3.5	--	H	I39
14.0-19.0	12.0-20.0	10.0-20.0	3.0-10.0	.20	6	--	H	I40
7.0-12.0	5.0-15.0	3.5- 5.0	2.5- 3.5	2.5	3.5	2.3	H	I41
8.0-13.0	6.1-15.0	4.2- 6.1	2.5- 4.2	1.5	4	1.0	H	I42
5.0-10.0	4.0-15.0	3.0- 4.0	2.0- 3.0	.5	4	.2	H	I43
9.0-14.0	6.9-15.0	5.4- 6.9	2.5- 5.4	.5	6	1.0	H	I44
9.0-14.0	7.0-20.0	5.5- 7.0	2.5- 5.5	1.5	8	5.9	H	I45
12.0-17.0	7.0-20.0	5.0- 7.0	2.5- 5.0	1.0	16	6.7	H	I46
5.0-10.0	4.0-15.0	--	2.5- 4.0	--	16	1.9	H	I47A
60.6-65.6	58.8-67.0	56.0-58.8	2.5-56.0	15	14	2.4	S	I47B
--	--	--	--	--	--	--	--	I47T
5.0-10.0	4.0-15.0	0 - 2.0	2.0- 4.0	1.5	10	2.5	H	I48
5.0-10.0	4.0-15.0	--	2.0- 4.0	.5	16	2.7	H	I49
14.0-19.0	12.0-20.0	8.0-12.0	2.5- 8.0	2.5	12	3.4	S	I50A
--	--	--	--	--	--	--	--	I50T
4.0- 9.0	3.5-15.0	2.5- 3.5	2.0- 2.5	1.5	0	2.1	H	I51
6.0-11.0	4.0-25.0	2.5- 4.0	2.0- 2.5	1	8	10.6	H	I52
5.0-10.0	4.5-15.0	3.5- 4.5	2.5- 3.5	1	4	8.6	H	I53
4.0- 9.0	3.5-15.0	2.5- 3.5	2.0- 2.5	1	8	5.2	H	I54A
49.0-59.0	47.0-59.0	45.0-47.0	3.0-45.0	7	8	17.3	S	I54B

Table 6.--Description of observation wells and test holes on Graces Quarters

[Driller: U.S. Army Corps of Engineers; method of construction: bored; Use of water: none; latitude and longitude: degrees (o), minutes ('), and seconds ("); (depths are measured from land surface datum, altitude is elevation of the land surface in reference to sea level). Type of pump: H = hand, S = submersible. Missing data are represented by dashes (--). NR denotes "not recorded". ft = feet]

Well no.	USGS Well no.	Latitude (o,',")	Longitude (o,',")	Altitude (ft)	Date of completion	Depth of well (ft)	Depth of hole (ft)	Diameter of screen casing (in.)	Aquifer
Q01	BA Eg 155	392106	762035	30.14	1977	22.3	--	2	surficial
Q02	BA Eg 200	392105	762029	37.19	1977	28.0	--	2	surficial
Q03	BA Eg 201	392100	762028	35.26	1977	30.0	--	2	surficial
Q04	--	--	--	--	1977	26.0	--	2	surficial
Q05	BA Eg 157	392054	762039	11.68	1977	22.0	--	2	surficial
Q06	BA Eg 204	392103	762053	7.00	1977	23.5	--	2	surficial
Q07	BA Eg 205	392107	762034	25.93	04-13-88	29.0	35.0	4	surficial
Q08	BA Eg 206	392104	762032	37.47	04-12-88	20.0	26.5	4	surficial
Q09A	BA Eg 207	392103	762029	35.88	04-12-88	25.0	25.0	4	surficial
Q09B	BA Eg 208	392103	762029	36.23	04-20-88	150.0	181.0	4	confined
Q09T	BA Eg 159	392103	762029	--	01-21-88	--	181.0	--	--
Q10	BA Eg 209	392101	762033	27.48	04-12-88	31.0	49.5	4	surficial
Q11	BA Eg 210	392059	762035	20.76	04-15-88	33.0	35.0	4	surficial
Q12	BA Eg 211	392058	762031	20.24	04-19-88	30.0	80.0	4	surficial
Q13	BA Eg 161	392102	762028	37.36	04-19-88	43.0	60.0	4	surficial
Q14	BA Eg 213	392051	762029	11.08	04-21-88	30.0	40.0	4	surficial
Q15	BA Eg 214	392045	762017	11.61	04-22-88	22.0	25.0	4	surficial
Q16A	BA Eg 162	392047	762024	12.09	NR	87.3	98.0	4	confined
Q16B	BA Eg 163	392047	762024	11.99	04-25-88	30.0	30.0	4	surficial
Q16T	BA Eg 164	392047	762024	--	02-05-88	--	176.0	--	--
Q17	BA Eg 217	392056	762038	14.08	04-15-88	14.0	19.5	4	surficial
Q18A	BA Eg 165	392054	762045	8.36	04-19-88	20.0	25.0	4	surficial
Q18B	BA Eg 166	392054	762045	8.11	04-19-88	75.0	86.0	4	confined
Q18T	BA Eg 167	392054	762045	--	12-10-87	--	142.0	--	--
Q19A	BA Eg 168	392113	762048	40.84	04-20-88	169.0	175.0	4	confined
Q19T	BA Eg 169	392113	762048	--	12-07-87	--	175.0	--	--
Q20A	BA Eg 172	392041	762050	10.17	02-03-88	90.0	120.0	4	confined
Q20B	BA Eg 171	392041	762050	10.59	04-19-88	24.0	25.0	4	surficial
Q20T	BA Eg 170	392041	762050	--	01-30-88	--	25.0	--	--
Q21	BA Eg 223	392056	762030	22.82	04-19-88	18.0	32.0	4	surficial
Q22	BA Eg 224	392102	762038	33.77	04-13-88	20.0	21.5	4	surficial
Q23	BA Eg 225	392050	762021	29.09	04-21-88	20.0	25.0	4	surficial
Q24	BA Eg 226	392051	762020	28.03	04-21-88	21.0	25.0	4	surficial
Q25	BA Eg 227	392049	762019	33.05	04-21-88	27.0	35.0	4	surficial
Q26	BA Eg 228	392043	762016	3.33	04-22-88	17.0	20.0	4	surficial
Q27	BA Eg 229	392043	762014	6.77	04-22-88	13.0	20.0	4	surficial
Q28	BA Eg 230	392042	762015	5.22	04-13-88	20.0	44.0	4	surficial

Screen (ft)	Sand pack (ft)	Bentonite seal (ft)	Grout (ft)	Pumping rate (gal/min)	Hours pumped	Type of pump	Remarks	Aquifer
7.3- 22.3	--	--	--	--	--	--	--	Q01
8.0- 28.0	--	--	--	--	--	--	--	Q02
10.0- 30.0	--	--	--	--	--	--	--	Q03
5.9- 25.9	--	--	--	--	--	--	Not located	Q04
7.0- 22.0	--	--	--	--	--	--	--	Q05
8.5- 23.5	--	--	--	--	--	--	--	Q06
14.0- 24.0	11.6- 35.0	9.3- 11.6	3.0- 9.3	--	--	H	5-ft sump	Q07
5.0- 15.0	3.8- 26.5	0 - 3.8	--	--	--	H	Shelby/5-ft sump	Q08
5.0- 20.0	4.0- 25.0	0 - 4.0	--	--	--	H	5-ft sump	Q09A
140.0-150.0	120.0-151.0	117.0-120.0	4.0-117.0	4.5	4.0	S	--	Q09B
--	--	--	--	--	--	--	Test hole	Q09T
21.0- 31.0	18.2- 31.6	16.4- 18.2	3.0- 16.4	.8	4.0	H	Shelby	Q10
18.0- 28.0	15.1- 35.0	13.4- 15.1	3.0- 13.4	--	2.0	H	5-ft sump	Q11
20.0- 30.0	16.8- 80.0	15.3- 16.8	3.0- 15.3	1.0	4.0	H	--	Q12
33.0- 43.0	29.6- 60.0	28.2- 29.6	3.0- 28.2	--	2.0	H	--	Q13
20.0- 30.0	15.0- 40.0	12.0- 15.0	3.0- 12.0	1.0	2.0	H	--	Q14
17.0- 22.0	16.0- 25.0	14.0- 16.0	3.0- 14.0	--	1.0	H	--	Q15
77.3- 87.3	73.8- 98.0	72.4- 73.8	3.0- 72.4	--	--	--	--	Q16B
5.0- 20.0	3.0- 30.0	0 - 3.0	30.0-175.0	6.0	4.0	S	10-ft sump	Q16A
--	--	--	--	--	--	--	Test hole	Q16T
9.0- 14.0	7.0- 19.5	5.0- 7.0	2.5- 5.0	--	1.0	H	--	Q17
10.0- 20.0	9.0- 25.0	7.0- 9.0	3.0- 7.0	--	1.5	H	--	Q18A
65.0- 75.0	61.4- 80.5	59.0- 61.4	3.0- 59.0	5.0	3.0	S	--	Q18B
--	--	--	--	--	--	--	Test hole	Q18T
159.0-169.0	155.3-175.0	153.8-155.3	5.0-153.8	4.0	3.0	S	--	Q19A
--	--	--	--	--	--	--	Test hole	Q19T
80.0- 90.0	76.8-101.2	75.2- 76.8	3.0- 75.2	6.5	3.0	H	--	Q20B
4.0- 14.0	2.2- 25.0	0 - 2.2	--	--	--	--	--	Q20A
--	--	--	--	--	--	--	Test hole	Q20T
8.0- 18.0	5.3- 32.0	4.1- 5.3	2.0- 4.1	--	1.0	H	Shelby	Q21
5.0- 15.0	3.0- 21.5	0 - 3.0	--	.1	3.0	H	Shelby/5-ft sump	Q22
10.0- 20.0	8.1- 25.0	6.9- 8.1	3.0- 6.9	NR	< .1	H	--	Q23
11.0- 21.0	8.7- 25.0	7.2- 8.7	3.0- 7.2	NR	< .1	H	--	Q24
17.0- 27.0	14.6- 35.0	13.3- 14.6	3.0- 13.3	NR	< .1	H	--	Q25
12.0- 17.0	10.0- 20.0	8.0- 10.0	3.0- 8.0	.1	2.0	H	--	Q26
8.0- 13.0	6.0- 20.0	4.0- 6.0	2.0- 4.0	.1	2.0	H	--	Q27
15.0- 20.0	14.0- 20.0	12.0- 14.0	3.0- 12.0	< .1	3.0	H	--	Q28

The potential for contaminant migration by transport of contaminated soils depends on the physical setting of the respective SWMU's and chemical-agent test area. Carroll Island is topographically flat, and there is little potential for soil erosion except along the shoreline. Graces Quarters exhibits more relief than Carroll Island, so there is more possibility for soil erosion.

Migration of contaminants through the soil is a potential problem on both Carroll Island and Graces Quarters. Much of the chemical-agent testing involved release of chemical materials onto the land surface, and disposal practices in some areas could have caused release of contaminants into the soil. Contaminants in these cases could potentially migrate laterally within the soil zone or vertically through the soil zone, or they could adsorb onto soil particles and remain relatively stationary. The migration of contaminants in the soil is governed by the chemical properties of the contaminant, soil chemistry, hydraulic properties, and site hydrology and meteorology. Soil sampling will be done to verify whether or not there is contamination in the soils. Biased samples will be taken from the SWMU's and test areas to address this medium.

Contaminant migration through the ground-water system is a concern for the majority of the SWMU's and chemical agent test areas on both Carroll Island and Graces Quarters. Releases can enter the ground-water system from SWMU's that are in direct hydrologic contact with the ground water or by percolating through the soil zone. Contaminated ground water could then discharge to adjacent surface-water bodies, which are used for recreational sports, or migrate to deeper aquifers that are used for domestic and industrial water supply. Characterization of releases to the ground-water system is being accomplished by sampling of observation wells.

There is some potential for migration of contaminants in the surface water. There are no perennial streams on either Carroll Island or Graces Quarters, but surface water does occur in ponds, ditches, wetlands, and sumps with the study areas. Runoff has been observed at Graces Quarters during storm events, and surface water is more common on both areas during storms and in the winter and spring months. Both areas are surrounded on at least three sides by the surface water of the Chesapeake Bay and associated estuaries.

Surface-water sampling was done to assess the contamination within this medium. Samples were taken from each of the surface-water environments described above. The location and technical rationale of sample sites is presented later in this report.

There is little potential for migration of contaminants through the air at Carroll Island and Graces Quarters. There is no indication from historical records of bulk disposal of chemicals at either site, and the last chemical-agent testing was done in 1971. It is therefore unlikely that significant contamination currently is being released to the air.

Air samples were collected during the drilling operations and during several other sampling activities that were performed during this study. These data will be presented in the HGA reports.

The methods of investigation to verify releases in the study areas include (a) data review, (b) implementation of an observation-well network, (c) sample collection, and (d) interpretation and comparison of data to background and regulatory standards. All data collected for this objective will be presented in the HGA reports.

The data review provides information to characterize the types of waste tested or disposed on Carroll Island and Graces Quarters and evaluates the previous environmental sampling. Waste characterization traditionally includes direct sampling of the waste; however, this is not practical due to the time that has elapsed since testing, the extremely toxic nature of chemical-warfare agents, and the explosive characteristics of possible unexploded munitions. Therefore, waste characterization will consist of written descriptions of the materials and their potential by-products. Moreover, the study is focusing on potential migration pathways since the waste cannot be directly sampled.

The types of materials tested or released at Carroll Island and Graces Quarters includes chemical-warfare agents and their associated decontamination agents, solvents and petroleum products, herbicides, and insecticides. The general chemical characteristics and environmental fate of these materials are discussed below. This information is presented to provide technical rationale for the selection of analytical compounds.

The types of chemical-warfare agents tested included blister, nerve, incapacitating, riot control, and smokes. The principal blister agent tested was mustard. Mustard is an oily liquid with a garlic or horseradish odor. The abbreviation for undistilled mustard is H and distilled mustard is referred to as HD. Variations of mustard include nitrogen mustard and mustard that contains arsenic in its structure such as Lewisite (L). The chemical name for HD is vesicant dichlorodiethyl sulfide. Distilled mustard contains at least 90 percent pure product. Undistilled mustard is typically 65-80 percent pure with the remaining percentage consisting of sulfur and polysulfides (U.S. Departments of the Army and Air Force, 1975). The persistence of HD depends upon the munition used and the weather. Heavily splashed liquid persists 1 to 2 days in original concentrations under average weather conditions, and a week to months under cold conditions (U.S. Departments of the Army and Air Force, 1975, p. 3-9). The solubility of HD in water is very low; however, once in solution it degrades to thiodiglycol, $(CH_2CH_2OH)_2S$ (Nemeth and others, 1983, p. 58). Mustard is decontaminated with STB, fire, or DS-2. Decontamination of mustard can produce several byproducts, including sulfate, chloride, chlorinated ethanes and ethylenes, divinyl sulfide, 1,4-dithiane and 1,4-thioxane (Nemeth, 1989, p. 185-187).

Nerve agents tested in the study areas include GA, GB, GD, and VX. These agents are organophosphorus compounds similar to pesticides such as parathion and malathion (Nemeth and others, 1983, p. 67). The agents persist for 1 to 2 days under average weather conditions and all are soluble in water and are degraded by hydrolysis (U.S. Departments of the Army and Air Force, 1975, p. 3-3 to 3-5). The principal hydrolysis products of the G-agents are hydrogen fluoride (HF), hydrogen cyanide (HCN), and isopropylmethyl phosphonic acid (IMPA). Hydrolysis products of VX include diethyl methylphosphonate, 2-diisopropylaminoethyl mercaptan, ethyl hydrogen methylphosphonate, bis S-(2-diisopropylaminoethyl), and methylphosphonodithioate.

The incapacitating agent tested was BZ. The chemical name for BZ is 3-quinuclidinyl benzilate. This agent has a half life of 3 to 4 weeks in water at 25 °C (degrees Celsius) and a pH of 7 (U.S. Departments of the Army and Air Force, 1975, p. 3-16). Hydrolysis products include 3-quinuclidinol and benzilic acid.

The riot control agents used included adamsite (DM), CN, and CS. All three materials are solids that vaporize when heated and then condense to form aerosols. The chemical name for adamsite is diphenylamino-chloroarsine. Hydrolysis is rapid in aerosol form but when solid adamsite is covered with water, a protective oxide coating is formed hindering further hydrolysis (U.S. Departments of the Army and Air Force, 1975, p. 3-16). Hydrolysis products are diphenylarsenious oxide and hydrogen chloride. The chemical name for CN is chloroacetophenone. Hydrolysis of CN is rapid when in aerosol form with the principal product being hydrogen chloride. The agent CS has a chemical name of O-chlorobenzylidene malononitrile. The hydrolosis products include O-chlorobenaldehyde and malononitrile.

Other materials tested at Carroll Island and Graces Quarters are smokes, which included WP, TEA, and FS. White phosphorous is used as a smoke and an incendiary. It burns when oxidized and the primary oxidation product is phosphorus pentoxide. The compound TEA has a chemical name of triethylaluminum and is used mostly as pyrophoric agent. The smoke FS has a chemical name of sulfur trioxide-chlorosulfonic acid. The hydrolysis is instantaneous, and products include sulfuric acid and hydrogen chloride.

The various decontaminating agents employed after chemical-agent testing include HTH, STB, sodium hydroxide, DANC, DS-2, and carbon tetrachloride. Calcium hypochlorite (HTH) and STB are chlorinating agents used to decontaminate mustard, Lewisite, and nerve agents. When introduced to the environment these chlorinating agents react and yield calcium, chloride, and hydroxide (Nemeth, 1989, p. 177). Sodium hydroxide or caustic soda (NaOH) is one of the most commonly used decontaminating agents and is highly soluble in water. The environmental persistence of these inorganic materials is expected to be short-term (Nemeth, 1989, p. 177). Both DANC and DS-2 are organic-based compounds. The DANC was an organic-based N-chloroamide compound solution with 1,1,2,2-tetrachloroethane. In the environment, the N-chloroamide degrades to an amide but the other compound persists (Nemeth, 1989, p. 178). The decontaminant DS-2 was developed around 1960, and contains diethylenetriamine, 2-methoxyethanol, and sodium hydroxide (Nemeth, 1989, p. 178). The carbon tetrachloride was mixed with chlorine and used to decontaminate mustard. These organic compounds could be persistent in the environment.

Insecticides that were mixed with fuel oil were applied to the study areas each summer from 1959 to 1971 (Ward, 1971, p. 24). Malathion, which is an organophosphate based compound, was used from 1959 to 1969. Dibrom 14, which is a chlorinated compound, was used after 1969. In general, the organophosphorus insecticides have a relatively rapid chemical and biological degradation, making them among the least environmentally persistent pesticides (Smith and others, 1988, p. 37). However, Dibrom 14 could be more persistent than the others because it is halogenated.

The herbicide Telvar was used on Carroll Island to control foliage near Test grid 1 (Ward, 1971, p. 25). The active ingredient is monuron, which is a generic name for 3-(para-chlorophenyl)-1,1-dimethylurea. In general, chlorinated herbicides, such as Telvar, are characterized by high solubilities and low vapor pressures and, as a result, do not bioaccumulate or sorb to sediments (Smith and others, 1988, p. 39).

Solvents and petroleum products were used at both study areas. Solvents were used for equipment maintenance and cleaning, while petroleum products were used as additive mixtures for some of the testing and decontamination practices. Chlorinated-aliphatic and aromatic hydrocarbons are the principal compounds associated with these materials. Aliphatic hydrocarbons are straight-chain molecules composed of only hydrogen and carbon. To form chlorinated aliphatics, chloride replaces one or more of the hydrogen atoms in the structure. The structure of the aromatic compounds is characterized by a benzene ring. Benzene consists of a cyclic arrangement of six carbon atoms with a single hydrogen bond bound to each carbon. One or more of the hydrogen atoms can be replaced in the ring to form other monocyclic aromatic compounds, such as toluene and chlorobenzene. In general, these compounds have high solubilities and volatility and low sorption capacity (Smith and others, 1988, p. 55).

Ground-water, surface-water, bottom sediment, and soil samples were collected and analyzed as part of the USATHAMA environmental survey performed in 1977 and 1978. On Carroll Island, 13 ground-water samples, 8 surface-water samples, 7 bottom-sediment samples, and 2 soil samples were collected. On Graces Quarters, five ground-water samples, three surface-water samples, three bottom-sediment samples, and one soil sample were collected. The samples were analyzed for general chemical quality and for volatile and semivolatile organic compounds.

Nemeth and others (1983) stated that the high concentrations of some indicator compounds such as total organic carbon (TOC), chloride, and iron, as well as the presence of volatile-organic compounds, suggest that there is some ground-water contamination on both Carroll Island and Graces Quarters. On Carroll Island the most significant finding was the 4,600 μg/L (micrograms per liter) level of methylene chloride in the sample from well I05 (table 7). Other chlorinated hydrocarbons were detected in the ground water near test grid 1 on Carroll Island (table 7). On Graces Quarters, chloroform and trichlorofluromethane were detected in the ground water (table 7). Most of these compounds were detected in wells near the Graces Quarters disposal area.

Nemeth (1989, p. 225-238) reviewed the ground-water quality data collected in 1977 and 1978 as part of the RFA work. Several of the organic compounds detected in the ground-water samples from Carroll Island and Graces Quarters could be caused by laboratory contamination. The laboratory blanks contained chloroform, trichloroethylene, tetrachloroethylene, and trichlorofluoromethane indicating possible laboratory contamination. Nemeth concluded these compounds might not be in the ground water but were detected in the samples where historical information suggested contamination was likely.

The surface-water analyses did not indicate any concentrations of organic compounds above drinking water standards at either Carroll Island or Graces Quarters (Nemeth and others, 1983, p. 3-89 to 3-112).

Two soil samples collected near well sites I01 and I02 in the aerial spray grid on Carroll Island were analyzed for semivolatile compounds. Nemeth (1989, p. 232-233) summarized the results of this sampling. One sample (I02) contained part-per-million levels of hydrocarbons. Other compounds were present in the samples, but at concentrations below 100 parts-per-billion. Both samples contained naphthalene compounds, and sample I01 contained chlorinated biphenyl compounds. A shallow soil sample was collected from a site near well Q05 on Graces Quarters, and naphthalene, and chlorinated biphenyl compounds were detected (Nemeth, 1989, p. 237).

The second method of investigation for verifying releases is with an observation-well network that was designed to detect releases from SWMU's and to detect the presence of previous releases at chemical-agent test areas. Well locations were selected according to the historical use of each unit, the likely ground-water-flow direction, and the results of an electromagnetic survey conducted at both study areas. Detailed rationale for the location and screen depth of each observation well is presented in the study approaches for individual sites.

Well-placement strategy was based on having at least three wells in the surficial aquifer at each SWMU to assess ground-water quality and determine flow direction. One well was placed in the perceived upgradient direction, with the remaining wells placed downgradient. The selection of well locations was determined from topography, water-level data presented in the USATHAMA study (Nemeth and others, 1983), and water-level measurements obtained from the

Table 7.--Volatile-organic compounds detected in ground water at Carroll Island and Graces Quarters, 1977 and 1978

[µg/L, *micrograms per liter; --, data not available; sampling and analysis performed by U.S. Army Toxic and Hazarardous Materials Agency, 1977*]

Volatile-organic compounds	*Carroll Island concentration,* in µ*g/L*	*(well)*	*Graces Quarters concentration, in* µ*g/L*	(well)
benzene	250	(I05)	6	(Q04)
carbon tetrachloride	1	(I13)	--	
chloroform	32	(I03)	24	(Q01)
	27	(I09)	1,130	(Q02)
	34	(I10)	100	(Q02)
	--		46	(Q01)
1,1-dichoroethylene	--		4	(Q01)
			4	(Q06)
methylene chloride	6	(I01)	--	
	2	(I03)		
	4,600	(I05)		
	9	(I07)		
	6	(I10)		
	13	(109)		
tetrachloroethylene	6	(I03)		
	13	(I09)		
	16	(I10)		
toluene	--		30	(Q04)
trichloroethylene	10	(I03)	--	
	5	(I09)		
	12	(I10)		
trichlorofluoromethane	118	(I03)	77	(Q01)
	40	(I09)		
	180	(I12)	530	(Q02)
	5	(I13)	85	(Q06)

existing USATHAMA wells. Wells were installed at the perimeter of the SWMU's. Well screens were placed near the top of the surficial aquifer in the most transmissive material to aid in immediate detection of releases to ground water. Most well screens were placed below the water-table surface in order for the wells to be useful for hydrologic testing.

Observation wells at the chemical-agent test areas were located at the most likely area of contamination, which is near the middle of the test areas or in the downgradient direction. These sites were used for testing, not disposal; therefore, active releases are not likely and only residual contamination from past releases is suspected.

Observation wells also were installed in the confined aquifers underlying Carroll Island and Graces Quarters. These wells were installed to determine if contamination from the surficial aquifer had migrated vertically, and to obtain an areal characterization of the confined aquifer.

The observation-well system is designed to characterize the background water quality of the surficial and confined aquifers at both study areas and also detect releases from individual units. Determination of the background water quality is complicated by several factors including: (1) ground-water flow directions in the surficial aquifer on Carroll Island are variable and sometimes reverse; (2) the surficial aquifer on Graces Quarters is discontinuous; (3) background water-quality samples at individual SWMU's and chemical-agent test sites could be affected by releases from other sites that are upgradient; and (4) naturally occurring geochemical processes such as brackish-water intrusion and water-sediment interactions might influence the constituents in the ground water.

Several methods will be used to determine background water quality. The initial method will involve interpreting the chemical data to characterize ground-water quality underlying Carroll Island and Graces Quarters. The presence of volatile or semivolatile organic compounds will aid in identifying contaminated versus background water quality. Another method will consist of using the chemical data from known upgradient (background) wells and compare these data to wells at other sites that might be influenced by migration of contaminated ground water from an adjacent site. For example, data from the upgradient well (I53) at the Bengies Point Road dump could be compared to data collected at test grid 1 where upgradient wells might not represent background water quality. Lastly, data collected at Carroll Island and Graces Quarters will be compared to data from off-site wells in the same aquifer. Potential areas for off-site data include several areas on Aberdeen Proving Ground (O-Field, J-Field, and Canal Creek) and domestic wells near Carroll Island and Graces Quarters.

The third task for verifying releases is sample collection. Data are being collected to characterize the ground water, surface water, bottom sediment, and soil. The general strategy for each of these media will be discussed. This will include rationale for sample location, frequency, and analytical compounds. The location and frequency of samples to be collected at each site is discussed under study approaches for individual sites.

All wells have been sampled twice to verify releases to the ground-water system. Conducting only two sampling episodes for the initial characterization of ground-water quality was agreed upon during the project planning meetings between the USEPA, the U.S. Army, and the U.S. Geological Survey. The two sampling episodes are intended to characterize seasonal variations (wet and dry season). The dry season sampling was conducted from July through September 1988. The wet season sampling was conducted during April and May 1989. The methods of sample collection are described in Appendix IV.

Surface water on and near Carroll Island and Graces Quarters is present in ponds, sumps, ditches, wetlands, and estuaries. There are no streams in the study areas. The study areas are surrounded by the surface-water bodies of the Chesapeake Bay and associated tributaries, which are tidally influenced and brackish. The environmental setting makes it difficult to characterize the surface-water quality. For example, from about December to May, water levels in the wetlands are above land surface and some ponding is present in low-lying areas, depressions, or ditches. However, these areas are relatively dry the remainder of the year. Moreover, the tidally influenced surface-water bodies are so dynamic that characterization of a release into this media could be technically impractical. With these limitations, the general strategy is to sample the surface water in the "wet and dry seasons." The sampling was biased towards ponds, sumps, drainage ditches, and marshes near SWMU's and primary test areas. Samples also were collected in the adjacent estuaries, but these probably will only be useful for general water quality because of the dynamic flow factors. The dry season sampling was conducted in October 1988. Many of the sites in the ditches or wetlands were dry, which limited sampling to several ponds and sumps, sluice pipes draining the marshes, and the adjacent surface-water bodies. The wet-season sampling was conducted in April and May 1989. Sites near the SMWU's and test areas that contain water were sampled in addition to the sites sampled during the dry season. The methods of sample collection are described in Appendix IV. The background water quality of the surface water will be determined by the same methods discussed for ground water.

The classification of the sediment in the study areas is complicated by intermittent appearance of water in the study area. For example, the drainage ditches or ponded areas that are exposed in the dry season could be called soils but also could be considered bottom sediments when submerged during the wet season. For purposes of this discussion, bottom sediments include those underlying surface-water bodies, permanently ponded areas, and marshes. Soils are defined as near-surface materials (less than 2 ft in depth) that are present in the rest of the study area including ditches that could be partially submerged during the wet season.

Sediment samples from the marshes or surface-water bodies adjacent to SWMU's and test areas could help characterize releases. One round of sampling is planned. Grab samples from the shallow horizon (upper 6 in.) will be collected. The proposed locations are discussed later in the document. These samples will be collected upon completion of a detailed safety and sample methods plan that is being prepared by the U.S. Army and U.S. Geological Survey. Potential unexploded munitions at the sampling sites precludes sampling until this plan is completed. Background chemical quality of soil and bottom-sediment samples will be determined using the same methods discussed for ground water.

Analytical compounds were selected for characterizing releases in the study areas. The technical rationale for parameter selection included reviewing the type of materials tested and disposed, identifying their chemical composition and potential degradation products, and reviewing the existing chemical data from the USATHAMA study (Nemeth and others, 1983). The information from these approaches was discussed previously. Most SWMU's and chemical-agent test sites had a mixture of materials disposed or tested. Additionally, information on practices prior to 1964 are incomplete, so the type of materials used then are not completely known. Therefore, selection of only a few indicator compounds to characterize releases is not adequate. Consequently, a fairly complete set of chemical compounds is needed to characterize potential releases. The selection of analytical compounds for ground water, surface water, soil, and bottom sediment is discussed.

Potential releases to ground water include degradation products of chemical-warfare agents and associated decontaminating agents. Initial sampling of all wells, conducted in the summer of 1988, included RCRA ground-water indicator compounds (table 8) and the volatile-organic compounds listed under the USEPA priority pollutants (table 9). The indicator compounds included inorganic constituents that were analyzed to provide an assessment of general water quality, inorganic contamination from decontamination agents, and agent-degradation products. Other indicator compounds such as TOC and total organic halogen (TOX) provide data to indicate the presence of organic compounds. The volatile compounds listed in table 9 were chosen to provide verification of the results from the USATHAMA report (Nemeth and others, 1983) and also are the most likely compounds to be present based on the chemical properties of the original waste.

Table 8.--Ground-water indicator compounds analyzed

[µg/L, micrograms per liter; --, µg/L not used]

Ground-water indicator parameters	*Detection limit (µg/L)*
Bromide [1]	100.0
Calcium	10.0
Chloride	100.0
Cyanide [1]	10.0
Fluoride [1]	100.0
Iron	5.0
Magnesium	25.0
Manganese	2.0
Nitrate [1]	10.0
Nitrite [1]	10.0
Phosphorus	20.0
pH	--
Silica	10.0
Sodium	30.0
Specific Conductance	--
Sulfate	100.0
Total Organic Carbon (TOC)	100.0
Total Organic Halogen (TOX)	20.0
Total Phenols	5.0

[1] These constituents were not analyzed during summer of 1988 but were analyzed during the spring of 1989.

Gary Nemeth (U.S. Army Environmental Hygiene Agency, written commun., 1988) and the USEPA recommended that more chemical compounds be included in the spring 1989 sampling to provide a more detailed characterization of potential releases. The additional analytical compounds include inorganic and organic compounds listed by USEPA as priority pollutants. The inorganic

Table 9.--Volatile-organic compounds analyzed in water and soil and bottom sediments

[*µg/L, micrograms per liter, µg/g, micrograms per gram*]

Compound	*Detection limit*	
	Water (µg/L)	*Soil (µg/g)*
Benzene	4.0	0.40
Bromodichloromethane	2.0	.20
Bromoform	5.0	.50
Carbon Tetrachloride	2.0	.20
Chlorobenzene	5.0	.50
Chloroethane	10.0	1.00
2-Chloroethylvinyl ether	10.0	1.00
Chloroform	2.0	.20
Chloromethane	10.0	1.00
Dibromochloromethane	3.0	.30
1,2-Dichlorobenzene	10.0	1.00
1,3-Dichlorobenzene	10.0	1.00
1,4-Dichlorobenzene	10.0	1.00
1,1-Dichloroethane	2.0	.20
1,2-Dichloroethane	2.0	.20
1,2-Dichloropropane	5.0	.50
1,3-Dichloropropane	5.0	.50
Ethylbenzene	5.0	.50
Methylene Chloride	3.0	.30
1,1,2,2-Tetrachloroethane	5.0	.50
Toluene	5.0	.50
1,1,1-Trichloroethane	5.0	.50
1,1,2-Trichloroethane	4.0	.40
Trichloroethane	2.0	.20
Trichlorofluoromethane	2.0	.20
Vinyl Chloride	2.0	.20
1,1-Dichloroethane	2.0	.20
1,2-Dichloroethane	2.0	.20
Tetrachloroethane	4.0	.40

constituents (table 8) include fluoride and arsenic that are degradation products of nerve agents and lewisite, respectively. Bromide data will be used to compare bromide-to-chloride ratios to delineate brackish water from potential contaminant sources. Trace metals listed in table 10 were analyzed to provide data to compare to regulatory standards. Selected semivolatile compounds (table 11) were analyzed to detect the presence of solvents, petroleum products, herbicides, or insecticides and chemical-agent degradation products.

Table 10.--Metals analyzed in water samples

[µg/L, micrograms per liter]

Metal	*Detection limit* (µg/L)
Antimony	30.0
Aluminum	45.0
Arsenic	1.0
Barium	2.0
Beryllium	0.5
Cadmium	2.5
Chromium	5.0
Copper	2.0
Lead	1.0
Mercury	.1
Nickel	15.0
Potassium	25.0
Selenium	75.0
Silver	5.0
Thallium	40.0
Zinc	2.0

Surface-water samples were collected in October 1988 and analyzed for general water quality (table 12) and volatile compounds (table 9). The second round of surface-water samples were analyzed for the expanded list of compounds including metals (table 10) and semivolatile compounds (table 11). The expanded analysis will provide a more complete data set to evaluate potential releases to surface-water bodies.

Sediment and soils were collected during the USATHAMA study (Nemeth and others, 1983) and analyzed for semivolatiles. Trace amounts of some chlorinated and aromatic hydrocarbons were detected. Proposed analytical compounds for soil and bottom sediments include major ions and trace metals (table 13), and volatile and semivolatile compounds (tables 9 and 11).

The mineralogy of selected aquifer material, soil, and bottom sediment will be determined to identify minerals that could effect background water quality and contaminant migration. Mineralogy of the sediments will be determined by x-ray diffraction for fine-grained material, petrographic analysis for coarse-grained sediments, and whole rock analysis.

The next task for verification of releases is comparison of data to health and regulatory-based standards. All chemical data will be compiled and background concentrations will be determined. The methods to determine background concentrations for organic compounds and inorganic constituents was previously discussed under observation-well design. The background concentrations will be used as criteria to determine if contamination is present and if phase II of the investigation is needed. Background concentrations for organic compounds will be assumed to be the detection limits for the compound. However, detection of some organic compounds that could be due to well construction, sample contamination, or

Table 11.--Semivolatile-organic compounds analyzed in water and soil and bottom sediments

[µg/L, micrograms per liter, µg/g, micrograms per gram]

Compound	*Detection limit* Water (µg/L)	Soil (µg/g)
Acenapthene	2.0	0.20
Acenapthylene	2.0	.20
Anthracene	2.0	.20
Aldrin	2.0	.20
Benzo (a) anthracene	8.0	.80
Benzo (b) fluoranthene	5.0	.50
Benzo (k) fluoranthene	2.5	.25
Benzo (a) pyrene	2.5	.40
Benzo (ghi) perylene	4.0	.25
Benzo (a) phthalate	2.5	.30
Beta-BHC	3.0	.30
Alpha-BHC	3.0	.60
Bis (2-chloroethyl) ether	6.0	.60
Bis (2-chloroethoxy) methane	10.0	.10
Bis (2-ethylhexyl) phthalate	2.5	.25
4-Bromophenyl phenyl ester	1.9	.19
Chlordane	2.0	.20
2-Chloronaphthalene	10.0	1.00
4-Chlorophenyl phenyl ether	4.2	.42
Chrysene	2.5	.25
4,4'-DDD	3.0	.30
4,4'-DDE	3.0	.30
Delta BHC	3.0	.30
Lindane	3.0	.25
Dibenzo (a,h) anthracene	2.5	.20
Di-n-butylphthalate	2.0	.20
1,3-Dichlorobenzene	2.0	.20
1,2-Dichlorobenzene	2.0	.20
1,4-Dichlorobenzene	2.0	.20
1,3'-Dichlorobenzene	16.5	1.65
Dieldrin	2.0	.20
Diethyl phthalate	2.0	.20
Dimethyl phthalate	1.9	.19
Dithiane	2.0	.20
2,4-Dinitrotoluene	2.0	.20
2,6-Dinitrotoluene	2.0	.20
Di-n-octylphthalate	2.5	.25
Endosulfan sulfate	1.0	.10
Endrin	2.0	.20
Fluoranthene	2.0	.20
Heptachlor	2.0	.20

Table 11.--Semivolatile-organic compounds analyzed in water and soil and bottom sediments--Continued

[*μg/L, micrograms per liter, μg/g, micrograms per gram*]

Compound	*Detection limit* Water (μg/L)	Soil (μg/g)
Heptachlor epoxide	2.0	0.20
Hexachlorobutadiene	1.0	.10
Hexachloroethane	2.0	.20
Indeno (1,2,3,cd) pyrene	4.0	.40
Naphthalene	1.0	.10
Nitrobenzene-d5-s	1.0	.10
N-Nitrosodi-n-propylamine	10.0	1.00
PCB-1016	6.0	.60
PCB-1221	6.0	.60
PCB-1242	6.0	.60
PCB-1248	6.0	.60
PCB-1254	6.0	.60
PCB-1260	6.0	.60
Phenanthrene	5.0	.50
Pyrene	2.0	.20
1,2,4-Trichlorobenzene	10.0	.10
1-4-Oxathiane (Thioxane)	2.0	.20
Malathion	1.0	.10
p-Chlorophenylmethylsulfone	2.0	.20
p-Chlorophenylmethylsulfide	2.0	.20
p-Chlorophenylmethylsulfoxide	2.0	.20
Benzothiozole	2.5	2.50
Thiodiglycol	2.5	2.50

analytical contamination will be noted and not considered as an indication of contamination in the study area. In some cases, background concentrations of inorganic constituents could exceed a particular health or regulatory standard because of natural geochemical processes. These instances will be noted and explained.

The health and regulatory standards that the data will be compared to for ground and surface water are the maximum contaminant levels (MCL's). When MCL's are not available for a particular constituent, the other levels listed for the primary and secondary drinking water standards (U.S. Environmental Protection Agency, 1987a and 1987b) will be used. The criteria used for soil or bottom sediment are the risk specific doses (RSD's) (U.S. Environmental Protection Agency, 1987c, p. 8.9). The RSD's are environmental concentrations that correspond to cumulative lifetime cancer risks for particular carcinogens. A detailed comparison of concentrations to other regulatory standards is performed by USEPA as part of the Health and Environmental Assessment (HEA) (U.S. Environmental Protection Agency, 1987c, p. 8.1). The information from the HEA will be used to evaluate if an interim remedial action or a Corrective Measures Study is needed.

Table 12.--Surface-water indicator compounds analyzed

[µg/L, micrograms per liter; --, µg/L are not used]

Indicator constituent	*Detection limit (µg/L)*	*Indicator constituent*	*Detection limit (µg/L)*
Biochemical Oxygen Demand (BOD)	--	Sodium	30.0
Calcium	10.0	Specific Conductance	--
Chemical Oxygen Demand (COD)	--	Sulfate	100.0
Chloride	100.0	Suspended Solids	--
Magnesium	25.0	Total Solids	--
Nitrate	10.0	Total Organic Carbon (TOC)	100.0
Nitrite	10.0	Total Organic Halogen (TOX)	20.0
pH	--	Total Phenols	5.0
Salinity	--		

Table 13.--Soil and bottom sediment indicator compounds to be determined
[µg/g, micrograms per gram]

Indicator parameter	*Detection limit (µg/g)*	*Indicator parameter*	*Detection limit (µg/g)*
Antimony	0.5	Manganese	0.2
Arsenic	.3	Mercury	1.0
Boron	1.0	Phosphorus	2.0
Bromide	10.0	Selenium	1.0
Cadmium	.25	Silica	2.0
Calcium	1.0	Sodium	1.9
Chromium	.5	Sulfate	2.9
Chloride	10.0	Total Kjeldahl Nitrogen (TKN)	10.0
Copper	.2	Total Organic Carbon (TOC)	10.0
Iron	.5	Total Organic Halogen (TOX)	20.0
Lead	.1	Total Phenols	5.0
Magnesium	2.5	Zinc	.2

Phase II

If releases from various units are verified from the results of phase I, discussions between the USEPA and the U.S. Army will be held to determine the amount of work needed in phase II to address the releases. Tasks under phase II will probably include (a) additional drilling and sample collection at the contaminated sites; (b) modeling of the hydrogeologic system; (c) a preliminary identification of remedial alternatives, and (d) evaluation of the hydrogeologic effects of selected remedial action scenarios. If phase II work is required, a second study approach will be prepared to describe the work that will be done.

Study Approaches for Individual Sites at Carroll Island

The number of ground-water, surface-water, bottom-sediment, and soil samples to be collected at each site on Carroll Island is presented in table 14. The technical rationale for each site is explained below.

Lower Island Disposal Site

The Lower Island disposal site consists of burial pits and dump sites near the Chesapeake Bay and associated marshes (fig. 10). The greatest potential for contaminant movement from the area is at the marsh dump site where beach erosion could cause the introduction of waste materials into the water and sediment of the Chesapeake Bay (Nemeth, 1989, p. 476). Nemeth (1989, p. 476) also suggests other possible modes of contaminant migration, such as seepage of contaminated water from the marsh dump site or movement of contaminants from the disposal pits into the shallow ground-water system. Transport within the shallow ground-water system is likely to be toward the Chesapeake Bay or possibly downward toward deeper aquifers.

The surficial aquifer in this area consists of interbedded silt, sand, and silty clay to a depth of 25 ft below land surface. The entire area is underlain by a confining unit that is about 25 ft thick. A confined aquifer underlies the confining unit and is about 10 ft thick. The ground-water pathway is addressed by the observation-well network. All wells shown on figure 10 are screened in the surficial aquifer except for well I16B, which is screened in the confined aquifer. Screen depths are given in table 5. Wells I11, I12, and I13 were installed during the USATHAMA study (Nemeth and others, 1983); the remaining wells were installed as part of this study.

Ground-water flow directions in the surficial aquifer are generally south and east towards the Chesapeake Bay and the marshes. There are some gradient reversals, however, during periods of high evapotranspiration (July to October). Wells I13, I15, I16A, I17, I18, and I19 are located downgradient of disposal pits. Well I16A was located in the site of an electromagnetic induction (EM) anomaly. Wells I11, I12, and I14 are adjacent but not directly downgradient of the disposal pits. Well I20A is the upgradient well for this unit. Continuous water-level recorders were installed on wells I13 and I19 to measure tidal influences and gradient reversals at the site.

Ground-water samples were collected from all wells, except I11 and I13, in July and August 1988. Water from wells I11 and I13 had a large amount of suspended sediment, indicating broken well screens or improper well development. All wells (except I11) were sampled again in the spring of 1989.

The direct introduction of chemicals into surface water from beach erosion at this site is difficult to assess because of the tidal characteristics of the Chesapeake Bay. One surface-water sample was collected directly offshore from well I19 to determine if detectable levels of contamination were present in the bay. Additional surface-water sampling was conducted during the spring of 1989. This included the previously mentioned site, one site each in the southern and eastern marshes, and a sample from a disposal pit near well I18 to determine if contaminants are leaching from the material in the pit. Soil samples will be collected from the open pit and upgradient near well I20A. Bottom-sediment samples will be collected from the surface-water sites near well I19 and from the southern marsh.

Table 14.--Location and number of ground-water, surface-water, soil, and bottom-sediment samples to be collected at Carroll Island

[See the Glossary of Acronyms and Abbreviations for chemical names]

Site	*Ground water*	Surface water	Soil	Bottom sediment
Lower Island disposal site	10 wells I12, I13, I14, I15, I16A, I16B, I17, I18, I19, I20A	4	3	2
Bengies Point Road dump site	6 wells I50A, I51, I52, I53, I54A, I54B	4	2	1
EPG dump site	3 wells I41, I42, I43	2	1	1
BZ test burn pit	4 wells I01, I38A, I39, I40	2	1	0
Decontamination pits	3 wells I34, I35, I36	0	1	0
Test grid 1	10 wells I04, I05, I06, I07, I08, I09, I10, I31A, I37A, I37B	2	1	1
Aerial spray grid	4 wells I02, I03, I32, I33	1	2	0
Wind tunnel	4 wells I27A, I27B, I28, I29	1	1	1
Test grid 2	5 wells I22A, I22B, I22C, I23, I25	2	1	0
HD test area	2 wells I26A, I26B	0	1	0
Dredge spoil area	2 wells I45, I46	0	1	0
Service area	4 wells I47A, I47B, I48, I49	2	0	1
Magazine area	No wells	1	1	0
CS Test area	1 well I30	0	1	0
VX Test area	2 wells I21, I44	0	1	0
Area across from HD test site	1 well I24	0	1	0
Totals	61 wells	21	19	7

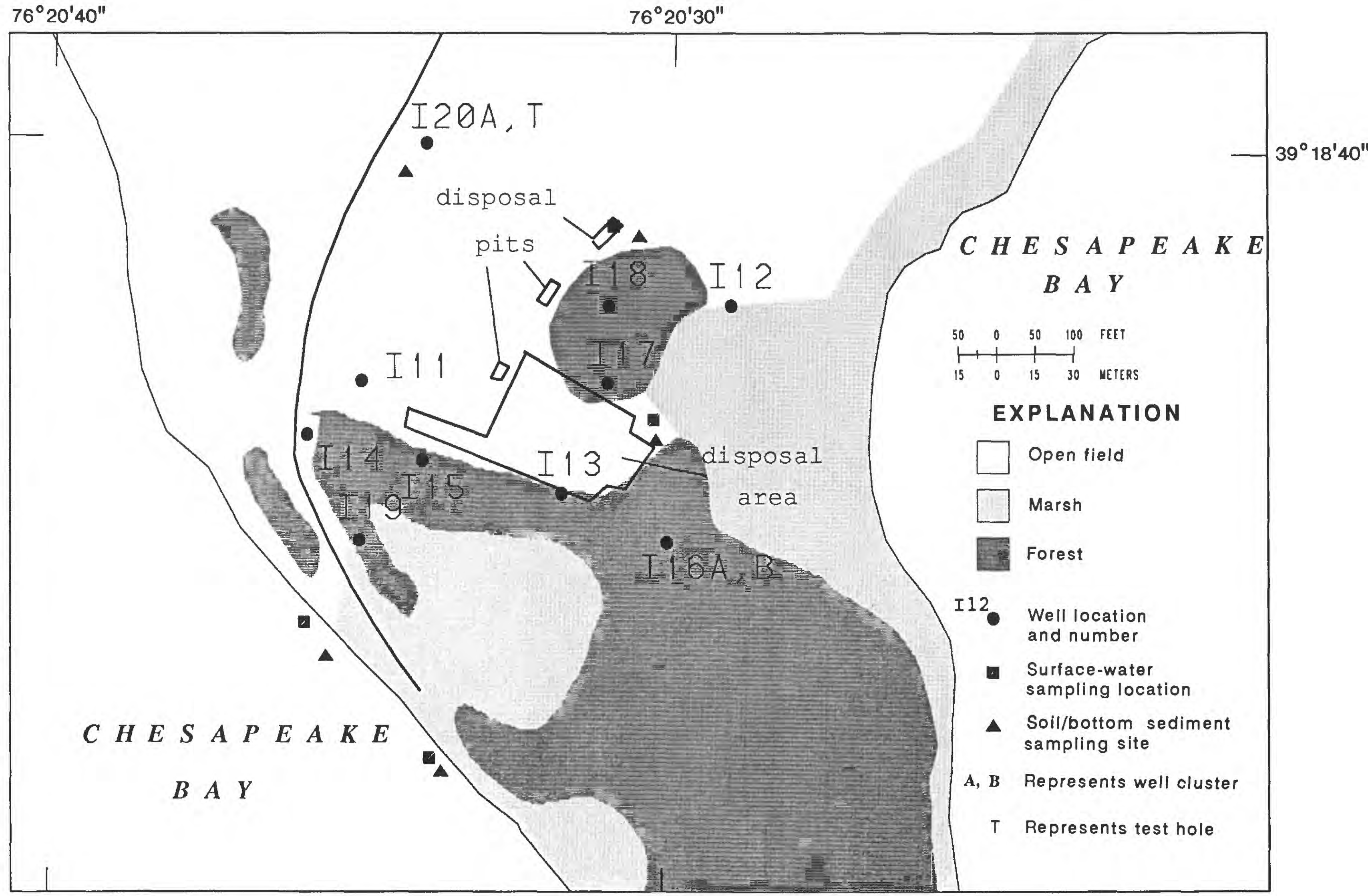

Figure 10.--Dimensions of units and locations of observation wells and sampling points at the Lower Island disposal site, Carroll Island.

Bengies Point Road Dump Site

The Bengies Point Road dump site is a marshy depression that is submerged during the winter and spring. Woods surround the area except for the marsh to the southwest and a small pond to the east (fig. 11). The most likely pathways of contaminant migration are within the shallow ground-water system and in the marsh area southwest of the site (Nemeth, 1989, p. 477).

The surficial aquifer consists of sand, silt, and clay to a depth of 30 ft. The underlying confining unit is 20 ft of clay. A confined aquifer (about 70 ft thick) underlies the confining unit. Ground water is being assessed with five observation wells. The EM data that were collected to help well placement showed higher readings corresponding to the marsh areas, which is probably related to brackish water. All wells shown on figure 11 are screened in the surfical aquifer except for well I54B, which is screened in the confined aquifer. Screen depths are given in table 5.

The direction of ground-water flow in the surficial aquifer is predominantly to the northwest and southwest with some seasonal variations. Wells I50A, I51, and I54A are downgradient; wells I52 and I53 are predominantly upgradient of the dump site. Continuous water-level recorders were installed on wells I54A and I54B to observe the effects of pumping at a production well about 1,500 ft southwest of the site.

All wells were sampled during July and August 1988 and in the spring of 1989. Two surface-water samples were collected during October 1988. One was collected from the pond just east of the site to determine if any releases have migrated to the pond through the ground water during gradient reversals. The other was collected from a sluice pipe about 1,000 ft south of the site. The sluice pipe drains the marsh area that is adjacent to this SWMU. These sites and two additional surface-water samples were collected in the spring of 1989. The additional sites included ponded water within the dump site and in the marsh southwest of well I51. Soil samples will be collected from one site in the dump and an upgradient site near well I53. One bottom-sediment sample will be collected from the marsh near well I51.

Edgewood Proving Ground Dump Site

The Edgewood Proving Ground dump site consists of a small dump (30 ft long) that is located in a berm and adjacent drainage ditch (fig. 12). The drainage ditch periodically contains water that discharges into Saltpeter Creek. The area is wooded and flat with a marsh to the southwest and Saltpeter Creek, which is a tidal estuary, to the north and west. Contaminant migration could be caused by movement of surface water and sediment a short distance northward to Saltpeter Creek (Nemeth, 1989, p. 473). Contaminants also could be transported within the shallow ground-water system, or within the deeper ground-water system if dense, nonaqueous phase liquids such as solvents were disposed of at the site (Nemeth, 1989, p. 473).

The shallow ground-water system is being assessed with three wells, I41, I42, and I43, which are screened in the surficial aquifer (table 5). The surficial aquifer consists of 12 or more feet of sand, silty sand, and silt underlain by a confining unit of unknown thickness. Ground-water flow in the surficial aquifer is generally towards well I43 and I42 (north and west). Well I41 is upgradient of the dump site.

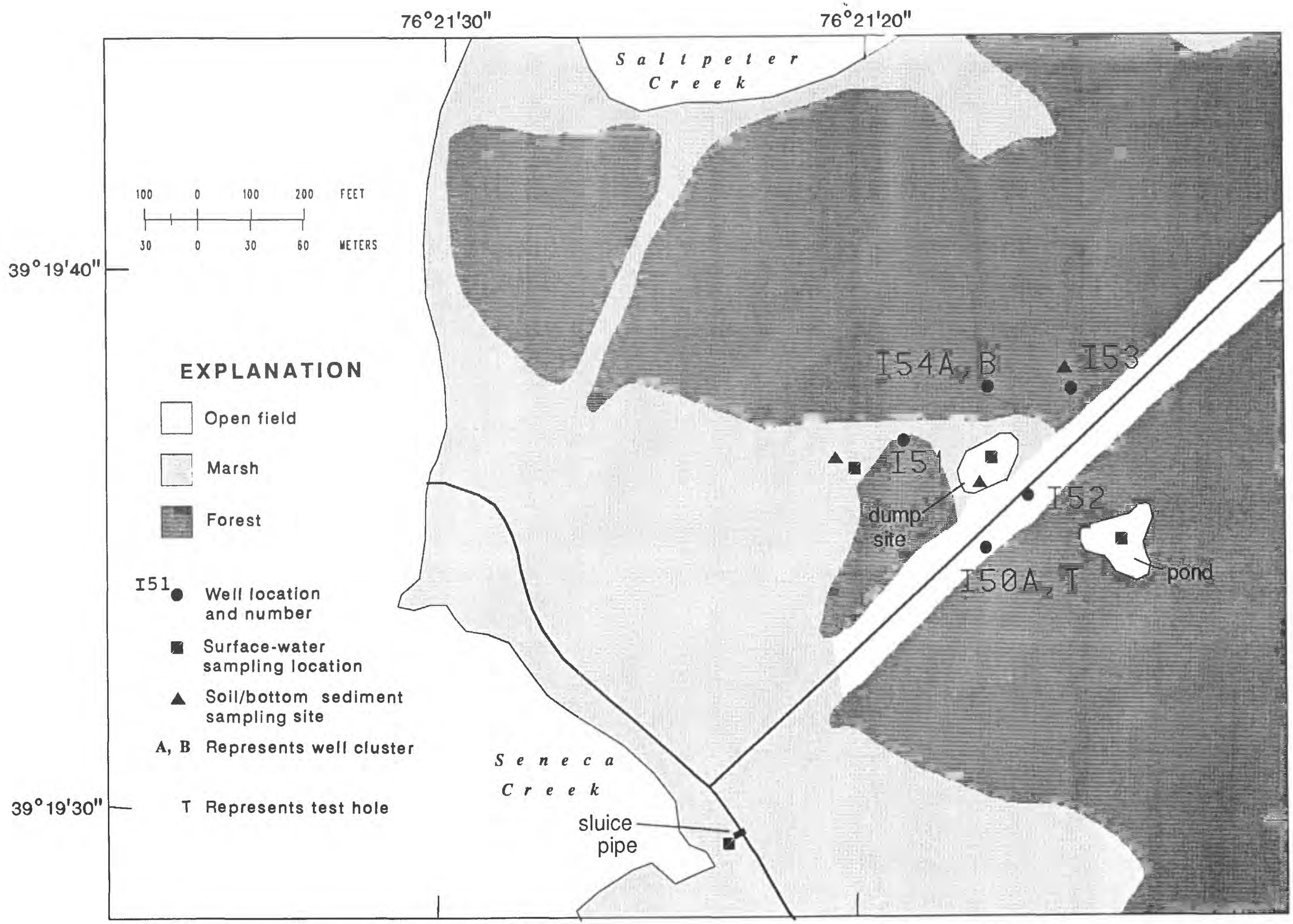

Figure 11.--Dimensions of units and locations of observation wells and sampling points at the Bengies Point Road dump site, Carroll Island.

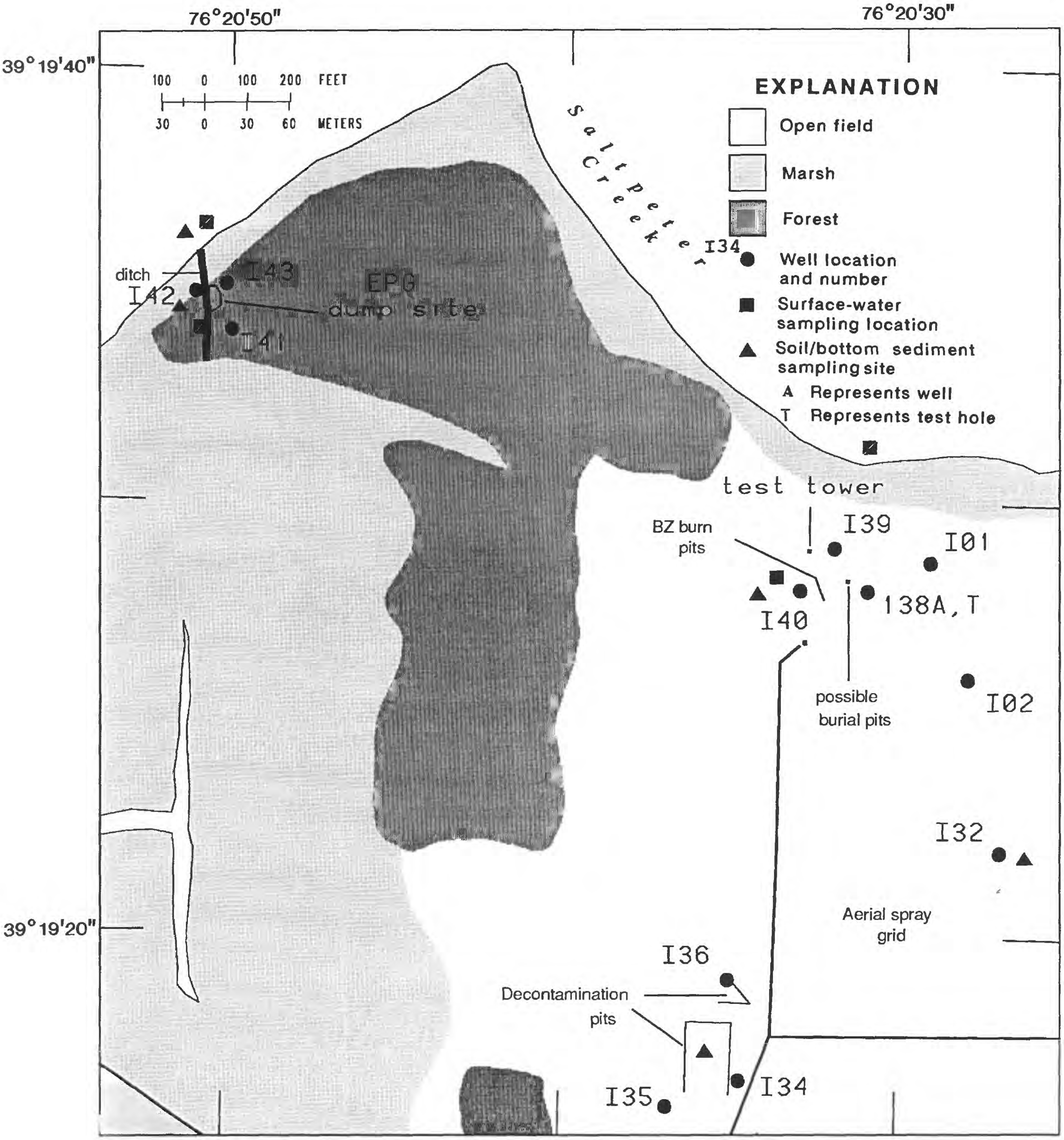

Figure 12.--Dimensions of units and locations of observation wells and sampling points at the Edgewood Proving Ground dump site, BZ test burn pit, and decontamination pits, Carroll Island.

All wells were sampled in July 1988 and in the spring of 1989. Surface-water samples were collected from the point where the drainage ditch enters Saltpeter Creek and a small ponded area about 30 ft northeast of the dump site to detect potential releases from the site. A sample from the Saltpeter Creek site and an additional surface-water sample from the drainage ditch were collected in the spring of 1989. A soil sample will be collected from a site in the drainage ditch adjacent to the drums. A bottom-sediment sample will be collected where the drainage ditch enters Saltpeter Creek.

BZ Test Burn Pit

The BZ test burn pit site includes an open test pit, which is about 5 ft deep, and two small burial pits to the southeast (fig. 12). The most likely pathway of contaminant migration is within the ground-water system (Nemeth, 1989, p. 481). There is no potential for airborne contaminant migration, and the pit construction prevents surface water from escaping.

The surficial aquifer consists of 10 to 20 ft of silt with some sand underlain by 5 ft of sand. Below that is a confining unit consisting of 40 ft of clay, silt, and sandy silt, followed by a 50-ft-thick confined aquifer. The ground-water system is being assessed with four wells screened in the surficial aquifer. Ground-water-flow direction is variable, generally to the north but also to the northeast and northwest. Wells I39 and I40 are directly downgradient. An existing USATHAMA well (I01) is in the northern part of the aerial spray grid about 200 ft east of the BZ test burn pit and is equipped with a continuous water-level recorder. Well I38A is upgradient from the site. Well-screen depths are given in table 5.

Ground-water samples were collected from all wells in July 1988 and in the spring of 1989. One surface-water sample was collected in the summer of 1988 from Saltpeter Creek, at a site directly north of well I39, to detect any potential ground-water discharge. The Saltpeter Creek site was sampled again in spring 1989, along with another sample consisting of standing water collected from the test pit. One soil sample also will be collected from the test pit.

Decontamination Pits

This site consists of two pits located in a rectangular area approximately 100 by 180 ft (fig. 12). The pits are 1 to 2 ft in depth. The site is located in the western part of the aerial spray grid. The most likely pathway of contaminant migration at this site is within the shallow ground-water system (Nemeth, 1989, p. 480). Migration of contaminants by surface water is unlikely because of the flat topography in the area.

The surficial aquifer in this area consists of 25 to 30 ft of sand and silt with some clay, overlying a 20- to 40-ft-thick confining unit. Ground water in this aquifer is being assessed with three observation wells (I34, I35, and I36). The predominant ground-water flow direction is southward. Wells I34 and I35 are downgradient of the pits, and well I36 is upgradient. Screen depths are given in table 5. All wells were sampled in July 1988 and in the spring of 1989. No surface-water samples were collected. One soil sample will be collected from the pit area.

Test Grid 1

Test grid 1 site is an open field located on the eastern part of Carroll Island (fig. 13). The elevation (10 ft) of the area is one of the highest on the island. The most likely pathway of contaminant migration is within the ground-water system (Nemeth, 1989, p. 483). During operation of the unit, a sump system carried ground water through a drain that discharges in the marsh near the headwaters of Hawthorn Cove.

The surficial aquifer is characterized by about 30 ft of sand, silt, and clay underlain by a clay confining unit 30 ft thick. Below this is a confined aquifer at least 5 ft thick. The ground water in the area is being assessed with seven existing USATHAMA wells and three wells installed during this study. All the wells, except for I37A, are installed in the surficial aquifer. Ground-water flow in the surficial aquifer radiates out from the center of the grid, which is a topographically high area. Well I06, which has a continuous water-level recorder, has the highest recorded water levels but is near the middle of the test grid itself. This means that samples from the upgradient well (I06) in test grid 1 probably do not represent background water quality. Background water quality for this area will have to be inferred from upgradient wells in areas away from the test grid, such as I41 or I52. Downgradient wells include I04, I05, I07, I08, I09, I10, I31A, and I37B. Screen depths are given in table 5.

All wells were sampled in July 1988 and in the spring of 1989. Two surface-water samples were collected to address water quality in the sump system. One was from the sump itself near the middle of the test grid and the other was from a sluice pipe located near the sump discharge point. Both of these sites were sampled again in the spring of 1989. A soil sample will be collected from the middle of the test grid, northwest of well I06. A bottom-sediment sample will be collected from the sluice pipe site.

Aerial Spray Grid

This site is a large open field located northeast of test grid 1 (fig. 13). Any contaminant migration from this unit is expected to be within the ground-water flow system (Nemeth, 1989, p. 484).

The surficial aquifer in the spray grid consists of interbedded sand, silt, and clay and is approximately 30 ft thick. A confining unit of 30 to 40 ft thickness is below the surficial aquifer. The thickness of the confined aquifer beneath the aerial spray grid is not known, but is probably between 5 and 50 ft. Wells to characterize the ground water in the surficial aquifer include three existing USATHAMA wells (I01, I02, I03) that are at the north end of the grid, and two wells (I32 and I33) installed at areas of high EM readings. Well I32 was located near the center of the site and well I33 at the southern end of the site. Screen depths are given in table 5. Wells associated with the BZ test burn pit, test grid 1, and the decontamination pits will provide additional data. Ground-water flow is north towards Saltpeter Creek, so wells I01, I02, and I03 are downgradient. Flow also is south toward Hawthorn Cove, where well I33 is located. Well I32 is in the area of the highest ground-water levels but is located near the center of the historical test activity. As with test grid 1, this may present a problem collecting a background water-quality sample from the upgradient well (I32). Background water quality will be inferred from upgradient wells in other locations (such as I52 or I20A).

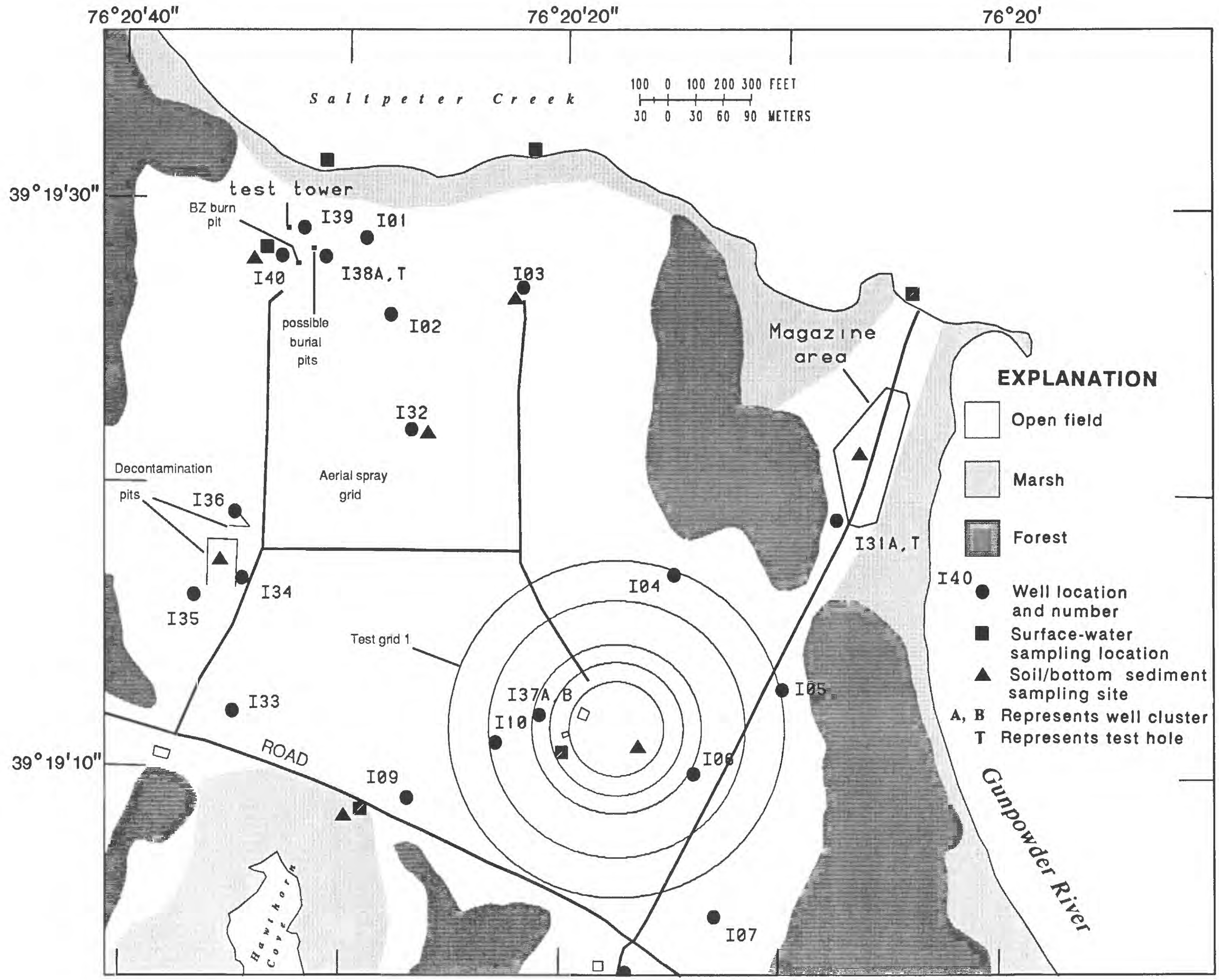

Figure 13.--Dimensions of units and locations of observation wells and sampling points at test grid 1 and the aerial spray grid, Carroll Island.

All the wells were sampled in July 1988 and in the spring of 1989. A surface-water sample was collected in the Saltpeter Creek offshore from well I03. The surface-water samples collected for the BZ test burn area and from the sluice pipe at the head of Hawthorn Cove might help characterize the aerial spray grid. Two soil samples will be collected in the spray grid from sites near wells I32 and I03.

Wind Tunnel

The wind tunnel building is located on the eastern part of Carroll Island near Carroll Point (fig. 14). During its period of use (early 1960's to 1971), the wind tunnel was chemically decontaminated after testing. The wastewater from the decontamination was discharged to a ditch and the marsh east of the wind tunnel (Nemeth, 1989, p. 485).

Nemeth (1989, p. 485) reports that the wastewater discharge probably contained chemical agent degradation products, small amounts of chemical agent, and chemicals from the decontaminating solutions. The decontaminants used included chlorinating agents such as STB, other inorganic decontaminants such as sodium hydroxide, and some alcohol-containing solutions. Organic-based decontaminants such as DANC and DS-2 were not used (Nemeth 1989, p. 485).

Site characteristics and historical activities suggest at least two possible migration pathways for any residual contaminants. Because the drainage ditch is unlined, chemicals may have infiltrated to the shallow ground water. Therefore, one potential pathway is within the shallow ground-water system. Nemeth (1989, p. 485) suggested that there is possible migration of chemicals by slow seepage of potentially contaminated water from the marsh into adjacent surface water of the Chesapeake Bay.

The surficial aquifer in the wind tunnel area consists of 8 to 15 ft of sand, silt, and clay underlain by a clay confining unit 35 ft thick. Beneath the clay is a confined aquifer of unknown thickness. Four observation wells were installed in the area. Well I28 is east (downgradient) of the building next to the drainage ditch. Well I29 is upgradient and wells I27A and I27B are south of the site but not in a primary ground-water flow direction. All wells are screened in the surficial aquifer except for I27A, which is in the confined aquifer. Screen depths are given in table 5.

All wells were sampled in July 1988 and in the spring of 1989. No surface water was present in the marsh near the drainage ditch to assess discharge into the marsh; therefore, only one sample located south of well I27A was collected to characterize background conditions. One soil sample will be collected in the drainage ditch and one bottom-sediment sample will be collected farther east in the marsh to address contaminant discharge in the ditch.

Test Grid 2

The test grid 2 site is an open field located north of the Lower Island disposal area. The site is bounded by Hawthorn Cove to the west and the Chesapeake Bay to the east. A marsh is located between the surface-water bodies and the open field (fig. 15). The most likely pathway for contaminant migration is within the ground-water system (Nemeth, 1989, p. 487).

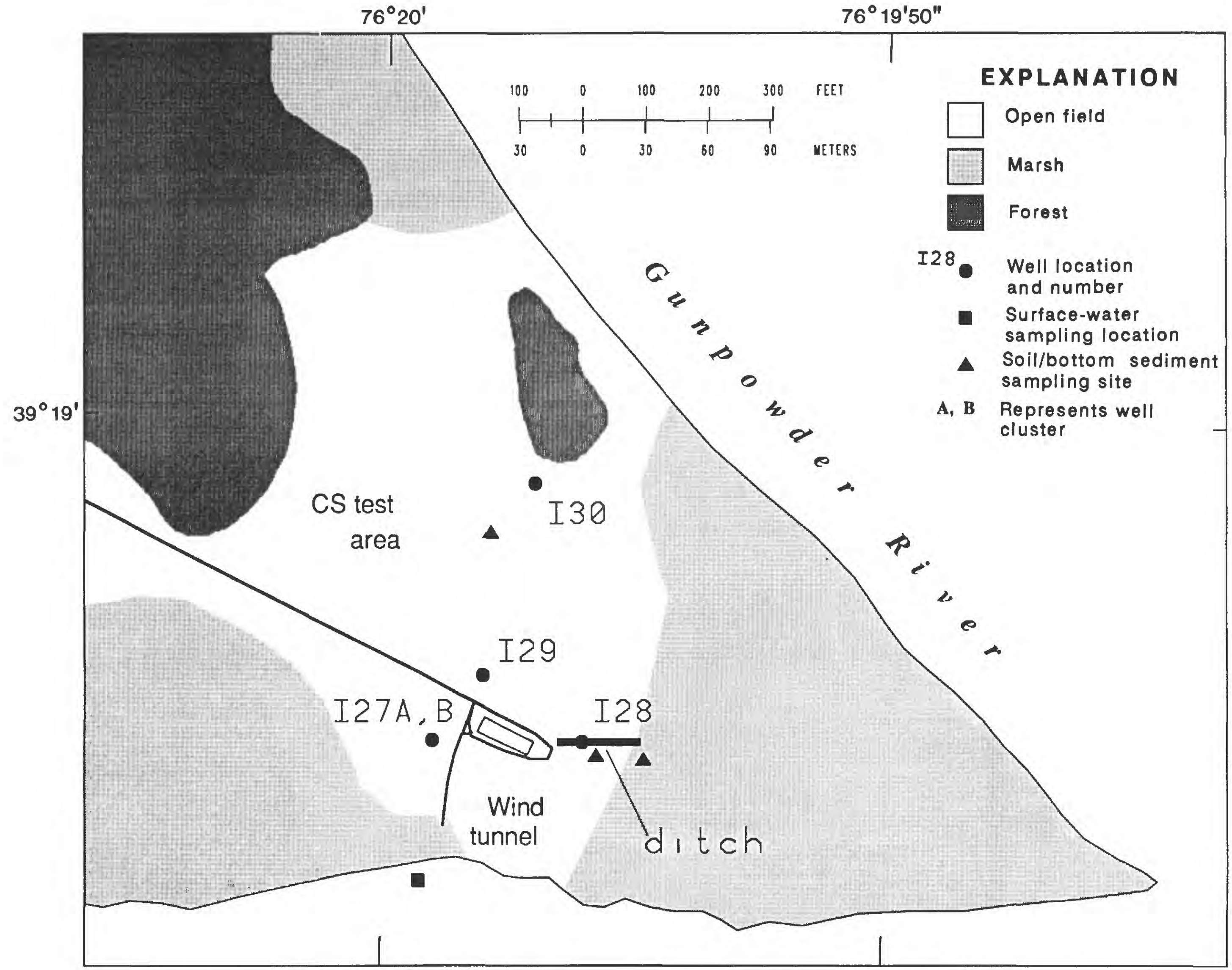

Figure 14.--Dimensions of units and locations of observation wells and sampling points at the wind tunnel and vicinity, Carroll Island.

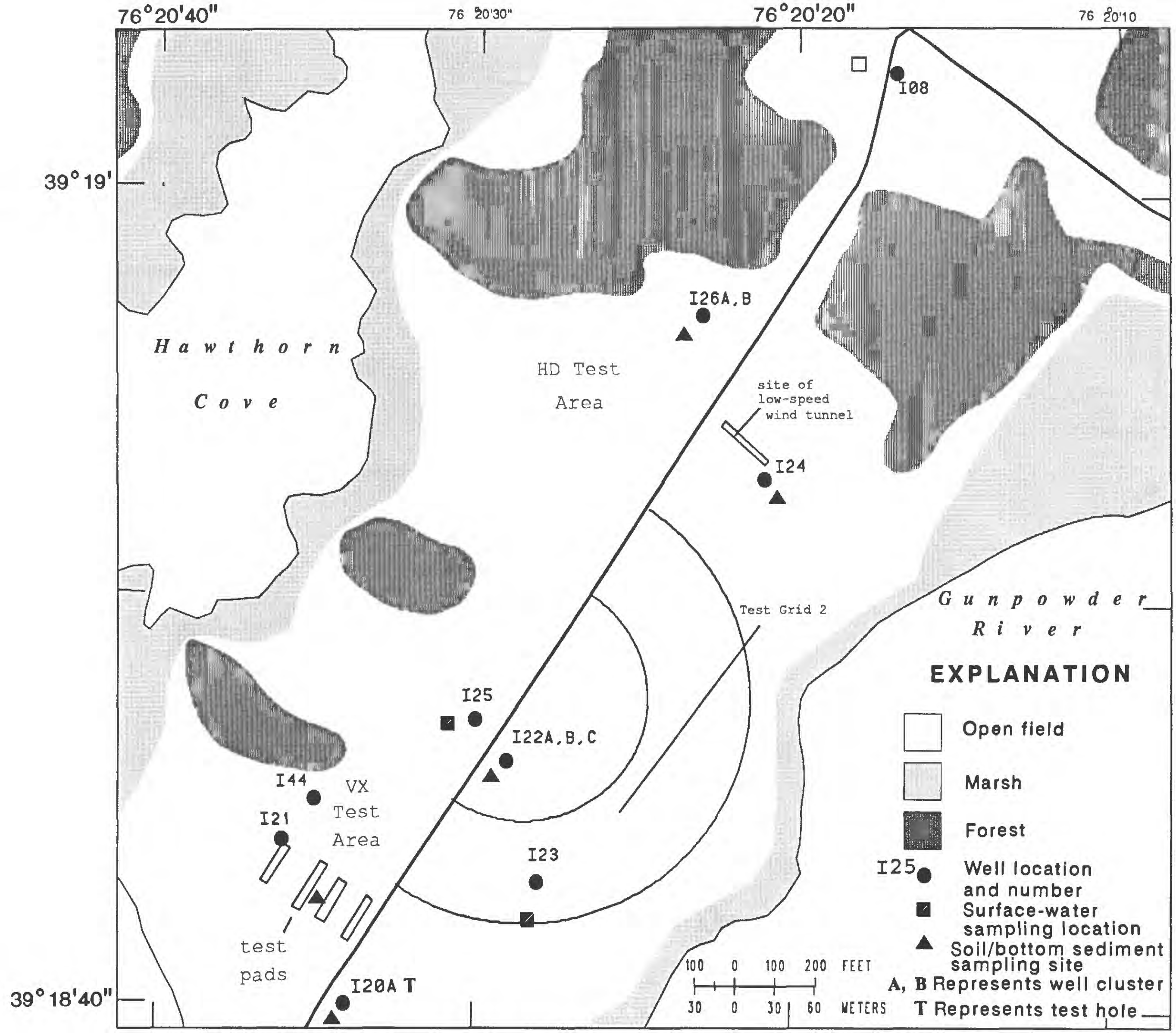

Figure 15.--Dimensions of units and locations of observation wells and sampling points at test grid 2, HD test area and vicinity, Carroll Island.

The surficial aquifer consists of one or two layers of sand with some silt and clay and is about 20 ft thick. The confining unit beneath the aquifer is about 30 ft thick and is underlain by a confined aquifer of unknown thickness. Ground-water flow in the surficial aquifer is toward both the east and west because the unit is located on a local ground-water divide. Three wells were installed at the center of the unit, two in the surficial aquifer (I22B and I22C) and one in the confined aquifer (I22A). Two wells were installed in the surfical aquifer to characterize the effects of a 4-ft silt bed in the middle of the aquifer. Wells I23 and I25 are downgradient to the east and west, respectively. All wells were installed in areas of high EM readings. Screen depths are given in table 5. Background water quality will be inferred from upgradient wells at other sites away from the test grid (such as I52 and I41).

The wells were sampled in August 1988 and in the spring of 1989. Some ponding is present during the wet season near wells I23 and I25 so surface-water samples were collected from both of these sites. One soil sample will be collected from the middle of the test grid.

HD Test Area

The HD test area site is an open field located north of test grid 2 (fig. 15). The site was used for ground-contamination studies of HD and VX. Migration of any residual chemicals is likely to be within the ground-water system (Nemeth, 1989, p. 488).

The surficial aquifer consists of two layers each of sand and silt to a depth of 33 ft. The thickness of the confining unit, which consists of silt and clayey silt sand, below the surficial aquifer is unknown but is greater than 10 ft. Ground-water flow is mostly west towards Hawthorn Cove but flow did reverse to the east during the summer of 1988. Wells I26A and I26B are located in the center of the site and screened at different intervals in the surficial aquifer (table 5). These wells will be used to assess water quality in the surficial aquifer beneath the test area. Other wells near the HD test area are used to determine flow directions. These include well I25 to the south and well I24 to the east. Background water quality will be inferred from upgradient wells in other areas. Wells I26A and I26B were sampled in August 1988 and in the spring of 1989. One soil sample will be collected near wells I26A and B.

Dredge-Spoil Area

The dredge-spoil area site was used for disposal of dredge spoil with the northern part used for some chemical agent testing. The site is an open field just south of the service area (fig. 16). Nemeth (1989, p. 487) recommended no RFI work at this site because the dredge spoil contained no hazardous materials. However, two wells (I45 and I46) were installed in the area that was previously used for testing in order to detect any releases to shallow ground water. Well-screen depths are given in table 5.

The surficial aquifer consists of 5 to 6 ft of sandy dredge spoil overlying silt, sand, and some clay and organic material. Drilling at this site did not extend into the confining unit, so depth and thickness of the confining unit in this area is not known.

Ground-water flow in the surficial aquifer is most likely towards Hawthorn Cove. The wells at this site were sampled in July 1988 and in the spring of 1989. One soil sample will be collected near well I46.

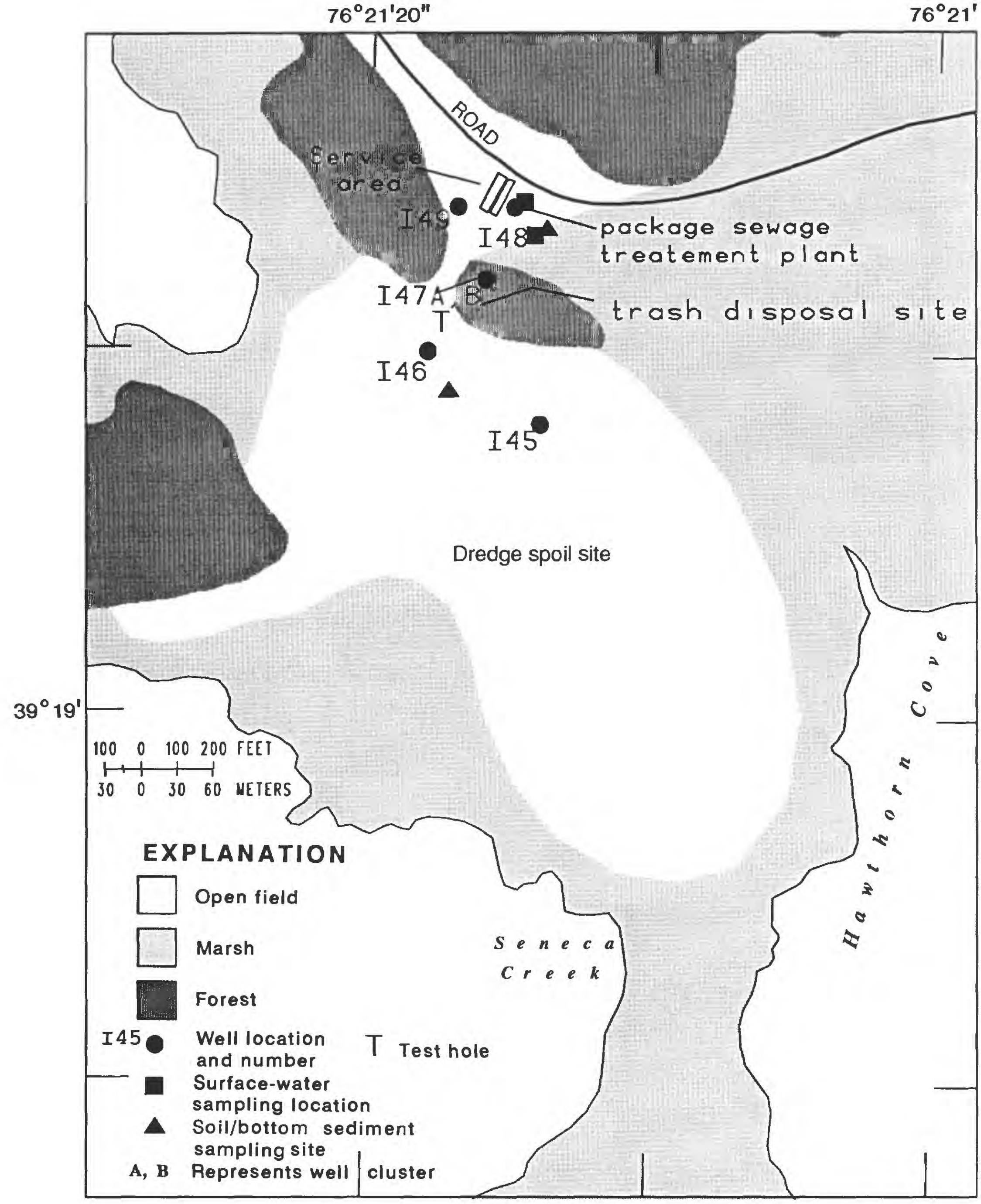

Figure 16.--Dimensions of units and locations of observation wells and sampling points at the dredge-spoil site and service area, Carroll Island.

Service Area

The service area is located north of the dredge-spoil site in an open area bounded by woods and marsh (fig. 16). The area was used for support activities and included a wastewater-treatment unit. Some discarded material associated with agent testing was located at the site. The most likely pathway of contaminant migration is within the shallow ground-water system. Transport of contaminants by surface water is not significant (Nemeth, 1989, p. 491). The surficial aquifer at this site consists of about 30 ft of sand, silt, and silty sand. The confining unit is 30 ft thick, and overlies a confined aquifer about 100 ft thick. Ground-water flow in the surficial aquifer is generally to the east but a reversal to the west was observed in the summer of 1988. Four wells were installed at this site; all were screened in the surficial aquifer except I47B, which was screened in the confined aquifer (table 4). Well I48 is directly downgradient of the wastewater-treatment plant and well I47A is downgradient of the discarded test material. Well I49 is upgradient of the site except during the flow reversals. Net gradients from 1988 show I49 to be upgradient of the other two wells in the surficial aquifer. Net gradients between the surficial and confined aquifer are downward.

All wells were sampled in July 1988 and in the spring of 1989. One surface-water sample was collected from the wastewater-treatment unit in October 1988. This site and the adjacent marsh were sampled in the spring of 1989. A bottom-sediment sample will be collected from the marsh site.

Other Areas

Other areas with some type of previous activity include the magazine area, a CS test area near the wind tunnel, a VX test area near test grid 2, and an area east of the HD test area. The characteristics of these sites are discussed in the study area descriptions.

The magazine area is northeast of test grid 1, adjacent to Saltpeter Creek (fig. 13). Nemeth (1989, p. 490) reported that the site was not used for managing solid wastes; any spillage or leakage of chemicals was not routine, systematic, or deliberate; therefore, limited sampling is recommended at this site. No wells were installed at this site because of the RFA recommendations; however, a surface-water sample was collected from Saltpeter Creek adjacent to the site. This site was sampled again in the spring of 1989. One soil sample will be collected from the middle of the area.

The CS test area is an open field near the wind tunnel that was used for ground-contamination studies (fig. 14). One well (I30) was installed in the northern end of the area and screened in the surficial aquifer. This well was sampled in July 1988 and the spring of 1989. One soil sample will be collected near well I30.

The VX test area consists of an open field and four rectangular pads made of asphalt and concrete. The site is located southwest of test grid 2 (fig. 15). Ground-water flow appears to be north toward the marsh adjacent to Hawthorn Cove. Well I21 is located downgradient of the pads and well I44 is located near the center of the historical test activity. Both wells are screened in the surficial aquifer (table 5). These wells were sampled in August 1988 and in the spring of 1989. One soil sample will be collected from a site midway between the pads.

The area across from the HD test area was used for limited testing. This site is an open field, fringed with marsh, that is adjacent to the Chesapeake Bay. One well (I24) was located in the middle of the area (fig. 15) and screened in the surficial aquifer (table 5). This well was previously sampled and was sampled again in the spring of 1989. One soil sample will be collected near well I24.

Study Approaches for Individual Sites at Graces Quarters

The number of ground-water, surface-water, bottom-sediment, and soil samples to be collected at each site is presented in table 15. The technical rationale for sample collection at each site is discussed below.

Disposal Area

The disposal area site is located on a topographic high point of Graces Quarters. To the east of the area is a cliff that leads to the shore of the Gunpowder River; the land slopes away to the north, west, and south from the disposal area (fig. 17). This area has disposal pits that contain materials from the testing operations. The greatest potential for contaminant movement at this site exists at the cliff east of the disposal pits where erosion could cause the slumping of pit contents into the Gunpowder River (Nemeth, 1989, p. 492). Potential also exists for contaminant movement through the shallow ground-water system (Nemeth, 1989, p. 493).

The geologic framework underlying this site consists of a series of discontinuous sand lenses in a fine-grained matrix to a depth of about 20 ft below land surface. The surficial sand lenses are underlain by about 100 ft of clay. A confined aquifer, which is about 10 ft thick, underlies the confining unit. Ground-water flow in the surficial sand lenses will be influenced by the degree of interconnection between the sand lenses. One possible ground-water flow path would follow the topography and flow to the northwest and southwest. Another possibility is for ground water to seep out the cliff face to the north. The well network in this area was designed to address these flow paths.

Four wells were installed at this site during the USATHAMA study; one was in the disposal area close to the cliff (well Q02), and three were located at the perimeter of the area (wells Q01, Q03, and Q04). Well Q04, however, has not been located. Six additional wells were installed in the winter of 1988. Wells Q02, Q08, Q09A, and Q09B are located within the perimeter of the disposal-pit area. Wells Q02, Q08, and Q09A are screened in surficial sand lenses while well Q09B is screened in an underlying confined aquifer. Wells to the northwest include wells Q01 and Q07. Well Q10 is about 200 ft southwest of the pit area. Wells Q03 and Q13 are located to the southeast to help define ground-water flow. Background water quality will be inferred from wells in other areas, such as Q20B or Q17. Screen depths for all wells are given in table 6.

Sampling of all wells was conducted in August 1988; however, some of the wells recovered so slowly that complete sample sets could not be collected. Incomplete sample sets (only organics) were collected from wells Q03 and Q09A. Complete samples were collected from the other wells, but wells Q01 and Q08 took 2 days of recovery in order to yield enough water to be sampled. All these wells were sampled again in the spring of 1989.

Two surface-water samples were collected from the Gunpowder River, one adjacent to the disposal pit area near a site on the cliff that had been eroded and another from a cove northeast of the site that is a potential ground-water discharge area. These two sites were resampled, along with another site just south of well Q10 and another just north of well Q07.

Both of these sites have intermittent ponding of water that could be a ground-water seep. No testing of agent occurred on the pit area so soil samples are probably of limited value; therefore, soil samples from surface-water runoff areas including the cliff north of the disposal area and near wells Q07 and Q10 will be collected. One bottom-sediment sample will be collected near the cliff area in the Gunpowder River.

Table 15.--Location and number of ground-water, surface-water, soil, and bottom-sediment samples to be collected at Graces Quarters

[See the Glossary of Acronyms and Abbreviations for chemical names]

Site	*Ground water*	Surface water	Soil	Bottom sediment
Graces Quarters disposal area	9 wells Q01, Q02, Q03, Q07, Q08, Q09A, Q09B, Q10, Q13	4	3	1
Primary test area	4 wells Q14, Q15, Q16A, Q16B	1	3	0
Test site, northern dump	3 wells Q23, Q24, Q25	0	1	0
Test site, southern dump	3 wells Q26, Q27, Q28	2	1	0
Graces Quarters dump	2 wells Q11, Q12	1	1	0
Secondary test area	1 well Q21	0	1	0
HD test annuli [1]	4 wells Q05, Q17, Q18A, Q18B	0	2	0
Bunker	1 well Q22	1	0	0
Service area	2 wells Q20A, Q20B	0	0	0
Other wells	Q19B, Q06			
Totals	31 wells	9	12	1

[1] HD is an abbreviation for distilled mustard.

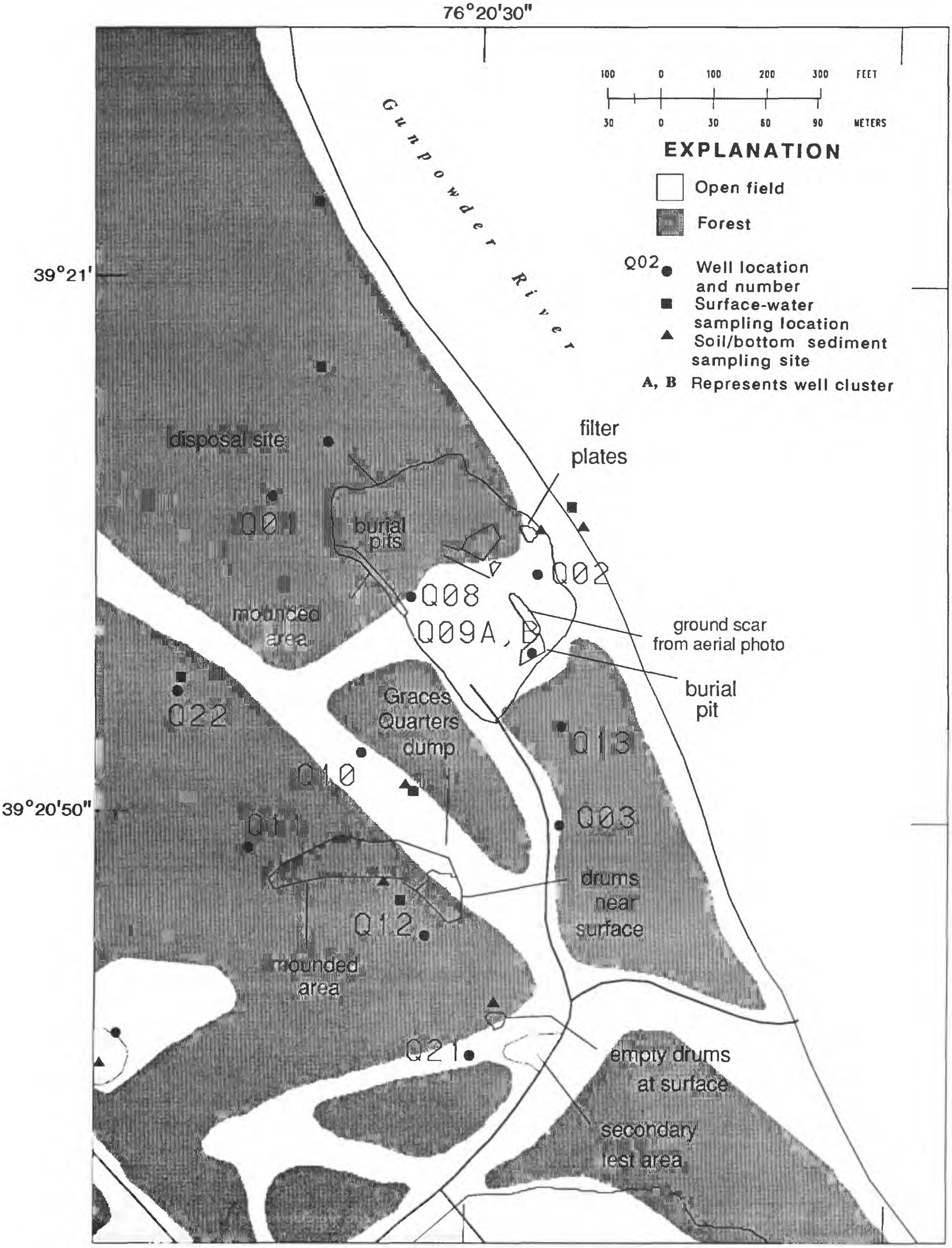

Figure 17.--Dimensions of units and locations of observation wells and sampling points at the Graces Quarters disposal area and vicinity.

Primary Test Area

The primary test area site has open fields and woods and is located in the eastern part of Graces Quarters (fig. 18). The northern and southern dumps are on the perimeter of the area. A trench used for decontamination studies is located within the primary test area. The most likely pathway of contaminant migration is within the shallow ground-water system.

The surficial aquifer consists of sand, silt, and clay to a depth of 20 to 35 ft. It is underlain by a confining unit about 35 ft thick. A confined aquifer underlies the confining unit. Ground-water flow in the surficial aquifer is primarily to the southeast. Wells Q14 and Q16B are located in the middle of the test area and screened in the surficial aquifer. Well Q16A is screened in the underlying confined aquifer. Well Q15 is directly downgradient of the decontamination pit. Wells at the southern dump also can be used to determine flow direction in this area. Background water quality will be inferred from wells in other areas, such as Q20B or Q17. Screen depths are given in table 6.

All wells were sampled in August 1988 and in the spring of 1989. The only surface water at this site results from intermittent filling of the decontamination pit. A sample of this water was collected in the spring of 1989. Soil samples will be collected from the decontamination pit and near wells Q14 and Q16A.

Test Site, Northern Dump

The northern dump site in the test area is located in a wooded area on top of a hill near the primary test area (fig. 18). The site contains surficial debris that includes discarded equipment and material. The most likely pathway of contaminant migration is within the shallow ground-water system. Geology of this site consists of 17 to 25 ft of silt and sand overlying a clay confining unit. The altitude of the top of the confining unit is above sea level, and wells screened in the surficial material at this site (Q23, Q24, and Q25) are dry for part of the year. Geology is similar to the Graces Quarters disposal site area, and ground-water flow probably follows topography (southwest to northwest). Wells were located with these flow paths in mind. Screen depths are given in table 6.

Preliminary water levels indicate that wells Q24 and Q23 are downgradient and well Q25 is upgradient. In August 1988, only well Q25 had enough water for a complete sample, a partial sample set (only organics) was collected from well Q24; well Q23 was dry. Wells Q24 and Q25 were sampled in the spring of 1989. A soil sample will be collected next to the drums near well Q23. No surface-water or bottom-sediment samples will be collected.

Test Site, Southern Dump

The southern dump site in the test area is located in a wooded area adjacent to a marsh and is about 200 ft from the shoreline of the Gunpowder River (fig. 18). The most likely pathway of contaminant migration is within the shallow ground-water system.

The surficial aquifer in this area consists of sand, clay, and silt and could be as much as 40 ft thick. Ground-water flow is predominantly to the east and south toward the Gunpowder River. Wells Q27 and Q28 are downgradient and well Q26 is upgradient. Screen depths are given in table 6. All wells were sampled in August 1988 and in the spring of 1989. One surface-water sample was collected from the Gunpowder River in October 1988. Another surface-water site in the marsh southeast of well Q26 was sampled along with the Gunpowder site in the spring of 1989. A soil sample will be collected near the STB cans just east of well Q26.

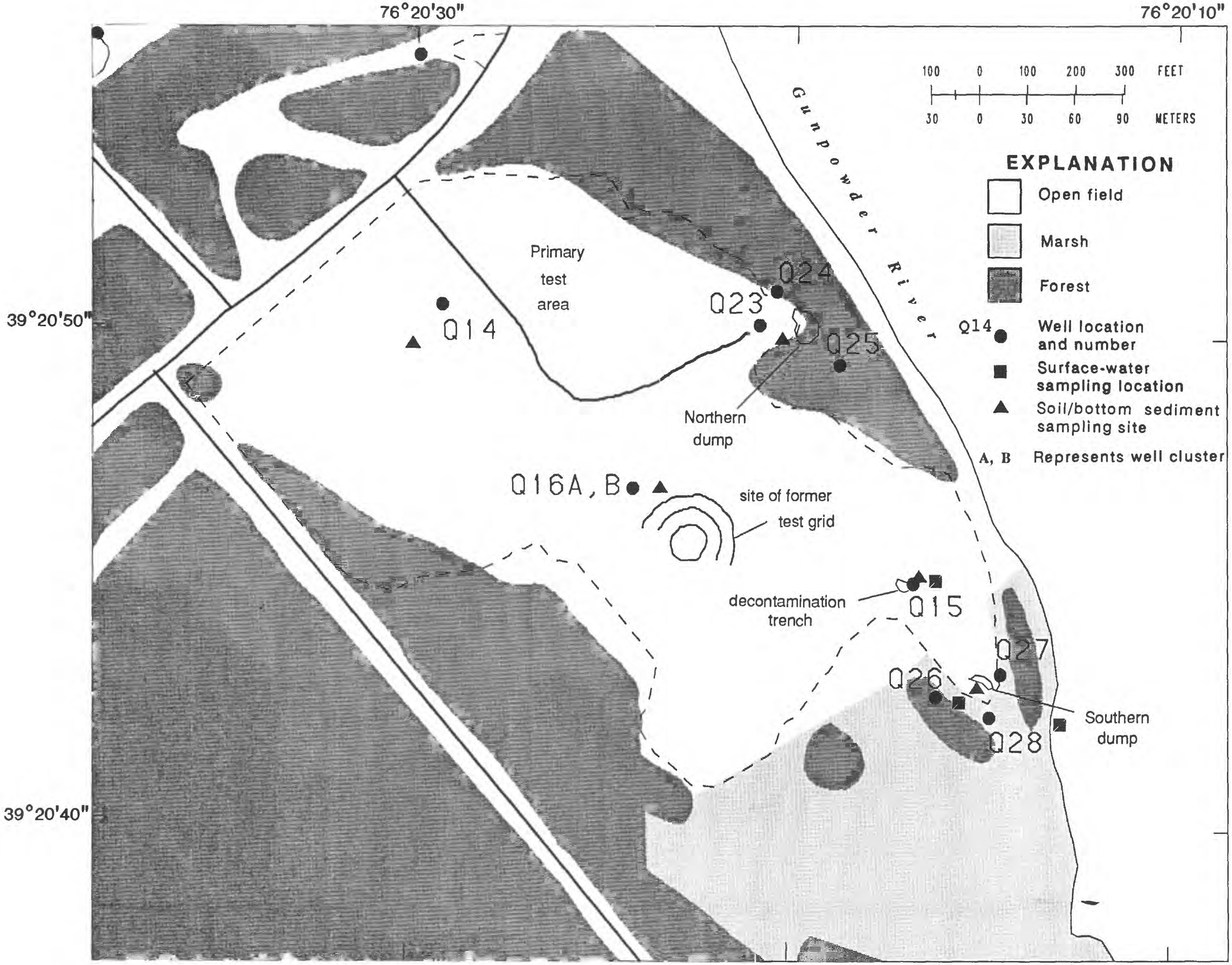

Figure 18.--Dimensions of units and locations of observation wells and sampling points at the primary test area, northern and southern dump, Graces Quarters.

Graces Quarters Dump

The Graces Quarters dump site is south-southwest of the disposal area (fig. 17). The site is in a wooded area adjacent to a large clearing. The most likely pathway of contaminant migration is within the shallow ground-water system (Gary Nemeth, U.S. Army Environmental Hygiene Agency, written commun., 1988). There is some seasonal ponding in this area.

The surficial aquifer in this area consists of interbedded sand and clay. Ground-water flow near this site is probably to the southwest but flow could be influenced by the heterogeneity of the sand lenses. Wells Q11 and Q12 are topographically downgradient and screened in surficial sand lenses (table 6). The disposal area is upgradient of the site; well Q10 is the closest upgradient well. All of these wells were sampled in August 1988 and in the spring of 1989. One surface-water sample was collected near well Q12 in the spring of 1989. One soil sample will be collected from the area where there is intermittent ponding near the bleach cans.

Secondary Test Area

The secondary test area site is located on a wooded slope southwest of Graces Quarters (fig. 17). A small amount of surveillance testing was performed here (Gary Nemeth, U.S. Army Environmental Hygiene Agency, written commun., 1988). Currently there are some empty STB cans. The most likely pathway of contaminant migration is within the shallow ground-water system.

Geology in the area consists of interbedded sand and clay. Topography indicates that the direction of ground-water flow is probably to the west. One well (Q21) was installed immediately downgradient from the site. The screen depth is given in table 6. This well was sampled in August 1988 and again in the spring of 1989. One soil sample will be collected next to the empty STB cans.

HD Test Annuli

The HD test annuli were three concrete rings located near the middle of Graces Quarters (fig. 19). Only two rings remain today. The most likely pathway of contaminant migration is within the shallow ground-water system.

The surficial aquifer is mostly sand and sandy silt and is about 20 ft thick. The confining unit below this is about 20 ft thick, and this overlies a confined aquifer.

Ground water in the surficial aquifer at this site flows southwest. Four wells, one an existing USATHAMA well (Q05), are located at this area. Well Q17 is upgradient of the two remaining annuli, well Q05 is downgradient of the northern ring; well Q18A is downgradient of the southern ring. All are screened in the surficial aquifer (table 6). Well Q18B also is downgradient of the southern ring but is screened in a confined aquifer (table 6). All wells were sampled in August 1988; however, a complete sample could not be obtained from well Q05 due to the amount of suspended sediment in water. All wells were sampled in the spring of 1989. Soil samples will be collected from the middle of each remaining test ring.

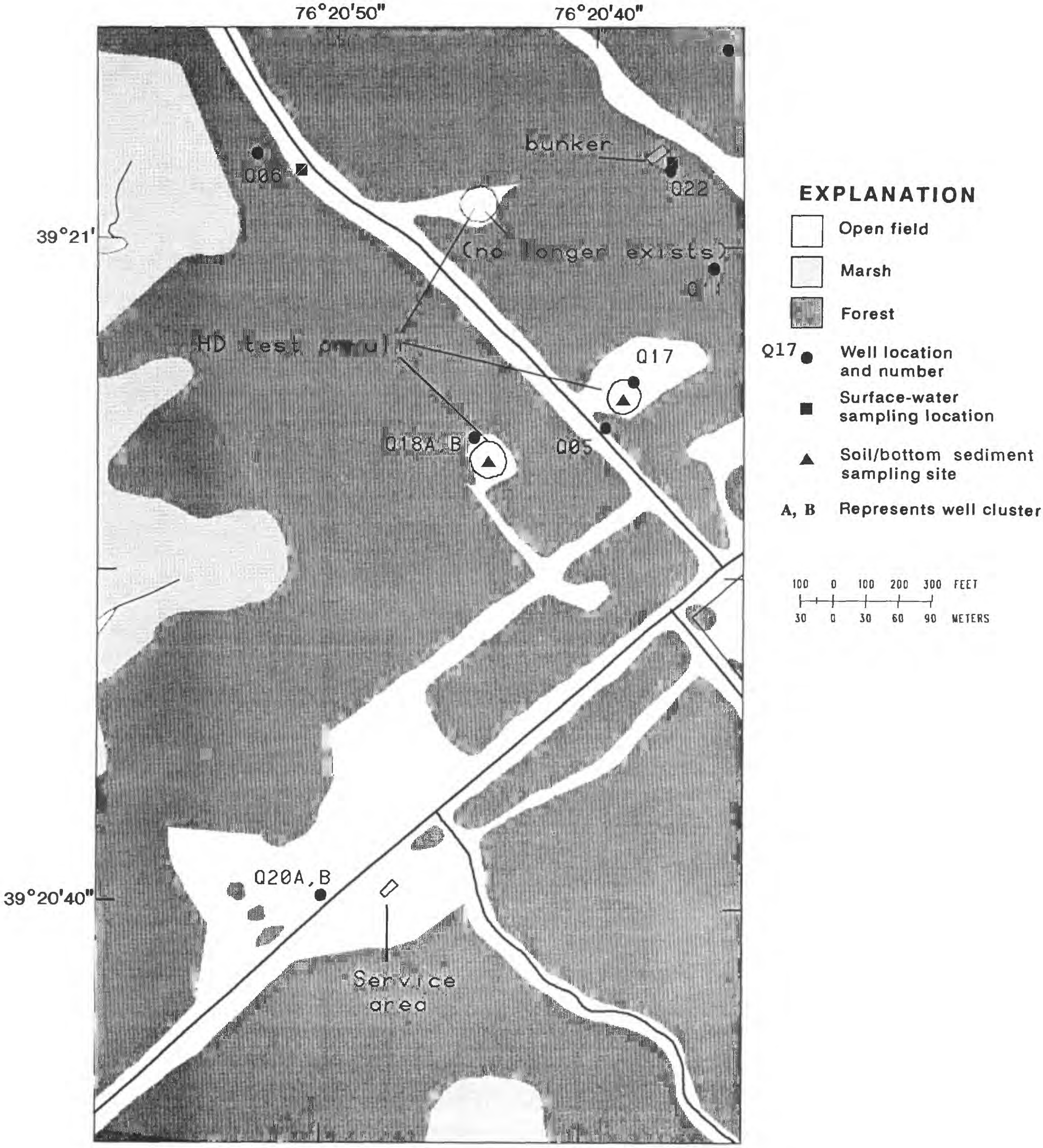

Figure 19.--Dimensions of units and locations of observation wells and sampling points at the HD test annuli and vicinity, Graces Quarters.

Other Areas

Two other areas on Graces Quarters are the bunker and service area. The bunker is a small water-filled depression located west of the disposal area (fig. 19). Nemeth (1989, p. 495) stated that the site was not associated with testing or disposal. However, a surface-water sample was collected from the bunker and a well installed (Q22) topographically downgradient. There is no surficial aquifer at this site. There is a hard, dry clay layer less than 12 ft below land surface with silt above it (the well was screened in the silt). The well that was drilled here did not recover sufficiently to provide a complete sample in August 1988. The well was sampled in the spring of 1989.

The service area is located south of the primary test area (fig. 19). Only wells Q20A and Q20B are located in the probable downgradient direction. Well Q20A is screened in the confined aquifer and Q20B is screened in the surficial aquifer. Both of these wells were sampled in the summer of 1988 and spring of 1989.

Two other wells exist on Graces Quarters, Q06 and Q19B. Well Q06 is an existing USATHAMA well screened in the surficial aquifer and Q19B is screened in the confined aquifer. Both wells provide data on background water quality.

SUMMARY

This report presents the study approach for a hydrogeologic assessment of two areas of Aberdeen Proving Ground known as Carroll Island and Graces Quarters. Carroll Island and Graces Quarters were used as open-air test facilities for chemical warfare agents from the late 1940's through 1971. The hydrogeologic assessment is a requirement of a U.S. Environmental Protection Agency Resource Conservation and Recovery Act permit to address solid waste management units (SWMU's) in the Edgewood Area of Aberdeen Proving Ground.

The approach of the Carroll Island and Graces Quarters hydrogeologic assessment is two-phased. This document presented the methods and rationale for Phase I of the study. The objectives for Phase I are as follows:

1) To identify the location and dimensions of SWMU's and chemical-agent test areas.
2) To define the hydrogeologic system.
3) To verify whether SWMU's in the study area have released or are still releasing chemicals into the environment, and whether there is residual contamination from chemical-agent testing activities in the study areas.

The information that fulfills Objective 1 is presented in this report. Seven SWMU's and nine test areas on Carroll Island were identified. Four SWMU's and three test areas were identified on Graces Quarters. The locations and dimensions of these units were reported with narrative descriptions and location maps in the Background and Study Approach Sections.

The study approaches and methods that were used to collect lithologic, geophysical, and hydrologic information to fulfill Objective 2 were presented. Lithologic and geophysical information was obtained during the drilling of wells and test holes. Hollow-stem augers, which were used during most of the drilling, allowed the collection of continuous lithologic cores. Deeper lithologic information was collected by drilling with the mud-rotary method and sampling at regular intervals with split spoons. Geophysical information was obtained by running gamma logs in each of the wells and test holes, and running electric logs in the test holes. Hydrologic information was obtained after the observation wells were installed. Aquifer properties were estimated with slug tests. Hydraulic gradients were determined with synoptic water-level measurements in the wells, and with automatic water-level recorders at selected wells. Surface-water levels were measured with a continuously-recording tide gage, and a precipitation gage measured rainfall. The methods used to fulfill Objective 2 can be found in the General Study Approach section, and in Appendixes I, II, and III.

Objective 3 required information on the materials disposed or released at SWMU's and test areas, possible migration pathways, and methods to determine whether or not there are current releases of hazardous material or past releases still present in the environment. Information was presented in the General Study Approach section to characterize the materials that were disposed or released, their possible migration pathways through the environment, and the chemical analyses that were performed to determine whether or not there were releases. The information in the General Study Approach was used as a basis for rationalizing the locations of observation wells and sampling sites. Specific locations were rationalized in the Study Approaches for individual sites at Carroll Island and Graces Quarters. Finally, the sampling methods and quality control used to obtain representative samples to accomplish Objective 3 were presented in Appendix IV.

The decision criteria for the implementation of Phase II of the HGA's were presented in the General Study Approach. The criteria were based on regulatory limits that are set by the USEPA. An overview of the methods that will be used for Phase II if it is necessary were presented in the General Study Approach section of this report. The chronology of the objectives and tasks of Phase I of the HGA's is presented; the chronology of the Phase II objectives is contingent upon the results of Phase I.

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APPENDIXES

APPENDIX I

Geophysical Methods

Surface Geophysics

Electromagnetic-induction survey

Geophysical techniques were used for various purposes in this study. Electromagnetic induction (EM) was used to help locate possible contaminant plumes for well placement; magnetometers were used to help delineate the location and dimensions of disposal pits and for safety purposes at drilling locations; and borehole geophysics were used for well-screen placement and clarification of subsurface geology.

Electromagnetic induction is a method that detects changes in ground conductivity. The method operates on a principle in which an electromagnetic field is induced into the ground; this field generates a secondary field, the strength of which is proportional to ground conductivity.

Many factors affect ground conductivity. In general, the factor that is of greatest interest in a study such as this is specific conductance of the ground water. Other factors tend to interfere with the detection of ground-water degradation. Natural interferences include changes in soil moisture, clay content, and depth to water table; manmade interferences include such things as buried pipelines, cables, and other metal objects, along with fences and overhead wires. It is important to be aware of these interfering factors, and to be able to adjust for them during the survey or filter them out during the data analysis.

The instruments used in this study were the Geonics EM31 and EM34-3[1]. Both instruments work under the same principle. An electromagnetic field is induced into the ground between a set of wire coils that may or may not be in contact with the ground. The primary field induces a secondary field; the coil configuration is controlled so the instrument can filter the primary field and measure the strength of the secondary field. The EM31 is a one-person instrument that has a fixed coil configuration; this allows for a continuous conductivity reading but limits the instrument to a single, fairly shallow depth of penetration. The EM34-3 can be used with different coil configurations; this varies the effective depth of penetration but means that two people are required to operate it and readings can only be taken at discrete intervals. Detailed information on the instruments and their use is available in two technical notes by McNeill (1980a; 1980b).

The EM34-3 was the instrument used during the surveys on Graces Quarters; both instruments were used on Carroll Island. The EM31 was used on Carroll Island because it is well suited to the conditions on the island; however, the EM31 was only available for a short period of time, so the EM34-3 was used for the greater part of the Carroll Island investigation. On Graces Quarters, geologic conditions were such that the EM34-3 was the better instrument to use.

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[1] Use of brand or firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

The EM34-3 can be used with different coil configurations and coil spacing to examine conductivity at different depth intervals. The coils can be oriented horizontally or vertically, and spaced 10, 20, or 40 m (meters) apart [2]. Generally, greater coil spacing means greater depth of penetration, and horizontal coils provide greater depth of penetration than the vertical coil configuration. At Carroll Island, the shallowest configuration (10-m spacing, coils vertical) was used because the water table is shallow, there was the possibility of conductive contaminants in the soil zone, and this configuration is the closest to the fixed configuration in the EM31.

The survey at Carroll Island was a series of transects that covered the areas within and around most of the SWMU's and all of the known test areas. The transects generally had a 50-ft station spacing, were 100 to 300 ft apart, and were designed to be long enough so that the background conductivity could be separated from the anomalies. The survey was conducted from May through October of 1987. Under ideal conditions, a survey should be completed in a short enough time span that soil moisture conditions and depth to water table do not change significantly. Because this could not be done in this study, a meaningful comparison of the absolute conductivity values could not be done. However, the relative changes within each transect were evaluated, and comparison of anomalies between transects was done on a qualitative basis.

Transects on Carroll Island were located in the following areas (fig. 20): Lower Island disposal site; Bengies Point Road dump site; test grid 1 and the aerial spray grid; the wind tunnel and CS test areas; and test grid 2, the HD test area and part of the VX test area. Areas that were not covered in the EM investigation include the EPG dump site, the BZ test burn pit, the dredge-spoil site, service area and the magazine area. The first two areas were not included because they were small enough that well placement could be chosen based on proximity to the unit. An EM survey was attempted at the dredge-spoil site, but background values were very high, making interpretation of the data very difficult. It is likely that salinity either from the dredge spoil or from the marshes that were reclaimed in this area was responsible for this interference. Coverage of the service area or the magazine area was not deemed necessary due to the nature of historical activity in these areas.

On Graces Quarters, EM data were collected in areas that included the disposal area, the bunker, Graces Quarters dump, and the primary and secondary test areas (fig. 21). The northern area, which included all the units mentioned above except for the primary test area, was done first, in April of 1987. This area was divided into a grid with 100-ft spacing; the area was surveyed using a 10-m coil spacing, and both vertical and horizontal coil configurations. At selected areas, the grid spacing was cut to 50 ft; at other selected areas, a 20-m coil spacing was used to see if conductivity varied significantly with the depth of penetration.

The primary test area was divided into three transects separated by distances of 175 and 200 ft. The station spacing in these transects was 50 ft. The coil orientation for this part of the survey was a 10-m spacing with coils vertical. This part of the survey was conducted on October 26 and November 9, 1987.

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[2] Metric units are used to describe the coil configuration and ground conductivities for the EM instruments because the instruments were manufactured to metric specifications.

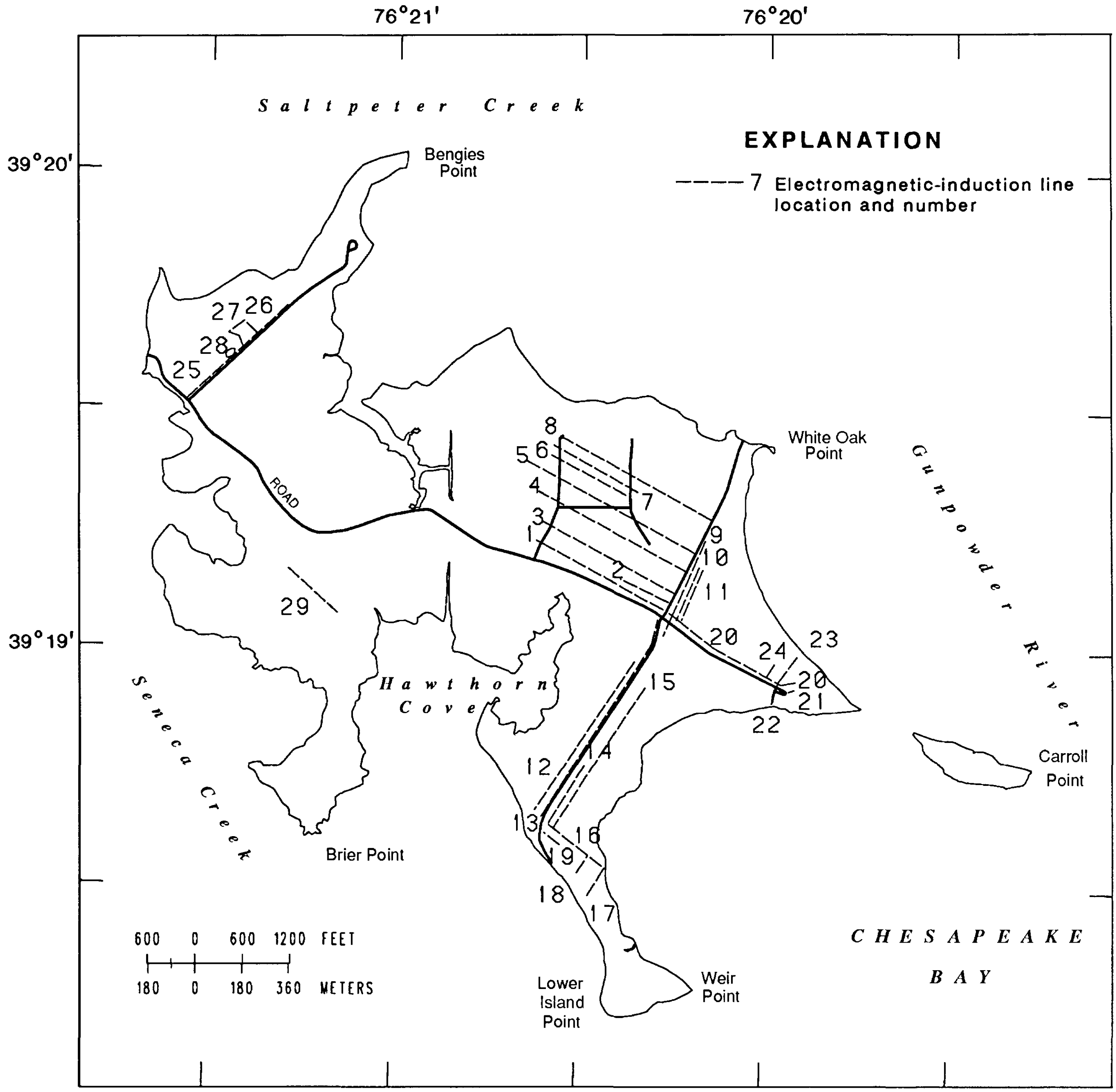

Figure 20.--Location of electromagnetic-induction lines at Carroll Island.

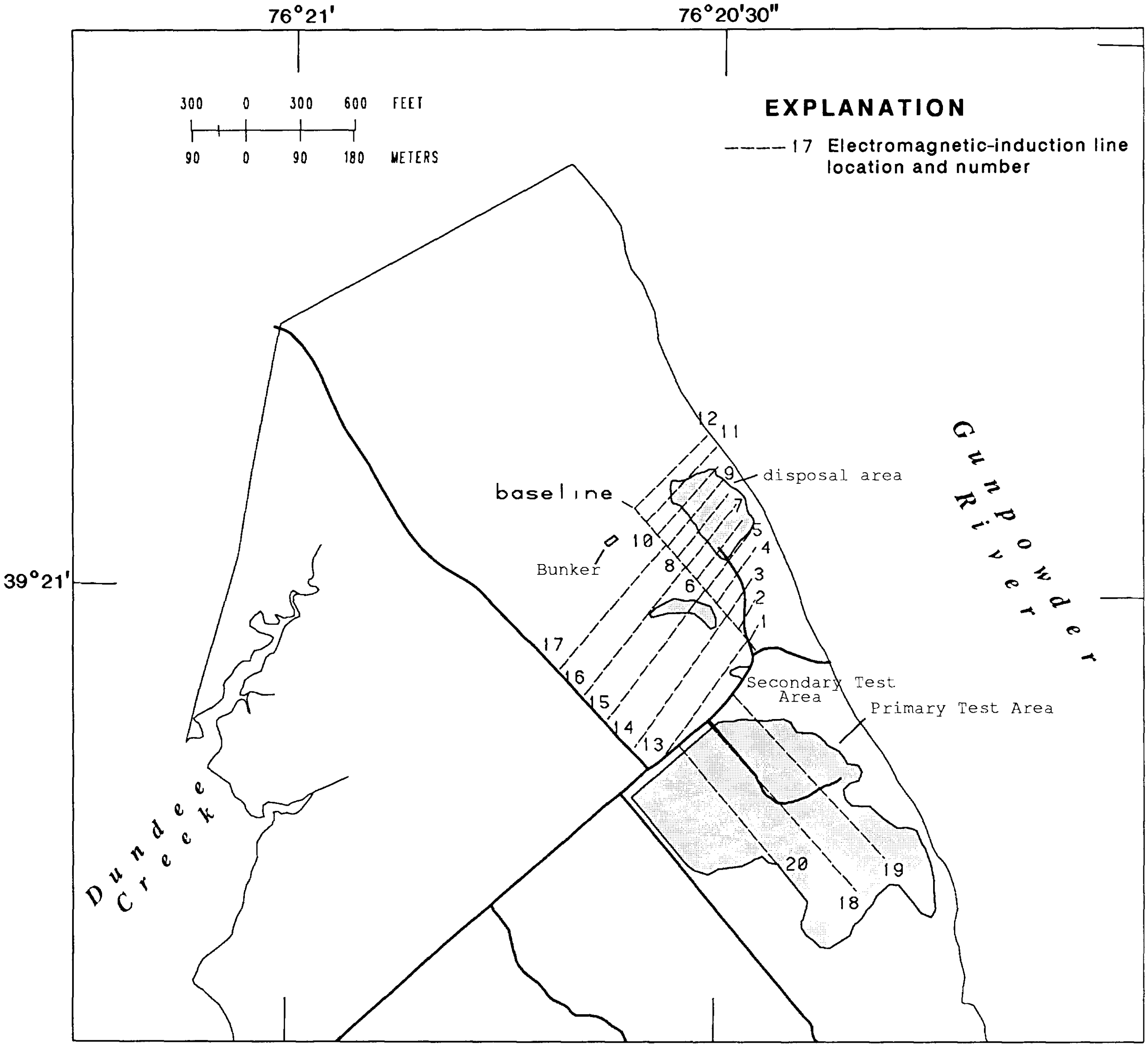

Figure 21.--Location of electromagnetic-induction lines at Graces Quarters.

Results from the surveys at Carroll Island and Graces Quarters were used to aid in well placement. Since there was uncertainty in both study areas about exact locations of testing and disposal, methods such as EM were used to provide additional information to increase the likelihood of finding areas of contaminated ground water. In several instances on Carroll Island and at least one instance on Graces Quarters, this method provided a basis for choosing a well location.

In general, the criterion for choosing a well location from EM work was the presence of an anomaly in which the change in conductivity value could best be explained by an increase in ground-water conductance due to manmade influences. The characteristics of such an anomaly were (1) a gradual change in conductivity over space, rather than the abrupt changes usually associated with interferences; (2) conductance values that were higher than background, but less than about 100 mS/m (millisiemens per meter), because higher values were often associated with interference; and (3) a lack of geologic or natural hydrologic influences on the anomaly, such as an increase in clay content in the near-surface material or brackish-water intrusion into the aquifer. If an anomaly could not be explained as natural or manmade interference, a well was placed in the area of the anomaly so it could be determined if the change in conductivity was due to the presence of contaminated ground water.

Magnetometer survey

Magnetometers were used in this study for two reasons: The first was to locate and delineate the extent of buried metal in SWMU's, and the second was to screen each well-drilling location to minimize the risk of drilling into hazardous material such as unexploded ordnance.

When used for the delineation of SWMU's, the magnetometer surveys were run in one of two ways, depending on the size of the area to be surveyed. In a situation like that at the Lower Island disposal site at Carroll Island, where there were multiple burial sites that were not visible at the surface, the area was gridded and surveyed systematically. The places where the magnetometer indicated that metal was buried were staked and included within the limits of the SWMU. Information about the location of the buried metal was then recorded and used to generate the maps that show the extent of the SWMU's.

If the SWMU were smaller, such as the EPG dump site on Carroll Island, the survey was less extensive. For most of the smaller sites, there was surficial evidence (such as mounding) that indicated where metal might have been buried. In these cases, the magnetometer surveys were limited to the mounded area and the areas immediately adjacent to the mounds. If there were any indication of buried metal beyond the mounded area, the survey was widened until the limit of the SWMU was found.

When magnetometers were used for safety purposes at the drill sites, the area that had been chosen for the well or test hole location was surveyed. The survey was centered around the chosen site, and an area with a radius of approximately 10 ft had to be determined to be free of buried metal before it was considered safe to drill. This often required that the drill site be moved slightly to decrease the risk of encountering buried objects with the drill bit.

Borehole Geophysics

Borehole geophysics were used in this study to help clarify the lithologic information obtained from the wells and test holes for purposes of well-screen placement and lithologic correlation. Borehole logs are obtained by measuring certain properties of the down-hole strata and plotting them on a strip chart against depth. Two types of borehole logs were run in this study: Gamma logs, and electric or E-logs.

Gamma logs were run on every well and test hole drilled during the study. With this method, the probes detect the natural radiation that is emitted from the rocks and sediments down the hole. In general, clay emits more radiation than silt, and silt emits more than sand or gravel. On the log, clay and silt show up as major deflections to the right, while sand and gravel produce less of a deflection. Gamma logs have several advantages over other types of geophysical logs. One advantage is that they are easy to interpret; another is that they can be run in open holes, through auger or casing, and with or without drilling fluids in the hole.

Electric logs can only be run in open holes with drilling fluid. For this reason, the electric logs were only done in the test holes, which were drilled using the mud-rotary method. The two types of electric logs that were run in this study were spontaneous potential (SP) and resistivity. Spontaneous-potential logs measure the naturally occurring voltages that result from chemical and physical changes at the contacts between different types of subsurface materials (Driscoll, 1986, p. 188). These potentials are measured with one electrode at the surface (usually in the mud pit), another electrode down the hole, and no source of external electric current. In general, impermeable beds such as clay produce a baseline on the log, with more permeable formations showing as deflections to the left.

Spontaneous-potential logs are generally run in conjunction with resistivity logs, as they were in this study. The resistivity logs measure the variation in resistivity that is caused by the different subsurface materials and by differences in total dissolved solids in the formation water. With resistivity logs, an external source of current is induced between two electrodes, and the current loss between the electrodes is measured. In general, sand with freshwater is much more resistive than clay, and appears on the log as a deflection to the right. However, sand with salty water looks similar to clay on the log; but when plotted in conjunction with the SP log, the differences are usually apparent. If the SP log deflects to the left, and the resistivity log shows little or no deflection, the formation is probably sand with salty water. If there is no deflection in either log, the layer is probably a clay.

With resistivity logs, different electrode configurations are possible and have different advantages and disadvantages, most of which affect only the quantitative interpretations of the logs. The configuration used in this study is called the normal log, and is done with both the current and the potential electrode on the same probe. Other types are the long normal and short normal, in which the distance between electrodes in the normal configuration is varied, and the single-point and lateral device, in which the number of electrodes that go down the hole is varied. More detailed descriptions of the various borehole logging methods and their interpretation are available in Driscoll (1986), and Keys and MacCary (1971).

Data from the borehole geophysics were used qualitatively in this study as an aid in well-screen placement and in geologic correlations. The standard procedure for well-screen placement was to drill the well until the lithologic core samples indicated that the desired depth had been reached. A gamma log was then run; the screen depth was then selected by a project hydrologist from the U.S. Geological Survey based on lithologic cores, depth to water table, and the deflections on the gamma log. The criteria for selecting screen depths included the quality of the sand or aquifer material, the possibility that the aquifer layer was a path for any releases, and the location of screens in other wells that were used to characterize releases from any particular unit. For geologic correlations, the geophysical logs were compared with information from the lithologic core samples, and used to either fill in gaps in the lithologic record, or give added accuracy to the locations of stratigraphic changes.

APPENDIX II

Well and Test-Hole Drilling and Installation

Two types of boreholes were drilled to fulfill the requirements of the study on Carroll Island and Graces Quarters. One type, known as test holes, was drilled simply for the purpose of determining the geologic framework of the study areas; these holes were sealed immediately after drilling was complete. The other type was drilled for the purpose of installing observation wells.

Drilling methods were different for the two types of holes. Test holes were drilled with the mud-rotary method, and observation wells were drilled (with two exceptions) using hollow-stem augers. The drilling, observation-well installation and development, and test-hole closure were done by the U.S. Army Corps of Engineers (COE).

The procedures for drilling were conducted to minimize risk of injury or toxic-chemical exposure to personnel, along with minimizing the chances of cross-contamination between aquifers and between drill sites. For safety purposes, the first 15 ft of each borehole (test holes and observation wells) was drilled using remote-control drilling with hollow-stem augers.

Remote-control drilling was used to prevent injury to personnel if a high-explosive or toxic agent filled round were encountered by the drill bit. The basic premise of remote-control drilling was that the drill rig was set up with pneumatic controls that could be operated from behind a bomb shelter located upwind at a safe distance from the drill site. The COE drillers and Technical Escort Unit (TEU) support personnel were in personal-protective equipment and remained behind the shelter while the auger was being advanced; all unprotected personnel remained in an area far removed from the drilling activities.

The remote drilling operation was similar to standard hollow-stem auger drilling, except that safety measures were much more pronounced. The auger flight would be advanced remotely in 5-ft increments, with continuous core samples taken during the drilling. After each increment was advanced, two TEU personnel moved to the drill rig and conducted tests on the borehole vapors with a U.S. Army M18A2 chemical-agent test kit, which consists of direct-reading colorimetric indicator tubes for different chemical agents (Vroblesky and others, 1988). If the tests indicated that the area were safe, the drillers moved to the rig and retrieved the core sample. The tests were repeated on the core sample, and the drillers then prepared the rig to advance another auger flight.

The process described above was repeated until 15 ft of auger was in the ground; after the final checks were completed and the area deemed safe, personnel were allowed to unmask, and outside personnel were allowed in the area. Total organic vapors from the core samples were checked by U.S. Geological Survey personnel using a photoionization detector, and the core samples were described, with descriptions recorded into the field notes. Details on the exact procedures used by the COE in setting up and operating the remote-drill rig are in Vroblesky and others (1988).

Because of logistical difficulties in implementing remote-control drilling operations, two drill rigs were used concurrently on this project. One rig was set up for remote-control drilling; the other was a standard drill rig, set up for either mud-rotary or hollow-stem drilling. Constraints on remote-control drilling included such things as weather conditions, equipment malfunctions, and the availability of various support personnel, laboratories and equipment. Therefore, operations were conducted so that the remote-control rig started a hole, drilled 15 ft, and then relocated so the rest of the hole could be drilled using standard drilling methods. Generally, several holes were started using remote-control techniques; these holes were finished by either (a) using the standard rig after the remote-control rig was moved to an area far removed from the drill site, or remote drilling operations ceased; or (b) using the same rig that started the hole, after removing the pneumatic equipment used in remote drilling. This was the most cost-effective way to drill, since logistical support for remote drilling was extensive and not always available.

Test holes

Five test holes were drilled on Carroll Island (fig. 22) before any observation wells were installed. The first 15 ft of each of the test holes was drilled using hollow-stem augers and remote drilling as described above. The remainder of each of the holes was drilled using the mud-rotary method with a 4-in.-diameter bit.

The Carroll Island test holes were designed primarily to obtain geologic information about the island. The 4-in. bit was used for speed, since no wells were to be installed in the test holes. Much of the geologic information was to be obtained from borehole geophysical logs. However, lithologic controls were needed to substantiate the information from the geophysical log; therefore, split-spoon samples were collected from each hole. A split-spoon is a 1-in.-diameter, 1.5-ft-long sampler that is attached to the end of a drill rod and advanced by dropping a weight at the top of the rod. The sample that is obtained is relatively undisturbed; it is retrieved from the hole and removed by unscrewing the sampler from the rod and splitting the two halves of the sampler. For most of the Carroll Island test holes, split-spoon samples were collected every 10 ft; on some of the test holes, samples were taken at less regular intervals. Depth of the test holes ranged from 140 to 180 ft.

When drilling was completed in each test hole, geophysical logs were obtained (see Appendix I). As soon as the geophysical logs were run, the test hole was grouted using Portland type IV cement. Holes were closed by pumping the cement from the bottom to the top while raising the tremie pipe. Drilling fluids were disposed of in accordance with APG policies (fluids were analyzed by APG and processed through a wastewater-treatment plant).

The five test holes on Graces Quarters (fig. 23) were drilled after all the drilling (test holes and observation wells) on Carroll Island was complete. A different strategy was adopted for these holes. Rather than drilling separate test holes, sealing them, and drilling wells adjacent to these holes, it was decided to install deep observation wells in the test holes after the lithologic and geophysical information was collected. The mud-rotary method was still used for drilling because the depth required for the test holes exceeded the depth capability of the auger rig. However, a 10-in.-diameter mud-rotary bit was used, rather than the 4-in. bit that was used on Carroll Island.

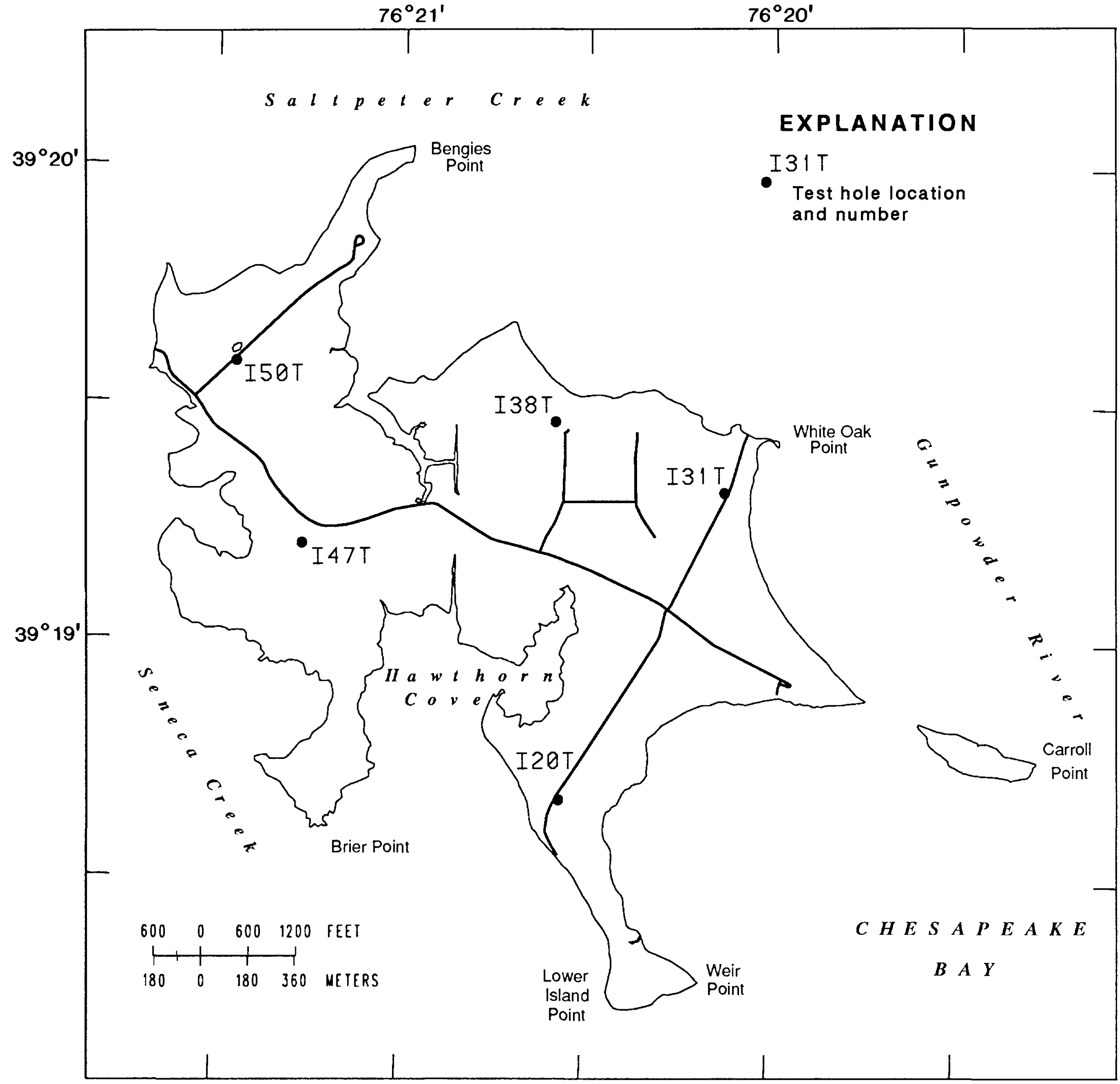

Figure 22.--Location of test holes on Carroll Island.

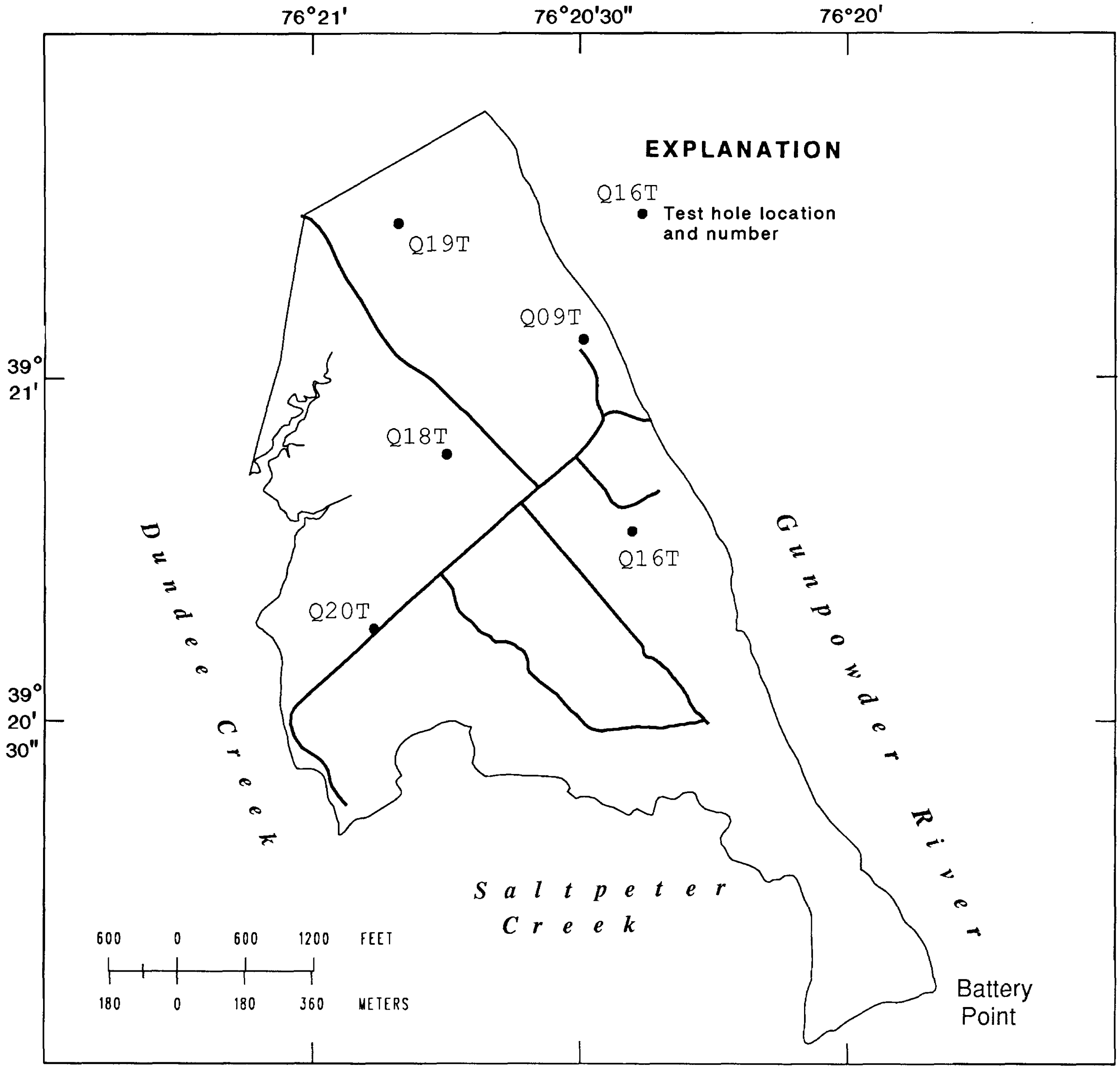

Figure 23.--Location of test holes on Graces Quarters.

Two of the test holes (Q09T and Q19T) were drilled with the 10-in. bit. This method proved to be very slow (often less than 10 ft per day); therefore, the remainder of the test holes were drilled with the 4-in. bit. Due to logistical constraints, the holes that were drilled as test holes were still needed for the installation of observation wells. To enable this, the 4-in. test holes were temporarily sealed with a thick slurry of bentonite mud; the holes were then drilled out to a 10-in. diameter with hollow-stem augers, and wells were installed as described below. Depth of test holes on Graces Quarters ranged from 140 to 180 ft.

Observation Wells

Drilling

Observation-well drilling was accomplished using continuous-flight hollow-stem auger with a 10-in. outside and 8-in. inside diameter. The first 15 ft of each well was drilled using the remote-control drilling techniques described above; the remainder of the hole was drilled using standard, non-remote drilling techniques.

Continuous lithologic samples were obtained using a 5-ft core-barrel sampler that was advanced with the auger. Auger flights were advanced 5 feet at a time; the core samples were removed by the drillers, placed in a trough, and described and recorded by U.S. Geological Survey personnel. Total organic vapors were checked with a photoionization detector to determine if personnel at the site should don gas masks; any readings above background were recorded. Representative samples from each stratigraphic layer were collected for later reference. The remainder of the drill cuttings were left on site.

Drilling proceeded in this manner until the aquifer of interest was encountered. Often, the aquifers contained sand that could not be collected in the core-barrel sampler. When this was encountered, drilling had to proceed without the core-barrel sampler, and representative samples could not be obtained. Subsequently, when clay was encountered, the material that was in the auger was removed and a gamma log was obtained. Lithologic and geophysical information was evaluated by Survey personnel, and a well-screen interval was chosen.

Installation

Well screens and casing were constructed with 4-in.-diameter threaded polyvinyl chloride (PVC) plastic. No glues were used during construction. Screen lengths were 5 ft for most wells, and 10 ft for selected wells, depending on aquifer thickness. Slot size for the screens was 0.01 in. Screen and casing were lowered to the specified depth with the hollow-stem augers still in place. A gravel pack of clean quartz sand was poured down the annular space between the well and the auger to a depth of 1 ft above the well screen (augers were raised as the well installation progressed). A 2-ft-thick bentonite seal was installed above the gravel pack; a grout of Portland type IV cement was installed above the bentonite seal to a depth of approximately 2.5 ft below land surface. A protective steel casing with locking cap was grouted in at this point with bentonite and cement. The protective casing was painted orange and labeled with the well number. Figure 24 is a schematic diagram of well construction.

In certain locations on Graces Quarters, the surficial sediments consisted of fine-grained material such as silt or clayey silt, and did not contain a significant amount of water. In these areas, saturated thickness above the confining layer was only 1 to 2 ft. The small saturated thickness and slow recovery rates would impede water-quality sampling. To

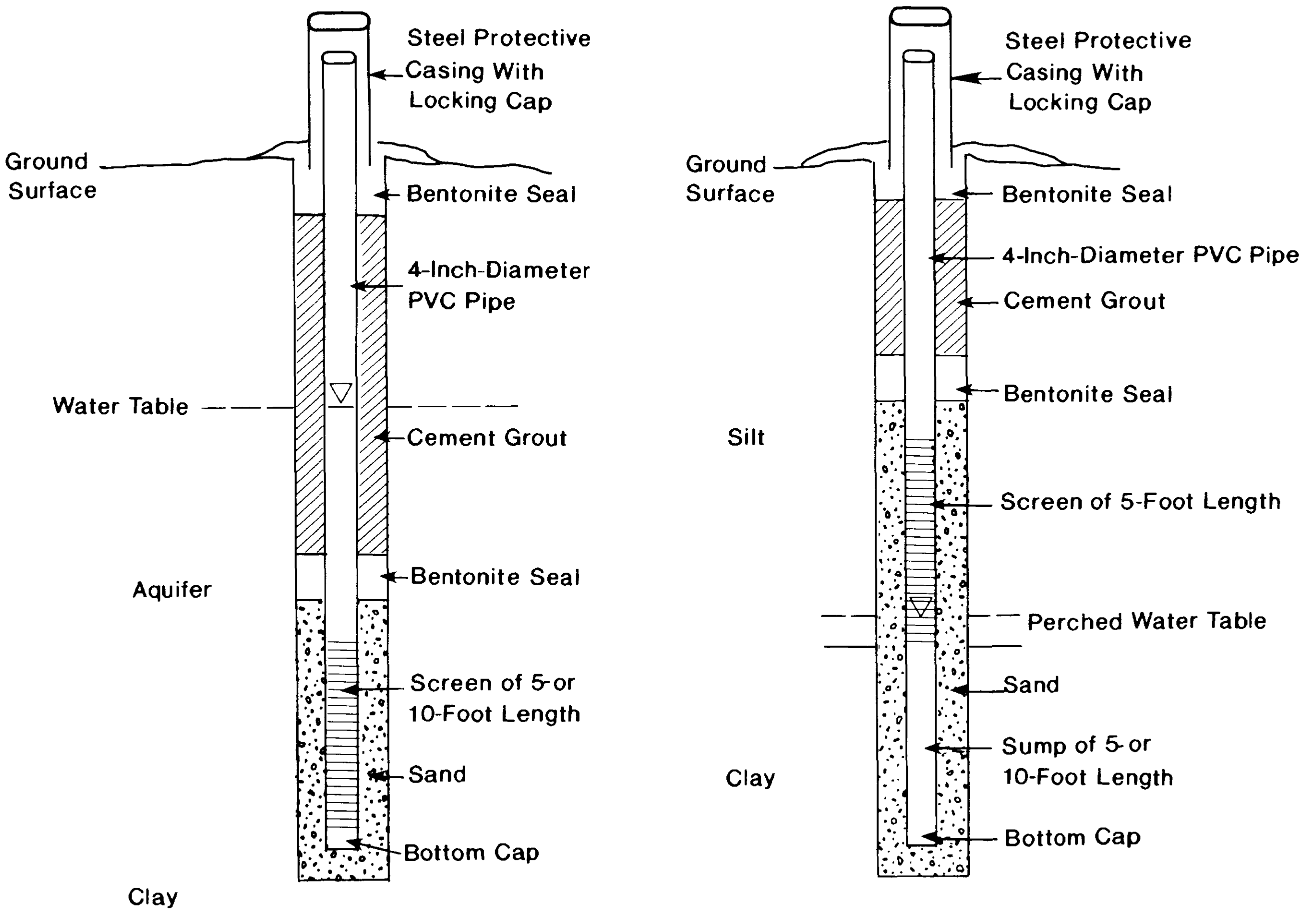

Figure 24.--Construction of observation wells on Carroll Island and Graces Quarters.

mitigate this, some of the wells on Graces Quarters were installed with a 5- or 10-ft sump of 4-in.-diameter PVC pipe attached between the screen and the bottom cap. This sump was designed to trap additional water at the bottom of the well, so sufficient water could be obtained for water-quality samples. A schematic of this type of well is also provided in figure 24.

Wells were developed using the surge-block method until the water was as free as possible of particulates; in low-yielding wells, some non-formation water was added to facilitate development. A sample of this water was collected for chemical analysis. All wastewater was disposed by the COE in accordance with APG policy (water was analyzed by APG and processed through a wastewater-treatment plant).

Construction information for pre-existing observation wells

Thirteen observation wells on Carroll Island and five observation wells on Graces Quarters that had been installed in 1977 for a previous study by USATHAMA (Nemeth and others, 1983) were used in this investigation. The location of these wells on each study area are shown in figures 10 through 19. Information about these wells is from Nemeth and others (1983), and is summarized below.

These wells were constructed of 2-in.-diameter PVC pipe. Screen length was generally 15 ft; screen slot size was 0.01 in. Screen depths were chosen so that the top of the screen was at the estimated level of the water table at the time of installation. A sand pack was placed in the boring around the slotted portion of the casing, and grout was placed around the casing above the water table to prevent surface-soil contamination from reaching the ground water (grout specifications were not available). Well heads were installed on each well to provide protection and permit easy access for sampling or water-level measurement. Drilling was done using hollow-stem augers and remote-control drilling methods.

In 1987, improvements were done to the USATHAMA wells by the COE. The existing well heads were cut off near the ground surface, and the sampling apparatus in each well was removed. A PVC standpipe (approx. 2.5 ft long) was installed by slipping a collar over the remaining well pipe and inserting the standpipe into the collar. No glues were used in this process. A protective metal casing with a locking cap was then installed by chiseling out some of the existing grout, installing the casing, and cementing the casing in place. The wells were then incorporated into the observation-well network for the study areas. A schematic diagram of the original well construction and the well configuration after the 1987 improvements is given in figure 25.

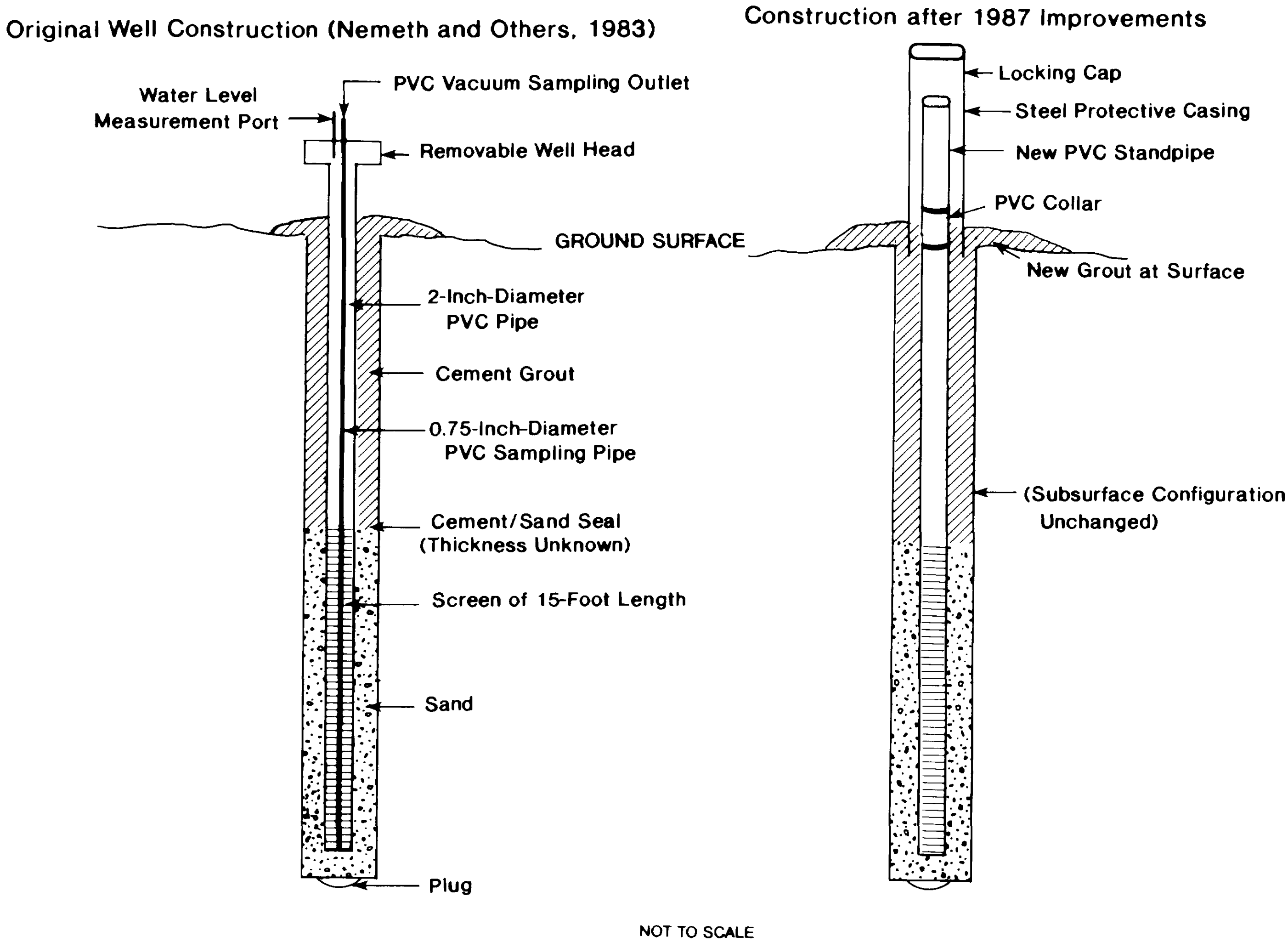

Figure 25.--Original construction of and improvements on pre-existing observation wells on Carroll Island and Graces Quarters.

APPENDIX III

Hydrologic Testing

Hydrologic testing was done on Carroll Island and Graces Quarters to determine aquifer properties of the areas. Because pumping tests were impractical due to potential contamination problems, the aquifer properties were determined using slug tests.

A slug test is done by rapidly changing the water level in a well and observing the response as the water level adjusts to the change. The response is a function of the well hydraulics and the properties of the aquifer in the area near the well. The aquifer properties that can be determined from a slug test are transmissivity and hydraulic conductivity; a rough estimate of storativity also can be obtained.

The ideal geometry for a slug test is a fully penetrating well in a confined aquifer (Cooper and others, 1967). If certain assumptions are met, the test can be valid for use in unconfined aquifers, or in situations where the well only partially penetrates either type of aquifer. In many stratified aquifers, the vertical permeabilities are only a small fraction of the horizontal permeabilities, and flow during a slug test is likely to be two-dimensional (Cooper and others, 1967). In unconfined situations, if the screened length of the well is far below the water table, and the perturbation in water level is small in relation to the active length of the well bore, the screened area acts as if it were confined (Ken Belitz, U.S. Geological Survey, oral commun., 1988).

Slug tests on Carroll Island were performed on all six of the wells that penetrated the confined aquifer, and on 22 of the wells in the surficial aquifer that contained sufficient water above the screened interval. On Graces Quarters, 10 slug tests were done; five each in the confined and surficial aquifers. The criterion for choosing wells for slug tests in the surficial aquifer was that the well have 8 ft or more of water above the top of the screen. Because most of the surficial aquifer on Carroll Island consisted of sand below a siltier layer, it was assumed that this criterion would be sufficient for the test to be valid. On Graces Quarters, there was sufficient fine-grained material in the surficial aquifer to make this assumption valid.

The slug tests were done using a Teflon-coated solid slug, a pressure transducer, and a digital data logger (data logger and transducer were the EL-200 Groundwater System, Envirolabs, Inc., California). The slug was introduced into the well, and the water level was allowed to equilibrate. The slug was then rapidly removed, and the response was recorded using the pressure transducer and data logger. The tests were run for approximately 16 minutes each; water levels were recorded at intervals that varied from 0.2 seconds at the beginning of the test to 100 seconds at the end.

Two methods were used to analyze the data from the slug test: the method of Cooper and others (1967), and the method of Hvorslev (1951). The Cooper and others (1967) method is mainly for use in confined aquifers, while the Hvorslev (1951) method is for use in point piezometers screened over a short interval at their base (Freeze and Cherry, 1979, p. 339). Because of the similarity in geometries of both the water-table and confined-aquifer wells that were tested on Carroll Island and Graces Quarters, both methods were used in the analysis of each slug test.

The Hvorslev (1951) method and the Cooper and others (1967) method both use a semilog plot of normalized heads over time. The Cooper and others (1967) method is a curve-matching technique in which the normalized heads are plotted on the linear scale, and time is plotted on the log scale. The resulting curve is overlain on a set of type curves, and a match point is used to calculate transmissivity. Horizontal hydraulic conductivity is then calculated by dividing transmissivity by the length of the screen. The type curve that best fits the data can be used to get a rough estimate of storativity. This estimate is not considered to be very reliable, however, because a small change in the shape of the curve results in a relatively large change in the storativity estimate. The Hvorslev (1951) analysis is used to calculate horizontal hydraulic conductivity directly. The data are plotted with the normalized head on the log scale and time on the linear scale. A straight line is fitted through the data points, and horizontal hydraulic conductivity is calculated from the time it took for a certain amount of the recovery to occur. A description of both methods can be found in Freeze and Cherry (1979, p. 339-342). Type curves for the Cooper analysis can be found in Reed (1980).

APPENDIX IV

Sampling Methods and Quality Control

The sampling methods for ground water, surface water, soil, and bottom sediments are discussed in this section. This section includes a discussion of sample equipment, sample withdrawal and preservation techniques, and equipment decontamination for each media. Components of the quality-control program that are discussed include the data-management procedures.

Ground Water

Ground-water samples were collected during two sampling episodes. The first was from July to September 1988. The second was in April and May 1989. The methods used in each sampling run were the same, and are described below.

Well evacuation

Stagnant water was purged from the wells in order to obtain a representative ground-water sample. The static water level and depth to bottom of the well were measured and recorded prior to purging. These measurements were used to calculate the volume of water to be purged from the well. Each well has a reference point marked on the well casing from which depth to water was measured. The reference point was surveyed in relation to sea level. Water-level measurements were made with a steel tape accurate to 0.01 ft. For 2-in.-diameter wells, the purge volume was 0.16 gal for each foot of standing water; for 4-in.-diameter wells, the purge volume was 0.65 gal for each foot of standing water.

Water was purged from the wells by using a bailer, bladder pump, or an air-lift pump. The water was withdrawn from the top of the column to induce flow through the screen. A bottom-filling bailer was used for the shallow wells (less than 30 ft of standing water). Bottom-filling and point-source bailers were constructed of Teflon, had an outside diameter of 1.7 in., and were either 2 or 3 ft in length. The bailers had a bottom discharge device made of Teflon to empty the bailer. A Teflon-coated steel cable was used to lower the bailers into a well. A bladder pump or submersible air-lift pump was used for deeper wells (greater than 30 ft of standing water). The bladder-pump assembly consisted of a stainless-steel pump with Teflon tubing. For some wells, a packer was used with the bladder pump to isolate the well screen and reduce the amount of water that had to be purged. The air-lift pump was constructed of stainless steel with polypropylene discharge hoses.

Dissolved oxygen concentration, temperature, pH, specific conductance, and total organic vapors at the well head were measured and recorded before purging. One to five well volumes of water were purged from each well. The number of volumes depended on the stability of temperature, pH, and specific conductance, which were measured after each well volume was purged. Once successive measurements were within 5 percent, the well was sampled. If the measurements were not stable after five well volumes were removed, purging was stopped and the well was sampled. This maximum purge criterion was established to minimize contaminant migration due to sampling procedures. If a well went dry during purging, it was sampled after the water level recovered above the screened interval.

Meters to measure field parameters included a YSI model 58 (dissolved oxygen), Beckmen model 21 (pH), YSI model 32 (specific conductance), and a Photovac Tip II (total organic vapors). All field meters were calibrated prior to purging and the results were documented in log books that were maintained for each instrument. The dissolved-oxygen concentration in each well was determined prior to purging using a dissolved-oxygen meter that was equipped with a probe attached to the meter with a 50-ft cable. The meter was calibrated using a standard supplied by the manufacturer. Water temperature was measured with a mercury-filled glass thermometer marked in increments of 0.1 ° C. Temperature also was recorded from the dissolved oxygen, pH, and specific-conductance meters. The pH was read on a meter equipped with a gel-filled combination pH electrode and an automatic temperature-compensating probe. The meter was calibrated with pH 4.00 and 7.00 buffers before the sample was collected. The specific conductance was measured using a meter with a glass conductivity cell. The meter was calibrated using laboratory prepared solutions having specific conductance of 200, 1,000, and 5,000 microseimens per centimeter at 25 degrees Celsius. The Photovac Tip II was calibrated to a laboratory sample containing 100 parts per million isobutylene in air.

Sample withdrawal and preservation

Specific sample-handling procedures, bottle requirements, and preservation techniques are discussed for all groups of constituents. Precleaned sample containers and sample preservatives were provided by the USATHAMA laboratories. The bottle-cleaning techniques are described in the USATHAMA QA Program handbook (1987, appendix H). Sample bottles were labeled prior to collection, and included the field identification number, name of collector, date and time of collection, place of collection, analysis requested, and preservatives used.

Once the water level in a well had recovered, a bailer or bladder pump was lowered to the well screen to collect the sample. The first sample collected was used to rinse the appropriate sample bottles, beakers, and collection containers. Thereafter, samples were collected in the following order of decreasing volatility: Volatile organics, total organic halogens, total organic carbon, total phenols, dissolved metals, anions, and field parameters.

The samples for analyses of organic compounds were collected at the well. The samples for volatile organics and total organic halogens were emptied from the bailer through a bottom-discharge device or from the discharge line on the bladder pump into a 40-mL (milliliter) glass vial with a Teflon-lined cap. Both of these methods produced a slow, steady stream of water into the sample vial, which minimized aeration of the sample. The vials were checked for air bubbles and a new sample was collected if bubbles existed. Samples were chilled on ice to 4 °C. Sodium sulfite was added to the total organic halogens vial to obtain a pH under two. The samples for total organic carbon and total phenols were collected in one 500-mL amber-glass bottle. Preservation of this sample included adding sulfuric acid to obtain a pH of less than 2 and chilling on ice at 4 °C.

Samples for inorganic analysis were collected in a clean, field-rinsed container and transferred to a field station that was located near the well. The field station consisted of meters to measure field parameters, filter equipment, and preservatives. Samples for inorganic analysis were filtered through a 0.45-micrometer membrane filter using a peristaltic pump. The filtration equipment consisted of a Masterflex pump with Teflon-lined tygon tubing. Before the samples for a new well were bottled, the filter stands and pump tubing were thoroughly rinsed with distilled water followed by sample water. Filter paper was changed between samples. The dissolved-metals sample was collected in a field-rinsed 500-mL polyethylene bottle. The sample was preserved with sufficient nitric acid to obtain a pH less than 2 and then placed on ice. The samples for total nitrogen and anions were filtered and collected in 500-mL polyethylene bottles and chilled to 4 °C.

Collection of field parameters, except for alkalinity, were previously described. Alkalinity titrations were performed on a 100-mL filtered sample. The sample was stirred continuously using a battery-powered magnetic stirrer while a Hach Digital tritrator was used to add sulfuric acid. Alkalinity was calculated as the end point of the curve generated from the pH as a function of the cumulative volume of acid added.

In addition to the groups of samples previously discussed, samples for semivolatile organic compounds and an expanded list of inorganic compounds (tables 6 and 9) were collected in the spring of 1989. The semivolatile samples were collected at the well in 1-L (liter) amber-glass bottles with Teflon-lined lids. The same collection techniques described for the total organic carbon were used. The samples were chilled to 4 °C. The additional inorganic constituents were collected in polyethylene bottles. The metals were preserved with nitric acid to a pH less than 2 and chilled.

All samples were recorded on chain-of-custody sheets and placed in coolers filled with ice. The coolers were sealed with tape and sent to the analytical laboratory within 24 hours.

Decontamination

All equipment was decontaminated between sample sites. Decontamination consisted of distilled water rinses as specified in the USATHAMA QA Program handbook (1987, p. 5-4). The U.S. Environmental Protection Agency (Jack Potosnak, written commun., 1988) has requested a different decontamination technique be used for any additional sampling. The technique involves cleaning the sample equipment with a nonphosphate detergent and rinsing with tap water, distilled water, acetone, and then hexane. In order to maintain consistent methodology, the USATHAMA method will be used. Equipment blanks will again be collected to test the adequacy of the decontamination.

Surface Water

Surface-water samples were collected from surrounding surface-water bodies, sluice pipes, ponded water, and sumps. The same equipment and techniques that were used to collect and perform field measurements for the ground-water samples were used for the surface-water samples when appropriate. The surface-water samples were collected directly into the specified container when possible. A bailer was used to retrieve the sample at sites with a sump or difficult access. The sample bottles, preservatives, and field measurements described for the ground-water samples were used for the surface-water samples. None of the samples, however, were filtered, so analyses of the sample would include any constituents sorbed onto suspended sediment in the surface water.

Soil and Bottom Sediment

Soil and bottom-sediment samples will be collected from the SWMU's and test areas on Carroll Island and Graces Quarters. Grab samples (about 4 L each) will be collected from the sites at a depth of less than 2 ft below the soil or sediment surface. The samples will be collected with a stainless-steel corer auger or shovel. The samples to be analyzed for semivolatile compounds will be put into a 1-L wide-mouth glass (amber) jar. Samples for volatile compounds will be placed in three 40-mL glass vials. The samples for indicator constituents will be placed in a 1-L wide-mouth glass (amber) jar. All samples will be chilled to 4 °C. The sampling tool will be decontaminated with distilled water and a stiff brush. A plan detailing safety constraints and collection techniques is being prepared by the U.S. Army and the U.S. Geological Survey and will be forwarded to the USEPA when it is completed.

Quality-Control Program

A quality-control program is being maintained during the project. The program consists of data-management procedures, the preparation of quality-control samples in the field, and a laboratory quality-assurance program.

Data-management procedures include recording field data, preparing chain-of-custody sheets to track samples and associated results, and verifying and loading the results into data bases. A field sheet (fig. 26) was prepared for each sample site and is kept in a field notebook. The sheet will be used for additional sampling and modified for different media. A chain-of-custody record for each sample was prepared in the field and contained the following information: Field-identification number, unique sample-identification number (assigned in laboratory), sample matrix, analyses requested, date and time of collection, preservative, and signature and initials of requester. The chain-of-custody procedures were continued at the laboratory. All samples were logged in and assigned a sample-identification number. The name of the person performing each sample-preparation technique or analytical procedure and the respective dates were recorded. Any problems arising during sample preparation or analysis were added to the chain-of-custody record (for example, if a sample required centrifuging at the extraction phase).

The analytical data are entered and loaded onto a computer tape that is sent to USATHAMA and loaded onto their data base. When the data are loaded, USATHAMA performs a review of the laboratory analytical procedures and data-reporting formats. The procedures are explained in the USATHAMA QA Program handbook (1987). The data are then sent to the U.S. Geological Survey and loaded onto the QWDATA data base. The data are reviewed by comparing dates, times, and field parameters recorded on the field sheets with laboratory values. Additionally, an ion balance is computed to assess the accuracy of some analytical results.

Field QC samples were prepared in order to assess the sample-collection and analytical techniques. The samples included trip blanks, wash blanks, and duplicate samples. Additionally, split samples from selected wells were sent to the USATHAMA contract laboratory and the U.S. Geological Survey Water-Quality Laboratory for analysis.

The cleanliness of a batch of precleaned bottles was investigated using trip blanks. For a trip blank, one of each container type was selected, filled with distilled water, and transported to the laboratory to be analyzed along with the rest of the samples.

Wash blanks were collected to determine if sampling equipment was properly cleaned between sites. Wash blanks were obtained by putting distilled water into the sampling equipment and then transferring it to sample bottles that were returned to the laboratory for analysis.

Duplicate samples were sent to the laboratory to determine the reproducibility of the data. The presence of duplicate samples were not disclosed to the contract laboratory; duplicate samples were labeled as unique, individual samples with different collection locations. Also split samples were collected from the same well and sent to two different laboratories.

CARROLL ISLAND/GRACES QUARTERS
Ground-water Quality Sampling and Analysis Field Sheet

Well No. ________________ Sample No. ___________ Sampled by ____________

PURGING

Method: _______________Total gallons purged:__________Date: ______________

Values:	Initial	Volume 1	Volume 2	Volume 3
Time	________	________	________	________
Uncomp cond	____@____	____@____	____@____	____@____
Comp cond	____@____	____@____	____@____	____@____
pH	____@____	____@____	____@____	____@____

Comments: ____

SAMPLE

Withdraw method: ____________________ Date: _____________ Time:_______

Field parameter

DO	________@________	Water temp.	____________
Tip II	________________	Alkalinity	____________
Uncomp cond	________@________	Bicarbonate	____________
Comp cond	________@________	Appearance	____________
pH	________@________		____________

Comments: ____

SHIPPING

Date samples mailed: ______________ Number of samples: _________________

Analysis	No. of bottles	Preservative
Var. Inorganics (C)	3	ice
HPLC Organics (LC)	1	ice
GCMS Extra. Org. (MS)	1	ice; add NA2S2O3
*** Metals (NF)	1	ice; HNO3 to get pH < 2
Nutrients (S)	1	ice; H2SO4 to get pH < 2
TOC (TOC)	1	ice;
Pesticides (UP)	1	ice; add NA2S2O3
Aromatic vol. (VP)	4	ice; HCL to get pH < 2
TOX (X)	1	ice
Total Phenols (Z)	1	ice; H2SO4 to get pH < 2

Figure 26.--Field ground-water-quality sampling sheet.

The approximate number of blank and duplicate samples was:

Constituents	QC Protocol
Organic analyses, including TOC, TOX, volatiles, semivolatiles	1 trip blank/10 samples 1 wash blank/10 samples 1 duplicate/10 samples 1 split/10 samples
Inorganic analyses, including trace metals, common ions, BOD, COD, and nutrients	1 trip blank/20 samples 1 wash blank/20 samples 1 duplicate/20 samples 1 split/10 samples

The laboratory quality-assurance procedures are detailed in the USATHAMA QA Program handbook (1987). The handbook explains the laboratory certification program (chapter 4), sample-collection techniques (chapter 5), analytical procedures (chapter 6), quality-control checks (chapter 7), instrument maintenance (chapter 8), and data-reporting requirements (chapter 9). All USATHAMA contract laboratories are required to follow the procedures set forth in the handbook. Laboratory adherence to the handbook is monitored by personnel of the Technical Division of USATHAMA at Aberdeen Proving Ground, Maryland.