Report GL-94-
August 1996

US Army Corps
of Engineers
Waterways Experiment
Station

Identification and Analysis of Wetlands, Floodplains Threatened and Endangered Species and Archaeological Geomorphology at Picatinny Arsenal, NJ

Volume I: Text

by U.S. Army Engineer Waterways Experiment Station

WES

Prepared for U.S. Army Environmental Center
Aberdeen Proving Ground, Maryland 21010-5401

and

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Picatinny Arsenal, New Jersey 07806-5000

Contents

List of Figures

List of Tables

Preface

This project was performed during the period February 1993 to June 1994 at the U.S. Army Engineer Waterways Experiment Station (WES). The project was conducted under the authority of the U.S. Army Environmental Center (AEC), Aberdeen Proving Ground, Maryland, and the concurrence and direction of the U.S. Army Armament Research, Development, and Engineering Center (PTA), Picatinny Arsenal, New Jersey.

The project was completed by a multidisciplinary team of scientists, engineers, and technicians at WES. The following individuals completed the following tasks of the project: Task One (geomorphology), Dr. Lawson Smith, Maureen Corcoran, Dr. Stephen Sprecher, Dr. Fred Briuer, Dr. Lillian Wakeley; Task Two (wetlands), Robert Lichvar, Russ Pringle, Ellis J. Clairain; Task Three (hydrology), Bill Johnson, David Abraham; Task Four (threatened and endangered species), Mike Waring, Darrell Evans; Task Five (development of data base), Gary Hennington, Rich Campanella, Beth Talbert, Angela Amrich, Fraser Roberts, Michael Bishop, Jim Hoff. Dr. Smith served as the project principle investigator. General supervision was provided by Mr. Joe L. Gatz, Chief, Engineering Geology Branch; Dr. A. G. Franklin, Chief, Earthquake Engineering and Geosciences Division; and Dr. W. F. Marcuson III, Director, GL.

The project managers for AEC were CPT Steven Oluic and Mr. Ira May. The project coordinators for PTA were Mr. Ted Gabel and Ms. Christina Gray. The authors acknowledge the invaluable assistance of AEC and PTA who had the foresight to make this project possible.

At the time of the issuance of this report, the Director of WES was Dr. Robert W. Whalin. The Commander was COL Bruce K. Howard, EN.

Summary

A multidisciplinary investigation of Picatinny Arsenal in northern New Jersey was conducted in support of ongoing and future CERCLA/SARA requirements. The investigation focused on the cooperative delineation, description, and analysis of key environmental factors and resources. Topics investigated included wetlands, floodplains, threatened and endangered animals, and geomorphology (including soils, geology, and cultural resources). Wetlands were delineated and evaluated at the planning level on the basis of field examination of botanical, hydrological, and soil indicators. Floodplains were identified through modeling of the hydrological response of local streams using the model CASC2D. The geographic limits of floods having predicted return intervals of 1, 2, 10, 25, 100, and 500 years were estimated. A planning level assessment of habitats for various types of usage by the threatened and endangered bald eagle (*Haliaeetus leucocephalis*), peregrine falcon (*Falco peregrinus*), Indiana bat (*Myotis sodalis*), bog turtle (*Clemmys muhlenbergii*), long-tailed salamander (*Eurycea longicauda longicauda*), timber rattlesnake (*Crotalus horridus horridus*) eastern woodrat (*Neotoma floridana*), long-tailed shrew (*Sorex dispar*), and the cerulean warbler (*Dendroica cerulea*). The geomorphological development of Picatinny Arsenal was investigated to provide critical information to the location, evaluation, and management of cultural resources. Identification, delineation, and analysis of these factors involved the construction of a large geographical data base which was analyzed with the help of a robust geographic information system (GIS). The GIS data base produced by this investigation includes 33 "coverages" of environmental and cultural information. This data will be of substantial value to many future projects at Picatinny Arsenal.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
square feet	0.09290304	square meters
tons (mass) per square foot	9,764.856	kilogram per square meter

1 Introduction

In fulfilling their responsibilities under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980, the Superfund Amendments and Reauthorization Act (SARA) of 1986, the National Environmental Policy Act (NEPA) of 1969, and additional federal and state environmental statutes, Department of Defense (DoD) installations are faced with a broad spectrum of requirements for restoration activities. These complex environmental issues and challenges associated with the restoration of military installations requires that they be considered and addressed in a multidisciplinary manner if they are to completed in the most efficient and timely manner.

This report describes a multidisciplinary approach to the development of information at Picatinny Arsenal (PTA) required by CERCLA, SARA, NEPA, and other appropriate statutes as identified by the *CERCLA/SARA Environmental Review Manual* (ERM) developed by Region II of the U.S. Environmental Protection Agency. The information is meant to not only satisfy specific compliance requirements but serve as an organized body of comprehensive environmental data for use in subsequent CERCLA/SARA activities and installation management. The information is presented in various forms designed for optimum and ready use: (1) text, describing what, how, and why data were developed (Volume One); (2) a collection of plates illustrating the geographic distribution of data across PTA (Volume Two); and (3) digital files compatible with a geographic information system (GIS).

Background

On 27 May 1992, a meeting was held at Picatinny Arsenal (PTA), Dover, NJ, between representatives of the Directorate of Engineering and Housing (DEH), the U.S. Army Engineer District, New York (NAN), and the U.S. Army Engineer Waterways Experiment Station (WES). The purpose of the meeting was to discuss the need for geomorphological information for use in cultural resource and wetlands identification and evaluation at PTA. Particular attention was given to fulfillment of the requirements identified in the CERCLA/SARA Environmental Review Manual (ERM) provided by the Environmental Protection Agency (EPA) Region II Office (January 1988). Following the meeting of 27 May 1992, a draft Scope of Work (SOW) and several subsequent modifications designed to accomplish various types of requirements were submitted by WES to PTA and NAN for consideration and discussion.

A second meeting was held at PTA on 23 November 1992 to discuss the WES draft SOW. Representatives from the U.S. Army Environmental Center (AEC), PTA, the EPA, and WES met to discuss the SOW submitted by WES. At the conclusion of this meeting, WES was requested to submit a revised SOW to address the delineation of wetlands and floodplains, and to conduct a geomorphological investigation that would provide critical environmental information for cultural resource management on installation restoration sites at PTA with particular attention given to the integration and coordination of the proposed investigation with a subsequent cultural resources survey. The SOW would also include the development of a data base of the results of the study in a GIS compatible with existing hardware/software systems at PTA. At the request of AEC in May 1993, the identification of threatened and endangered (T&E) plants and animals was added to the SOW.

A SOW was proposed that addressed the requirements stated in the meeting of 23 November 1992 and in subsequent discussions with AEC. The SOW was divided into four tasks: (1) geomorphological information for cultural resource management; (2) identification and delineation of wetlands; (3) identification and delineation of floodplains; and (4) identification and delineation of T&E plants and animals. In addition to the four principle tasks, the development of a GIS digital database of the existing data used and data developed for and by this project is also presented. This database, when used in the GIS, will represent a powerful and valuable resource for managing a wide variety of projects at the arsenal.

Purpose

The primary purpose of the proposed project is to provide critical information for locating and evaluating the archeological record and identifying and delineating wetlands and floodplains at PTA in direct support of CERCLA/ SARA Installation Restoration (IR) requirements. The detailed information provided will be used in cultural resources identification and evaluation and identification and delineation of wetlands, T&E plants and animals, and floodplains as described in the CERCLA/SARA ERM (EPA Region II, January 1988). The geomorphological information will provide the necessary context for National Historic Preservation Act (NHPA) and Sec. 404 determinations of cultural resources significance and will support the identification and delineation of floodplains and wetlands.

Tasks and Objectives

As stated above, the project consists of five separate but interrelated tasks. In the following paragraphs, each task is described in terms of its principle goal and objectives. The completion and results of each task is documented in Sections Three through Seven of this report.

Task one: geomorphological information for cultural resource management

The goal of Task One is to provide critical information for locating and evaluating the archeological record at PTA in direct support of IR requirements. The detailed geomorphological and environmental information developed will also be used in the identification and delineation of wetlands (Task Two) and floodplains (Task Three). The geomorphological and other environmental information will provide the necessary environmental context for NHPA and National Environmental Policy Act (NEPA) determinations of significance of the archeological record.

Objectives. There are two objectives of Task One:

a. Identify specific locations where a significant possibility exists that elements of the archeological record may exist both at and below the land surface (definition of archaeologically sensitive areas).

b. Describe the geomorphological and paleoenvironmental context of the known archeological record in terms of (a) landform, (b) past, present, and probable future geomorphic processes, (c) subsurface conditions, (d) integrity of the archeological record, (e) probable site environment at the time of site occupation, (f) probable impact of mitigation activities, and (g) recommendations for subsequent studies, as identified in the ERM for CERCLA/SARA projects (EPA Region II, 1988).

Task two: identification and delineation of wetlands

Several questions must be considered when managing wetland resources. Initially one must determine *where* the wetlands occur, then identify *which* functions are provided by them, *what* impacts may occur if an alteration of the wetland is necessary, and finally, *how* can one restore or enhance remaining wetlands. Studies to address each question could be conducted to provide a comprehensive picture of the wetland resources at PTA and for determination of management options compatible with mission requirements of the facility.

Section Four of this report is designed to address the first question; *Where* are the wetlands? Although information gathered in identifying where the wetlands occur will be useful in addressing other concerns, details for implementation of those types of studies are beyond the scope of this effort.

Wetlands are often the source of valuable environmental information used in the reconstruction of the landscape history of the area (subtask 1.5), which in turn, is important to the identification and evaluation of cultural resources. Wetlands such as bogs, ponds, and lake fringes (all of which may occur at PTA) are natural sinks for indicators of past climates, hydrological regimes, vegetation communities, and geomorphological processes. Multidisciplinary study of wetlands by biologists, archaeologists, soil scientists, hydrologists, and geologists, when conducted as a true team effort, results in a synergistic product of significant value to many natural and cultural resource management issues as well as installation restoration. Restoration of some hazardous and toxic waste sites at PTA may impact wetlands, particularly the ability of the wetlands to continue to provide specific wetland functions like water quality improvement, sediment stabilization, and waterfowl habitat. The information gathered by this proposed study will be used to evaluate potential impacts of IR activities on wetland integrity and functions.

Objectives. The objectives of Task Two are to:

a. Identify and locate wetlands within PTA for planning purposes.

b. Delineate wetland boundaries at priority locations designated by staff from PTA and the AEC.

c. Prepare maps displaying wetland locations at scales commensurate with the planning and delineation efforts.

d. Verify the wetland mapping efforts through site investigations.

e. Provide general recommendations for managing (including restoration and enhancement options) wetland resources compatible with Federal laws and the mission objectives at PTA.

Task three: identification and delineation of floodplains

The goal of Task Three (Section Five of this report) will be to provide a detailed and analytical delineation of areas of PTA which would be inundated by floods of various return frequencies. The specific return frequencies of floods will be identified by PTA and/or AEC.

Objectives. There are two objectives of Task Three:

a. Identify and delineate areas at PTA which would be inundated by floods of various return frequencies.

b. Provide hydrological information for use in Tasks One and Two.

Delineation of floodplains is accomplished through the use of the two dimensional hydrologic model "CASC2D," a two dimensional model that provides simulated flow and stage information for drainage basins. Using CASC2D, flow velocities and water depths can be calculated at selected grid cells for the entire database, in this case, PTA. CASC2D is well suited to GIS methods and will be integrated into the other geomorphological and wetland analyses conducted by GIS methods. Floodplain delineation focuses on simulating a period of hydrologic record to generate flow frequency and stage-duration curves for all areas of PTA which may be subjected to floods. Data required by CASC2D include landuse, soil type, detailed topography of overbank and channel cross-sections, rainfall distributions, and observed streamflow hydrographs. Upon completion of the hydrologic analyses, stage-discharge curves and frequencies of inundation can be rapidly simulated for every location on the arsenal using the GIS. The hydrological analyses will then be used in the wetland delineation (along with field observations) to determine the hydrological conditions of potential wetland areas.

Calculation of flood flows and stages requires the use of some detailed topographic cross sections in a number of areas which will necessitate surveys of a number of cross sections. WES was aware that a number of cross sections have already been surveyed for use in previous floodplain determinations at several PTA locations. These data were obtained and incorporated into the CASC2D data files for use by this project.

Task four: habitat characterization for threatened and endangered species

The goal of Task Four is to provide information on T&E plant and animal species on PTA. The task focuses primarily on identification and evaluation of existing and potential habitat, based on existing information. The task was not intended to address specific impacts from future projects, and should not be considered to be a Biological Assessment as defined in the EPA guidance. The results of Task Four represent a planning level assessment of T&E habitat that, when combined with data from other tasks, will provide PTA with an integrated baseline from which to make planning decisions.

Objectives. The objectives of Task Four are to:

a. Identify plant and animal species of concern.

b. Delineate existing and potential habitat for those species.

c. Prepare habitat maps for species of concern.

d. Provide management recommendations for addressing potential future actions.

Task five: development

of a digital database

A major product of this project will be the development of a large digital database of many environmental and cultural features at PTA. The digital data consist of GIS "layers" of such parameters as wetlands, floodplains of various frequency floods, surface geology, geomorphic features, topography, hydrology, soils parameters, archeological sensitivity areas, areas of significant historical land modification, T&E plant and animal distribution and habitat and various other types of data, both previously existing and developed by and for this project. WES will provide the data to other appropriate offices in a format to be used on the GIS used at PTA at the request of PTA.

Objectives. There were four objectives of Task Five:

a. Digitize all relevant data into GIS compatible data layers.

b. Screen and correct the data for inconsistencies, incompatibilities, and spatial resolution.

c. Assist in the identification and analysis of features and themes required by Tasks One through Four (above) through the completion of relational database analyses.

d. Develop geographical depictions of the data for compilation of Volume Two of the Report.

In the following sections, the completion and results of each of the five tasks is documented. Collectively, completion of these five tasks has resulted in the development of a substantial database which will be of significant value to a broad range of environmental and installation management issues at PTA.

2 Environmental Setting

Physiography and Geology

Picatinny Arsenal is located in the New Jersey Highlands of the New England Physiographic Province (Figure 1) (Wolfe 1977). The Arsenal is primarily contained within a southwest to northeast trending valley extending from several miles south of the Rockaway River to the Pequanock River approximately three miles north of the northern limit of the Arsenal. On the northwest boundary, Green Pond Mountain, a downfaulted synclinal belt of Paleozoic rocks, rises to an elevation of approximately 1,280 ft msl, almost 600 ft above the valley floor. Much of the southeastern slope of Green Pond Mountain is steep to near vertical. On the southeastern side of Picatinny valley, the valley side slopes are more gentle, rising to a maximum elevation of near 1,160 ft msl. The valley floor grades downward southwesterly from elevations of about 830 ft msl in the northeast to 700 ft msl at the southern boundary of the Arsenal.

Most present-day geomorphic features of Picatinny Arsenal are at least partly attributable to Wisconsin-age glaciation. The central valley of the Arsenal is thickly covered with sediments derived from some aspect of glaciation or its aftermath. However, events that occurred much longer ago in geologic time still strongly control the shape and appearance of landforms. Rock units of preCambrian, Cambrian, and Silurian ages were folded and faulted during Paleozoic time. Erosion of these tightly folded strata left the long, narrow ridges trending northeast to southwest and defining the Arsenal boundaries.

Gneissic preCambrian rocks underlie more than half of the Arsenal, in contact with younger strata in the subsurface along a northeast-southwest trending line (Figure 2). This contact is a nonconformity, representing an indeterminate length of geologic time missing from the rock record and is faulted along the northwest edge of Picatinny Lake (Figure 3). These harder, older gneisses form the ridge along the southeast boundary of the Arsenal, the crest of which is more than 300 ft above the valley floor and Green Pond Brook.

Green Pond Mountain forms the northwest boundary of the Arsenal. It exists because of the Green Pond Conglomerate, a hard, erosion-resistant quartzose rock unit of Silurian age. The flat valley floor between these two ridges of hard rock is underlain by softer rock units of Cambrian age. The valley floor has been drilled extensively during several studies, to identify high-yield water-bearing zones and to determine the extent of contaminated zones. The Cambrian-age Leithsville Formation is almost always intersected by drillholes when they extend below the glacial sediments.

A weathered zone of the Leithsville Formation commonly is present under the oldest glacial till of the valley floor. The weathered zone is discontinuous because it is a remnant of an ancient erosional surface, predating glaciation, and was locally thinned or removed by moving ice. Where it remains, it has been described variously in drilling logs as weathered rock fragments in a silty clay matrix, or a weathered, tan argillaceous (clayey) dolomite. This weathered zone is often several feet thick, grading downward into unweathered gray dolomite representing the pre-weathering condition of this formation.

Another Cambrian unit, the Hardyston Quartzite, is present nonconformably over the preCambrian gneiss, and immediately underlies glacial sediments in a narrow band trending southwestward from the southern edge of Picatinny Lake, along the base of the ridge. This unit continues under the valley floor where it underlies the Leithsville Formation, and has been encountered in drilling.

The geologic underpinnings for the geomorphic details of the present land surface are provided by the ridge-forming preCambrian and Silurian rocks, and the softer, valley-forming Cambrian rocks between them. Properties of these older, folded rock units also control the hydrology of this region. The hard, ridge-forming rocks have very low water yields, usually only as small amounts of water from fractures and joints. Because of its carbonate mineral composition, the Leithsville Formation has been susceptible to solutioning and formation of cavities. When water has had access to this formation, it could move along fractures and locally dissolve an interconnected flow system. Where it is not highly weathered, the present-day Leithsville Formation has water yields of up to 380 gal/min.

The properties of the older rocks also influenced the action of glaciation in this region during Pleistocene time. Deposits from glacial events earlier than Wisconsinan have been identified in the area as Illinoisan and Pre-Illinoisan in age (Stanford 1990). During Wisconsinan time, ice extended over these ridges and valleys. The present-day Arsenal is a short distance north of the terminal moraine which represents the southernmost extent of Wisconsinan glaciation. Because this area was so near the margin of the glaciers glacial erosion removed only a thin veneer from the Pleistocene land surface. The ice gave more than it removed: layers of till, glacial Lake Picatinny, and of water-sorted glacial sediments reach thicknesses of 180 ft over the deeply weathered Cambrian bedrock of the valley floor. Well sorted and finer grained sediment layers represent the influence of Lake Picatinny, a temporary lake that formed as the land responded to changing drainage patterns as the late-Wisconsinan glacier receded. Properties of surficial geologic units are given in Table 1.

Table 1
Surficial Geologic Units at Picatinny Arsenal

Geologic Unit[1]	Description	Geologic Processes	Geologic History
af-Artificial Fill	"Excavated till, sand, gravel, and rock...brick, concrete, asphalt... cinders, and slag" (ibid), sometimes covered with concrete, asphalt, or buildings. 10-20 ft thick	High run-off, very slow infiltration	Artificially emplaced, compacted, and often drained.
aft-Trash Fill	"Trash and construction debris mixed and covered with excavated till." Includes pits and landfill. 25 ft thick.	Infiltration	Excavated till and bedrock.
Qs-Swamp and Marsh Deposits	Highly and moderately decomposed black muck and mucky peat (usually over 0.5 ft) overlying gray sand, silt, and rock deposits. <10 ft thick; may be 25 ft thick in places	Organic matter accumulation, reduction and re-oxidation of both mineral and organic constituents, sediment accumulation from upstream locations	In beds of peri-glacial lakes: alluvial and lacustrine accumulation of sands and silts; colluvial deposition of till and alluvial resorting thereof; drainage and bog formation; sediment accumulation from run-off and entrapment by vegetation; lake-bed filling
Qta-Talus	"Angular boulders of bedrock with little or no matrix material. Forms stepaprons along base of cliffs" (ibid). ≤20 ft thick	Vertical accretion of upslope sediments, organic matter accumulation, vertical soil growth	Post-glacial rockslides and colluviation following physical weathering of cliffs and steep faces along southeast side of Picatinny Peak.
Qpo-Cobble gravel fining to sand	"Cobble gravel, fining ... to pebbly sand" (ibid), mostly covered with buildings and road surfaces.	Rapid infiltration, slow pedogenesis, bioturbation	Fluvial and Deltaic deposition in Glacial Lake Picatinny, subsequent fluvial reworking by Green Pond Brook
Qlwt-Till: unstratified and unsorted stones	"Unstratified and unsorted boulders, cobbles, and pebbles in a yellowish-brown...silty fine sand to fine to medium sand matrix" (ibid). In places a thin (<2 ft) silt loam cap forms the matrix for the coarse materials."	Deposition of ablation and flow tills at base of glacier, locally reworked by Green Pond Brook	Most of the sediment was carried by subglacial drainage from rock eroded from valley bottom
Qlwtm-Terminal Moraine	"Yellowish brown to grayish brown till ... forming ridge and kettle topography" (ibid).	Deposition of ablation till and stratified glacio fluvial deposits	Southernmost advance of Late Wisconsinan glaciation
Qlbv2-Sand and Gravel in proglacial lakes dammed by TM	Sand and gravel in sorted strata. Of very minor extent on northwest boundary of installation. Not visited. Soil maps do not agree with mode of origin. It may be preferable to delete this unit from the legend.	Deltaic deposition (Gilbert type) in glacial Lake Picatinny. Vertical accretion sediments interbedded with lacustrine silts.	"Deposited in a proglacial lake dammed by the Terminal Moraine ... during [glacial] retreat" (ibid).
Qlpi2-Cobble gravel over sand gravel	"Cobble gravel overlying probable sand and pebble gravel along both sides of Picatinny Lake" (ibid).	Mixed deltaic and colluvial deposition interbedded with lacustrine deposition	Growth of small deltas on Lake Picatinny followed by colluviation.

[1] Stanford, S. D. (1989). Surficial geology of the Dover Quadrangle, New Jersey. New Jersey Geological Survey, Williams and Heintz Map Corporation, Capitol Heights, MD.

Climate

The moisture and temperature regimes of the Picatinny Arsenal area are controlled by the seasonal dominance of three different air masses (Figure 4). During the summer, the Bermuda High pressure cell centered over the western Atlantic Ocean and the eastern Gulf of Mexico results in the drawing of warm, moist air from the Gulf of Mexico into the area. The occasional summer passage of cold fronts through the area collide with the warm moist air resulting in 24 hr precipitation events which may be equal to average monthly precipitation totals.

Figure 4. Air masses influencing climate of Picatinny Arsenal

During fall months, the primary source of moisture is the Atlantic Ocean, when infrequent tropical storms come ashore, with possible widespread heavy precipitation. These storms may cause damaging floods over large areas.

Winter months are strongly influenced by the occurrence of a semipermanent high pressure system of cold air to the north. The passage of clod fronts through the area during winter months often results in rain or snow followed by clear, dry, cold air. During early spring, frontal passage may cause flooding due to rain fall on frozen snow covered ground.

The average annual precipitation for the Picatinny Arsenal area is approximately 48 in. (Morris Plains weather station). Although average monthly precipitation totals are surprisingly similar in the 3 to 5 in. per month range, maximum precipitation usually occurs in August and September, with lowest precipitation in February (Figure 5). Annual variation in daily temperatures is illustrated in Figure 6. As expected, lowest daily high temperatures of 38 deg (Fahrenheit) and daily low of 20 deg are recorded in January. Highest daily high and low temperatures usually occur in July at 85 and 61 deg, respectively. Typical daily variation in temperature is 20 to 26 deg.

Figure 5. Average annual precipitation near Picatinny Arsenal (Morris Plains, NJ)

Figure 6. Annual average daily temperatures, Picatinny Arsenal (Morris Plains, NJ)

Hydrology

The principal hydrologic features of Picatinny Arsenal include three small streams and two small lakes. The streams are Green Pond Brook, which flows completely through the Arsenal, Burnt Meadow Brook, a small tributary to Green Pond Brook, and Bear Swamp Brook, which enters Green Pond Brook in the central part of the Arsenal. The two lakes at Picatinny Arsenal are Lake Denmark and Picatinny Lake. Lake Denmark is the larger of the two and is approximately 194 acres in size at normal pool elevation. Lake Denmark is relatively shallow with depths of 6 to 7 ft at maximum. Picatinny Lake is approximately the same length (one and a half miles) as Lake Denmark but is slightly deeper and more narrow covering approximately 100 acres. Maximum depths in Picatinny Lake are approximately 11 ft below normal pool elevation.

Both Lake Denmark and Picatinny Lake are artificial reservoirs created by the construction of dams and weirs in the late 1880's.

The principal hydrologic feature of Picatinny Arsenal is Green Pond Brook which originates in Green Pond to the north of Picatinny Arsenal. Green Pond Brook enters Picatinny Arsenal from the northeast and flows parallel to Green Pond Mountain, entering the Arsenal just below Lake Denmark. Green Pond Brook then enters into the northern end of Picatinny Lake, flows through Picatinny Lake, and then out the southern end of Picatinny Arsenal to its confluence with the Rockaway River at Wharton, New Jersey.

The U.S. Geological Survey (USGS) maintains three gaging stations on Green Pond Brook. Station SW-1 is located just upstream from Picatinny Lake and represents a drainage area of 7.65 square miles. This drainage station gage has been active since 1982. Just below Picatinny Lake on the Arsenal is Station SW-2 on Green Pond Brook. It gages an area of 9.16 square miles and has been in operation since October 1984. Station SW-3 occurs near the confluence of Green Pond Brook with the Rockaway River and is approximately 100 ft upstream from the point where Green Pond Brook exits the Picatinny Arsenal. Station SW-3 has a drainage area of approximately 12.0 square miles and has been active since October 1982. Hydrographs for Green Pond Brook show that the stream reacts rapidly to local precipitation events. Peak discharges are achieved within several hours following precipitation. The recession of the hydrograph is prolonged, however, due to the storage capacity of Lake Denmark and Lake Picatinny. Mean daily discharge during the 1986 forty year for Stations SW-1, SW-2, and SW-3 were 4.7, 16.1, and 26.5 cu ft/sec, respectively.

One of the key hydrologic elements at Picatinny Arsenal are the wetlands. Section Four of this report describes in detail the location and the character of wetlands which occur at Picatinny Arsenal. These wetlands serve a number of important hydrologic functions, including flood flow conveyance, groundwater recharge, groundwater discharge, and sediment stabilization. Prior to historic landuse changes in the 19th century, the lower third of Picatinny Valley on the Arsenal was primarily wetland.

A useful illustration of the hydrology of Picatinny Arsenal is given in the response of Green Pond Brook to the record floods of 5 to 7 April 1984, in northern and central New Jersey. During this period of time the weather station at West Wharton, New Jersey (approximately 2 miles south of the southern entrance of Picatinny Arsenal) recorded 4.34 in. of rainfall. At USGS gaging station SW-1, the maximum discharge recorded was 333 cu ft/sec, more than twice the previous maximum peak discharge of 142 cu ft/sec. At Station SW-3, the maximum peak discharge was 572 cu ft/sec, which exceeded the previous peak discharge of 445 cu ft/sec. The flood of 5 to 7 April 1984, was one of the worst floods in the history of northern New Jersey. The flood was primarily caused by excessive precipitation during the flood period but was set up by a storm that occurred the week before. This previous storm deposited up to 8 in. of snow over much of northern New Jersey. During the flood precipitation, snow rapidly melted and ran over soil that was previously saturated, quickly raising the stages of most of the streams and lakes in the area. Table 2 shows the elevations of flood flow in Green Pond Brook during the flood of 1984.

Table 2
Elevation of Flood Surface, Green Pond Brook, Flood of 4 to 7 April 1984

Miles Above Mouth	Elevation (ft above sea level)	Miles Above Mouth	Elevation (ft above sea level)
3.9	176.2	4.7	691.3
2.4	174.5	4.7	691.2
2.4	174.3	4.4	690.3
7.4	771.9	4.3	689.8
7.1	749.1	4.3	689.8
6.6	716.0	3.6	688.7
5.4	699.0	3.0	687.4
5.4	698.2	3.0	687.2
5.2	692.3	2.7	684.6

Soils

The soils of Picatinny Arsenal represent a complex adjustment of pedogenic processes to the climate, hydrology, geology, topography, and geologic history of the Arsenal area. Most of the information regarding the soils of Picatinny Arsenal comes from the soil survey of Morris County, completed by the Soil Conservation Service in 1977. The Morris County soil survey identifies 24 different soil types in the Picatinny Arsenal Area. These soil types comprise six soil groups including two humaquept soils, two muck soils, three fragiaquept soils, nine fragiudult soils, five dystrochrept soils, and three soils classified as made land. The most common type of soil at Picatinny Arsenal, fragiudult, occur on the glacial till areas on the valley side slopes and ridge crest. The fragiudult soils include both the Hibernia and Rockaway soil series. Dystrochrept soils occur in the valley bottom and include the Riverhead, Pompton, Otisville, and Netkong soil series. The fragiaquept soils include the Ridgeberry and Whitman soil series and occur in low narrow drainage areas within the glacial till covered uplands. The fragiaquept soils are all hydric. In the lowermost part of Picatinny Valley near the southern end of the Arsenal, two muck soils occur, the Adrian and the Carlisle, both of them hydric. The two humaquept soils that occur are both of the Preakness series and also occur in the lower end of Picatinny Valley in association with the muck soils. Both of the humaquept soils are also hydric.

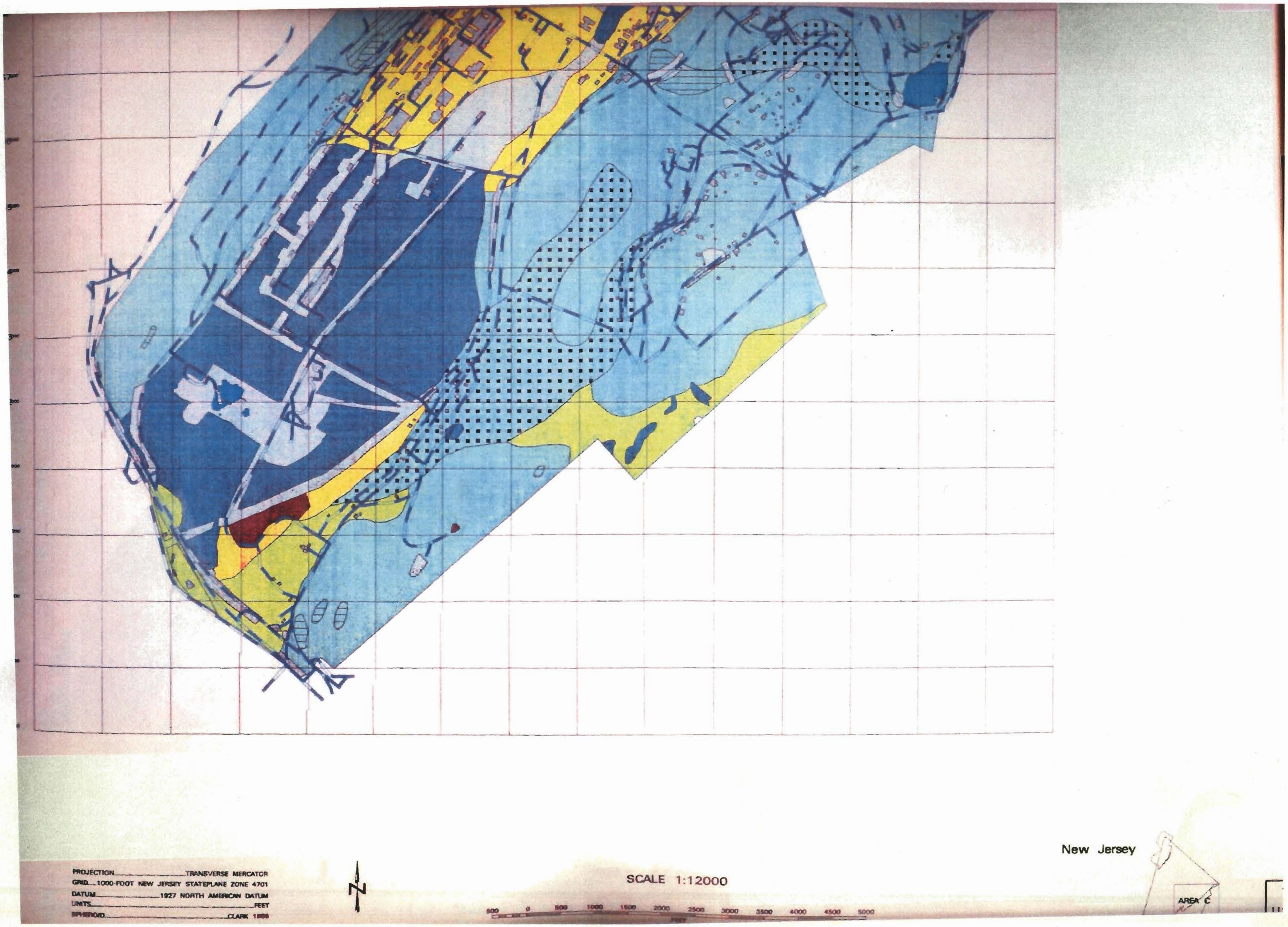
The initial review of the Morris County soil survey in the Picatinny Arsenal area indicated that there were several areas where soil boundaries could be in need of revision. Consequently, a number of sites were examined in the field to determine the accuracy of soil boundary locations. Descriptions of these soils at the 22 sites visited in the field are included in Appendix 1.

Examination of the distribution of the soil series with respect to the surficial geology of Picatinny Arsenal reveals that in fact the soils are closely related to their parent material as expected. Table 3 identifies the relationship between surficial geologic units, the soil series, and the characteristics, processes, and processes of soil development for each of the soil series.

The characteristics of surficial soils in geologic units are, of course, critically important to management activities at Picatinny Arsenal. Table 4 identifies by soil unit and geologic unit the implications for management of these soils with respect to cultural resources, threatened and endangered plant and animal species, wetlands, and other considerations.

Vegetation

The distribution of vegetation at Picatinny Arsenal has been the subject of a number of investigations over the last 10 years. A series of plates in Volume 2 represents four different vegetation maps for Picatinny Arsenal. All of these maps illustrate the significant impact of European man on the distribution of vegetation across the landscape. A detailed discussion of the vegetation of Picatinny Arsenal is included in Section 4, the delineation of wetlands.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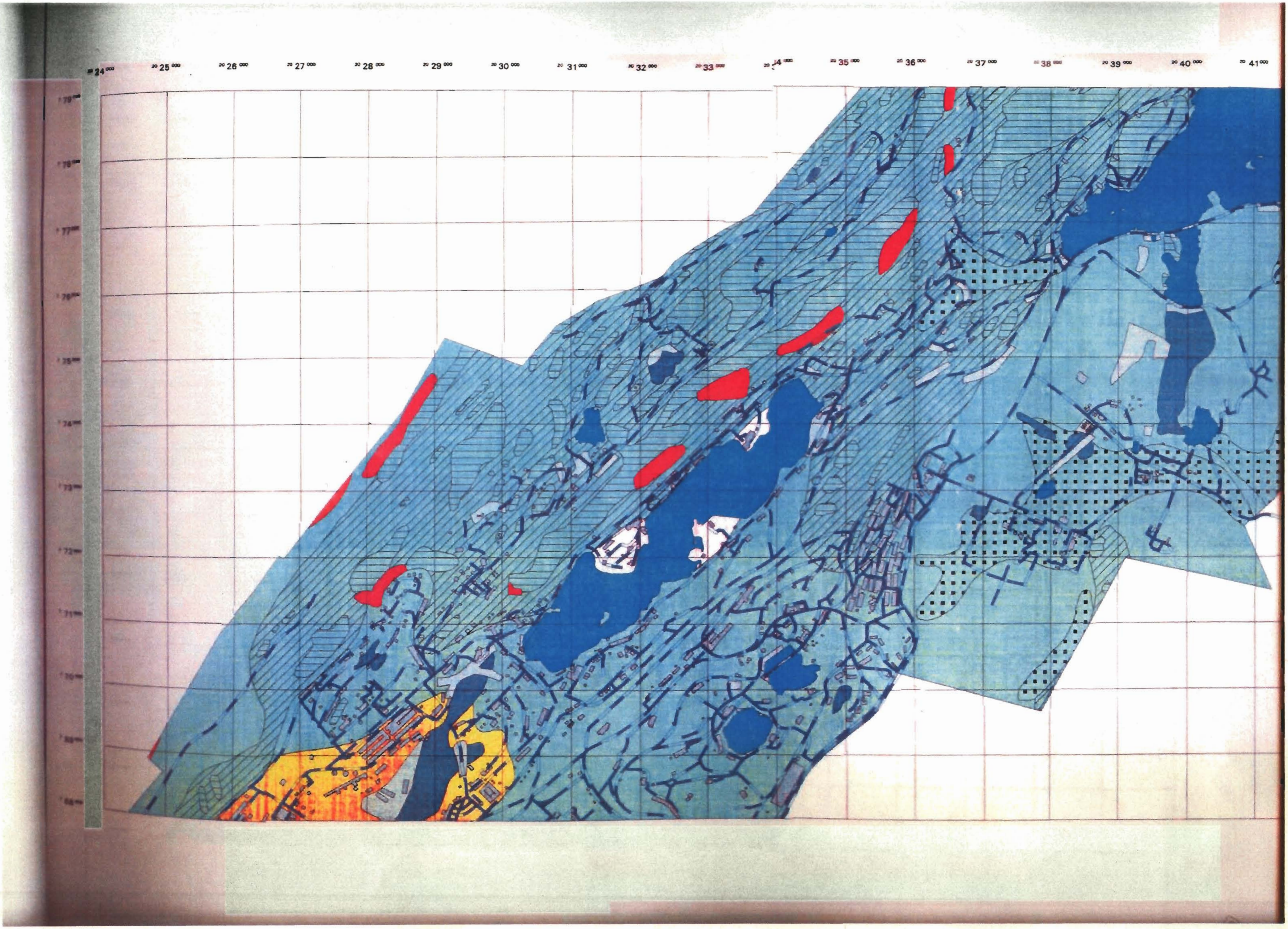

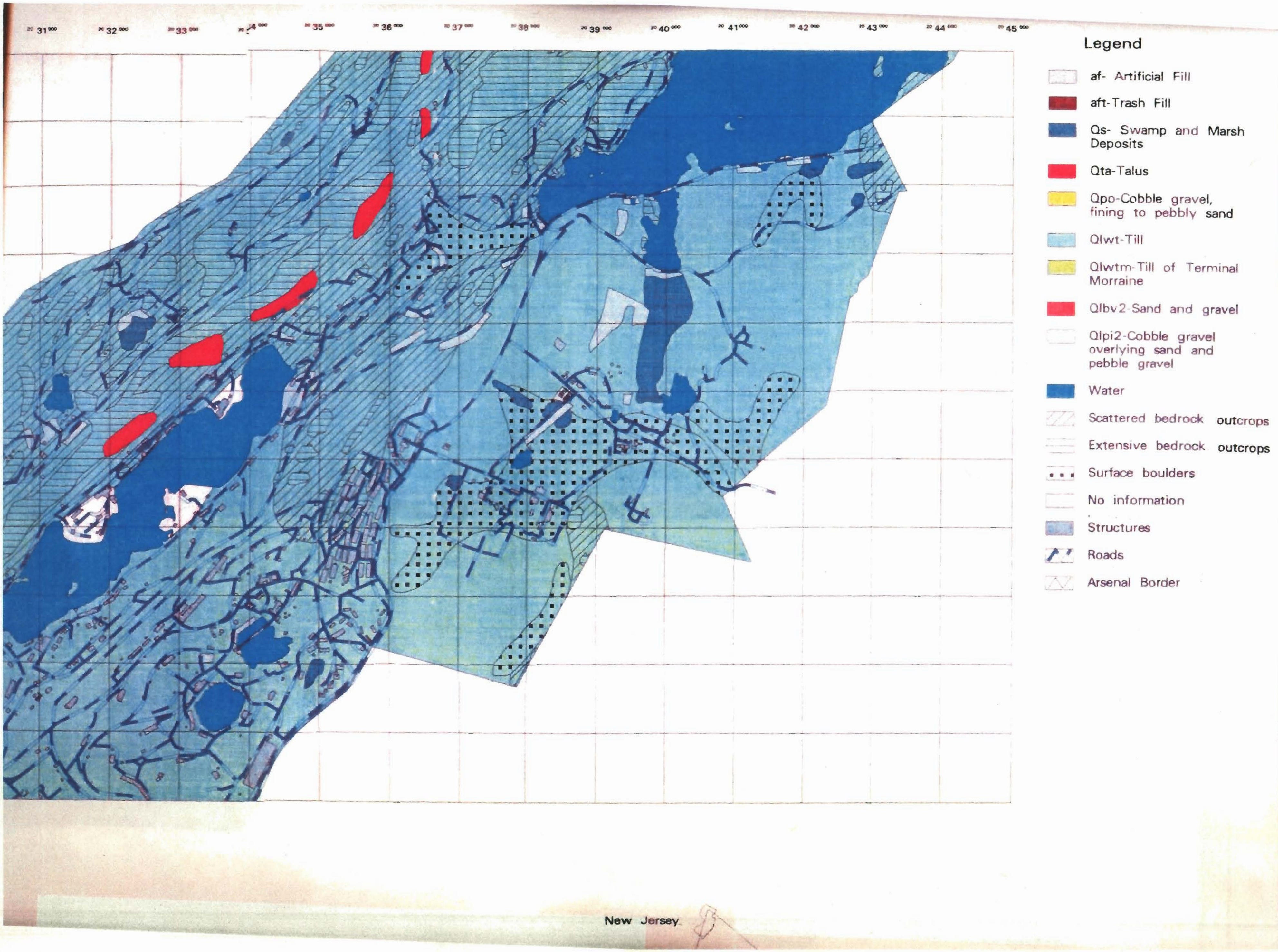

Legend
af- Artificial Fill
aft-Trash Fill
Qs- Swamp and Marsh Deposits
Qta-Talus
Qpo-Cobble gravel, fining to pebbly sand
Qlwt-Till
Qlwtm-Till of Terminal Morraine
Qlbv2-Sand and gravel
Qlpi2-Cobble gravel overlying sand and pebble gravel
Water
Scattered bedrock outcrops
Extensive bedrock outcrops
Surface boulders
No information
Structures
Roads
Arsenal Border
New Jersey

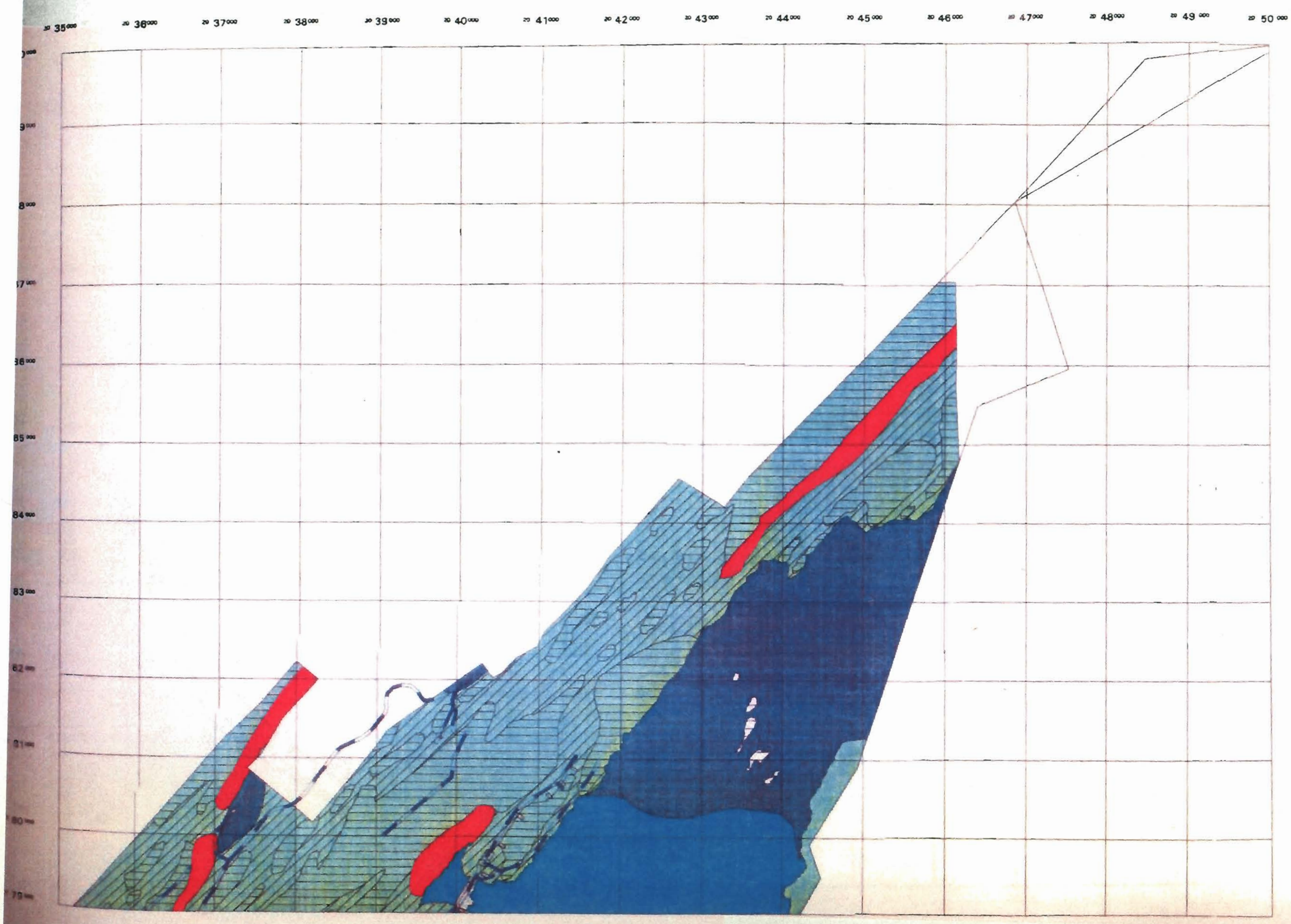

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Table 3
Correspondence Between Soil and Geologic Units

Geologic Unit	Soil Units	Soil Characteristics	Soil Processes	Soil Development
af-artificial fill	Ma, Ua, UrD	Land surface paved or built upon, or greatly enough disturbed that original soil cannot be recognized. Sometimes mapped in association with moderately steep till soils.	Surfaced areas have minimal infiltration, are abiotic, run-off dominates hydrologic budget, experience cryoturbation if substratum is wet, most pedogenic processes arrested. Areas of unsurfaced fill (as on golf course) have moderate to rapid infiltration, are subject to erosion if abandoned, will experience long term settling as soil structure begins to develop and mineral weathering and translocation commence. In areas of fluctuating high water tables redox processes will corrode sensitive materials and accelerate structural reorganization.	Artificial compaction, truncation, fill; often in areas of former marsh.
aft-dumps	Ma	Dumps or landfill. Of minor extent and probably inaccurately mapped. Unit should be consolidated with Ua unless installation can provide accurate maps of dumps.	Settling, decomposition of dumped material, unidentified processes associated with decay of industrial chemicals in soil.	Artificial excavation and turbation.
Qs-swamp	Ad, Cm, Wm	More than 16 in. of muck overlying coarse-textured (sandy to cobbly) substrata (Ad, Cm), or Organic-rich, overthickened topsoil overlying grey, poorly drained subsoil (Wm). Organic materials are largely sapric, occasionally with hemic layers below 2 ft.	Accumulation of organic material through retarded decomposition and strong reduction. Reduction of ferromanganese minerals if present, and subsequent migration in soluble, reduced state. Minimal horizonation.	Proglacial lakes and kettles filled with decaying herbaceous (and, to a lesser extent, woody) material that accumulated in place and filled shallow margins of water bodies. Sediment from upslope erosion accumulates as well. In mineral soils horizons form minimally in water-logged conditions, but iron reduces and causes gray colors throughout subsoil.
Qta-talus	Rt-rock outcrop RvF-Rockaway steep	Slopes over 30 percent, rock outcrops (gneiss and conglomerate) extensive; boulders cover more than 40 percent of surface; discontinuous, broken horizonation, fragipan at bedrock contact.	Downslope movement of fines, accumulation of organic debris in cracks between rocks, rapid runoff and subsurface flow of water.	Rain, frost, and biologic stresses weaken soil and rock fabric, causing landslides and talus formation. Consequently, soils poorly developed and often most active in pockets of organic accumulation between rocks.

(Continued)

Table 3 (Concluded)

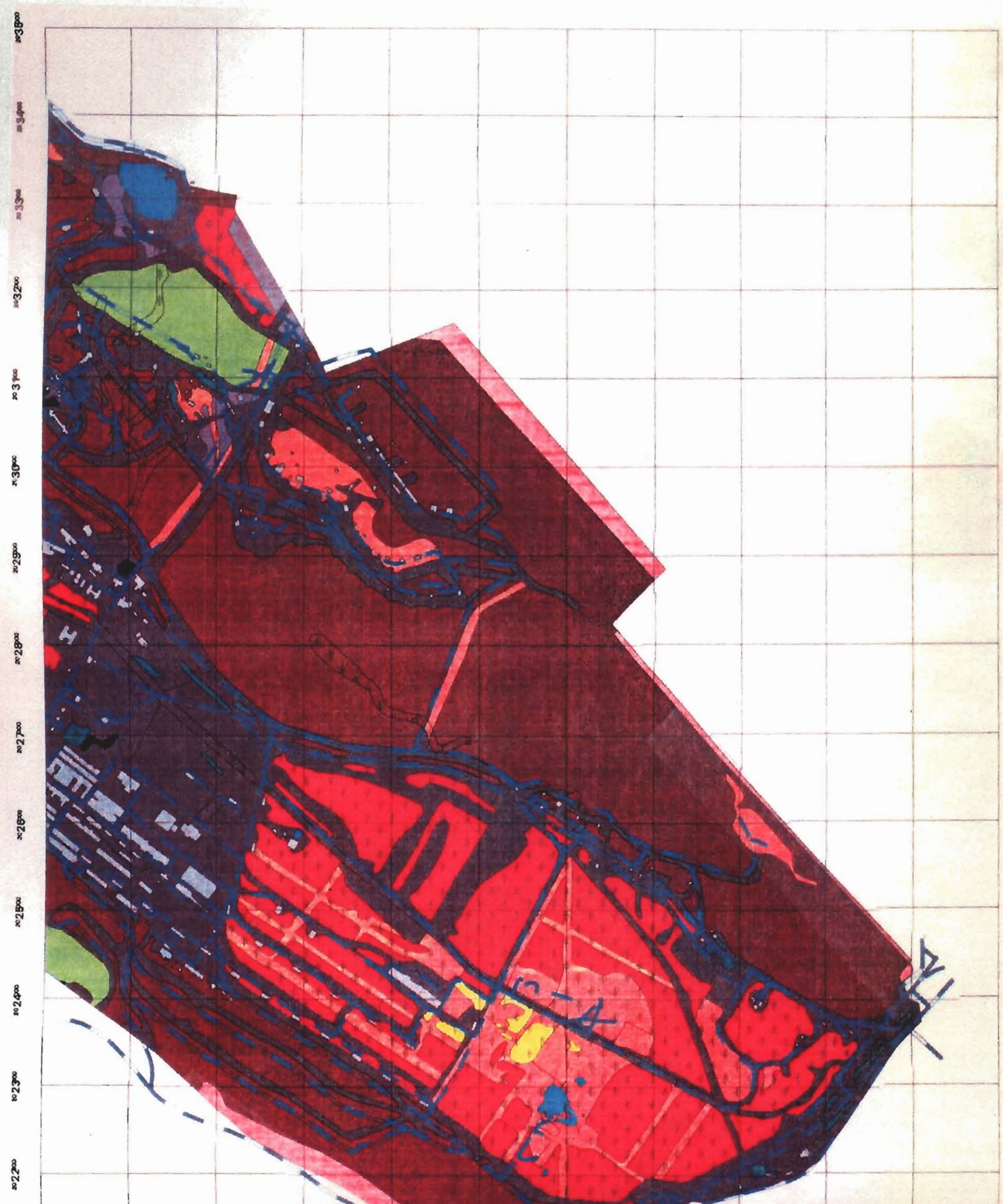
Geologic Unit	Soil Units	Soil Characteristics	Soil Processes	Soil Development
Qpo-cobble/ gravel/sands	Ua-urban land OtC-Otisville 3-15 percent slopes.	This unit has been almost entirely filled and built up on the arsenal. We recommend that the Qpo geologic delineations be remapped as af-artificial fill.	As for unit af above.	As for unit af above.
Qlwt-till	Rockaway, Hibernia, and Ridgebury, Map Units	Cobbly sandy loams to cobbly silt loams over argillic horizons at 1-2 ft and fragipans at one to three feet; bedrock at four to ten feet. Well drained except in drainageways. Slopes vary from 0 to >45 percent. Hues generally 10YR. Acid pH's.	Moderately rapid vertical permeability to fragipan, where water movement becomes lateral; most soils well oxidized; translocation of clays downward; fragipan development poorly understood; little evidence of creep except on steep slopes.	Deposition from glacial debris; compaction during dewatering; colluviation on steep slopes; fragipan development often at bedrock contact; eluviation and illuviation of clay to form Argillic horizon; transformation and translocation of ferromanganese redox products where water tables fluctuate.
Qlwtm-terminal moraine	Rockaway and Hibernia Map Units; Ad and CM in closed depressions.	As above.	As for unit Qlwt above.	Deposition at edge of glacier; otherwise as above.
Qlbv2-sandy and gravelly lake deposits	NtB, RmB, and PtB	Geologic and soil maps do not agree on mode of deposition. Unit is of such minor extent (three small delineations on northwest boundary of base) that they were not visited. Considering small acreage and discrepancies between maps, it may be easier for the client if these delineations were subsumed into the more extensive Qlt unit.	NA	NA
Qlpi2-Deltas	RpC and Ua	Mostly disturbed land due to long-term industrial construction and manufacturing. Natural soils have one to two feet of cobbly silt loam surface overlying stratified coarse sands and pea gravels.	Most soils disturbed and subject to erosion, settling, structural reorganization; at lower depths near shallow water reorganization will be accelerated due to cryoturbation and redox processes. Purported presence of toxic industrial chemical in soil may inhibit some faunal activity, though floral growth seems vigorous.	Coarse sands and pea gravels deposited by flowing water on lake edges. Overlying cobbly silt loam shows evidence of pedogenesis (horizonation, structure, some clay bridging), indicating natural deposition prior to DOD occupation and disturbance.

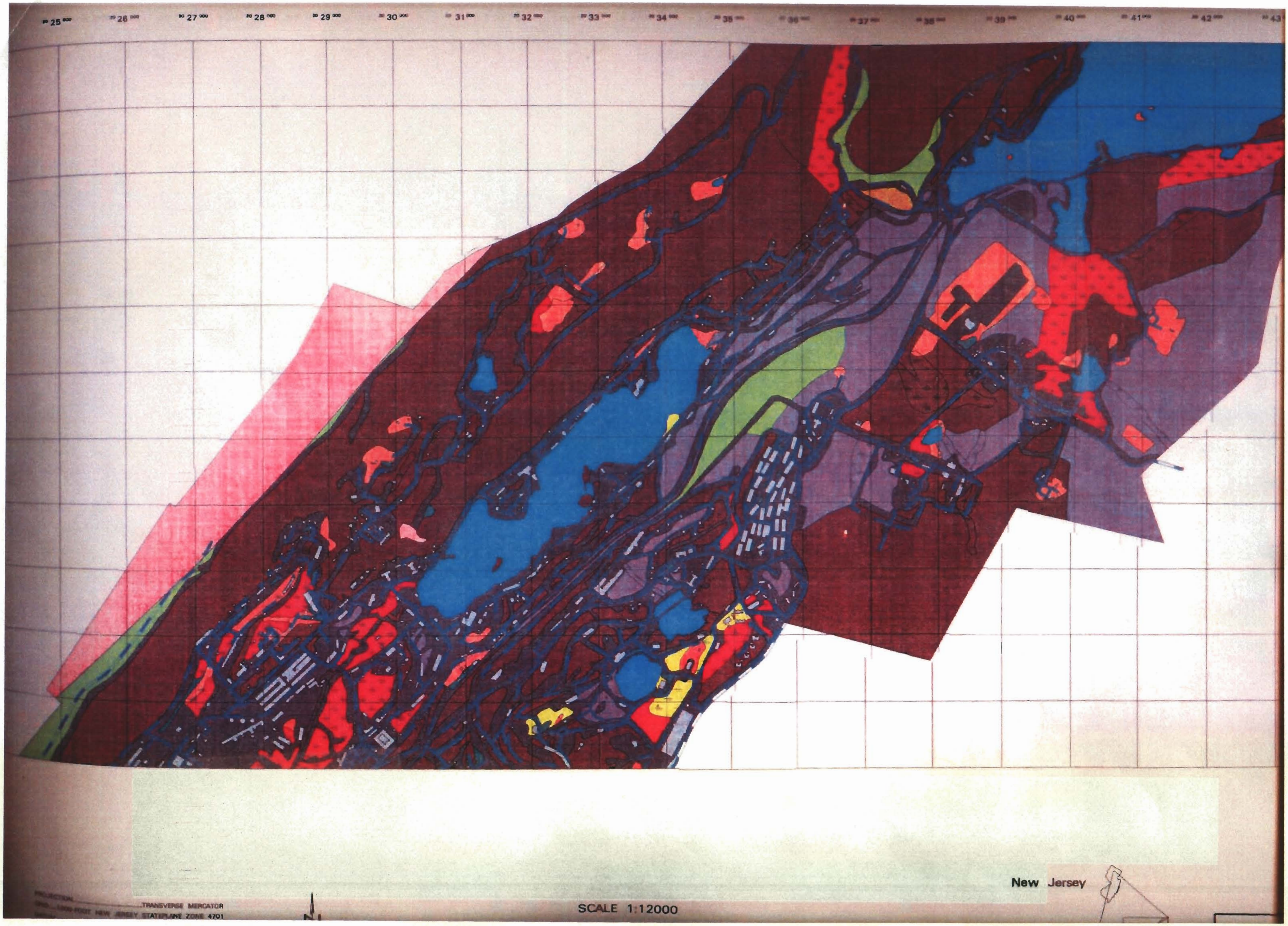
Table 4
Management Implications of Soils on Geologic Units

Geologic Unit	Soil Units	Cultural Resources	Threatened and Endangered Species	Wetlands	Other
af-artificial fill	Ma, Ua, UrD	Pre-industrial resources destroyed. Some standing buildings may be of historic significance.	No significance.	Already filled, though permits may be necessary for expansion into adjacent areas. Some filled but unsurfaced areas may be candidates for wetland restoration and mitigation if hydrology were restored and fill removed.	Recommend splitting unit af into 3 units: (1) ≥80 percent impermeable surface; (2) 20-80 percent impermeable surface; (3) ≤20 percent impermeable surface, which distinctions are significant to hydrologic modeling of runoff and infiltration (Billy Thompson, pc).
aft-dumps	Ma	No significance	No significance	Contact Corps of Engineers before excavating if dumps are in wet areas.	Areas subject to DA and EPA regulations.
Qs-swamp	Ad, Cm, Wm	Pre-historic sites probably close to Lakes Denmark or Picatinny but not in Qs unit.	Likely location for species with dwindling habitat.	Areas are subject to all provisions of and regulation under Section 404 of the Clean Water Act. Water quality should be determined before opening connection to neighboring waters of the US. Many areas mapped as Qs on geology map have been filled and converted to unit af. If converted before 1985 (?date?, see Corps) then not subject to 404 regulation.	Local informants indicate that these areas may be contaminated through disposal of ordinance and manufacturing materials.
Qta-talus	Rt-rock outcrop RvF-Rockaway steep.	No significance	Rare habitats??	No significance	Probable little hydrologic storage. Stability and erosion hazard. Unsuitable for most uses.
Qpo-cobble/gravel/sands	Ua-urban land OtC-Otisville 3-15 percent slopes.	Most areas so mapped filled and artifacts destroyed.	Converted to urban habitats.	Areas so mapped probably had wetland hydrology before filling and therefore may be amenable to restoration if fill removed and hydrology restored.	Same as for unit af.

(Continued)

Table 4 (Concluded)					
Geologic Unit	**Soil Units**	**Cultural Resources**	**Threatened and Endangered Species**	**Wetlands**	**Other**
Qlwt-till	Rockaway, Hibernia, and Ridge-bury, Map Units.	Most likely sites of cultural importance are within this unit on terraces near Lakes Denmark and Picatinny. Most upland acreage is within this unit.	Depends on species.	Narrow wetlands are found within this unit in valley bottoms and ket-tles. Check wetlands map for exact locations. Substrata of this unit are thick enough to hold and conduct water at slope breaks to isolated seeps.	
Qlwtm-terminal moraine	Rockaway and Hibernia Map Units; Ad and Cm in closed depressions.	The delineation of this map unit near the visitor's center has probably experienced so much distur-bance that cultural arti-facts have been destroyed or removed. The delineation northeast of the visitor's center is proba-bly too far removed from permanent sources of water to have significant artifacts.	Depends on species.	Wetlands found in iso-lated kettles with thick muck soil. Those less than one acre in size may fall under the rules of Nationwide Permit 26 for Section 404 regula-tion, depending on scope of filling project; check with the local Corps Regulatory Office.	Although the moraine may have greater water storage capacity than most of the Qlt unit, permeability is probably relatively slow due to compaction and steep slopes. With erosion control the unit is proba-bly as stable as any on station and would be a good location for dumps.
Qlbv2-sandy and gravelly lake deposits	NtB, RmB, and PtB		Depends on species.	Soils of this unit are mapped as non-hydric. Likelihood of wetlands is minimal.	
Qlpi2-Deltas	RpC and Ua	Pre-industrial resources probably destroyed during exten-sive use for manufacturing in this century.	No significance.	No wetlands on these highly disturbed sites; construction at edge of Lake Picatinny may require Section 10 per-mits from the Corps.	High water tables con-trolled by Lake Picatinny. Proximity to the lake increases chance of water pollution. Pollution hazards increase likeli-hood of regulation under state and Federal water quality rules. Highly permeable soils and sub-strata conduct water from the site to the lake.

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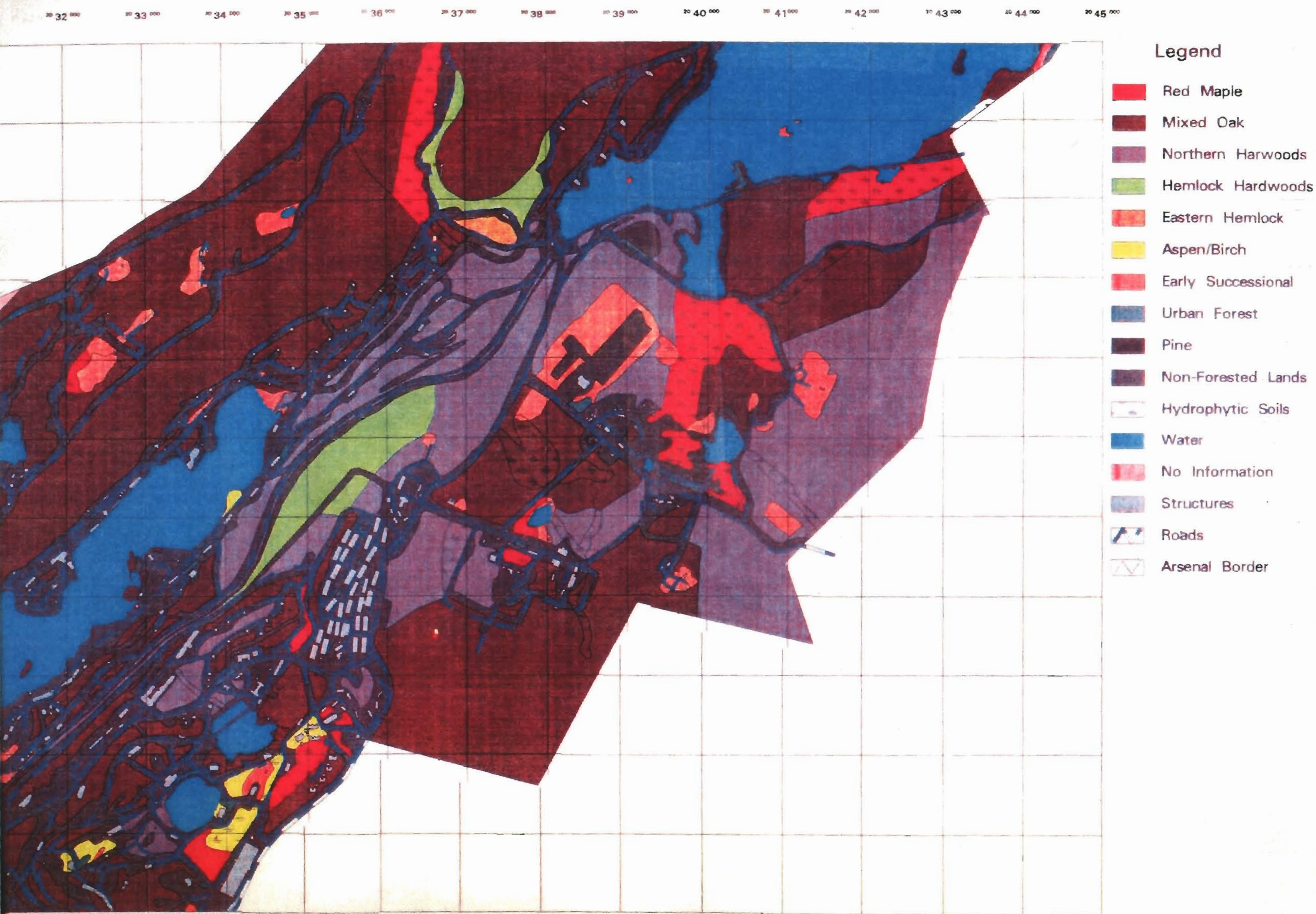
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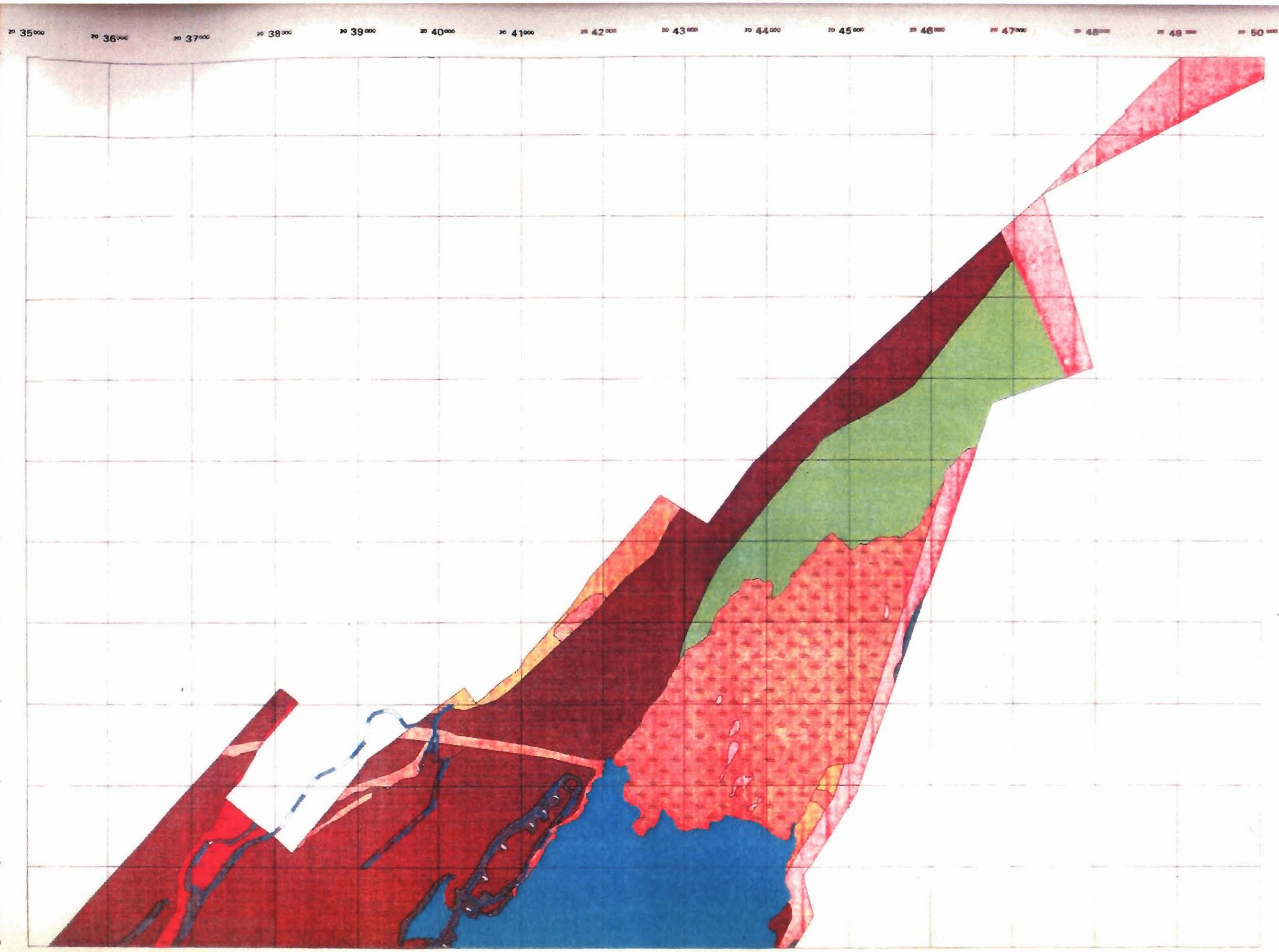

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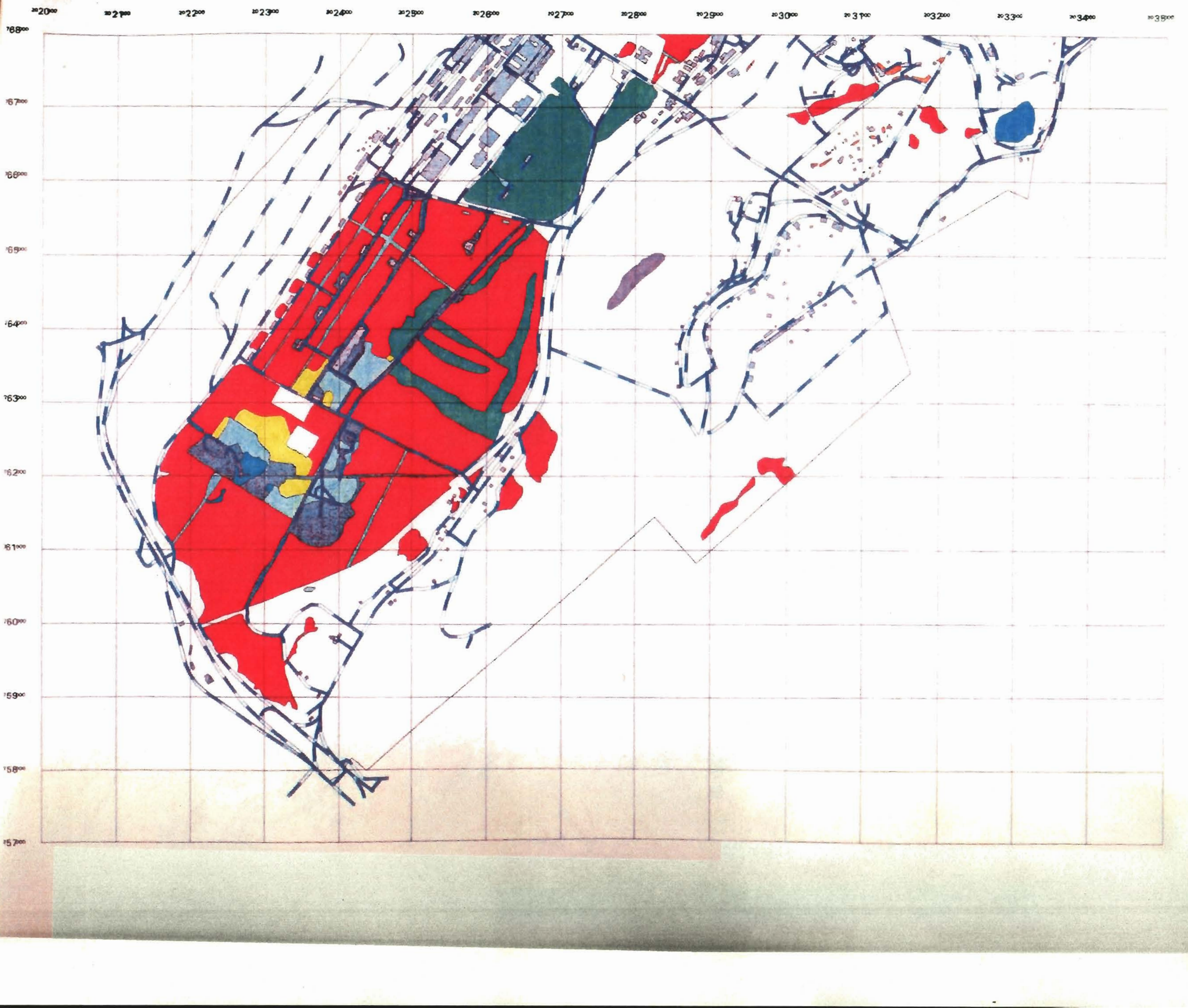
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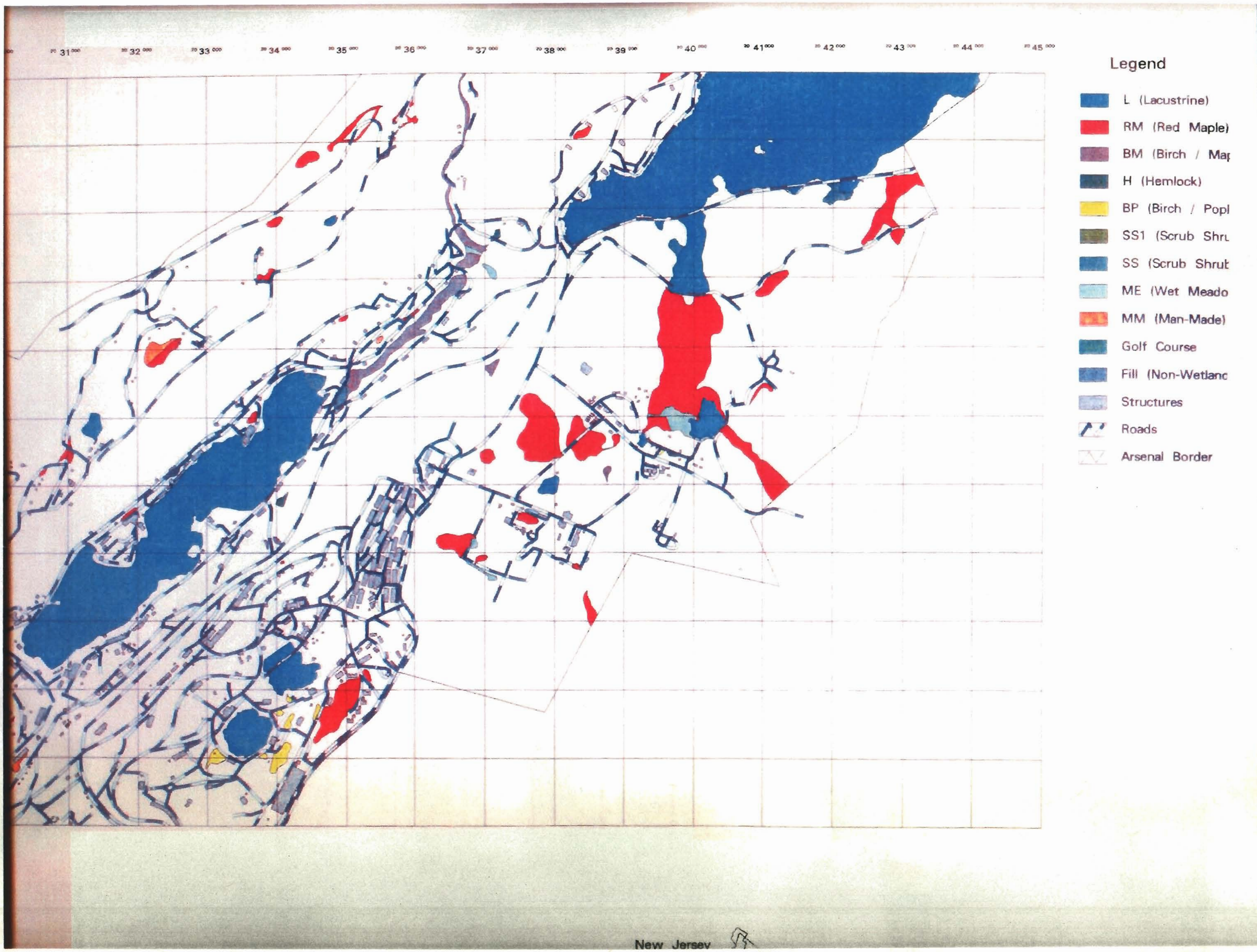
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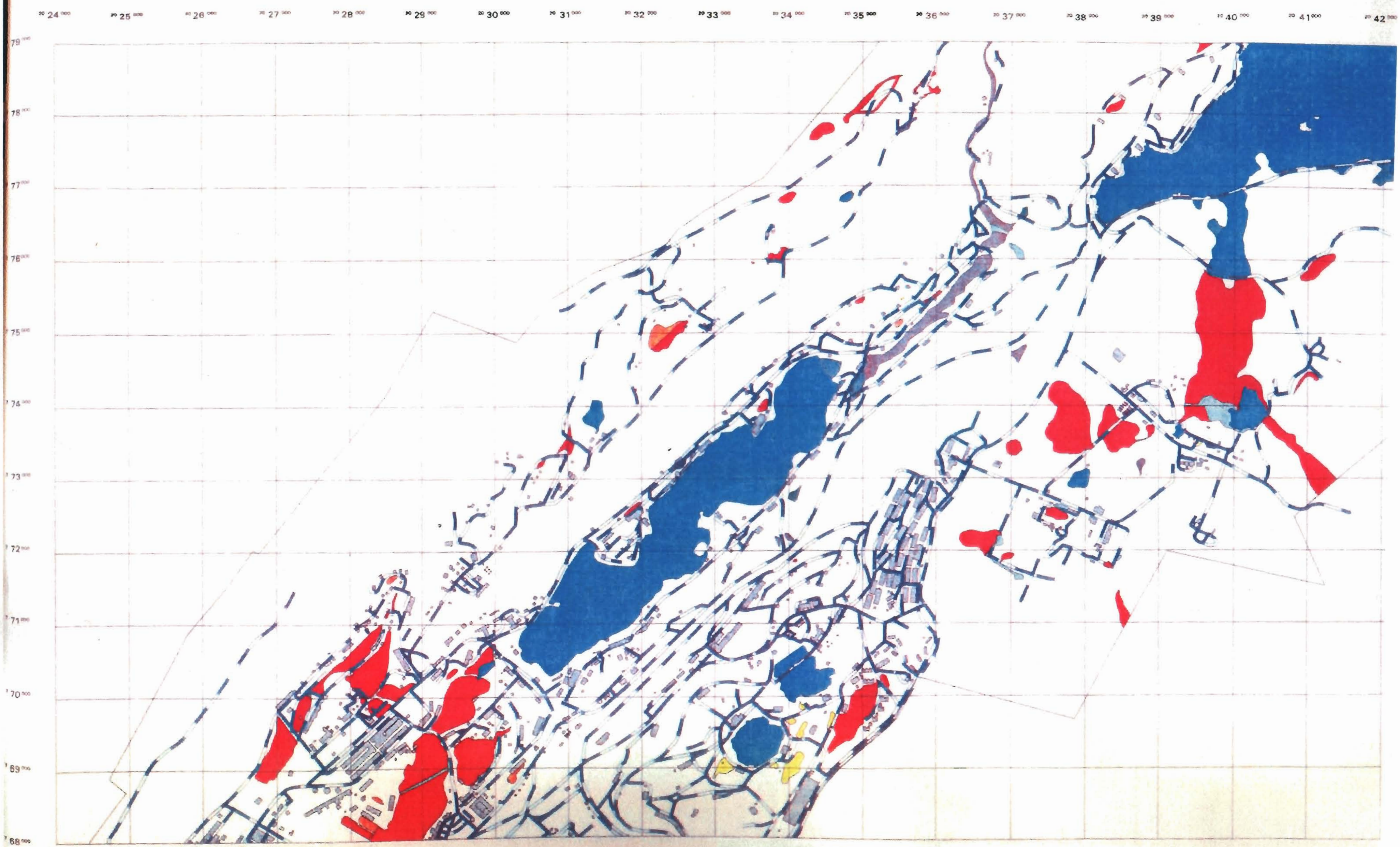

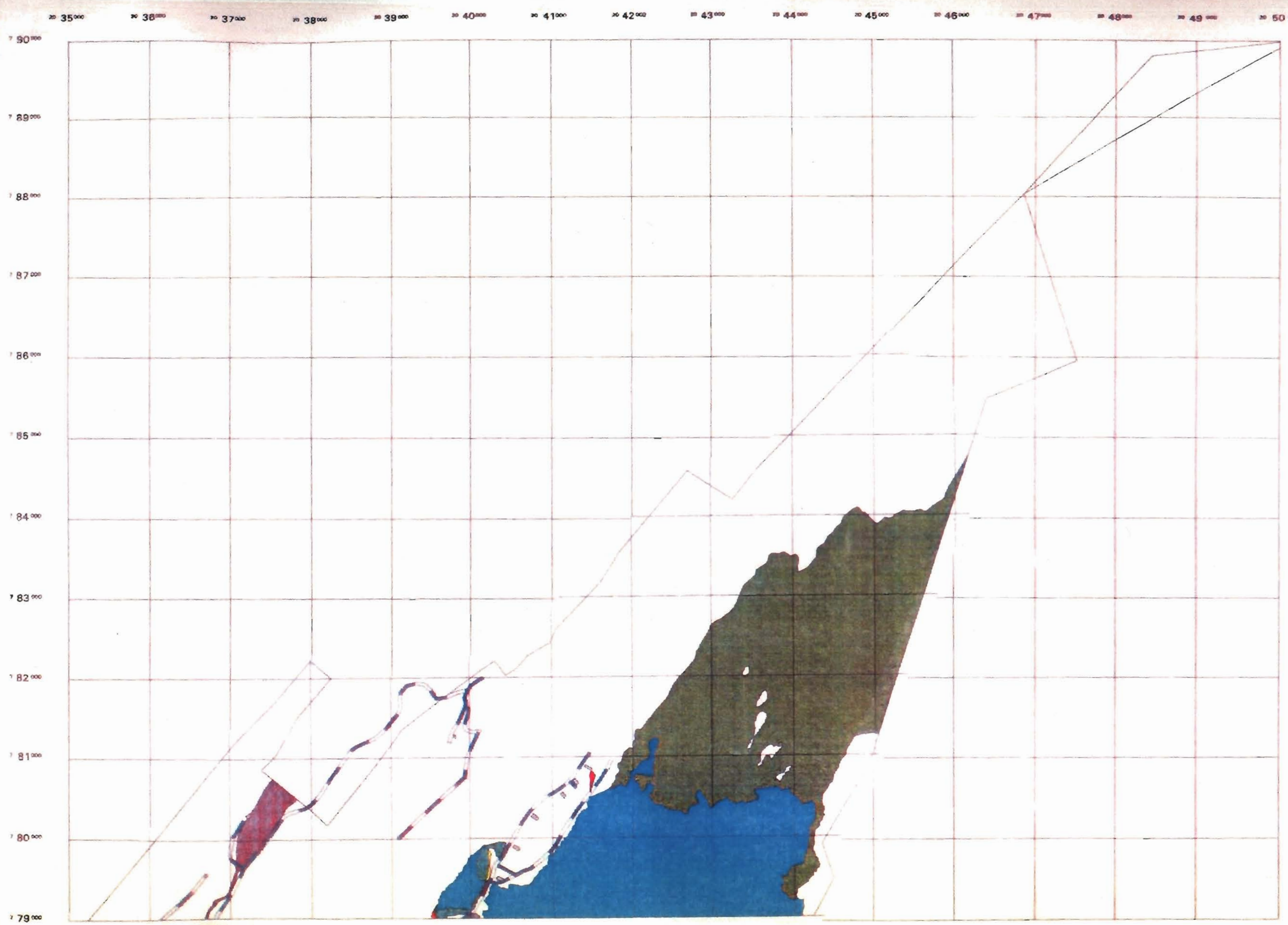

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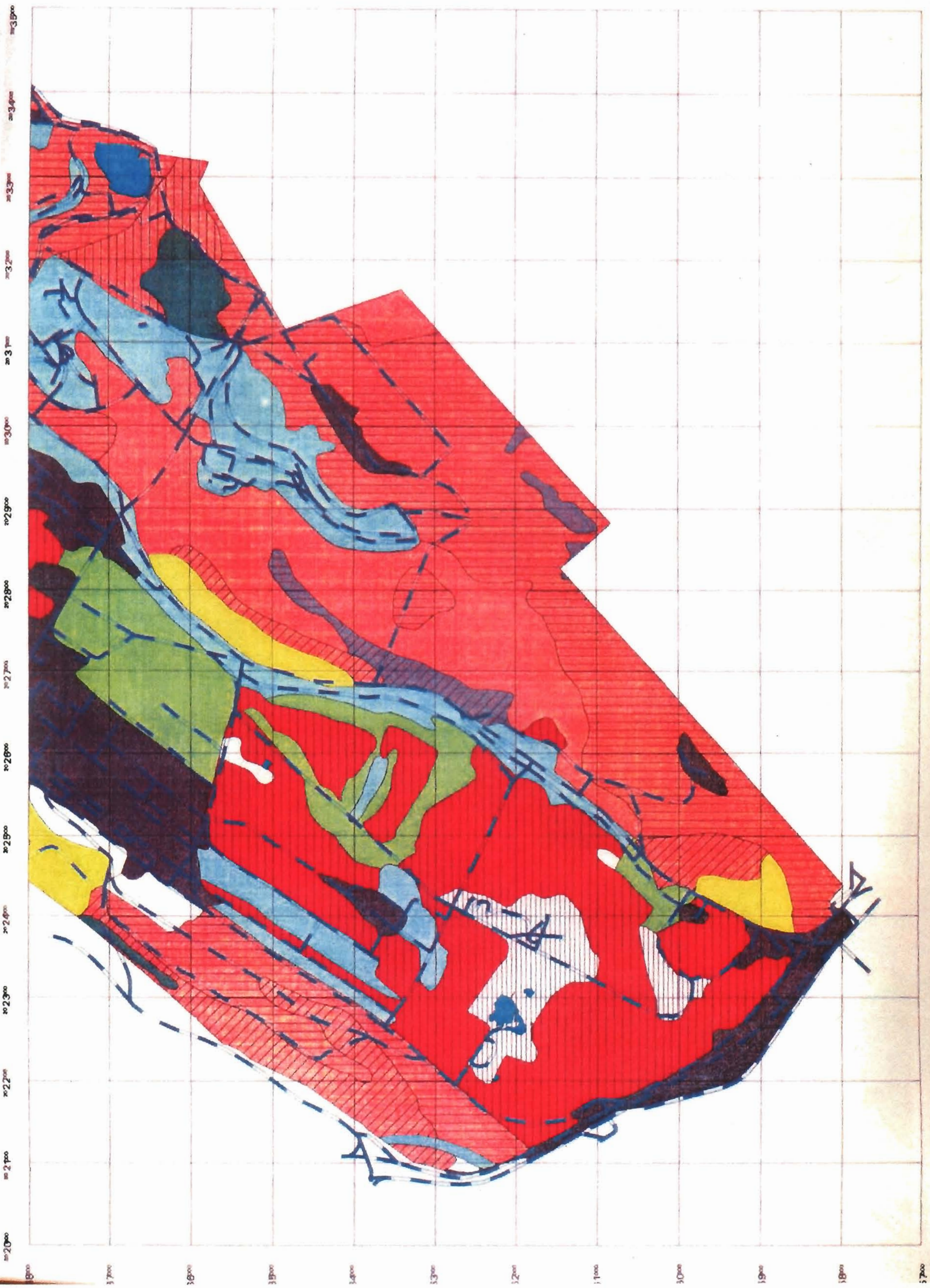

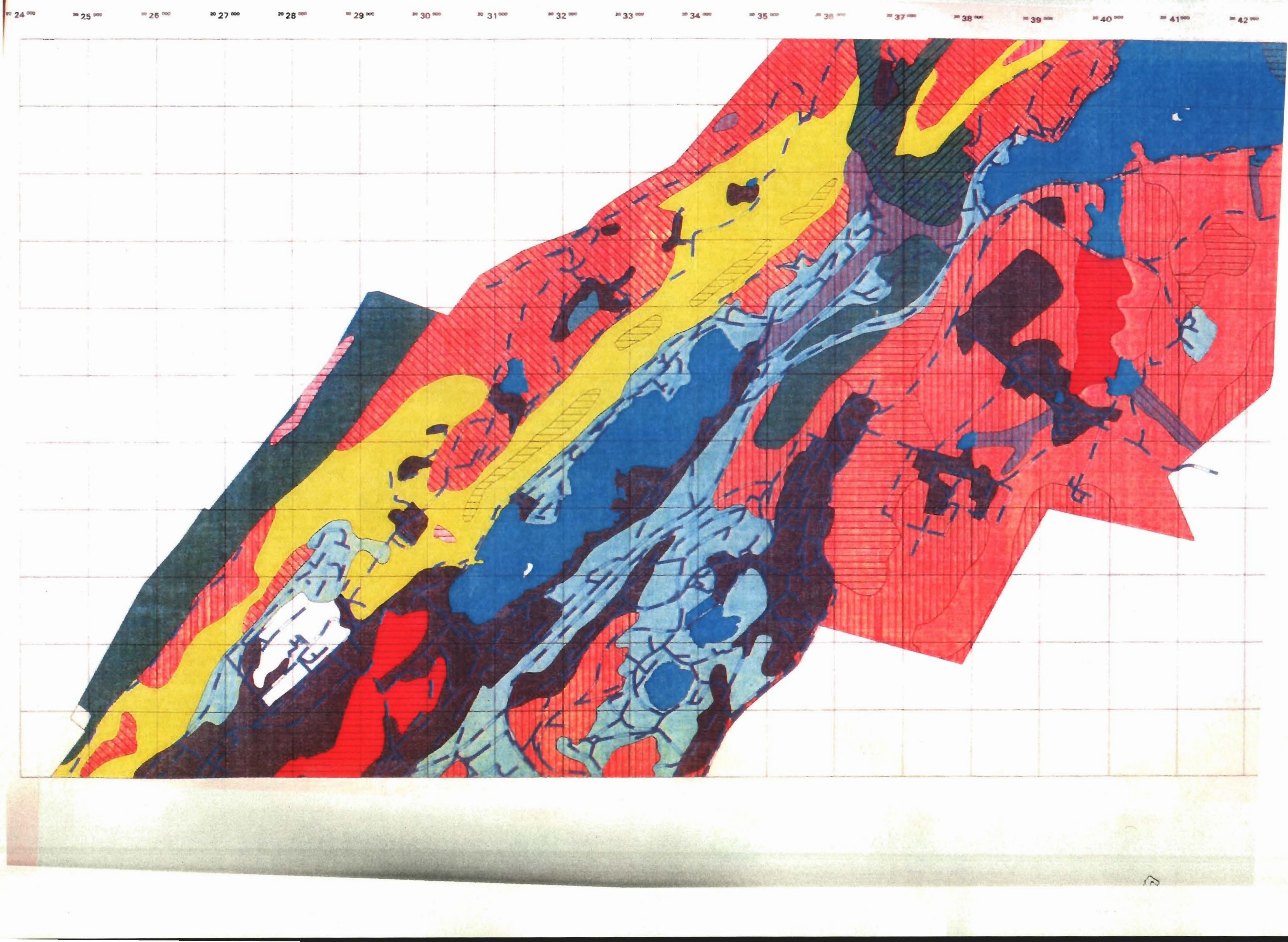

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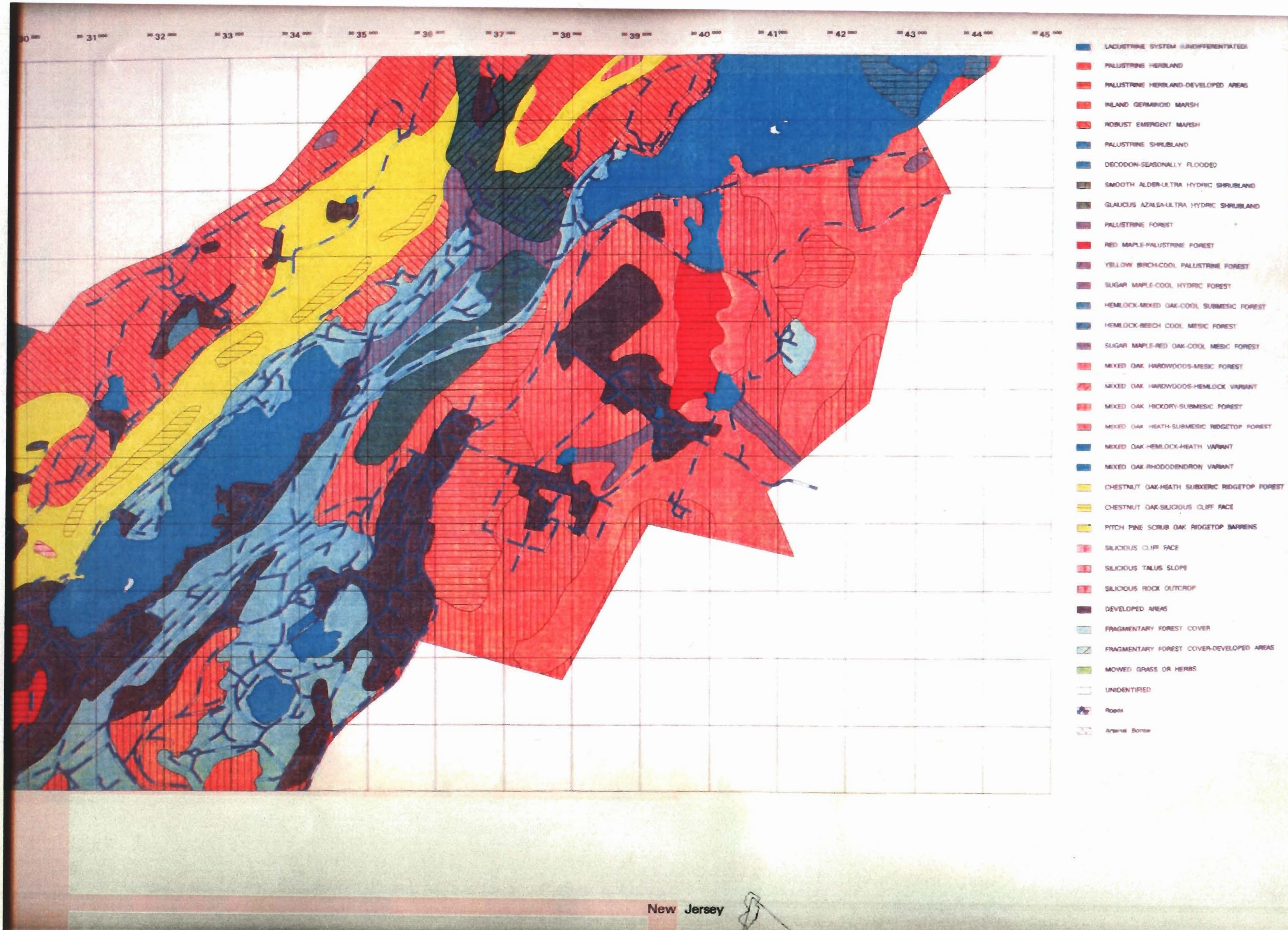
LACUSTRINE SYSTEM (UNDIFFERENTIATED)
PALUSTRINE HERBLAND
PALUSTRINE HERBLAND-DEVELOPED AREAS
INLAND GERMINOID MARSH
ROBUST EMERGENT MARSH
PALUSTRINE SHRUBLAND
DECODON-SEASONALLY FLOODED
SMOOTH ALDER-ULTRA HYDRIC SHRUBLAND
GLAUCUS AZALEA-ULTRA HYDRIC SHRUBLAND
PALUSTRINE FOREST
RED MAPLE-PALUSTRINE FOREST
YELLOW BIRCH-COOL PALUSTRINE FOREST
SUGAR MAPLE-COOL HYDRIC FOREST
HEMLOCK-MIXED OAK-COOL SUBMESIC FOREST
HEMLOCK-BEECH COOL MESIC FOREST
SUGAR MAPLE-RED OAK-COOL MESIC FOREST
MIXED OAK HARDWOODS-MESIC FOREST
MIXED OAK HARDWOODS-HEMLOCK VARIANT
MIXED OAK HICKORY-SUBMESIC FOREST
MIXED OAK HEATH-SUBMESIC RIDGETOP FOREST
MIXED OAK-HEMLOCK-HEATH VARIANT
MIXED OAK-RHODODENDRON VARIANT
CHESTNUT OAK-HEATH SUBXERIC RIDGETOP FOREST
CHESTNUT OAK-SILICIOUS CLIFF FACE
PITCH PINE SCRUB OAK RIDGETOP BARRENS
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SILICIOUS ROCK OUTCROP
DEVELOPED AREAS
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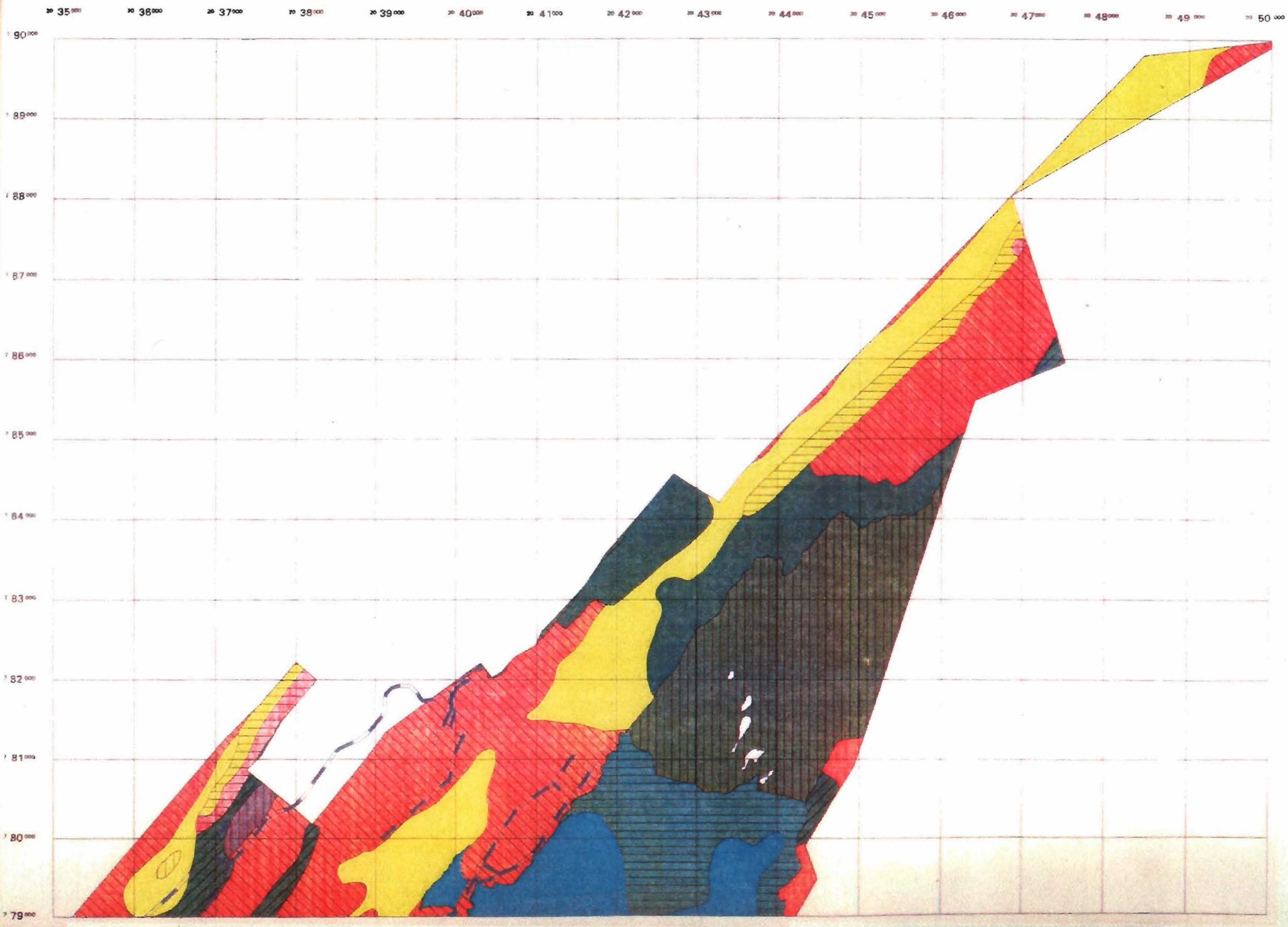

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3 Geomorphology of Picatinny Arsenal

Introduction

Geomorphology is the study of the earth's landforms, the processes by which the landforms originate and evolve, and the natural history of landform creation and evolution. Geomorphological studies of areas provide the identification, delineation, description, and analysis of landforms, geomorphic processes, and geomorphic history of the area at an appropriate level of detail for the subsequent use of the information. Typical products of a geomorphological investigation of an area such as a military installation include geomorphological maps and cross-sections, diagrams illustrating the geomorphic development of the area, a report outlining the purpose, scope, investigative procedures, results, applications of the results to specific problems (such as resource management), and recommendations. Specifically, the products of a geomorphic investigation describe the nature of the earth's surface in terms of surficial and shallow subsurface materials, surficial processes, and the evolution of the earth surface, all at a relevant level of detail.

Some other studies provide similar types of information as geomorphological studies, but none of them provide the range of relevant information that an appropriately scoped and conducted geomorphological study provides. Soil surveys (when available) provide detailed maps and descriptions of surficial soils at a level of detail greater than most geomorphological studies. For instance, a modern soil survey will show the distribution of different types of soils (to a depth of 5 to 6 ft) on a stream terrace and describe the average properties of the soil in substantial detail. A geomorphological study of the same area will show the boundaries of the terrace, describe the terrace materials in general (soils and sedimentary units) to the base of the terrace (20 to 100 ft below the surface), describe the past, present, and probable future natural processes (such as erosion, sedimentation, and mass movement), and describe the origin and probable future of the terrace (it was created by downcutting through older alluvial deposits and will probably be destroyed by lateral stream erosion, but not in the next 400 years). Geologic studies usually focus on broad scale mapping of surficial and subsurface geologic units at a relatively coarse scale.

Understanding the nature of the earth's surface, the surficial processes, and their history is important to many activities at military installations. All natural phenomena and most cultural features are related at least indirectly to the local characteristics, processes, and/or history of the land surface. In the following paragraphs, the significance of geomorphological information to three important issues at U.S. military installations, cultural resource management, installation restoration, and installation management and planning is presented.

Investigative Procedure

The initial effort of the project consisted of the acquisition and detailed review and evaluation of existing data for PTA. Considerable effort has already been expended in the hydrogeological study of a number of areas at PTA in support of CERCLA and SARA projects. The USGS has also conducted detailed geological studies in the area. With the help of the appropriate offices at PTA, a concentrated effort focused on the acquisition and evaluation of the results of these and other studies to determine their use in this project and the existence of data and information gaps.

Once the survey and evaluation of existing topographic, geologic, soils, hydrologic, historic land use, and aerial imagery had been completed, those data to be used in the project by any of the Tasks were digitized. The digital data were analyzed and combined using the GIS and other computerized graphical display techniques for subsequent analyses.

The digital data were analyzed to identify and delineate the principle geomorphic features of PTA at an appropriate scale (1:6,000). The geomorphological maps depict areas of both known and suspected land surface modification by historic activities at PTA. A typical type of geomorphological analysis involved the computerized overlay of aerial photographs or images on a pseudo-three dimensional portrayal of the land surface with the major geological boundaries and boring locations displayed. Geomorphic features were then delineated on the computerized image through the simultaneous interpretation of the land form, aerial photographic characteristics, general geology, and subsurface geologic units (from boring logs). During this subtask, the locations of subsequent field investigation sites were determined.

Upon completion of the preliminary geomorphological analyses, detailed field investigations were conducted at the sites identified. The detailed field investigations focused on and around CERCLA sites and areas where potential impacts of IR activities are most likely to occur. Field data acquisition consisted primarily of geological, geomorphological, soils, and hydrological data and were recorded on a standard site investigation form developed for this project. Shallow borings were made at a number of locations in support of the geomorphological and wetland studies. These borings vary in depth from one to three meters, depending on the nature of the substrate at the location.

During field investigations in particular, and during the completion of all subtasks, coordination and communication was maintained with archaeologists, historians, and other appropriate individuals from other offices who are or will be using the results of this project to conduct future surveys and investigations. Optimally, the preliminary geomorphological analysis and maps will be field tested by archaeologists, historians, and others during the field investigations. Once the geomorphological maps have been field tested by archaeologists, general site location models can be developed for the area to be surveyed. These tested site location models can significantly reduce the time and cost and increase the success of subsequent field surveys for cultural resources.

Reconstruction of the geomorphic development of PTA for the last 20,000 years provides the environmental context for the evaluation of the distribution, relative significance, and integrity of the archeological record, including both the known record and that which will be uncovered in subsequent surveys at PTA. Geomorphic reconstruction of PTA also provides the basis for the definition, delineation, and ranking of archeological sensitivity zones through the understanding of the distribution of landforms preferred by prehistoric cultures and the natural geomorphic processes which may have destroyed, modified, or preserved the archeological record. These archeological sensitivity zones vary from areas requiring detailed surface and subsurface testing to areas requiring little to no additional cultural resources survey.

Environmental Factors Influencing Local Geomorphology

The geomorphic development of Picatinny Arsenal area has been influenced by the interaction of a number of environmental controls. The complex geological history of the New Jersey Highlands of deposition, burial, folding, and faulting of sedimentary rocks has laid the basic foundation for the New Jersey Highlands landscape of parallel ridges and valleys. Radical changes in climate causing the onset of glaciation, lowering of sea level, and changing of weathering processes has also created major impacts on the landscape of the Picatinny Arsenal area. The most dramatic result of changing climate in the last several million years is the onset of Pleistocene glaciation in the area. Most of the surficial deposits and landforms of Picatinny Arsenal are due to the existence of at least three glacial advances and retreats through the area. Consequently, the landscape of Picatinny Arsenal is largely in disequilibrium with modern climate. Changes in the climate from a cold moist glacial regime to the warmer drier Holocene climate has resulted in changes of processes from glacial to fluvial - glacial to periglacial and then to predominantly fluvial processes in the Holocene. Consequently, the relic landscape of Picatinny has been produced by geomorphic processes which are for the most part not active today.

Landforms and Geomorphic Processes

Picatinny Arsenal area can be divided into four primary types of landforms of four landscapes. These landscapes include montane, glacial, fluvial and lacustrine landforms. These four types of landforms have been produced by erosional and depositional processes and various weathering processes on relatively stable geomorphic surfaces. The four primary landform types have been produced over various time periods. Montane landforms have been formed over several million years, glacial landforms over tens to thousands of years, and fluvial and lacustrine landforms over thousands of years. As previously mentioned, most of the active geomorphic processes of the Picatinny area today can be classed as some type of fluvial process, either erosional or depositional. In the following paragraphs, each of the four landscapes are discussed with respect to the predominant landforms which occur and the geomorphic processes which have created them.

Montane landforms and processes

The oldest landscape at Picatinny Arsenal is the montane landscape, best illustrated by the ridge crest and valley side slopes of Green Pond Mountain. A typical transect across the montane landscape includes broad to narrow ridge crests of stable geomorphic surfaces, valley side slopes which may be erosional, stable, or depositional, steep rock faces plucked by glacial scour, upland benches and depressions produced by glacial erosion, and talus slopes at the base of the valley side wall. With the exception of the talus slopes and the lower depositional side slopes, montane landforms are primarily erosional and as previously mentioned, have been formed over relatively long periods of time. Montane landscapes are typically covered by glacial till of various thicknesses. Glacial till is particularly thick on northwest facing slopes at Picatinny Arsenal.

Glacial landforms and processes

Landscapes at Picatinny Arsenal which owe their origin primarily to glacial processes include the landforms of various types of moraines, deltas, upland boulder fields, and glacially eroded steep sided valleys. One of the most prominent landscapes of Picatinny Arsenal is the terminal moraine which occurs on the south end of the Arsenal. This terminal moraine of the late Wisconsinan glaciation is composed of a rough undulating terrain of kettles and ridges and marks the southernmost advance of the late Wisconsinan glacier.

As the late Wisconsinan glacier retreated, ground moraine was formed in the valley between the wasting glacier front and the terminal moraine. This ground moraine is locally described as stratified drift in Picatinny Valley. During the recession of the late Wisconsinan glacier in Picatinny Valley, a large glacial lake was formed, glacial Lake Picatinny. Small tributary streams feeding in from the valley side slopes formed deltas in glacial Lake Picatinny resembling cone-shaped ramps of cobbles and gravels grading down the valley side walls. On the southeastern side of Picatinny Valley, on the more general upland slopes where glacial till deposits are of maximum thickness in the area, large extensive boulder fields occur on the landscape. These boulders represent deposits of the waning glaciation as it retreated from the terminal moraine. As the late Wisconsinan glacier melted and retreated from terminal moraine, erosion from flow from the base of the glacier also caused the scouring of lower Picatinny Valley. The valley was later filled by a sequence of sediments including a basal glacio-fluvial gravel, cobbles, and sand capped by a fairly thick lacustrine deposit of silts and clays from glacial Lake Picatinny and then another fluvio-glacial deposit consisting of deltas and stream deposits from the filling of Lake Picatinny occurs at the top of the section.

Fluvial landforms and processes

As previously mentioned, fluvial landforms are produced by both depositional and erosional processes. An example of depositional and erosional processes are the deltas which formed into glacial Lake Picatinny along its margins with the valley side wall. Erosional processes caused the Holocene development of small channels and valleys in the glacial till of the valley side wall. Depositional landforms of the Picatinny Arsenal landscape include deltas, the thin colluvial aprons at the base of the valley side slopes and the very modest stream alluvial produced by primarily Green Pond Brook as it winds through Picatinny Arsenal.

Lacustrine landforms and processes

Most of the direct evidence of glacial Lake Picatinny is buried beneath fluvio-glacial and fluvial deposits in Picatinny Valley. As previously mentioned, during the wasting of the late Wisconsinan glacier in the Picatinny Arsenal area, a proglacial lake was formed between the terminal morane and the terminus of the ice mass. This large proglacial lake covered most of the valley floor of Picatinny Arsenal. As the glacier wasted away to the northeast, glacial Lake Picatinny was eventually filled with sediments. The resulting landscape produced by these lacustrine processes are the relatively flat depressional areas which are now occupied by Lake Denmark, Picatinny Lake, and the golf course area in the southern end of Picatinny Arsenal. A prominent landform associated with the modern Lake Denmark, a man-made reservoir, is the broad extensive wetland being formed in the northeast end of the lake. This wetland is a product of relatively rapid infilling of the Lake Denmark depression by streams from the northeast.

Geomorphic Development of Picatinny Arsenal

The geomorphic development of Picatinny Arsenal can be divided into three periods. The first period is the preglacial period which covers many millions of years of landscape development prior to the onset of glaciation in the Pleistocene. The Pleistocene epoch in the New Jersey Highlands radically modified the terrain, producing a variety of glacial landforms as previously discussed. The Holocene or post-glacial period has been much shorter than the Pleistocene which in turn was much shorter than the pre-Pleistocene land forming period. Consequently, the geomorphic development of Picatinny Arsenal during the post-glacial period has been relatively minor. In the following sections, the pre-glacial, glacial, and post-glacial histories of the geomorphic development of Picatinny Arsenal are discussed.

Pre-glacial history of Picatinny Arsenal

The salient elements of the landscape of the New Jersey Highlands are the product of the long-term pre-glacial history of the area. The development of long linear parallel ridges and valleys in the New Jersey Highlands of which Picatinny Arsenal occurs, has been the product of folding and faulting of pre-Cambrian and Cambrian sedimentary rocks. The subsequent erosional development of stream networks in this highly folded and faulted complex suite of sedimentary rocks produced a drainage pattern which is only vaguely related to the modern landscape. The previous discussion of the geology of Picatinny Arsenal includes a brief history of the pre-glacial development of the landscape of the New Jersey Highlands.

Glacial history of Picatinny Arsenal

For many years geologists working in New England and the New Jersey Highlands thought that the area had experienced only two glacial advances and retreats. Recent work by Stanford (1993) suggests that there have in fact been three glaciations which have covered the New Jersey Highlands. The terminal moraine of the pre-Illinoisan glacier is considered to be south of the terminal moraine of the late Wisconsinan and Illinoisan glaciations. The evidence of the pre-Illinoisan glaciation is primarily from the occurrence of thin scattered and highly weathered till on relatively low valley side walls and glacial erratics on steeper slopes. The ice flow directions for the pre-Illinoisan glacier is highly uncertain due to the large removal of the evidence of this early glacial period. Although the pre-Illinoisan glacial advance certainly covered Picatinny Arsenal, no evidence of this earliest glaciation has been positively identified at Picatinny Arsenal.

A second glaciation classified as occurring during the Illinoisan period also covered most of the New Jersey Highlands. Occasionally moderately weathered glacial tills dating from the Illinoisan period are discovered beneath Wisconsinan tills in the deeper valleys. Illinoisan tills are considerably more intact than the pre-Illinoisan highly scattered and weathered till. Illinoisan tills are also particularly thick on the general slopes and are moderately weathered. Flow directions of the Illinoisan glacier appear to mirror those of the late Wisconsinan glaciation. Like the pre-Illinoisan glacial evidence, no positively identified Illinoisan glacial evidence has been documented at Picatinny Arsenal.

Unlike the pre-Illinoisan and Illinoisan glaciers, there is ample evidence of the late Wisconsinan glacial advance and retreat across Picatinny Arsenal. The advance of the late Wisconsinan glacier appears to be generally from north to south at an oblique angle crossing Green Pond Mountain. Striations on large boulders and bedrock on the top of Green Pond Mountain indicate this north to south ice flow direction. During the advance of the late Wisconsinan ice mass, extensive glacial scouring occurred on Green Pond Mountain with removal of previous soils and tills and plucking of the southeast facing mountain side walls. This glacial plucking of the southeast side walls of Green Pond Mountain produced vertical rock faces which overlook modern Lake Picatinny. The late Wisconsinan till is a pale brown to yellowish brown (where oxidized) to light gray (not oxidized) matrix of sand with boulders primarily of gneiss and pre-Cambrian conglomerate. The greatest thickness of the late Wisconsinan till is in ramps on the southeastern slopes of Picatinny Valley. Advance of the late Wisconsinan glacier occurred sometime prior to 20,000 years before present (Cotter, et al. 1986).

Retreat of the late Wisconsinan glacier from New Jersey was complete by about 18,000 years ago (Reimer 1984; Stone, et al. 1989). Unlike the advance in the late Wisconsinan glacier, the retreat of the thinner ice mass between 20,000 and 18,000 years ago in the Picatinny Area roughly paralleled Picatinny Valley from southwest to northeast. Pro-glacial Lake Picatinny was ultimately fed by Lake Greenwood to the north. A fairly thick valley fill of basal till over Leithsville dolomite with stratified glacio-fluvial deposits on top of the basal till is in turn capped by lacustrine silts and clays, fluvial sands and gravels and locally fine-grained muck soils of surficial wetlands.

A series of 13 geologic sections (Figures 7 through 19) were prepared to illustrate the infilling of Picatinny Valley during the recession of the late Wisconsinan glaciation 18,000 to at least 20,000 years ago. The stratigraphy illustrated by these geologic sections was compiled from the many groundwater borings and wells installed by USGS and Picatinny Arsenal over the last 10 to 15 years. The sections begin at the southern end of Picatinny Arsenal and are spaced approximately every third of a mile up the valley. In section AA and BB the maximum thickness of the valley fill is illustrated. Progressing up valley through sections DD and EE, the valley fill becomes more complicated and reflects reworking of the valley fill by Holocene actions of Green Pond Brook. North of the bedrock lip at the southern end of modern Lake Picatinny, the valley fill becomes very thin.

Post-glacial history of Picatinny Arsenal

As previously mentioned, the glaciation of Picatinny Arsenal was complete by at least 18,000 years before present. Filling of the deep part of Picatinny Valley south of the lower end of Picatinny Lake was rapidly completed by a tremendous amount of sediment being produced by the ablation of the late Wisconsinan glaciation. A modest amount of fluvial reworking of Picatinny Valley has occurred due to the lateral migration of Green Pond Brook. The reestablishment of the surficial drainage network of the area is still largely incomplete as indicated by the large number of closed depressions and poorly organized drainage networks. Depressions caused by glacial scour and melting of large ice blocks have been filled with silts, clays, and uppermost peats during the Holocene to form small wetlands. Talus deposits at the base of the vertical slopes along the southeastern facing slopes of Green Pond Mountain have slowly accreted during the Holocene. Colluvial aprons have also formed at the base of steep slopes, however, their thickness is somewhat minimal. A number of springs have developed in the till on the slopes particularly on the southeast side of Picatinny Valley but their downslope streams associated with them are fairly shallow with small sapping basins occurring at the head of the streams at the location of the spring. From all available evidence it is apparent that the post-glacial geomorphic development of Picatinny Arsenal has been somewhat minimal, particularly when compared to the glacial development of the landscape.

Geomorphological Basis for Cultural Resource Management

Introduction

The results of cultural resource surveys show that prehistoric cultures gave considerable thought to environmental conditions when selecting locations for many types of activities. One of the most important environmental factors was the geomorphic feature or landscape position. Whereas Native Americans did not necessarily know that the sandy ridge next to the abandoned meander of a local stream was in fact a natural levee in geomorphological terms, they did know that the sandy ridge had relatively well drained soils, the slight rise in elevation would protect them from many floods, and the lake formed by the abandoned meander would be rich in natural resources. Consequently, natural levees next to abandoned meanders, when located by a geomorphological study, contain a significant portion of the archeological record of stream valleys. Detailed geomorphological studies provide the delineation of geomorphic features which were exploited in varying degrees by prehistoric cultures. Once the geomorphological maps have been field tested by archaeologists, general site location models can be developed for the area to be surveyed. These tested site location models can significantly reduce the time and cost and increase the success of subsequent field surveys for cultural resources.

Identification and delineation of past and present geomorphic processes in the survey area is also critical to the development of a survey strategy for cultural resources. Areas where sedimentation has occurred since the establishment of an archeological site possibly thousands of years ago are areas where the archeological record may be preserved beneath the surface. Conversely, areas where the lateral migration of a stream during the last several hundred years has been active would result in the destruction of all but the most recent archeological record, which would be found at the surface and not buried.

Once the landforms have been delineated and the geomorphic processes have been described, the geomorphological study usually focuses on unraveling the geomorphic history of the area, the story of how the landscape came to look as it does today. The resulting reconstruction of past landscapes provides an environmental background upon which the archeological record may be superimposed for analysis. Careful extrapolation of the evolution of the landscape history into the future also may provide useful information on areas where the archeological record may be at risk from geomorphic processes such as erosion and mass movements.

IRL level information

During the Interagency Review Letter (IRL) level of project definition a determination is made for the need of a cultural resource survey in the project area. The kinds of information that the geomorphic investigation provides to this phase of the project are threefold. Of significant importance is the environmental characterization of the known sites in the project area. From the geomorphic analysis, the critical landscape position and uniqueness of the archeological site setting can be determined. Secondly, the environmental context of the known archeological record may be determined from geomorphological information. In particular, the paleoenvironmental conditions may be interpreted from landforms, soil stratigraphy and other paleoenvironmental information obtained during geomorphic investigations. These kinds of data help to answer the question of how much of the archeological record is likely missing from the known archeological site.

A third important level of information provided by the geomorphic investigation for the IRL level of the project is the potential integrity of the archeological record due to the actions of natural geomorphic processes. The kinds of processes which impact archeological sites include those which are preservational, destructional, and the complex surface accumulation of the archeological record on stable surfaces. Preservation processes are primarily those which cause soil deposition on top of parts of the archeological record which are in their original province. Destructional processes are typically erosional or bioturbational processes which disturb the original provenance of the elements of the archeological record. In some specific geomorphic settings landscapes are very stable and are the locus for cultural adaptation over long periods of time. Consequently, these locations have complex overprinting of the archeological record. In summary, during the IRL level of the project, geomorphic information can provide critical information needed to determine if a cultural resource survey is in fact necessary for the project area.

RI/FS stage 1A and 1B information

During the Remedial Investigation/Feasibility Study (RI/FS) stage of the project, a cultural resource survey is typically conducted if necessary. The conduct of the cultural resource survey is largely dictated by the results of the geomorphic study which describe how and where to look for the archeological record in the project area. The geomorphic analysis of the area should identify, delineate, and rank sensitivity zones which should provide the probabilities for encountering the archeological record either in the disturbed or in the original provenance. Another type of information which is particularly useful in the RI/FS phase of the project, is a definition of areas of historic land modification. Knowledge of the areas of land modification and disturbance is particularly useful in the development of field sampling strategies. Additionally, during the RI/FS stage of the project, the environmental setting and history of the known archeological sites can be developed from the detailed geomorphological information. Finally, recommendations for subsequent surveys can be developed from the analysis of the geomorphic history of the project area.

RI/FS stage II information

During Stage II of the RI/FS, an evaluation of the identified cultural resources is completed. The kinds of geomorphological information which are critical to the successful evaluation of the archeological record include information on site boundaries, the integrity of the extant geological record, and the significance of the occurrence of the archeological record at discrete points on the landscape. In determining the impact of the project on known archeological sites, geomorphological information may be particularly useful. For instance, in the identification of areas where soil erosion or deposition may occur as the result of project related activities.

RD/RA level information: mitigation

During the Record of Decision/Remedial Action stage of the project, it may be determined that archeological sites must be mitigated instead of protected. During the mitigation process geomorphic information is particularly valuable in determining the engineering concerns at the mitigation sites. In particular, it is important to understand the magnitude, frequency, and duration of natural geomorphic processes at the site such that the engineering activities don't exacerbate them; such as causing accelerated erosion or destruction of offsite areas. Another major concern during the mitigation process is the environmental issues of offsite migration pathways for potential contaminants. Many of the offsite migration vectors are in fact natural geomorphic processes like overland flow, groundwater recharge, and soil erosion in transport. Understanding these geomorphic processes on a site will allow for the best solution for minimizing the impact of these processes on the offsite migration of contaminated materials.

Protection of cultural resources should be the principle focus of CRM activities during the mitigation of the impacts of remedial actions. Long-term cultural resources protection should also be a goal of resource management programs at the installation. Cultural resources should be protected from natural geomorphic processes of erosion, deposition, and weathering (physical disintegration and chemical decomposition) as well as anthropomorphic impacts. Protection of cultural resources requires knowledge of the occurrence and distribution of impacting processes. The geomorphological information contained within this report will be useful in understanding the occurrence and distribution of geomorphic processes which are impacting the cultural record.

Review of Existing Cultural Resources Information

As part of the geomorphological investigation in support of CRM at Picatinny Arsenal, a thorough review of previous CRM activities at the arsenal was conducted. The purpose of the review was to glean every bit of information which could be used in the development of a comprehensive GIS-based CRM data base to support this investigation and subsequent CRM requirements and initiatives at the arsenal. This review and a summary of recently and soon to be completed CRM projects conducted by WES at the arsenal is presented in the paragraphs to follow.

The information reviewed includes earlier cultural resource surveys of both Picatinny and northern New Jersey, and descriptions of the Arsenal's historic buildings, maps, and histories of the Morris County area. The review is organized around three periods: Pre-historic; Historic - Pre-Arsenal; and Historic - Arsenal. The discussion is based on the most authoritative or earliest treatments. For example, the best work on the area's pre-history is found in the Department of the Army report (1990). Williams (Klein 1986) provides the most informative overview of the historic period. Although her treatment of the early iron industry relies heavily on Munsell's *History of Morris County* (1882), Williams' account of the acquisition of land for the Arsenal comes from Rogers (War Plans Division 1931).

Prehistoric period

The two primary sources for the area's pre-history are the Department of the Army (DOA 1990) report and Klein (1986). Both reports present prehistoric cultural chronologies (Table 4-1, pages B135 - B136 in the DOA report; Table 2-1, page 2-5 in Klein) and are used to analyze potential site types and distributions. Since no sites had been recorded on the Arsenal at the time the reports were written, data were extrapolated from sites in the Northeast and New Jersey Highlands. Despite differences in their periodization schemes (the DOA being the more complex), the two tables are mutually supportive. Klein provides information on general settlement patterns, subsistence systems, and the kinds of remains representative of the period while the DOA report includes temporal subdivisions and cultural aspects. Of the two reports, the DOA is more informative, especially its discussion of Picatinny's prehistoric cultural context and potential for prehistoric sites, within a cultural geographic context (follows Chesler, ed. 1982).

Both DOA and Klein agree that no sites have been recorded at the Arsenal, but that the area would have been available for exploitation. Klein states that the lack of remains may be due to the lack of farming activity which would expose artifacts, while the DOA attributes this lack to the bias of collectors. Rutsch (1986), referring to an Envirosphere survey of the site, reports that although none were recorded during the survey, artifacts had been found during farming activities and construction. Glenn Wershing, a former employee, is personally aware of at least two pre-historic sites within the arsenal grounds (personal communication). Both of these sites were visited by Dr. Fred Briuer in the spring of 1993 as part of this investigation. No prehistoric archeological surface remains were recorded at that time. additionally, it should be noted that only a small percent of the facility has been surveyed (less than 10 percent). Areas subjected to intensive surface survey are included in the GIS database (Plates 17A-C).

Paleo-Indian period rockshelters have been found within three miles of Picatinny. The DOA report (1990) states that a recently discovered site from the Middle Archaic period, Ground Bee, is less than one mile west of Picatinny Arsenal at the base of the escarpment near Longwood Lake.

Few Early and Middle Woodland sites have been found in the Highlands. Sites from outside the area are small and contain few cultural materials, suggesting short-term campsites used by small bands. The DOA report speculates that populations declined and then increased again during the two periods. There is evidence of influences from the midwestern Adena culture during the Early Woodland period, especially cremation burials. The DOA report states the possibility that these types of burials could be located in the Picatinny area.

At the time of European Contact (400 - 300 BP), Delaware groups such as the Munsee-speaking Lenape or Minisink were settled in area. The most typical Contact-period sites are rockshelters with evidence of European artifacts. These sites are thought to be seasonal occupations by small groups exploiting natural resources of the mountain and lake regions from open air hunting and gathering camps in river valleys. Although the DOA report does not mention Indians in the area at the time of colonization, Klein says that the surveyor John Reading encountered Indians in the Highlands in 1715.

An extensive Contact Period trail system passed from the upper Delaware River Valley through central New Jersey to the coast and Hudson River Valley. The most notable was the Minisink trail, which led from the well established Minisink Island Village settlement on the upper Delaware in a southeasterly direction to Lake Hopatcong. Here the trail turned east, split in two, and continued on to the Atlantic. Later trails made Lake Hopatcong a crossroads. It is reasonable to infer that, because of the proximity of Lake Hopatcong to Picatinny Arsenal, Indian groups were probably living in the Green Pond and Rockaway areas.

Historic period

The historic period begins circa 1660 (Klein 1986), when the colony of New York was established. For the purposes of this discussion, the historic period can be divided into pre-Arsenal and Arsenal periods. The National Park Service (1985) maintains that the site's historical record can be characterized by its history of ammunition manufacturing. Good overviews of this period are found in National Park Service (1985), Klein (1986), and Department of the Army (1990).

Iron manufacturing provides the context for development during the pre-Arsenal period. Unlike other regions of British controlled North America, the New Jersey Highlands were an industrial frontier of the British Empire, fully integrated within the trans-Atlantic economy. The site's economic system, transportation network, and settlement pattern were all developed within an industrial, not an agricultural, framework. Roads were constructed to bring iron ore and charcoal to forge sites. Settlements were located at waterpower sites and consisted primarily of industrial structures and housing for workers.

The primary source for the pre-Arsenal period is Munsell (1882) (also cited as Anonymous and *History of Morris County*), from whom Boyer (1931) and Rogers (1931) (also cited as War Plans Division (1931)) obtained most of their information. These documents were used by the National Park Service (1985), Klein (1986), and DOA (1990) as the foundation for their investigations. Munsell (1882) is a historical compendium containing historical sketches about two of the known forges on the Picatinny site, individuals, and communities, including churches and graveyards. The document also includes a very good history of the iron working industry from it's beginning up to circa 1880. Although they have not been examined, two books by Rolando (1977, 1992) include the following relevant topics: Pioneer American Ironworks and Construction and Operation of Early Blast Furnaces (Rolando, 1977); and Historical Overview of Iron Making, Forges, Furnaces, and Foundries, Iron Mines and Ore Pits, and Historical Overview of Lime Burning (Rolando, 1992).

Three forges were built on the Picatinny site in the middle of the Eighteenth century. The earliest forge was the Mount Pleasant Forge built around 1748. This forge was operated sporadically for about 100 years. Today, the Mount Pleasant Forge site is under the right of way of New Jersey Highway 15 in the vicinity of the "Gulf" gas station near the interaction with Highway 80 (Rutsch, 1995).

The second forge built was the Middle Forge, erected in 1749 by Jonathan Osborn at the foot of Picatinny Peak and on a fall of Green Pond Brook. The dam for this forge created Picatinny Lake. Rogers (1931) states that the forge was originally called "Picatinny" but that the name was changed in 1772. Munsell (1882), in a statement repeated in most of the later works, says that the bar iron produced by the forge was formed into large horseshoes and carried to the coast on horseback. Forge machinery and other implements from this period are on display at the arsenal museum.

The raw materials for these forges, including ore, limestone, and charcoal, came from a variety of locations. Rogers (1931), DOA (1990), (citing Acroterion 1986/87), and Klein (1986) name and locate quarries and mines both within the site and in the immediate area. Hopkins (1867) also located many of these features.

The third forge on the Picatinny site is the Denmark Forge, also known as John Harriman's Iron Works and Burnt Meadow Forge (Boyer 1931). This forge was erected in about 1750 by COL. Jacob Ford, Sr., on Burnt Meadow Brook, a tributary of Green Pond Brook. Denmark Lake is formed by the dam associated with Denmark Forge. The place name "Herman" on the 1778 Faden map may be a corruption of the word Harriman and a reference to the forge site north of Walton (Faden 1778).

Munsell (1882) stresses that these forges were "bloomary" forges, not blast furnaces. There were only two of the latter, located at Hibernia and Dover, in Morris County. Bloomary iron was made by loading a hearth with charcoal, ore, and limestone. Since temperatures were too low to liquify the iron, a "bloom," or semi-molten glob of metal and slag, was produced. The final product, wrought iron, was made by hammering the glob, while hot, to remove the slag. For a current and comprehensive discussion of the iron working industry at Picatinny Arsenal, see Rutsch (1995). Morell and Rutsch (1995) have also recently prepared an exhaustive annotated bibliography of the region's iron working industry (Appendix J).

Agricultural settlement period

The earliest information on agricultural settlement in the Picatinny area is the Faden map (1777). Four names appear in or near the present boundaries of the site: Herman or Hermen (Harriman ?), Walton, Tuttle, and Benen (?). Munsell speaks of a David Beman during his description of circa 1750 Picatinny area roads. Early maps cited in the DOA report are Erskine's 1777 map of the New Jersey Highlands and Hill's 1781 sketch of Northern Parts of New Jersey. Rogers (1931) provides a list of names and place names found on the original deed (Book S-7, page 130, assumed to be Morris County, June 1, 1774). Later maps with owner names, forges, and roads are Lightfoot and Geil (1853), Beers (1868), and Hopkins' Map of a Group of Iron Mines (1867) which includes contours, land use, and roads. Rutsch (1991) says that historic maps (including maps of the Arsenal period) identify 85 potential historical archeological sites, and that the pre-Arsenal maps show tenant houses. These sites have been included in the GIS database along with attribute files for each site (Appendix I).

The Walton family cemetery is located within the site. This name, along with Tuttle, appears on most maps. Illig (1994) and Perry (1994) have provided information on this cemetery. Illig's information is based on his personal genealogical work. Perry relies heavily on Munsell as well as his deed research. Simms and Bevins (1995) describe the results of archeological and geophysical investigation of the Walton Cemetery. The geophysical investigation was an attempt to locate graves without disturbing the subsurface. Simms and Bevin's investigation was extended by Briuer and Rutsch (1995) through the analysis of the archeological and geophysical observations and measurements in a GIS developed specifically for the cemetery. This investigation was conducted to determine the pattern and distribution of graves.

Structural development period

Klein (1986) discusses the types of buildings that would have existed on the site during the pre-Arsenal period but that have since disappeared. These include a larger number of residential, commercial, and industrial buildings associated with the ironworks, and farm outbuildings. Klein reports that there is no historical documentation for precisely what structures existed at the site. Title searches have been recently conducted for the Walton cemetery and the three forges by Perry (personal communication, 1995) and Morell and Rutsch (1995).

Transportation system development

The best source for the pre-Arsenal road system, and other locational information, is Rogers (1931). Lowenthal (1981) offers a history of railroad construction in the area, and of interest is his discussion of the Morris County Railroad and photographs of depots within the Arsenal. Klein (1986) argues that the ironworks needed to locate near roads but, since these complexes had to assemble large quantities of raw materials, it is more correct to say that these early ironworks attracted roads to them. Rutsch and Briuer are developing a data layer for the GIS database summarizing the main 18th and 19th century transportation arteries.

Arsenal period

The original arsenal site was acquired by the Federal government in 1880. It would appear that the valley's population declined as the forges profitability declined. (See Rutsch,(1995) for a more detailed discussion of the dynamics of the iron working industry of the region). DOA (1990) provides statistics showing the decline of the county's population as the iron industry died out. The National Park Service (1985) and Rogers (1931) provide the names of the property owners, the amount of property they owned, and how much they received. A sourcebook of available archeological information is available in Morell and Rutsch (1995).

A great deal of information is available for the Arsenal period. Once the site was acquired by the Federal government, record-keeping and map-making improved dramatically. The National Park Service (1985) and Klein (1986) provide good overviews of the Arsenal period. Both of these works provide periodization schemes for construction phases: Depot/Storage, 1880-1907; Manufacturing, 1907-1941; and Research and Development, 1941-present. Rogers (1931) is the best source for the site's history before the 1926 explosion, and contains a great deal of information on surveys, place names, residents at the time of purchase, and buildings. As Rogers' discussion demonstrates, the recommendations of a Court of Inquiry that investigated the explosion profoundly effected the site's architecture and spatial layout.

Historic maps

There are a large number of maps of the area and Arsenal. The earliest is Robinson (1887) showing both Denmark and Picatinny lakes, Picatinny (assumed to be referring to the arsenal), and Denmark, Spicertown, Mt. Hope Post Office, and roads, including the Morris County Railroad. The earliest map of the Arsenal is an undated manuscript map with the word "Depot" crossed out and replaced by "Arsenal," suggesting that the map shows roads and buildings around the time that the facility's function was changed. Two maps of the facility are dated 1904 and 1914 and demonstrate the rapid early growth of the facility. The 1904 map shows few buildings and a great deal of marsh. The 1914 map is an updated version of the 1904 version and includes approximately 124 buildings (based on a numbered list in the margins). This map also delineates the Navy depot but does not show any buildings. The undated Department of the Army "Programmatic Agreement Among the Department of the Army, the ACHP, and the New Jersey State Historic Preservation Office for the Operation, Maintenance and Development of Armament Research, Development and Engineering Center (ARDEC)" contains maps of the Arsenal and poor photocopies of maps of "archaeologically sensitive" areas as well as historic and modern ground disturbance.

Documents dealing exclusively with historical buildings on the site have been produced by the Picatinny Arsenal Historical Office (1991) and Harrell (1992 and 1993). The first document, an historical tour of the Arsenal, includes photographs, descriptions, brief histories, and the location of structures considered to be of historical interest. Harrell (1992, 1993) provides lists and descriptions of Picatinny Arsenal's historic buildings: the first document being an annotated catalogue of buildings drawings and architectural features; the second evaluates these historical structures in terms of their architectural importance. The Historical Office uses a location system that appears to differ from that used by Harrell. The "Programmatic Agreement" (n.d.) provides a list of potential historic archeological resources with the location and description of each historical site and its occupant's name; a computer printout of the Arsenal's real property (codes and variable names on the printout are not explained); and a list of buildings to be demolished. The 1992 "Draft Nomination to National Register of Historic Places: Picatinny Arsenal," describes and inventories building based on individual historic districts within the Arsenal. Klein (1986) also provides a list historical structures.

Ongoing CRM investigations

Further investigations concerning cultural resources at PTA is nearing completion. Two projects have been undertaken as part of a team effort headed by Dr. Frederick L. Briuer that include other WES personnel as well as the contract Firm of Historic Conservation and Interpretation Inc. headed by Mr. Ed Rutsch.

With funding provided by the Legacy Resource Management Program, an archaeological and geophysical survey was conducted at the Walton Burial Ground (Simms and Bevin 1995). Ground penetrating radar, magnetometry, conductivity and resistivity measurements were inconclusive in precisely locating Eighteenth and Nineteenth Century graves, although some geophysical anomalies were defined that are consistent with surface indications including known and probable headstones and depressions. Detailed mapping of cemetery features such as headstones, depressions, stones, and trees was accomplished at a contour interval of fifty centimeters. The archaeological and geophysical data have been integrated into a GIS and can be viewed as Arc/View files. A draft source book and bibliography (Rutsch and Morrel 1995) has been prepared describing the Walton Cemetery project including detailed maps that will serve as the basis for a brochure on the cemetery to be distributed to the public.

A second Legacy project focuses on the Eighteenth and Nineteenth Century iron working industry that occurred at Picatinny Arsenal. As part of that study Arc/Info and dBase IV databases were upgraded to add new information about archaeological surveys and historic sites. A draft source book/annotated bibliography (Morrell and Rutsch 1995) was prepared describing the results of archival research on the subject of the local iron working industry. A draft brochure aimed at the general public and describing the Picatinny iron working industry is also being prepared. As part of this Legacy project an archaeological field survey will be undertaken this summer to test a predictive model being generated in a Geographic Information System. The model will predict the location of charcoal kiln sites associated with the iron working industry. These sites were probably very common occurrences in the past but are not at all obvious and only rarely encountered on the surface today.

Management of Cultural Resources Using Geomorphological Information

A major focus of the geomorphological investigation of Picatinny Arsenal was the development of information needed for comprehensive management of cultural resources at the installation. The information contained in the following paragraphs is designed to aid in the inventory, evaluation, and management of cultural resources as required for CERCLA/SARA projects. The information will also be valuable to other similar requirements in cultural resources management (CRM) at Picatinny in support of installation master planning and NEPA.

A survey and analysis of existing cultural resources information was conducted as part of the geomorphological investigations in support of CRM at Picatinny Arsenal. The results of this effort are summarized in the following discussion.

In the preceding discussion of the "Geomorphological Basis for Cultural Resource Management," the integration of geomorphological information in CRM was presented conceptually. In the following section, the results of the geomorphological investigation of Picatinny Arsenal are considered in the requirements for CRM at each stage of the CERCLA/SARA project. As stated above, this geomorphological information will not only be useful to the ultimate compliance with CRM regulations associated with CERCLA/SARA activities, but will also support other current and future CRM initiatives and requirements at the installation.

The application of geomorphological information in CRM is presented in terms of it's use in identifying, evaluating, and managing both prehistoric and historic cultural resources. Historic and prehistoric cultural resources are discussed separately for several reasons. Exploitation of the landscape by native Americans prior to the coming of EuroAmericans was similar in some ways to EuroAmerican landscape exploitation. It is apparent that both prehistoric and historic exploitation/occupation strategies were the product of the their perception of a variety of geomorphological considerations. These considerations included the occurrence of natural hazards and the characteristics (slope, elevation, aspect, drainage, water and lithic resources) of the landform to be occupied or exploited. EuroAmerican exploitation and occupation of the landscape was also influenced by the suitability of sites for such uses as farmsteads, transportation arteries, ironworking natural resources, and strategic considerations. Native American strategies seem to have been focused on adjustments to geomorphic systems (like streams and hillslopes). EuroAmerican strategies have allowed for the conquest of geomorphic systems and imposition of a significantly different cultural pattern on the landscape. The utility of information on geomorphological impacts on the preservation of a cultural record that may be thousands of years old is substantially greater than the utility of that information for a cultural record that may be tens or several hundreds of years old. Correspondingly, the value of paleoenvironmental information derived from the geomorphological analysis is greater for the older prehistoric cultural record.

In the determination of the need to conduct a cultural resources survey of project areas during this phase of a CERCLA/SARA project, there are three applications of geomorphological information to CRM requirements. These three applications (and CRM tasks) are (1) environmental characterization of the known sites in the project area; (2) description of the environmental context of the known cultural record, and (3) evaluation of the integrity of the known cultural record. In the paragraphs which follow, the knowledge of the geomorphology of Picatinny Arsenal will be applied to each of these CRM tasks.

As presented above, previous cultural resources surveys of Picatinny Arsenal have not identified prehistoric sites. Failure to locate prehistoric sites by the geographically limited survey should not be interpreted as an indication that no prehistoric sites occur on the arsenal. Environmental characterization, description of the environmental context, and evaluation of the integrity of the known historic sites may not be appropriate, relevant, or necessary. However, if it is determined that this information is needed for historic sites, the important environmental characteristics of each location (bedrock geology, surficial geology, geomorphology, soils, hydrology, wetlands, vegetation, etc;) may be obtained directly from the GIS for each of the 87 known historic sites.

The environmental context of the known historic sites may be infered from modern environmental information taken from the GIS database as discussed in the preceding paragraph. The primary environmental variable which has changed significantly during the historic period is vegetation. It is reasonable to assume that all of the native vegetation that existed at Picatinny Arsenal at the beginning of the historic period has been either totally removed or substantially modified in composition and structure. Vegetation data in the GIS database consist of four coverages: (1) the "hand-drawn" vegetation maps (Plates 10A C) generated from field delineation during the late 1980's; (2) the "cadd map" vegetation information (Plates 9A-C), also developed in the 1980's, (3) vegetation information in the wetland data layer (Plates 11A-C) and Natural Communities (Plates 12A-C). The integrity of the cultural record of the known 87 historic sites has been impacted primarily by anthropomorphic activities (such as structural demolition).

Delineation of areas of archeological sensitivity

One of the principle uses of the results of the geomorphological investigation of Picatinny Arsenal is the planning and execution of cultural resources surveys of project areas. In support of a variety of CRM requirements at Picatinny Arsenal, recommendations on *where and how* to survey should be a product of the geomorphological investigation and other considerations, including cultural and other environmental factors. Definition of where to survey, in the interest of minimizing survey costs and maximizing information acquisition, often results in the identification and ranking of "archeological sensitivity zones." Just as important as the identification of the sensitivity zones is the recommendation of *how* to look for archeological information, in particular where the archeological record may be buried by geomorphological processes which have been active during and after the period of occupation. In the following paragraphs, the basis for the identification and delineation of archeological sensitivity zones at Picatinny Arsenal is presented. Imbedded within the conceptual and methodological basis is the consideration of the possibility of buried elements of the archeological record.

All archeologists have at least intuitive or conceptual "models" of the probable distribution of the archeological record of an area based on their experience and interpretation of the results of previous investigations. These models are usually based on the consideration of both cultural and physical aspects of the landscape. In a previous identification of archeological sensitivity zones at Picatinny Arsenal (DOA, 1990), three types of factors were considered, including existing environmental conditions, degree of soil disturbance, and the presence of known cultural resources. Zones of high, moderate, and low archeological sensitivity were delineated on the basis of distance to hydrological features, land slope, soil drainage, soil disturbance (from field observations and installation records), and the location of unreported "surface finds" of archeological resources (DOA, 1990).

Development of a conceptual basis for the distribution of archeological sensitivity zones in this investigation involved the combination of both physical and cultural considerations into the postulation of landscape locations that may have been preferred by prehistoric cultures and relatively preserved from (or by) geomorphological processes. Factors of site selection by prehistoric cultures that were considered were natural hazards, natural resources, and landscape/landform. Natural hazards that were considered included floods and landslides. Natural resources that were considered were plants, water, animals, and lithics. Landscape and landform were evaluated on the basis of accessibility and mobility, slope, drainage, landform diversity, and landscape position. Each of these factors were considered in terms of the data in the GIS database that could be used to estimate the geographic distribution of the factor.

The definition of "archeological sensitivity zones" is one of the most important applications of the GIS database at Picatinny Arsenal. After considerable thought, discussions with archeologists (principally Fred Briuer), and review and analysis of what we know about Picatinny Arsenal, a reasonable estimation of the occurrence of zones of different "archeological sensitivity" at PTA was developed. For the purposes of this analysis, "archeological sensitivity" is defined as *the probability that a significant occurrence of the archeological record may occur in a part of the landscape, defined as a conceptually homogeneous "zone."* The selection of landscape criteria for the various "archeological sensitivity zones" is based on the interpretation of the results of previous archeological investigations in the region and prevailing theories about prehistoric man-land relationships. The zones are defined by landscape criteria in the GIS database.

Factors considered in delineating archeological sensitivity areas

The consideration of the significance of floods as a natural hazard to site establishment was accomplished through the use of hydrologic and geomorphic data in the GIS. The distribution of the floodplains for the 1,2, 10, 25, 100, and 500 year return frequency floods was initially considered. A problem associated with the use of these data for determining potential flood hazards to prehistoric cultures is that the floodplains are predicted from modern hydrologic and drainage basin characteristics. In most areas of the eastern United States, including Picatinny Arsenal, modern hydrologic conditions differ substantially from prehistoric conditions. Typically, a flood producing precipitation event will result in modern floods that are more frequent, of greater magnitude, and of shorter duration than a similar precipitation event occurring during prehistoric times. It is also important to consider the appropriate magnitude of the potential flood in the evaluation of this natural hazard to prehistoric cultures. In this evaluation, it was determined that the modern annual flood would be used to represent the distribution of a relatively frequent (2-3 years) prehistoric flood that would be perceived by prehistoric cultures as of significant hazard to the establishment of a relatively intense use area such as a living structure.

Geomorphological information was also used in the consideration of floods as a natural hazard to prehistoric cultures. The classification of "valley floor" in the geomorphic data base includes all areas within Picatinny Arsenal formed by streams capable of building floodplains. The valley floors are also areas of relatively poor site drainage. The occurrence of the valley floor landscape was used primarily in the consideration of site drainage as a site selection factor.

Mass failures of soil and rock (landslides, mudflows, debris flows and rock falls) are natural processes which have played a role in shaping the landscape of Picatinny Arsenal. In fact, the principle geomorphic processes responsible for the development of the colluvial aprons are mass failures of various types. Geomorphological and soil field reconnaissance studies at Picatinny Arsenal revealed the occurrence of mass failure deposits on the lower slopes of uplands and colluvial aprons. Examination of modern (surficial) soils on the colluvial aprons revealed that the soils were relatively well developed, indicating that they were dominated by stable soil processes (primarily horizonation) rather than by burial from mass failure deposition. The degree of development of the soils on the old mass failure deposits and the appearance of prehistoric stability of upland slopes (thick accumulation of weathered slope material and high degree of surface weathering on boulders) suggests that mass failures have not been a major active geomorphic process for at least the last half of the Holocene. It is probable that mass failures were most frequent and significant immediately following deglaciation of the area in the late Wisconsinan and decreased in importance as a geomorphic agent as the landscape adjusted to the new climatic regime of the Holocene. Consequently, mass failures may not have been frequent enough throughout the Holocene to have been considered by prehistoric cultures as a natural hazard to be avoided. Mass failures have occurred at Picatinny Arsenal during the Holocene, however, and they may have served to bury elements of the archeological record on the colluvial aprons, a landform which has a number of attractive attributes for prehistoric settlement.

Vegetation type, distribution, and abundance was undoubtedly one of the most important natural resources considered by prehistoric cultures in resource exploitation strategy. Natural and cultivated vegetation was an important source of food, shelter, and raw material for a variety of activities. Vegetation also influenced the occurrence of wildlife habitat, another important natural resource. There are four types of vegetation data in the GIS data base: CADD-Based Vegetation, Hand-Drawn Vegetation, Wetlands, and Natural Communities. Development of these data bases is discussed in Chapter 4 of this report. Like surface hydrology, the vegetative cover of Picatinny Arsenal has changed significantly since the prehistoric period. Consequently, use of the vegetation data in the GIS for evaluating prehistoric vegetative resources must be done in view of the highly changed nature of the modern vegetation of the area. For this reason, natural vegetation as a natural resource was evaluated in terms of the "accessibility" of a location to a variety of vegetative landscapes (upland hardwood forest, riparian forest, bottomland forest). The evaluation of the accessibility factor will be discussed below.

Like vegetation, the type, distribution, and abundance of native animals was critically important to prehistoric cultures of the area. Also like vegetation, the distribution of animals in the area today is substantially different than that which occurred during most of the Holocene. The GIS data base includes a variety of information useful in evaluating the occurrence of animals which may be found at Picatinny Arsenal today. These data include the Threatened and Endangered Species Habitat data bases and Natural Communities. Evaluation of the probable occurrence of a variety of animals as a natural resource in prehistoric site selection was accomplished in the same manner as the evaluation of vegetation: the evaluation of "accessibility".

Water for drinking and other activities has proven to be one of the most important factors in the location of prehistoric sites. Countless archeological surveys have documented that prehistoric sites cluster around various types of water bodies for obvious reasons. Hydrologic features at Picatinny Arsenal have also changed substantially during the historic period, particularly the creation/enlargement of the two lakes. Green Pond Brook has also been channelized and re-routed from it's late prehistoric position. Hydrologic features (as geomorphic features) are also naturally spatially dynamic over time, a phenomenon which many archeological site location models do not adequately take into consideration. For these reasons, and the general accessibility to water from most locations in the installation, the consideration of water as a prehistoric natural resource was considered through the general location of streams (in the Hydrology GIS data base) and landscape positions adjacent to hydrologic features as identified by the "accessibility" factor defined below.

The availability of lithic resources for tool manufacture has also been frequently documented as an important factor in the location of prehistoric sites. Unlike vegetation, animals, and water, the availability of various types of lithic resources has not substantially changed throughout the period that humans have likely inhabited the Picatinny Arsenal area. The variety of lithic resources in the area is highly variable in abundance and type ranging from local sedimentary and metamorphic rocks to the glacial sediments rich in igneous rocks. The gravels and cobbles associated with glacial deposits appear to have been favored for tool manufacture due to their variety of desirable petrographic qualities, handy size, and ease of exploitation. In the analysis of the availability of lithic resources in the location of prehistoric sites, the Surficial Geology data base in the GIS was queried for the occurrence of surface boulders in the areas of glacial till. These areas occur in the southern third of Picatinny Arsenal where the late-Wisconsinan terminal moraine occurs.

Accessibility to a variety of natural resources was evaluated on the basis of landscape position. Specifically, those landforms immediately adjacent to different resource communities or ecosystems such as valley floor, riparian, uplands, and intermontane valleys were identified. The landforms which best fit this location are colluvial aprons and lacustrine deltas whose location are defined in the Geomorphology GIS data base. Both of these landforms occur at the juncture of upland and valley floor or intermontane landscapes. Sites situated on these landforms would have maximum access to all resource communities in the area while also having the attributes of protection from floods and optimum site drainage.

The factor of site drainage combines a number of site attributes and GIS data. Site drainage is a function of soil, topographic, and geomorphic conditions. Well drained (but not stony) soil surfaces were obviously preferred for the establishment of significant activities, such as the construction of structures. Surface slope and aspect is also important, with optimum conditions being 1-5 percent slope and generally south facing aspect. Geomorphic characteristics include the location of the site with respect to other geomorphic features, such as streams, kettles, wetlands, and other sources of moisture. The landforms which are characterized by optimum drainage characteristics are the colluvial aprons and lacustrine deltas.

The final factor considered in defining areas of various levels of archeological sensitivity is landscape diversity, the proximity of the location to a variety of landforms. Landscape diversity is similar to the "accessibility" factor, but the focus is on landforms and the attributes which they offer and not necessarily other natural resources. Landform attributes which appear to have been desirable to prehistoric cultures include elevation, size, uniqueness, and position, as well as other factors previously discussed such as slope and aspect. Those landforms which have optimum landscape diversity at Picatinny Arsenal are intermontane valleys, colluvial aprons, and lacustrine deltas.

The description of the factors considered in the delineation of zones of various levels of archeological sensitivity discussed in the preceding paragraphs are summarized in Table 5. This table also describes how the GIS data bases were used to delineate the zones illustrated on Plates 33A-C.

Table 5
Factors Used in Determining Archeological Sensitivity

Site Selection Factor	Factor Definition	Factor in GIS Data Layer	GIS Use in Factor Consideration

Natural Hazard: Floods	1 Year Flood Frequency	Annual flood plain; Geomorphology	*Annual flood plain*; *Valley floor*
Natural Hazard: Landslides	Areas susceptible to mass failures of soil and rock	Geomorphology	*Upland erosional* and *colluvial apron* areas
Natural Resource: Vegetation	Natural vegetation for food and shelter	CADD-Based veg.; Hand-Drawn veg; Wetlands; Natural Communities	Natural vegetation highly disturbed; see factor "Accessibility" below
Natural Resource: Animals	Food, clothing	Natural Communities; T&E Habitat data layers	See "Accessibility" factor
Natural Resource: Water	Drinking, other uses	Hydrology	Proximity to *streams*
Natural Resource: Lithics	Tool manufacture	Surficial Geology	Areas of *surface boulders*
Accessibility	Proximity to a variety of natural resources	Geomorphology	*Colluvial apron* and *lacustrine delta*
Mobility	Ease of movement across the landscape	Geomorphology	*Valley floor, colluvial apron, lacustrine delta, intermontane valley*
Site Drainage	Areas of good (but not excessive) surface and soil drainage	Geomorphology; Soils	*Colluvial apron, lacustrine delta;* Non-hydric soils
Landscape Diversity	Proximity to a variety of landforms	Geomorphology	*Colluvial apron, lacustrine delta, intermontane valley*

Using the factors described above and in Table 5, six classes of archeological sensitivity zones were differentiated (Plates 33A-C) for the Picatinny Arsenal area. The method of using the GIS data for delineation of these areas is summarized in Table 6. Areas classified as "very high" are zones where the possibility of the occurrence of a significant element of the archeological record exists for both surficial and buried provenances. They are areas where optimal natural resources, landscape conditions, and preservational geomorphological processes occur. Areas designated as "High" have preferred landscape characteristics, good natural resources (close proximity to upland, valley, and water settings as well as the surficial occurrence of boulders for lithic materials), and a general absence of destructional geomorphological processes and natural hazards (not on erosional landforms such as "upland erosional surface"). "Moderate" zones are characterized by preferred landscape positions (upland stable surface, valley floor, and intermontane valley) and the general absence of destructional processes and natural hazards (also defined by geomorphological information). Areas having "Low" sensitivity are all other areas on the arsenal that have not experienced significant land disturbance.

Table 6
Rationale for Archeological Sensitivity Zones Delineation Using GIS Data Layers

Sensitivity Zone	Factors Considered	GIS Data Layers Used

Very High	Avoidance of floods; maximum accessibility to natural resources; high mobility and landscape diversity; good site drainage; high preservation potential for buried artifacts	*Geomorphology* layer - *colluvial apron* and *lacustrine delta* areas
High	Preferred landscape settings; accessible to natural resources; general absence of floods and natural artifact destructional processes	*Geomorphology* layer - *upland stable* and *intermontane valley*; *Surficial Geology* layer - areas of *surface boulders*
Moderate	Preferred landscape settings; limited lithic resources; general absence of floods and natural artifact destructional processes	*Geomorphology* layer - *upland stable* and *intermontane valley*; *Surficial Geology* layer - areas other than *surface boulders*
Low	Areas of poor landscape mobility and diversity; most limited natural resources; susceptible to natural artifact destruction	Areas classified as other than very high, high, moderate, or disturbed
Moderately Disturbed	Areas of significant ground disturbance (grading, filling) that may still contain some undisturbed prehistoric cultural resources	*Wetlands* layer - *golf course*
Highly Disturbed	Areas of major ground disturbance; not likely to contain undisturbed prehistoric cultural resources	*Soils* layer - *made land, sand and* Rockaway Complex *gravel pits, urban land, urban land -*; *Wetlands* layer - *fill, man-made, structures*; *Surficial Geology* layer - *artificial fill, trash/fill*

It is important to note that these four archeological sensitivity classes are relative for cultural resource management issues at Picatinny Arsenal. Classification of an area as "Very High" (or any of the other classifications) does not necessarily imply that a given number of prehistoric cultural artifacts occur in that area. It does imply, however that the likelihood of encountering prehistoric cultural artifacts in that area is most likely with respect to the rest of the Arsenal. Conversely, the likelihood of encountering undisturbed prehistoric cultural artifacts is lowest in the areas classified as "Low". These archeological sensitivity classes have no established relationship to the actual occurrence of undisturbed prehistoric cultural artifacts in the New Jersey Highlands or the northeastern area of the United States (or any other area).

It is logical to assume that almost all of the land surface of Picatinny Arsenal has been disturbed by historic activities of man. Most of the non-upland surfaces have been extensively plowed to depths of at least 30 cm. Many areas of the arsenal have been significantly disturbed by various landuse activities to depths greater than a normal plow zone and should be delineated accordingly. Land disturbance areas were differentiated on the basis of field mapping investigations associated with some of the project task areas (geomorphology, soils, wetlands, threatened and endangered species, hydrology) and the evaluation of existing soils and geologic information. After review of field and existing data, it was determined that two classes of surface disturbance should be discriminated, areas classified as "highly" or "moderately" disturbed (Table 6). "Highly Disturbed" areas identified on Plates 33A-C generally are characterized by subsurface soil disturbance to depths which likely exceed 50 cm. These areas include sand and gravel pits, "made land", fill, and urban land. Areas delineated as "Moderately Disturbed" generally will have soil disturbance to depths greater than 30 cm and less than 50 cm and is primarily the golf course. There are also many other areas of significant soil disturbance which occur on Picatinny Arsenal that were not mapped due to their small size. Included among these are obvious locations such as narrow strips adjacent to structures and roads.

There are six separate areas that were classified as having "Very High" archeological sensitivity (Plates 33A and 33B). As a percentage of total Picatinny Arsenal area, the "Very High" zones are small, comprising less than 1 percent. All of these areas are located along the edge of the valley floor next to upland areas in the lower third of the Arsenal. The largest of the "Very High" areas extends along the south side of the valley floor from UTM map coordinate 768,000N/2,029,400E approximately 1600 m southwest to coordinate 763,600N/2,026,800E. A number of buildings and roads occur in this particular area which have more than likely impacted any elements of the archeological record which may be preserved there. It is possible that elements of the archeological record may be buried at some depth (several meters) in this area and not impacted by construction activities at and near the surface. A similar "Very High" area occurs in the same landscape setting southwest of the largest area, extending from UTM coordinate 762,000N/2,025,900E southwest to coordinate 759,900N/2,024,300E. This second area also has been locally impacted by construction of roads and buildings but may retain deeply buried undisturbed prehistoric cultural artifacts.

Two small areas of "Very High" sensitivity occur northeast of the largest area. These two elliptically shaped areas along the edge of the valley floor are in the vicinity of UTM coordinates 769,600N/2,030,500E and 768,900N/2,030,500E. Both of these areas contain some structures on them and major roads next to or on them. Natural burial of prehistoric cultural artifacts has quite possibly occurred in these locations as well, but probably not as deeply (less than 2 m) as those areas previously discussed. The last two "Very High" areas are very small and are located on the north side of the valley floor in the vicinity of UTM coordinates 771,800N/2,028,700E and 771,300N/2,028,900E. These two small areas were part of a larger area that was substantially disturbed. Potential burial of artifacts is probably relatively shallow in these areas, less than 1.5 m.

A substantial part of the Picatinny Arsenal is classified as having "Low" archeological sensitivity. While it is certainly possible that prehistoric cultural artifacts may occur in these "Low" areas, the chances that they are in an undisturbed provenance or numerous in number is low. It is unlikely that traditional cultural resource survey procedures will locate significant (more than random occurrences of individual artifacts) undisturbed prehistoric cultural artifacts in these areas.

The information given on Plates 33A-C on the distribution of archeological sensitivity zones and disturbed land will be useful to a variety of activities at the arsenal, including all phases (identification, delineation, and management) of CRM. Inappropriate use of the information could be deleterious to CRM, however. This information must be used judiciously to insure that it supports responsible CRM. The archeological sensitivity and land disturbance information is meant to serve as a *guideline for planning cultural resources surveys*, in particular *where to focus efforts* and *where to look in detail at the subsurface*. Optimally, the information will be used to rank areas during a site selection process or plan a preliminary investigation strategy. For almost all projects, some field surveys will be required. As always, it is far better to locate sensitive (legally regulated) resources prior to the initiation of the engineering activity and avoid costly delays during the project implementation/construction phase.

4 Identification of Wetland Areas

Introduction

Background

This study is in response to a request from Picatinny Arsenal (PTA) to inventory certain natural and cultural resources. Part of that request included the identification and delineation of wetlands. The results of these efforts will be used to help meet certain environmental regulation requirements and assist with wetland management at PTA.

Objectives

The purpose of this study is to identify the location, types, and acreage of wetlands within the study area. Wetlands were delineated and mapped at the planning level. A planning level wetland delineation is the identification and location of jurisdictional wetlands, under Section 404 of the Clean Water Act, to the nearest contour interval on a base map without formal surveying techniques. PTA will use the results of this wetland delineation for assisting in developing remediation measures for contaminants and for compliance the National Environmental Policy Act (NEPA) requirements.

Specifically, objectives for the planning level wetland delineation report are (each item is referenced to its location in the report):

a. Identify and locate wetlands within PTA for planning purposes (Appendix II).

b. Delineate wetland boundaries at priority locations designated by staff from PTA (Sec. 3.6.2.).

c. Prepare maps displaying wetland locations at scale commensurate with the planning and delineation efforts (Appendix II).

d. Verify the wetland mapping efforts through site investigations (Sec. 3.6.1.).

e. Perform a general wetland assessment for each priority wetland after the identification task is completed (Sec. 4).

f. Provide general recommendations for managing (including restoration and enhancement options) wetland resources compatible with Federal laws and the mission objectives at PTA (Sec. 6).

Methodology

A planning level wetland delineation was conducted in the field during late 1993. Potential wetland locations at the PTA site were assessed using the following resource information; April 1991 true color, leaf-off aerial photographs, USDA Soil Conservation Service (SCS) soil survey maps, U.S. Fish and Wildlife Service (FWS), National Wetlands Inventory (NWI) maps, topographic maps, selected literature, and a forest inventory map for PTA. Wetland boundaries were located, sampled and mapped in the field during five one-week periods and later digitized into a Geographic Information System (GIS) for display on a wetland baseline map. Each of these procedures is described in detail below.

Resource information

USGS topographic maps. The PTA study area is located on the Boonton, Dover, and Newfoundland, New Jersey, topographic maps published by the U.S. Geologic Survey in 1976. The scale of these maps is 1:24,000.

National wetlands inventory maps (NWI). NWI maps for this site was obtained in both hard and digital format. The digital data were entered onto the GIS baseline map file for the study area. The NWI maps were developed in 1987 using 1972 and 1976 aerial photographs. All symbols recorded on the NWI maps were labeled according to the *Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin, et al. 1979) (Table 1).

Morris County soil survey. Soils on the PTA are described in the Soil Survey of Morris County, New Jersey (Eby, et al. 1976). The study area is located on map sheets 4, 5, 8, 9, and 14. Twenty seven map units for eleven soil series and five miscellaneous land classifications were entered into the GIS soil layer in digital format, resulting in 192 soil map delineations. A list of hydric or non-hydric with hydric inclusions soils for Morris County, New Jersey was obtained from the U.S. Department of Agriculture, Soil Conservation Service (SCS) field office in Morristown, New Jersey.

Aerial photography. April 1991 true color, leaf off 1:9,000 (1" = 750") scale aerial photographs were used with a magnifying stereoscope with stereo

Table 7
National Wetlands Inventory (NWI) Areas and Frequency Cowardin (1979) Classes

Cowardin	Name	Acres	Ha	Freq.
LLOW	Lacustrine, Limnetic, Open Water	106.2	43.00	1
PEM	Palustrine, Emergent	2.5	1.00	1
PFO/SSI	Palustrine, Forested/Scrub-shrub, Broad-leaved deciduous	9.5	3.84	3
PF01	Palustrine, Forested, Broad-leaved deciduous	481.4	194.81	25
POW	Palustrine, Open Water, Unknown Bottom	35.1	14.20	11
PSS1	Palustrine, Scrub-shrub, Broad-leaved deciduous	583.88	236.30	22
PSS1/EM	Palustrine, Scrub-shrub, Broad-leaved deciduous/emergent	35.5	14.38	1
PSS1/OW	Palustrine, Scrub-shrub, Broad-leaved deciduous/open water	6.3	2.53	1
U	Unknown	20.3	8.22	3
TOTAL		1,280.7	518.28	68

pairs, to delineate water bodies, streams, drainageways, and potential wetland areas. Delineations were checked, verified or corrected in the laboratory or in the field by a separate investigator. The delineated areas on the aerial photographs were then located on the baseline map by using common ground control points. These locations were then georeferenced and digitized into the GIS wetland baseline map file.

Knowledgeable individuals. Information about vegetation, rare species, plant communities and wetlands was obtained from several individuals.

Mr. Jon Van de Venter of PTA supplied various documents and information about vegetation and wetlands within the study area. He provided copies of *Special Plants of New Jersey* (1992), *A Preliminary Natural Community Classification for New Jersey* (1989), data and maps for the existing forest inventory map by Robert Paris, and the CADD vegetation map for PTA. The information he provided for wet forest types and known wetland occurrences was incorporated into the development of the study design. He supplied an initial species list of vascular plants reported for PTA from his files. Also, he provided information on logistics and other concurrent studies about wetlands.

Mr. Rick Radis, Botanist, of The Nature Conservancy provided information about wetlands, plant communities, and rare plants that occurred at PTA. In several meetings with our field team, he shared his knowledge about the distribution of these resources at PTA. He provided information about access points into certain areas. And, he supplied personal time to take a photograph of Lake Denmark after being told the WES slides for this area did not develop.

Mr. Ted Gabel of PTA provided guidance, information, and general support to our field team. He made us aware of ongoing studies that might pertain to wetlands. Also he provided our field team with priority needs of PTA that helped to establish the sampling periods for this study. Other members of his team provided copies of existing wetland delineations and logistical support for this study.

Ms. Christiania Gray of PTA provided technical and logistical support critically important to our field team. She made us aware of numerous ongoing studies at PTA that might be about wetlands. She was our point of contact for obtaining access to all areas within PTA.

Mr. Patrick Sullivan of the U.S. Army Corps of Engineers, New York District provided support for a jurisdictional wetland determination at the DRMO salvage yard. Mr. Sullivan spent one day in the field assisting in the wetland determination at this site. He provided guidance about state and Federal regulations for wetlands.

Prior wetland delineations. Four known wetland delineations exist for selected areas at PTA. Two of these delineations were for wetlands inside developed areas (Environmental Systems & Services, Inc. 1992; RBA Engineers, Architects, Planners 1991), one for the testing grounds areas (Environmental Systems & Services, Inc. 1993), and the other for a proposed transmission line crossing in the northern end of the study area (Environmental Resource Specialists, Inc. 1992). Each of these delineations was evaluated for its wetland decision and accuracy in depicting the wetland boundary. All four of these delineations fell within the accuracy requirements of this planning level wetland delineation. Because of limited access to the testing ground areas, the delineations for that area were incorporated into this report (Environmental Systems & Services, Inc. 1993). Before incorporating the wetland boundaries from the testing grounds delineation into this report, they were spot-checked in the field.

GIS wetland baseline map

Digital baseline map. A baseline wetland map was developed using the ArcINFO GIS program. Topographic, vegetation, and cultural features at PTA were used as a digital base in the ArcINFO GIS program. The NWI information was entered into the baseline file in digital format and corrected with ArcINFO. The soil series distribution data from the Morris County Soil Survey for the site were digitized by personnel at U.S. Army Engineer Waterways Experiment Station (WES) and entered into the baseline map file.

Wetlands resource data. Information on wetland classification and occurrence data from the NWI maps, location of soil map units that are hydric or non-hydric with hydric inclusions, and additional hydrological information about the floodplains was recorded on the wetland baseline map.

Field wetlands baseline maps. For wetland field inventory purposes, 26 maps were made for the study area. These maps were developed at a scale of 1:2,400 (1 in. = 200 ft). These maps depicted contours, roads, buildings, waterways, and the wetland boundaries from previous aerial photographic interpretations. The contour intervals of these maps were 1.5 m (5 ft). The map scale allowed for accurate location of wetland positions in the field.

Wetland field study

Wetland definition. The U.S. Army Corps of Engineers regulates specific activities in waters of the United States under Section 404 of the Clean Water Act. Section 404 of this Act regulates the discharge of dredged or fill materials into waters of the United States (U.S.). Waters of the U.S. are oceans, lakes, rivers, streams, playas, and other special aquatic sites, including wetlands (33 CFR 328.3). Wetlands by law are defined as: "Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (33 CFR 328.3 (b)). The methods for identifying and delineating jurisdictional wetlands are outlined in the *Corps of Engineers Wetland Delineation Manual* (Environmental Laboratory 1987). This delineation also used techniques presented in the *Federal Manual for Identifying and Delineating Jurisdictional Wetland* (Federal Interagency Committee for Wetland Delineation 1989).

Wetland parameters. Wetlands are identified by three different parameters: (1) hydrophytic vegetation, (2) hydric soils, and (3) wetland hydrology. Hydrophytic vegetation is determined by sampling the vegetation to establish if the dominants are wetland species. Dominants were determined by using the 20 percent rule as defined in the *Federal Manual for Identifying and Delineating Jurisdictional Wetlands* (ibid.). That procedure is as follows: for each stratum (e.g., tree, shrub and herb) in each plant community, dominant species are the most abundant species (when ranked in descending order of abundance and cumulatively totaled) that immediately exceed 50 percent of the total dominance measure (e.g., basal area or areal coverage) for the stratum, plus any additional species comprising 20 percent or more of the total dominance measure for the stratum. All dominants are treated equally in determining the presence of hydrophytic vegetation. Cover estimates per species at each sample point were established by ocular estimates made within a 9.1 m (30 ft) sampling radius. Plant species determined to be dominants according to this method are then assigned a wetland plant indicator rating from the *National List of Plant Species that Occur in Wetlands: Northeast Region (Region 1)* (Reed 1988). When 50 percent of the dominants were wetland plant species, the vegetation was considered hydrophytic.

Hydric soils are defined as soils that are "saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions in the upper part" (U.S.D.A. Soil Conservation Service 1987). In general, hydric soils are flooded, ponded or saturated for usually one week or more during the period when soil temperatures are above biological zero (5 deg C) (41 deg F) as defined in *Soil Taxonomy* (U.S.D.A. Soil Conservation Service 1975). Additionally, the National Technical Committee for Hydric Soils (NTCHS) has identified field indicators of hydric soils including soil colors, organic content, sulfidic materials, iron or manganese concretions and organic streaking. Soil samples were taken at each sample point using a standard tubular soil probe pushed to depth of 45.7 cm (18 in.). Using the NTCHS field characteristics, soil samples were evaluated for hydric conditions.

Wetland hydrology is defined by terms of permanent or periodic inundation, or saturation to the soil surface, at least seasonally, and is the driving force behind wetland formation (Federal Interagency Committee for Wetland Delineation 1989). The presence of water for a week or more typically creates anaerobic conditions in the soil, which affects the types of vegetation and soils that develop on a site. Many factors influence the wetness of an area, including precipitation, stratigraphy, topography, soil permeability, and plant cover. Water in a wetland can come from precipitation, overbank flooding, surface runoff, or ground water discharge. Field indicators for identification of wetlands include: visual observations of ponding or saturated soils, oxidized root channels, water marks, drift lines, sediment deposits, water-stained leaves, drainage patterns, and morphological plant adaptations. These field characteristics were used to evaluate each wetland's hydrologic condition.

Sampling design

Initial field reconnaissance of the area estimated over 100 possible wetland occurrences within the study area. The occurrences were dominated by larger wetlands, but many small or fragmented wetlands were observed. Sampling and characterization of each individual wetland would produce hundreds of field data sheets and many redundant descriptions. To provide for a concise analysis and written description of each wetland type, it was decided that wetlands would be characterized by a classification system of vegetation cover types. This descriptive system would meet field inventory needs and provide for a reasonable presentation of wetland distribution data.

Sampling schedule

For the purposes of locating, sampling and mapping wetlands, a sampling schedule and protocol were developed to provide sufficient coverage. The site was divided into three sampling zones: southern, middle and northern. The northern zone was defined as that area above the outlet of Lake Denmark. The middle zone is located between Parker Road and northward to the outlet of Lake Denmark. The southern zone begins near the entrance gate and includes the area northward to Parker Road.

Each of these zones was sampled and mapped in the field for a minimum period of one and half weeks. Each of these zones was then revisited during a later field trip to complete the mapping of either problematic areas or areas not surveyed. These field efforts represent 45 person days in the field. The sampling periods were during the weeks of 27 September, 1, 15, and 29 November 1993. Sampling began in the southern area and proceeded north to Lake Denmark. Because many human altered and problematic wetlands occur in the southern zone, it was sampled first to ensure adequate coverage before leaf off. At the end of each field trip, a reconnaissance of other unsurveyed areas was done. This overview of unsurveyed areas provided information on obtaining permission to enter certain areas and an orientation to the area.

Each sampling zone was further divided into smaller field survey units and inventoried. Accessible areas next to roads were sampled and mapped during short hikes. Because most of each section was not accessible from a road, surveys of the remainder of the area were done by long distance hiking. Field maps and aerial photographs were carried during each hike to guide the direction of the wetland's search. Approximately 80 km (50 miles) were hiked during this phase.

Sampling protocol

Study area. The routine wetland identification method, discussed in both the COE 1987 and the Federal 1989 manual were used to sample and organize the field data. Briefly, the routine method involves the observer walking the entire area, identifying the plant communities, selecting representative observation points or relevés, characterizing the plant community, recording indicator status of dominant species, determining if hydrophytic vegetation is present, evaluating wetland hydrologic indicators, determining if hydrology is present, characterizing the soils, determining if soils are hydric, and making a wetland determination. Sixty-eight (68) representative sample points were taken at Picatinny Arsenal. Sample points 1-6 and 68 were taken within PTA but located in the part of PTA excluded from the study boundary; thus, these sample points are not depicted on the wetlands map or baseline map. All other sample points are located on the baseline map and shown on the wetland map (Appendix II). The field data (including data on sample points 1-6 and 68) collected at each sample point during the study are presented in Appendix F.

Jurisdictional delineation. A jurisdictional level wetland delineation was completed for one area as part of this study. This area, called the DRMO yard, is located near buildings 314B and 314E and on the west side of the Green Pond Brook. The site was delineated using the routine method described in the *Corps of Engineers Wetland Delineation Manual* (Environmental Laboratory 1987).

Most of the area delineated at the jurisdictional level was affected by previous human use. An area dominated by Common Reed Grass (*Phragmites australis*) was an old ordnance disposal site. In other parts of the wetland, fragments of ordnance were detected by an Explosives Ordnance Disposal (EOD) team assigned to the delineation field team. Seven sample points were taken for the delineation. These points, numbers 29 through 36 are presented in Appendix F. As sample points were taken, the wetland boundary was marked with flagging, located by field measuring, and mapped. The map scale was 1 in. equals 80 ft. The jurisdictional wetland boundary was later incorporated into the wetland map for PTA. The two wetlands were determined to be 1.26 ha (3.11 ac) in size (Figure 21).

Vascular plants, liverworts, and mosses species checklist. During the wetland delineation, a species list was compiled for vascular plants, liverworts, and mosses (Appendix III). This list represents species observed during the sampling of wetlands and those previously reported in three other sources. These are: (1) the *Environmental Assessment for Application for Grant of Easement, Picatinny Arsenal* (1992), (2) an in house list supplied by Jon Van de Venter, and (3) the *Natural Community Inventory of Picatinny Arsenal, New Jersey* (1993). This checklist represents occurrence but not location data. Because the checklist was compiled during the later part of the growing season, it is composed mostly of species identifiable during that period. The PTA species checklist for vascular plants, liverworts, and mosses is arranged alphabetically by genus. Synonymy for vascular plants follows Gleason and Cronquist (1991) and Anderson (1989). Synonymy for mosses follows Crum (1983) and liverworts follows Crum (1991).

PTA's existing vascular plant list reported approximately 420 species. This study added 118 new species to that list. Also, species reported by Windisch (1993) were included and noted on the list. The current list comprises 544 species. Forty-five mosses and 17 liverworts were observed during this study and added to the plant species list (Appendix E).

Orientation in the field

To sample all potential areas for wetlands, both wetland field indicators and field experience of the investigators were used to orient searches. Search images for potential areas with wetlands were obtained from a combination of other field indicators and resource materials depicted on the GIS baseline field maps. These included areas identified as potential wetlands on the aerial photographs, drainage patterns, ponded water, mapped areas with water symbols, areas with little slope, and depressional areas.

Mapping

Wetlands were mapped on the field wetland baseline map. Each wetland was located on the baseline map by positioning them in relationship to topography and, if possible, to other features such as roads and streams. Each wetland was mapped as a polygon and labeled with a vegetation cover type. Narrow streams that were not large enough to map as wetland polygons were designated as linear features. Many wetlands were not mapped to the nearest contour line because they were located on slopes or their boundaries did not match the shape of the contour lines. The wetland maps represent an effort to identify wetland boundaries as closely as possible in the field by ocular positioning.

Field team

The field team for this study consisted of Robert W. Lichvar, Botanist, and Russell F. Pringle, Soil Scientist. Mr. Lichvar is from the Wetlands Branch of the Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. Mr. Pringle, during this study, was detailed to WES by the U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS).

Characterization of Wetlands

Soils

The major hydric soils at PTA developed from organic and mineral sources. These hydric soils developed under certain conditions in the geologic past. The hydric organic soils developed in depressions that were formerly or are now partly occupied by lakes or ponds. Over a period of thousands of years, these lakes or ponds have gradually been filling by the accumulation of organic material or a mixture of mineral sediment and organic material. Lake Denmark and Green Pond are examples of lake basins that are now partly filled with organic soils.

Hydric mineral soils developed in small isolated kettles, undrained depressions on terraces, shallow drainageways, and pitted outwash plains. These soils formed in glacial till and glacial outwash. Other soils that are non-hydric with hydric inclusions are generally located in depressions or less sloping areas where runoff water can collect.

Soils on the study area are described in the Soil Survey of Morris County, New Jersey (Eby, et al. 1976). The site is located on map sheets 4, 5, 8, 9, and 14. Within the study area, 27 different map units were recorded and mapped in the county soil survey. Of the 27 map units that occur here, 10 have the potential of supporting the occurrence of wetlands. These ten potential wetland map units are divided into two groups: (1) those listed as hydric in "Hydric Soils of the United States (USDA SCS 1991); (2) those listed as non-hydric with hydric inclusions in the county (Table 2). The four soil series listed as hydric are Adrian, Carlisle, Preakness, and Ridgebury. Soil series listed for PTA as non-hydric with hydric inclusions are Hibernia and Pompton.

Table 8
Hydric Soils of Picatinny Arsenal

Symbol	Soil Name	1[1]	2[2]	3[3]
Ad	Adrian muck	X		
Cm	Carlisle muck	X		
HbC	Hibernia stony loam, 3-15 percent			X
HID	Hibernia very stony loam, 15-25 percent		X	
Ma	Made land, sanitary land fill		X	
NtB	Netcong gravelly sandy loam, 3-8 percent		X	
OtC	Otisville gravelly loamy sand, 3-15 percent		X	
Ps	Pits, sand and gravel		X	
PtB	Pompton sandy loam, 3-8 percent			X
PvA	Preakness sandy loam, 0-4 percent	X		
Pw	Preakness sandy loam, dark surface var.	X		
RgA	Ridgebury very stony loam, 0-3 percent	X		
RIB	Ridgebury extremely stony loam, 3-10 percent	X		
RmB	Riverhead gravelly sandy loam, 3-8 percent		X	
RmC	Riverhead gravelly sandy loam, 8-15 percent		X	
RoB	Rockaway gravelly sandy loam, 3-8 percent			X
RpC	Rockaway very stony sandy loam, 3-15 percent		X	
RrD	Rockaway extremely stony sandy loam, 15		X	
RsC	Rockaway-Rock outcrop complex, 3-15 percent		X	
RsD	Rockaway-Rock outcrop complex, 15-25 percent		X	
RsE	Rockaway-Rock outcrop complex, 25-45 percent		X	
Rt	Rock outcrop		X	
RvF	Rock outcrop-Rockaway complex, steep		X	
Ua	Urban land		X	
UrD	Urban land-Rockaway cpx. mod steep		X	
Wm	Whitman very stony loam	X		
Wtr	Water	X		

1 Hydric.
2 Non-Hydric.
3 Non-Hydric with Hydric Inclusions.

Described below are the hydric soil map units that either are hydric soils or non-hydric with hydric inclusions.

Adrian muck (Ad). This deep soil is located in nearly level depressions that are poorly drained. It formed in organic deposits over sand.

Typically, the surface tier is black (10YR 2/1) muck (sapric material) about 30 cm (12 in.) thick. The next tier is very dark brown (7.5YR 2/2) muck (sapric material) about 61 cm (24 in.) thick. The lower tier to a depth of 107 cm (42 in.) is dark brown (7.5YR 3/2) peaty muck (hemic material). Below this to a depth of 1.5 meters (m) (60 in.) is gray (10YR 5/1) loamy sand.

Permeability is rapid. Available water capacity is high. The seasonal high water table is at a depth of 30 cm (12 in.) above the surface to 30 cm (12 in.) below the surface from November to May. Runoff is slow and the hazard of erosion is slight.

Included with this soil in mapping are small areas of Biddeford, Carlisle, Parsippany, and Preakness soils and Muck, shallow over clay.

The Adrian muck (Ad) soil map unit comprises 86.89 ha (214.70 ac) within the study area. This soil map unit was at sample points 16, 17, 24, 25, 46, 47, 50, and 68 (Table 9). The vegetation cover types most commonly associated with this map unit at the site were the Golf Course (GC) and Wet Meadow (ME) (Table 10).

Table 9
Mapped Soil Units Located at Representative Sample Points

Unit	Map Unit Name	Sample Point #[1]
Ad	Adrian muck	16, 17, 24, 25, 46, 47, 50, 68
Cm	Carlisle muck	2, 3, 5, 18, 22, 23, 30, 32-36, 45, 58, 59, 62, 64, 66
HbC	Hibernia stony loam, 3-15 percent	28, 57
Ma	Made land, sanitary land fill	21, 29, 31, 40, 41
Pw	Preakness sandy loam, dark surface var.	19, 20, 26, 27, 37-39, 42-44, 65, 67
RlB	Ridgebury extremely stony loam, 3-10 percent	1, 6, 7, 8, 9, 10, 52, 54, 60
RpC	Rockaway very stony sandy loam, 3-15 percent	14, 15, 48, 49, 53, 55, 56, 61, 63
RrD	Rockaway extremely stony sandy loam, 15-25 percent	4, 51
Wtr	Water	11, 12, 13

[1] Sample points 1-6 and 68 do not occur within the study area.

Carlisle muck (Cm). This deep, nearly level, very poorly drained soil is located in depressions that were formerly or are now partly covered by lakes or ponds. It formed in organic deposits or a mixture of mineral and organic material.

Typically, the surface tier is black (10YR 2/1) muck (sapric material) about 45 cm (18 in.) thick. The lower tier is very dark grayish brown (10YR 3/2) muck (sapric material) to a depth of about 1.5 m (60 in.).

Permeability is rapid. Available water capacity is high. The seasonal high water table is at a depth of 15 cm (6 in.) above the surface to 30 cm (12 in.)

Table 10

below the surface from September to June. Runoff is slow and the hazard of erosion is slight.

Included with this soil in mapping are small areas where there is mineral material at less than 1.5 m (60 in.) in depth.

The Carlisle muck (Cm) soil map unit comprises 150.07 ha (370.82 ac) within the study area. This soil map unit was at sample points 2, 3, 5, 18, 22, 23, 30, 32-36, 45, 58, 59, 62, 64, and 66 (Table 9). The vegetation cover types most commonly associated with this map unit at the site were Scrub Shrub 1 (SS1) and Red Maple (RM) (Table 10).

Hibernia stony loam, 3 to 15 percent slopes (HbC). This deep, gently undulating, somewhat poorly drained soil is on rolling topography or in depressions in areas of such topography. It formed in glacial till and colluvium derived from glacial till.

Typically, the surface layer is very dark gray (10YR 3/1) and yellowish brown (10YR 5/6) stony loam about 18 cm (7 in.) thick. The upper subsoil is yellowish brown (10YR 5/6) and dark yellowish brown (10YR 4/4) gravelly sandy loam, with thin strong brown (7.5YR 5/8) clay bridges and clay films between sand grains and few, medium, distinct and prominent light gray (10YR 7/2) and yellowish red (5YR 5/8) mottles about 33 cm (13 in.) thick. The lower subsoil is strong brown (7.5YR 5/8) and dark brown (7.5YR 4/4) gravelly sandy loam with many, coarse, distinct pinkish gray (7.5YR 6/2) mottles about 25 cm (10 in.) thick. The upper substratum is light gray (10YR 7/2) very gravelly sandy loam with many, coarse, prominent yellowish red (5YR 5/8) and brownish yellow (10YR 6/8) mottles about 40 cm (16 in.) thick. The lower substratum to a depth of 1.5 m (60 in.) is brown (10YR 5/3) and pale brown (10YR 6/3) stony sandy loam.

Permeability is moderate to the fragipan and slow in the fragipan. Available water capacity is low. The seasonal high water table is from 15 cm (6 in.) to 46 cm (18 in.) from November to March. In addition, water is locally perched on top of the fragipan and moves laterally over the fragipan.

Included with this soil in mapping are small areas of Netcong, Ridgebury, and Rockaway soils.

The Hibernia stony loam (HbC) soil map unit comprises 89.19 ha (220.39 ac) within the study area. This soil map unit was at sample points 28 and 57 (Table 9). The vegetation cover types most commonly associated with this map unit at the site were Birch/Popular (B/P) and Birch/Maple (B/M) (Table 10).

Preakness sandy loam, dark surface variant, 0 to 3 percent slopes (Pw). This deep, nearly level, very poorly drained soil occupies low positions on the landscape, generally in small isolated kettles or other undrained depressions on terraces and pitted outwash plains. It formed in glacial outwash.

Typically, the upper surface layer is black (N 2/) fibrous muck about 20 cm (8 in.) thick. The upper 25 cm (10 in.) of the subsoil is olive gray (5Y 5/2) coarse sandy loam with few and common, medium and coarse prominent strong brown (7.5YR 5/6 and 7.5YR 5/8) and yellowish red (7.5YR 4/8) mottles. The lower 36 cm (14 in.) of the subsoil is gray and dark gray (5Y 5/1 and 5Y 4/1) loamy coarse sand with common, fine, prominent strong brown (7.5YR 5/6) and few, fine, prominent yellowish red (5YR 4/8) mottles. The substratum to a depth of 1.5 m (60 in.) is varicolored, stratified sand and loamy sand.

Permeability is moderately rapid. Available water capacity is moderate. The seasonal high water table is from the surface to 30 cm (12 in.) below the surface from October to May. Runoff is slow and the hazard of erosion is slight.

Included with this soil in mapping are small areas of Adrian, Pompton, and Preakness Variant soils.

The Preakness sandy loam, dark surface variant (Pw) soil map unit comprises 64.13 ha (158.46 ac) within the study area. This soil map unit was at sample points 19, 20, 26, 27, 37-39, 42-44, 65, and 67 (Table 9). The vegetation cover types most commonly associated with this map unit at the site were Golf Course (GC) and Wet Meadow (ME) (Table 10).

Ridgebury extremely stony loam, 3 to 10 percent slopes (RlB). This deep, gently sloping, poorly drained extremely stony soil is at the base of slopes, where it receives runoff and seepage from higher areas, and in shallow drainageways. Stones in the soil are spaced less than 1.5 m (5 ft) apart. It formed in glacial till derived largely from granitic gneiss and a small amount of micaceous gneiss and many kinds of quartzite, sandstone, and shale.

Typically, the upper 10 cm (4 in.) surface layer is black (N 2/) gravelly loam. The lower part of the surface layer to a depth of 23 cm (9 in.) is light yellowish brown (10YR 6/4) sandy loam, with many, fine and medium, faint brownish yellow (10YR 6/6) mottles. The upper subsoil to a depth of 35 cm (14 in.) is light brownish gray (2.5Y 6/2) gravelly sandy loam with many, fine and medium, distinct yellowish brown (10YR 5/6) and few, coarse, faint, brown (10YR 4/3) mottles. The lower part of the subsoil to a depth of 90 cm (36 in.) is a very firm and dense fragipan that is light olive brown (2.5Y 5/4) and dark yellowish brown (10YR 4/4) gravelly sandy loam, with many, medium, faint, light brownish gray (2.5Y 6/2) and distinct yellowish brown (10YR 5/6) mottles. The substratum to a depth of 1.5 m (60 in.) is varicolored, yellowish brown (10YR 5/6), dark yellowish brown (10YR 3/4), light olive brown (2.5Y 5/6) and olive brown (2.5Y 4/4) gravelly sandy loam.

Permeability is moderate above the fragipan and slow in the fragipan. Available water capacity is moderate. The seasonal high water table is from the surface to 45 cm (18 in.) below the surface from November to May. Runoff is slow and the hazard of erosion is slight.

Included with this soil in mapping are small areas of more or less sloping and less stony Ridgebury soils and Hibernia soils.

The Ridgebury extremely stony loam, 3 to 10 percent slopes (RlB) soil map unit comprises 97.16 ha (240.09 ac) within the study area. This soil map unit was at sample points 1, 6-10, 52, 54, and 60 (Table 9). The vegetation cover types most commonly associated with this map unit at the site were Scrub Shrub (SS) and Birch/Maple (B/M) (Table 10).

Rockaway very stony sandy loam, 3 to 15 percent slopes (RpC). This deep, gently sloping, well drained and moderately well drained soil is on uplands. It formed in sandy loam glacial till that contains various kinds of rock but is mainly granitic material.

Typically, the surface layer is very dark grayish brown (10YR 3/2) and strong brown (7.5YR 5/6) very stony sandy loam about 20 cm (8 in.) thick. The upper part of the subsoil is strong brown (7.5YR 5/6) gravelly sandy loam about 30 cm (12 in.) thick. The lower part of the subsoil to a depth of 90 cm (36 in.) is a very firm and dense fragipan that is strong brown (7.5YR 5/6) gravelly sandy loam with common, medium, faint brown (7.5YR 5/4) mottles. The upper substratum is a very firm and very compact pale brown (10YR 6/3) gravelly sandy loam about 10 cm (4 in.) thick. The lower substratum to a depth of 1.5 m (60 in.) is a loose, pale brown (10YR 6/3) gravelly sandy loam.

Permeability is moderate above the fragipan and slow in the fragipan. Available water capacity is moderate too low and in many places' water perches on top of the fragipan and moves laterally down slope. The seasonal high water table is from 45 cm (18 in.) to 3 m (10 ft) from November to May. Runoff is slow and the hazard of erosion is slight.

Included with this soil in mapping are small areas of more sloping and less stony Rockaway soils, and Hibernia soils. On Green Pond Mountain there are areas that have a high proportion of siliceous minerals, are redder, contain red quartzite coarse fragments, and are underlain by red quartzite bedrock.

The Rockaway very stony sandy loam, 3 to 15 percent slopes (RpC) soil map unit comprises 545.29 ha (1,347.40 ac) within the study area. This soil map unit was at sample points 14, 15, 48, 49, 53, 55, 56, 61, and 63 (Table 3). The vegetation cover types most commonly associated with this map unit at the site were Man Made (MM) and Scrub Shrub (SS) (Table 4).

Rockaway extremely stony sandy loam, 15 to 25 percent slopes (RrD). This deep, very strongly sloping, well drained and moderately well drained soil is on uplands. It formed in sandy loam glacial till that contains various kinds of rock but is mainly granitic material.

Typically, the surface layer is very dark grayish brown (10YR 3/2) and strong brown (7.5YR 5/6) extremely stony sandy loam about 20 cm (8 in.) thick. The upper part of the subsoil is strong brown (7.5YR 5/6) gravelly sandy loam about 30 cm (12 in.) thick. The lower part of the subsoil to a depth of 90 cm (36 in.) is a very firm and dense fragipan that is strong brown (7.5YR 5/6) gravelly sandy loam with common, medium, faint brown (7.5YR 5/4) mottles. The upper substratum is a very firm and very compact pale brown (10YR 6/3) gravelly sandy loam about 10 cm (4 in.) thick. The lower substratum to a depth of 1.5 m (60 in.) is a loose, pale brown (10YR 6/3) gravelly sandy loam.

Permeability is moderate above the fragipan and slow in the fragipan. Available water capacity is moderate too low and in many places' water perches on top of the fragipan and moves laterally as seepage. The seasonal high water table is from 45 cm (18 in.) to 3 m (10 ft) from November to May. Runoff is rapid and the hazard of erosion is severe.

Included with this soil in mapping are small areas of less sloping and less stony Rockaway soils and Hibernia soils. On Green Pond Mountain there are areas that have a high proportion of siliceous minerals, are redder, contain red quartzite coarse fragments, and are underlain by red quartzite bedrock.

The Rockaway extremely stony sandy loam, 15 to 25 percent slopes (RrD) soil map unit comprises 423.92 ha (1,047.50 ac) within the study area. This soil map unit was at sample point 4 and 51 (Table 9). The vegetation cover types most commonly associated with this map unit at the site were Hemlock (H) and Birch/Maple (B/M) (Table 10).

Whitman very stony loam (Wm). This deep, nearly level, very poorly drained soil is in depressions and seepage areas. It formed in weathered glacial till.

Typically, the surface layer is black (10YR 2/1) very stony loam about 20 cm (8 in.) thick. The upper 30 cm (12 in.) of the subsoil is light brownish gray (10YR 6/2) gravelly sandy loam with few, fine, distinct reddish brown (5YR 4/3) mottles. The lower 13 cm (5 in.) of the subsoil is a fragipan of grayish brown (10YR 5/2), very firm, dense gravelly sandy loam. The upper 38 cm (15 in.) of the substratum is part of the fragipan and is gray (5Y 5/1), firm sandy loam. Below this to a depth of 1.5 m (60 in.) is mottled light brownish gray (10YR 6/2), pale brown (10YR 6/3), and grayish brown (2.5Y 5/2) loose gravelly loamy sand.

Permeability is moderate above the fragipan and slow in the fragipan. Available water capacity is moderate. A perched water table is from 30 cm (12 in.) above the surface to 15 cm (6 in.) below the surface from September to June. Areas of this soil receive runoff and seepage water from the surrounding higher land. Runoff is slow or ponded and the hazard of erosion is slight.

Included with this soil in mapping are small areas of Carlisle, Hibernia, and Ridgebury soils.

The Whitman very stony loam (Wm) soil map unit comprises 10.80 ha (26.68 ac) within the study area. This soil map unit was at sample points 48 and 49 (Table 7). The vegetation cover type most commonly associated with this map unit at the site was Red Maple (RM) (Table 10).

Vegetation

Plant community information is presented in a hierarchal classification of systems and cover types (Figure 22). The system level rankings follow those established for wetlands by Cowardin, et al. (1979). The term "system" represents a complex of wetlands and deepwater habitat that share the influence of similar hydrologic, geomorphologic, chemical, or biological factors (ibid. 1979). The two systems located within PTA are lacustrine and palustrine. These two systems are: (1) lacustrine areas that include lakes, reservoirs, and large ponds, and (2) palustrine areas that include marshes, bogs, swamps, and small shallow ponds.

The classification group below the system level is the major wetland type. The five major wetland types at PTA are: lakes, man made, shrublands, emergent marshes, and forested areas. Each of these major wetland types is further divided into cover types.

Following major events such as fire, logging, farming, or other human or natural disturbances, vegetation progresses through a series of plant communities (seral communities) toward the climax community (Daubenmire 1952). This process is called succession. Succession is a continuous process, but is usually divided into five classes. These are the disturbance, early, mid, late, and the climax stage. These five classes are called cover types (Despain 1990). In this study, cover types were named based on the dominant species cover data gathered during the delineation.

Cover type information can be gathered rapidly in the field and is compatible with data requirements for a wetland delineation, i.e., ranking of dominants to determine hydrophytic vegetation. Data gathered from representative areas were used to delineate and describe the cover types. Representative sample points are referred to in each cover type discussion (Table 11). Data sheets for each type is attached in Appendix F.

Table 11
Representative Sample Point Numbers by Cover Type

Cover Type	Sample Point Number[1]
Lacustrine (L)	None
Scrub Shrub (SS)	13, 54, 64
Scrub Shrub 1 (SS1)	66
Scrub Shrub 2 (SS2)	3, 5
Wet Meadow (ME)	19, 21, 40, 44
Red Maple (RM)	2, 8, 16, 17, 18, 22-28, 32-37, 42, 45, 47-53, 56, 58, 61-63, 65
Birch/Maple (B/M)	1, 4, 6, 7, 9, 10, 14, 68
Birch/Poplar (B/P)	20, 43, 57
Hemlock (H)	67
Man Made (MM)	11, 12, 15, 29, 30, 31
Golf Course (GC)	59
Fill	41
Upland (UPL)	38, 39, 46, 55, 60
Total	68

[1] Sample points 1-6 and 68 do not occur within the study area.

To refine the wetland classification, the data sets from each relevé was analyzed using TWINSPAN (Hill 1979). TWINSPAN is a dichotomized ordination analysis based on progressive refinement of a single axis ordination from reciprocal averaging or correspondence analysis. The analysis clustered all plant species occurrence and abundance data by relevé at PTA. These clustered sample relevés were used to refine and sort cover types. The most similar samples were sorted into groups (Figure 23). These groups were then named to reflect the dominant species that best described the cover type.

Some PTA wetland cover types are similar to vegetation units in other vegetation classification systems for PTA. These include the Natural Community Inventory of Picatinny Arsenal (NCIPTA), the National Wetland Inventory (NWI) classifications, and a general vegetation map based in CADD. Each cover type is cross referenced to the appropriate NCIPTA, NWI, and CADD vegetation map (Table 12). The comparison's presented in

Table 12
Wetland Plant Community Classification

Major Wetland Type	WES Cover Type	TNC Classification	Cowardin Classification
Lacustrine	L	L	LLOW
Man Made	MM	Dev, Frag	PEM
			PSS
			PFO
Shrublands	SS	PS	PSS1
	SS1	PS2	
	SS2	PS3	
Emergent Marsh	ME	PH2	PEM1
Deciduous Forest	RM	Arpf	PFO1
	B/M	Bapf	
	B/P	Frag	
	H	TcBamf	PFO4

Table 12 allow for contrast of information within each of these three classification systems.

The NCIPTA (1993) was based on a natural community concept. Natural Communities are defined by a combination of physiognomy, vegetation structure and composition, topography, substrate, and soil moisture and reaction (Breden 1989). The Natural Community classification is divided into seven systems: marine, estuarine, riverine, lacustrine, palustrine, terrestrial, and subterranean. Vegetation cover types are used as descriptors at the community level. Because wetlands were described in the field using cover types, the overlap of methods allowed for certain sections of the NCIPTA results to be cross referenced to the wetland cover type classification.

The general landscape of PTA is one dominated by large tracks of forested areas, several large lakes, and areas effected by human development. The east and west ridges are composed mostly of upland hardwood forests. In cool ravines and bottoms are stands of Hemlock, occurring either as dominants or mixed with other species of deciduous trees. The flat valley floor is mostly dominated by a Red Maple wetland forest. Several large marsh and shrubland zones are located along the edge of Lake Denmark and Green Pond Brook. Scattered throughout the southern half are large tracks of developed areas and fragmented forest in areas that have been historically used by the military.

The wetland types, including both natural and man made, are scattered throughout PTA. Several graminoid emergent marshes are found near Lake Denmark and within the Red Maple swamps at the southern end of PTA. The major shrublands are mostly at the edges of Lake Denmark. The forested wetlands are usually associated with cool ravines and bottoms. And because of the historical land use patterns within PTA, many man made wetlands are located within areas impacted by human activities.

A description of the degree of hydrophytic vegetation is included in each cover type. By assigning a numerical rating to each species present in a cover type based on its appropriate indicator status and using a weighted average formula, a prevalence index for indicator status can be determined for the cover type. This prevalence index is determined by assigning the numerical value from 1 to 5 for obligate to upland species (Federal Interagency Committee for Wetland Delineation 1989). For example, an obligate (OBL)is a value of 1, a facultative wetland (FACW) is a 2, facultative (FAC) is 3, facultative upland (FACU) is 4, and upland (UPL) is a 5. The cover types under the lacustrine association were assigned a value of 1 because no aquatic species were sampled or they were lacking due to the autumn sampling season.

The association between vegetation and the edaphic features of different soils types are well recognized (Whittaker 1975). Because each vegetation cover type and soil mapping unit was entered into the GIS database, the degree of association between each cover type and a soil map unit can be established. An "index of association" between cover types and soil units can be established. The index has values from +1 to -1. Zero shows no association or the common occurrence between random events established by the Chi-square test (Cole 1949). Positive numerical values show positive association and negative values indicate avoidance. The magnitude of the index represents the strength of the association or avoidance. The soil map units and wetland cover types from PTA were analyzed and the magnitudes of association or avoidance are shown in Table 10.

The wetland types and cover types are described below. Wetlands are grouped within their respective system and wetland type, i.e., Red Maple cover type under the forested wetland type in the palustrine system.

Lacustrine

a. *Wetland type: lakes*. The lake wetland type is principally a deepwater habitat system of freshwater lakes and ponds. Vegetated zones are generally located in shallow water and along the margins. This type is dominated by rooted aquatics or persistent emergent species. Some dominants and co-dominants of the lacustrine aquatic beds include green algae, Duckweeds (*Lemma* spp.), Bladderworts (*Utricularia* spp.), Yellow Cow Lily (*Nuphar luteum*), Pickeral Weed (*Pontederia cordata*), Pondweeds (*Potamogeton* spp.), and White Water Lily (*Nymphaea odorata*).

- Cover type: lake (L). This cover type includes the open water areas at lakes and ponds within PTA. This includes Lake Denmark, Picatinny Lake and several small lakes and ponds (Appendix C). The mean area size of this type is 8.17 ha (20.18 ac) (Table 13) (Figure 24). Besides algae and other benthic organisms, macrophytic vegetation does occur in some shallower water areas. The macrophytic vegetation is composed of floating-leaved and free-floating aquatic species. Dominants and co-dominants of this type include Yellow Cow Lily (Nuphar luteum), Pickerel Weed (*Pontederia cordata*), White Water Lily (*Nymphaea odorata*), Duckweeds (*Lemna* spp. and *Spirodela polyrhiza*), Water Shield (*Brasenia shreberi*), Broadleaf Cattail (*Typha latifolia*), and Beaked Sedge (*Carex rostrata*). All species located in this type are obligate wetland plants, therefore the prevalence index rating is 1.0 (Figure 25). The map unit associated with this type is water (Table 10). The hydrology of this type is permanent inundation with seasonal variation of depth. No sample points were taken in this type.

Table 13
Mean Area for Cover Types in Hectares

Cover Type	Freq.	Mean-Area	Min/Max-Area
Lacustrine (L)	21	8.17	0.03/109.07
Scrub Shrub (SS)	8	0.34	0.05/0.67
Scrub Shrub 1 (SS1)	1	79.74	79.74/79.74
Wet Meadow (ME)	29	0.54	0.01/1.76
Red Maple (RM)	99	1.89	0.01/15.33
Birch/Maple (B/M)	14	0.87	0.02/4.39
Birch/Poplar (B/P)	15	0.47	0.03/3.34
Hemlock (H)	2	0.14	0.12/0.15
Man Made (MM)	20	0.10	0.01/0.61
Total	209	10.25	0.01/109.07

b. *Wetland type: shrubland.* All shrublands at PTA are palustrine wetlands. The hydrology of this type is mostly permanently inundated. The shrubland association is dominated by hydrophytic tree saplings or shrub species. This association is commonly found along the margin of Lake Denmark where it is intermixed with emergent marsh. Some dominants and co-dominants of this type are Swamp Azalea (*Rhododendron viscosum*), Red Maple (*Acer rubrum*), Common Button Bush (*Cephalanthus occidentalis*), Maleberry (*Lyonia ligustrina*), and Speckled Alder (*Alnus rugosa*).

- Cover type: scrub/shrub (SS). This cover type is scattered throughout PTA. The dominants vary from tree saplings to shrubs (Appendix I). The mean area size of this type is 0.34 ha (0.83 ac) (Table 13) (Figure 24). Dominant species in this type include Red Maple (*Acer rubrum*), Common Button Bush (*Cephalanthus occidentalis*), Highbush Blueberry (*Vaccinium corymbosum*), Black Chokeberry (*Aronia melanocarpa*), Gray Birch (*Betula populifera*), Speckled Alder (*Alnus rugosa*), and Hairy Swamp Loosestrife

(*Decodon verticillata*). This undifferentiated shrub type in many areas is a result of impacts from previous human activities. The prevalence index for this type is 2.34 (Figure 25). The hydrology of this type varies from seasonally saturated to inundated most of the year. Soil series associated with this type is Urban Land (Ua) and Ridgebury (R1B) (Table 10). Representative sample points for this type are numbers 13, 54, and 64 (Table 11). Included here is the Palustrine Shrubland (PS1) from the NCIPTA classification and the Moist Soil Sites from the PTA forest inventory map.

- Cover type: scrub/shrub 1 (SS1). This cover type is at the northern end of Lake Denmark. This type is characterized by a dominance of deciduous tree saplings and shrubs (Appendix C). The mean area size of this type is 79.74 ha (197.03 ac) (Table 13) (Figure 24). Occasionally emergent wetlands are an inclusion in this type. Dominant species in this type include Brookside Alder (*Alnus serrulata*), Maleberry (*Lyonia ligustrina*), Red Maple (Acer rubrum), Swamp Azalea (*Rhododendron viscosum*), Black Chokeberry (*Aronia melanocarpa*), Common Winterberry (*Ilex verticillata*), Uptight Sedge (*Carex stricta*), and Marsh Fern (*Thelypteris palustris*). The prevalence index for this type is 1.75 (Figure 25). The hydrology of this type is seasonally flooded or saturated. The soil series most frequently associated with this type is Carlisle Muck (Cm) (Table 10). A representative sample point for this type is 66 (Table 11). Included here is the Smooth Alder-Maleberry-Glaucus Azalea from the NCIPTA classification and the Water and Moist Soil sites from the PTA forest inventory map.

c. *Cover type: scrub/shrub 2 (SS2).* This cover type is located within PTA but not included in the study boundary. This type is presented for general information. This cover type is intermixed with swamps along Green Pond Brook. This type is characterized by being dominated mostly by shrub species with occasional tree saplings of Red Maple (*Acer rubrum*). Dominant species in this type include Swamp Azalea (*Rhododendron viscosum*), Coast Pepperbush (*Clethra alnifolia*), Maleberry (*Lyonia ligustrina*), Common Winterberry (*Ilex verticillata*), Spoonleaf Sundew (*Drosera intermedia*), and Sphagnum (*Sphagnum palustre*). The prevalence index for this type is 2.11 (Figure 25). The hydrology of this type is seasonally flooded or saturated. Representative sample points for this type are 3 and 5 (Table 11). Included here is the Glaucus Azalea-Clethra-Highbush Blueberry Ultrahydric Shrubland (PS3) from the NCIPTA classification and the Water and Moist Soil and Early Successional (ES) sites from the PTA forest inventory map.

Wetland type: emergent marsh. The emergent marsh type is dominated by persistent graminoids and other herbaceous species. Two cover types occur at PTA under the wetland type. These are wet meadow and emergent marsh. The wet meadow generally is associated with previous disturbed sites. The emergent marsh is usually intermixed with shrublands along Lake Denmark.

The hydrologic regime of this type varies from seasonally flooded too permanently inundated. Some dominants and co-dominants of this type are Hairy Swamp Loosestrife (*Decodon verticillatus*), Broadleaf Cattail (*Typha latifolia*), Common Reed Grass (*Phragmites australis*), Cinnamon Fern (*Osmunda cinamomea*), and Lakebank Sedge (*Carex lacustris*). Only the wet meadow type was mapped during the study at PTA.

- Cover type: wet meadow (ME). This cover type is located in many disturbed areas (Appendix I). Examples of disturbed wetlands include areas bisected by power lines and pipelines or mowing of brush, and sites that are in early successional stages. The mean area size of this type is 0.54 ha (1.34 ac) (Table 13) (Figure 24). Dominant species in this type include Common Reed Grass (*Phragmites australis*), Soft Rush (*Juncus effusus*), Red Top (*Agrostis alba*), Northern Arrowwood (*Viburnum recognitum*), and Giant Goldenrod (*Solidago gigantea*). The prevalence index for this type is 2.09 (Figure 25). The hydrology of this type is seasonally flooded or saturated. Soil series associated with this type is Adrian Muck (Ad) and Preakness (Pw) (Table 10). Representative sample points for this type are 19, 21, 40, and 44 (Table 11). Included here is the Inland Graminoid Marsh (PH1) from the NCIPTA classification and parts of the Early Successional (ES) sites from the PTA forest inventory map.

Wetland type: palustrine forest. Five palustrine forest wetland types occur at PTA. The largest and most frequent is Red Maple (*Acer rubrum*). The hydrology of these forested swamps is seasonally saturated to the surface in late winter and early spring and usually dry the remainder of the year. Some co-dominants of this type are Black Gum (*Nyssa sylvatica*), Yellow Birch (*Betula allegheniensis*), Green Ash (*Fraxinus pennsylvanica*), and American Elm (*Ulmus americana*). This wet forest type typically has a dense understory comprising Coast Pepperbush (*Clethra alnifolia*), Common Winterberry (*Ilex verticillata*), and Northern Spicebush (*Lindera benzoin*).

a. *Cover type: red maple (RM)*. This cover type is the most frequent wetland type occurring at PTA (Appendix C). Most of the valley floor either is or was a Red Maple swamp at one time. Many Red Maple forests in the southern end were partially drained by a series of drainage ditches. The mean area size of this type is 1.89 ha (4.67 acres) (Table 13) (Figure 24). Dominant woody species in this type include Red Maple (*Acer rubrum*), Green Ash (*Fraxinus pennsylvanica*), American Elm (*Ulmus americanus*), Swamp White Oak (*Quercus bicolor*), Highbush Blueberry (*Vaccinium corymbosum*), Northern Arrowwood (*Viburnum recognitum*), and Northern Spicebush (*Lindera benzoin*). Herbaceous species include Crested Shield Fern (*Dryopteris cristata*), Royal Fern (*Osmunda regalis*), Sensitive Fern (*Onoclea sensibilis*), Uptight Sedge (*Carex stricta*), and Stout Wood Reed (*Cinna arundinacea*). The prevalence index for this type is 2.41 (Figure 25). The hydrology of this type is seasonally flooded or saturated. Soil series associated with this type is Rockaway (RpC) and Carlisle (Cm) (Table 10). Representative sample points for this type are 2, 8, 16-18, 22-28, 32-37, 42, 45, 47-53, 56, 58, 61-63, and 65 (Table 11). Included here is the Red Maple-Spicebush Palustrine Forest (ASPF) from the NCIPTA classification and parts of the Red Maple (RM) sites from the PTA forest inventory map.

b. *Cover type: birch maple (B/M).* This cover type is generally located in cool moist drainage areas within PTA. Usually this type is associated with small streams and tributaries (Appendix C). This type is more frequent in the northern end of PTA where drainageways have been less impacted by human activity. The mean area size of this type is 0.87 ha (2.16 ac) (Table 13) (Figure 24). Dominant woody species in this type include Yellow Birch (*Betula alleghaniensis*), Red Maple (*Acer rubrum*), Eastern Hemlock (*Tsuga canadensis*), Green Ash (*Fraxinus pennslyvanica*), Tulip Tree (*Lirodendron tulipifera*), American Witch Hazel (*Hamamelis virginiana*), and American Hornbeam (*Carpinus americanus*). Herbaceous species associated with this type include Skunk Cabbage (*Symplocarpus foetidus*), American Starflower (*Trientalis borealis*), Hop Sedge (*Carex lupulina*), Sensitive Fern (*Onoclea sensibilis*), and Cardinal Flower (*Lobelia cardinalis*). The prevalence index for this type is 2.69 (Figure 25). The hydrology of this type is flowing to intermittent streams too seasonally saturated. Soil series associated with this type is Urban Land (Ua) and Ridgebury (R1B) (Table 10). Representative sample points for this type are 1, 4, 9, 10, 14, and 68 (Table 11). Included here is the Yellow Birch-Red Maple-Hemlock-Sphagnum Cool Forest (BAPF) from the NCIPTA classification and parts of the Red Maple (RM) and Moist Water (MS) sites from the PTA forest inventory map.

c. *Cover type: birch/popular (B/P).* This early successional forest type is commonly located in the southern end of PTA. This type is located in many wet areas that have been previously disturbed by human activity (Appendix C). The mean area size of this type is 0.47 ha (1.67 ac) (Table 13) (Figure 24). Dominant woody species in this type include Gray Birch (*Betula populifera*), Big Tooth Aspen (*Populus grandidentata*), Black Cherry (*Prunus serotina*), Green Ash (*Fraxinus pennslyvanica*), and Northern Spicebush (*Lindera benzoin*). Herbaceous species associated with this type include Wool Grass (*Scirpus cyperinus*), New England Aster (*Aster novae-anglae*), Canadian Goldenrod (*Solidago canadensis*), Uptight Sedge (*Carex stricta*), and Giant Reed Grass (*Phragmites australis*). The prevalence index for this type is 2.47 (Figure 25). The hydrology of this type is seasonally ponded to saturated. Soil series associated with this type is Hibernia (HbC) and Man Made (Ma) (Table 10). Representative sample points for this type are 20, 43, and 57 (Table 11). Included here are the Fragmented and Disturbed cover types from the NCIPTA classification and parts of the Aspen/Birch (A/B) and Early successional (ES) sites from the PTA forest inventory map.

d. *Cover type: hemlock (H).* This type is located in 2 areas just south of Lake Denmark. This type is dominated by Eastern Hemlock (*Tsuga* *canadensis*) (Appendix C). This type is separated from the Birch/Maple type based on the dominance of Eastern Hemlock. The mean area size of this type is 0.13 ha (0.34 ac) (Table 13) (Figure 24). Dominant woody species in this type include Eastern Hemlock (Tsuga canadensis), White Oak (Quercus alba), and Sweet Birch (*Betula lenta*). The understory of this type is depauperate and lacks significant herbaceous cover. The prevalence index for this type is 3.39 (Figure 25). The hydrology of this type is seasonally ponded to saturated. Soil series associated with this type is Urban Land (Ua) and Rockaway (RrD) (Table 8). The representative sample point for this type is 67 (Table 9). Included here is the Yellow Birch-Red Maple-Hemlock-Sphagnum Cool Palustrine Forest (BAPF) cover type from the NCIPTA classification and parts of the Red Maple sites from the PTA forest inventory map.

Wetland type: man made. Human development has modified the landscape within the valley floor of PTA. Historically many forested swamps have been drained and many activities associated with the facility have disturbed areas. Some of these disturbances have modified the hydrology such that wetlands have developed within some of these effected areas. These sites are usually dominated by early successional and introduced species. This has left many of these wetlands without a clear set of dominants that meaningfully describe the vegetation. In this study, these areas are designated as man made. Three man made types were surveyed and mapped at PTA. These were the golf course, fill, and man made. Of these three types, only the man made type was mapped as a wetland cover type. The golf course and fill were assigned labels, but they are considered land use types.

a. *Cover type: man made (MM)*. This cover type is frequently located in the southern end of PTA. The mean area size of this type is 0.1 ha (0.25 ac) (Table 13) (Figure 24). Species generally associated with this type include Common Reed Grass (*Phragmites australis*), Soft Rush (*Juncus effusus*), Sensitive Fern (*Onoclea sensibilis*), Red Maple (*Acer rubrum*), Fall Panic Grass (*Panicum dichotomiflorum*), Gray Birch (*Betula populifera*), Red Osier Dogwood (*Cornus stolonifera*), Climbing Nightshade (*Solanum dulcamara*), and Common Pokeberry (*Phytolacca americana*). The prevalence index for this type is 2.04 (Figure 25). The hydrology of this type is seasonally ponded to saturated. Soil series associated with this type is Rockaway (RpC and RrD) (Table 10). Representative sample points for this type are 11, 12, 15, and 29-31 (Table 11). Included here are the Disturbed and Fragmented cover types from the NCIPTA classification and parts of the Red Maple, Aspen/Birch (AB), and Early Successional (EA) sites from the PTA forest inventory map.

b. *Land use type: golf course (GC)*. An eighteen-hole golf course is located within PTA at the southern end. The golf course has been here since the late 1940's. It was built in a Red Maple wetland type on hydric soils. In this study, the golf course was determined to be a problematic wetland decision.

The golf course was evaluated for the occurrence of wetlands. Several sample points were taken for making wetland determinations. Some soil borings taken during the sampling encountered fill while others were in native soils. One area specifically chosen to evaluate a wetland decision within the golf course was determined not to be a wetland. This decision was problematic. At sample point 59, the soils are an organic muck, the vegetation is mowed grass with an overstory of a few Red Maple trees, and hydrology was present. The vegetation was determined to be non-hydrophytic, the soils were hydric, and water was located to within 15 cm (6 in.) of the surface. The hydrology decision was complicated by the sampling period. The sample was taken outside the growing season. A hydrologic determination partially hinges on the occurrence of water within the growing season. Growing season as it relates to wetland hydrology is defined by the *Corps of Engineers Wetland Delineation Manual* (1987) as "an area has wetland hydrology if it is inundated or saturated to the surface for at least 5 percent of the growing season in most years (most defined 51 years out of 100) . . . and in absence of soil temperature data, growing season can be estimated from the SCS county soil survey. Starting and ending dates generally are based on 28 deg F air temperature threshold for the average year." At PTA, the 5 in 10 growing season ends on 23 October (Eby 1976). Based on the growing season, the hydrology observation was not useful in determining the wetland decision. Therefore, the site lacked two of the three parameters required to be considered a jurisdictional wetland.

Problematic wetlands were not identified within the golf course in this study for the following reason: a spring sampling period is required to evaluate ponded water areas for wetland decisions. Some efforts required to locate wetlands within the golf course are: (1) aerial photographs showing ponded water in the spring of the year before leaf out, (2) field surveys during spring rainy periods to locate areas that may not have been drained, and (3) evaluation of ponded water zones for fill materials. Because this set of conditions did not occur during the study, we were not able to accurately locate areas that might be considered wetlands.

No wetlands were mapped and characterized as a golf course cover type (GC). Although this cover type is currently classified as "upland," parts of the golf course that may pond water during the growing season were included on the wetlands map and baseline map. This cover type is also used to distinguish between different cover types that occur in the areas surrounding the golf course. No frequency of volume data will be presented or discussed for this map symbol.

c. *Land use type: fill (FILL)*. This is not a wetland cover type. It is a mapping unit used to clarify wetland boundaries. In delineating several wetlands that had been previously impacted by human activity, including the discharge of fill materials, it was necessary to map filled areas. Sample point 41 was taken in fill to clarify a wetland boundary. No frequency or volume data will be discussed for this map symbol.

Delineation Results and Discussion

The NWI maps reported 517.57 ha (1,279.0 ac) of wetlands within the study area (Table 5). There were 81 wetlands mapped at PTA by NWI. Of these, the two most frequently occurring wetland types mapped were the Palustrine Forested Broad Leaved Deciduous (PFO1) and Palustrine Scrub Shrub Broad Leaved Deciduous (PSS1). Of these the PSS1 (Palustrine Shrub/ Shrub, Broad-leaved deciduous) type was the largest wetland type at PTA with 236.34 ha (584.0 ac).

This study, a planning level wetland delineation, located and mapped 209 wetlands (Appendix D). The total area of wetlands mapped during the delineation was 478.6 ha (1,182.6 ac). Based on this study, wetlands represent 20.9 percent of PTA landscape.

The ground truthed results from this delineation were similar only in area compared to NWI. This study mapped 7.5 percent less wetlands in size from those reported by NWI. However, the frequency of wetland occurrence varied greatly. This study found 209 wetland locations compared to 81 by the NWI. This represents a 66 percent difference in reported occurrences. Of the 209 wetlands, 77 were located in areas not reported by NWI (Figure 28). This represents a 36 percent difference in locations. NWI reported 7 locations not reported by WES (Figure 28). Some NWI differences appeared to be map resolution problems.

Wetlands delineated during this study were dominated mostly by woody species. Seven of the nine vegetation cover types are dominated by tree or shrub species. Wetlands dominated by woody species comprise 39.2 percent of the total wetland area.

Three of the nine wetland cover types dominate the wetland area, they are: Lakes (L), Red Maple (RM), and Scrub Shrub 1 (SS1). These three cover types comprised 92 percent of the total wetlands (Figure 26). The most common wetland cover types at PTA are Red Maple (RM). This type comprises 39 percent of the wetland area at a frequency of 47.4 percent (Tables 14 and 15). The total area coverage for this type is 187.2 ha (462.58 ac). The mean area of this cover type is 1.89 ha (4.67 ac) (Table 13). The second most common cover type is Lakes (L) that comprise 171.58 ha (423.98 ac) at a frequency of 10 percent. This type has a mean area of 8.17 (20.19 ac). The third most common is Scrub Shrub 1 (SS1). This type comprises 16.7 percent of the wetland area at a frequency of 0.04 percent. The mean area of this cover type is 79.74 ha (197.03 ac) (Table 13) (Figure 24).

Table 14
Percent Area of Wetland Cover Types

Cover Type	Hectares	Percent Volume
Lacustrine (L)	171.6	35.86
Scrub Shrub (SS)	2.7	00.56
Scrub Shrub 1 (SS1)	79.7	16.65
Wet Meadow (ME)	15.7	3.28
Red Maple (RM)	187.2	39.11
Birch/Maple (B/M)	12.2	2.55
Birch/Poplar (B/P)	7.1	1.48
Hemlock (H)	0.3	00.06
Man Made (MM)	2.1	00.44
Total	478.6	99.99

Table 15
Percent Frequency of Wetland Cover Types

Cover Type	Frequency	Relative Frequency
Lacustrine (L)	21	10.05
Scrub Shrub (SS)	8	3.83
Scrub Shrub 1 (SS1)	1	00.48
Wet Meadow (ME)	29	13.88
Red Maple (RM)	99	47.37
Birch/Maple (B/M)	14	6.69
Birch/Poplar (B/P)	15	7.18
Hemlock (H)	2	00.96
Man Made (MM)	20	9.57
Total	209	100.01

The other 6 cover types share the remaining 8 percent of wetland area. Of this 8 percent, Wet Meadow (ME) and Birch/Maple (B/M) comprise 5.8 percent. The Wet Meadow (ME) cover type comprises 3.28 percent of the area at a frequency of 13.9 percent (Tables 14 and 15). The total area coverage for this type is 15.73 ha (38.88 ac). The mean area of this cover type is 0.54 ha (1.34 ac). The Birch/Maple (B/M) cover type comprises 2.5 percent of the wetland area at a frequency of 6.7 percent. The total area coverage for this type is 12.22 ha (30.22 ac). The mean area of this cover type is 0.87 ha (2.16 ac).

The remaining 2.2 percent of the wetlands at PTA are divided between 4 cover types. These are: Birch/Popular (B/P), Scrub Shrub (SS), Man Made (MM), and Hemlock (H). The Birch/Popular (B/P) cover type comprises 1.5 percent of the wetland area at a frequency of 6.6 percent (Tables 14 and 15). The total area coverage for this type is 7.09 ha (17.51 ac). The mean area of this cover type is 0.47 ha (1.16 ac). The Scrub Shrub (SS) cover type comprises 0.6 percent of the wetland area at a frequency of 3.8 percent (Tables 14 and 15). The total area coverage for this type is 2.7 ha (6.67 ac). The mean area of this cover type is 0.34 ha (0.12 ac). The Man Made (MM) cover type comprises 0.43 percent of the wetland area at a frequency of 9.5 percent (Tables 14 and 15). The total area coverage for this type is 2.07 ha (5.1 ac). The mean area of this cover type is 0.1 ha (0.25 acres). And the smallest and least frequent cover type is Hemlock (H) which comprises 0.057 percent of the wetlands at a frequency of 1 percent (Tables 14 and 15). The total area coverage for this type is 0.26 ha (0.68 ac). The mean area of this cover type is 0.14 ha (0.34 ac).

The wetlands at PTA can be divided into 6 groups of similar degrees of hydrophytic vegetation as expressed by the prevalence index (Figure 25). The wettest cover type, or prevalence index, by hydrophytic vegetation is the Lakes (L). Because all the species are OBL wetland plants, this type has a prevalence index of 1.0. The second wettest cover type is Scrub Shrub 1 (SS1). This type has a prevalence index of 1.75. The third group, composed of Wet Meadow (ME) and Man Made (MM), has an average prevalence index of 2.06. The fourth group, composed of Red Maple (RM) and Scrub Shrub (SS), has an average prevalence index of 2.38. The fifth group, composed of Birch/Maple (B/M) and Birch/Popular (B/P), has an average prevalence of 2.58. The least hydrophytic cover type is Hemlock (H) with a prevalence index of 3.39. Except for the few aquatic cover types, the wetness indexes of the forested wetlands found at the PTA study area were dominated by FAC to FACW species.

Of the 27 soil mapping units occurring at Picatinny Arsenal, the three most frequent are Rockaway very stony sandy loam, 3-15 percent (RpC) with a frequency of 35, Water (Wtr) with a frequency of 23 and Rockaway extremely stony sandy loam, 15-25 percent (RrD) with a frequency of 22 (Table 16). These three soil mapping units in addition to Rock outcrop-Rockaway complex steep (RvF), comprise 59 percent (Figure 31) of the total soil coverage at a frequency of 45 percent (Figure 30). The soil map unit with the largest area is Rockaway extremely stony sandy loam, 3-15 percent (RpC) with 545.29 ha (1,347.40 ac). This soil mapping unit comprises about 24 percent of the total soil coverage. Of the 27 soil map units at PTA, 30 percent are classified as hydric (Table 8). Soils classified as hydric at PTA comprise 26 percent of the landscape (Figure 31). The most frequently occurring hydric soil map unit is Water (Wtr) with a frequency of 23 followed by Carlisle muck (Cm) with a frequency of 17 (Table 16). Of the hydric soils at PTA, Water (Wtr) is the largest with an area of 169.14 ha (417.95 ac).

Table 16
Mean Area for Soil Map Units in Hectares

Soil Symbol	Mean Area	Freq.	Min/Max Area
Ad	12.41	7	0.54/66.99
Cm	8.83	17	0.07/80.46
Hbc	5.95	15	0.07/18.56
HID	5.10	2	1.46/8.74
Ma	7.68	2	1.09/14.28
NtB	0.31	1	0.31/0.31
OtC	8.94	6	2.06/25.35
Ps	1.92	1	1.92/1.92
PtB	3.46	3	0.30/7.46
PvA	4.76	3	1.91/10.20
Pw	16.03	4	0.03/37.22
RgA	2.69	1	2.69/2.69
RlB	8.10	12	0.14/24.38
RmB	1.16	2	0.90/1.42
RmC	0.14	1	0.14/0.14
RoB	0.36	1	0.36/0.36
RpC	15.58	35	0.49/89.90
RrD	19.27	22	0.02/261.17
RsC	8.59	6	0.15/26.55
RsD	5.49	8	0.11/14.53
RsE	27.17	1	27.17/27.17
Rt	20.78	3	0.83/44.63
RvF	34.94	6	4.71/69.99
Ua	21.12	7	0.19/136.77
UrD	3.70	1	3.70/3.70
Wm	5.40	2	1.78/9.01
Wtr	7.35	23	0.01/107.36
Total	9.53	192	0.01/261.17

Cole's coefficient of interspecific association between cover types and soil series suggested that some cover types were more positively associated with certain soil series (Figure 27). The cover types with the strongest magnitude of association were Lakes (L) and Scrub/Shrub 1 (SS1). The frequency of occurrence for SS1 was 1 within PTA. This explains its strong association with Carlisle Muck (Cm). Lakes were strongly associated at PTA based on there high similarity of occurrence of our cover type compared to the soil series Water (WtR). The most frequently occurring cover type at PTA is Red Maple (RM) (Figure 29). This cover type consequently corresponds with the most frequently occurring soil map unit, Rockaway (RpC) (Figure 31). This makes sense since both the Red Maple cover type and the Rockaway soil map unit are located in many different types of landscape positions at PTA.

Observations and study conclusions from this wetland delineation are summarized below.

a. A total of 209 separate wetlands was located and mapped within the study area.

b. A total of 478.6 ha (1,182.6 ac) of wetlands was mapped in the study area. This represented a 7.5 percent decrease in wetlands over the NWI maps.

c. A 66 percent increase of frequency of wetlands with a 33 percent difference in location are reported between this study and the NWI map. The differences between the two maps are mostly for smaller and more fragmented wetlands.

d. Three cover types comprised 92 percent of the wetland area. These three types are: Lakes (L), Red Maple (RM), and Scrub/Shrub 1 (SS1).

e. Red Maple (RM) is the most frequent and largest wetland cover type at PTA.

f. Wetlands delineated in this study comprise 20.9 percent of the study area.

g. The 9 wetland cover types at PTA were divided into 6 groups based on their hydrophytic plant prevalence index. The Lakes (L) Scrub Shrub 1 (SS1) cover types were dominated by OBL and FACW plant species. The Wet Meadow (ME) and Man Made (MM) were dominated by FACW plant species. The remaining wetland types were mixed with FACW to upland species.

h. Picatinny has 27 soil map units, 30 percent of which are hydric. The most frequently occurring soil mapping unit is Rockaway very stony sandy loam, 3-15 percent (RpC), and the soil mapping unit with the largest area is also Rockaway very stony sandy loam, 3-15 percent (RpC). Twenty-six percent of the PTA landscape is composed of soils classified as hydric, with Water (Wtr) being the most frequent and the largest map unit.

i. The cover types with the strongest positive index of association with certain soil series are Lakes (L) and Scrub/Shrub 1 (SS1). Red Maple, the most frequent cover type at PTA, did not show a strong association for any particular soil map unit. This reflects its wide distribution with PTA.

j. The wetlands identified and delineated are shown on the wetland baseline map (Appendix II).

Wetland Management

Because 21 percent of the landscape at PTA is a wetland, proper management of these resources can provide benefits attributed to functional wetlands. Some benefits include flood water storage, water quality, nutrient retention, and fish and wildlife habitat. Besides proper management of wetlands at PTA, several opportunities exist to restore and enhance wetlands. The suggestions made here are based on observations made during the delineation of wetlands and are not intended to represent a comprehensive evaluation of wetlands at PTA. The following suggestions are:

Red Maple swamp

Impact. The Red Maple swamp at the southern end of PTA has been altered and impacted by previous human activities. The most detrimental impact to these wetlands has been the alteration of hydrology. Numerous drainage ditches, acting as laterals, are connected to Green Pond Brook. These lateral ditches move surface water during peak saturation periods during the year. This causes the surface hydrology to be modified. These modifications, combined with severe logging pressure, have eliminated the typical Fern and Sedge hummocks associated with this type.

Recommendation. Wetland areas need to be identified where ditches could be plugged or filled. Those areas that might cause flooding should not be considered. Restoration of some Red Maple swamps in the southern part of PTA could help in retaining storm water. Areas to be evaluated are located from the southern end of the golf course to the south boundary of PTA.

Recharge areas

Impact. Development of facilities in some upland areas may need to consider impacts to surface and ground water recharge areas vital to the Red Maple swamps at the southern end of PTA. Some of these upland areas are located along the eastern slopes of PTA. Included here are the 3 to 10 percent slopes near Parker Road-Maxwell Road located on the poorly drained soil map unit Ridgebury. This type is also found within the 1,300 and 1,400 enclosure areas.

During this survey, these areas were evaluated several times for the occurrence of wetlands. Only a few areas qualified as wetlands but water was present near the surface in these sloping areas. These slopes move water due to the soil texture of the glacial materials. These rocky slopes are part of the recharge area for the Red Maple swamps at the south end of PTA. Therefore, any future restoration of Red Maple swamps at the southern end of PTA could be affected by loss of recharge water from these areas.

Recommendations. Delineate where these sloped areas are that have ground water near the surface. Before placement of any construction projects in these areas, impacts to ground water should be evaluated. If recharge water is located and the plans call for control of the water, consideration should be given to routing the water toward the wetlands.

Man made

Impact. As discussed in this report, the frequencies of man made and man influenced wetlands is common at PTA. Many of these wetlands are degraded and are dominated by non-native species. Similarly the hydrology has been modified which limits the ability of these wetlands to perform certain functions.

Recommendations. Using this report, select those man made and meadow wetland cover types that have the greatest ability to be restored. Selection of wetlands to be restored should consider fragmented habitat, ability of a wetland to hold water, and location.

Burning grounds

Impacts. This area has been filled, burned, drained, and degraded from human uses. Some of these areas are proposed to be cleaned up as part of the CERCLA program. Some of these same areas could be restored as functioning wetlands if fill materials were removed and hydrology returned to the site.

Recommendations. Locate the areas that have the potential to have the hydrology restored. Remove fill and other materials. Consider planting arrangements for restoring wetland habitat. Habitat restoration should be similar to adjacent Red Maple swamps.

Logging

Impacts. Logging or clearing of forested wetlands can reduce the habitat quality and functional level of wetlands. Logging of trees opens the canopy and changes the species composition of the wetland. Also, in wetlands that receive storm or flood waters, the removal of woody vegetation can reduce the ability of a wetland to store or slow storm waters.

Recommendations. Logging, or other physical impacts, to wetlands should be considered in the planning process, not only for regulatory compliance, but for maintaining habitat, water quality, and integrity of wetlands.

5 Hydrologic Analysis

Introduction

Scope of work

There were two objectives to the Identification and Delineation of Floodplains Analysis. The first was to identify and delineate areas at Picatinny Arsenal which would be inundated by floods of various return frequencies, and the second was to provide hydrological information for use in the Geomorphological Information for Cultural Resource Management Analysis and in the Identification and Delineation of Wetlands Analysis.

Delineation of floodplains was accomplished through the use of the hydrologic model "CASC2D," a two dimensional model that provides simulated flow and stage information for drainage basins. Using CASC2D, flow velocities and water depths can be calculated at selected grid cells for the entire data base, in this case, the Picatinny Arsenal drainage basin. CASC2D models overland flow on a square grid cell basis and is well suited for GIS databases. The results can easily be integrated into the other geomorphological and wetland analyses conducted by GIS methods. Floodplain delineation will focus on simulating runoff hydrographs due to various frequency rainfall events and generating maximum stage data for all areas of Picatinny Arsenal which may be subjected to floods. Data required by CASC2D include landuse, soil type, detailed topography, overbank and channel cross-sections, rainfall distributions, and observed streamflow hydrographs.

CASC2D Methodology

Overland flow routing

Overland flow is generally a two-dimensional process which is controlled by spatial variations in slope, surface roughness, excess rainfall, and other parameters. As the overland flow drains into stream channels, one dimensional flow prevails. The diffusive wave equation for channel flow can predict the possible backwater effects in main channels and tributaries. As in the other watershed processes, the spatial variations in channel parameters must be accounted for in the model.

The Saint-Venant equations for continuity and momentum describe the mechanics of overland flow. The two-dimensional continuity equation in partial differential form reads as:

$$\frac{\partial h}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = e \qquad (1)$$

where

h = surface flow depth

q_x = unit flow in x-direction

q_y = unit flow in y-direction

e = excess rainfall equal to (i-f)

i = rainfall intensity

f = infiltration rate

x,y = cartesian spatial coordinates

t = time

The momentum equation in the x and y directions may be derived by equating the net forces per unit mass in each direction to the acceleration of flow in the same direction. The two-dimensional form of the equations of motion are:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = g\left[S_{ox} - S_{fx} - \frac{\partial h}{\partial x}\right] \qquad (2)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = g\left[S_{oy} - S_{fy} - \frac{\partial h}{\partial y}\right] \qquad (3)$$

where

u,v = average velocities in x and y direction respectively

S_{ox},S_{oy} = bed slopes in x and y direction respectively

S_{fx},S_{fy} = friction slopes in x and y direction respectively

g = acceleration due to gravity

The right hand side of the momentum equations describes the net forces along the x and y directions while the left hand side represents the local and convective acceleration terms.

In simplifying the momentum equations, the kinematic wave approximation assumes that all terms, except the bed slope and the friction slope, are negligible. This assumption, which is particularly valid for steep bed slopes, has been the basis for many rainfall-runoff models. However, a kinematic wave can not predict backwater effects due to downstream disturbances that may be important when simulating floods. On the other hand, a diffusive wave model can simulate backwater effects and is considered to be applicable for overland flow over rough surfaces as well as for channel flows. The momentum equation based on the diffusive wave approximation reduces to:

$$S_{fx} = S_{ox} - \frac{\partial h}{\partial x} \tag{4}$$

From the three equations of continuity and momentum, five hydraulic variables need to be determined. Therefore a resistance law should be established to relate flow rate to depth and to other parameters. A general depth-discharge relationship may be written, in the x-direction for example, as:

$$q_x = a_x h^b \tag{5}$$

where a_x and b are parameters which depend on flow regime; i.e., laminar or turbulent. For laminar flow in the x-direction, the value for b is taken to be 3, and the following expression gives a_x:

$$a_x = \left(\frac{8g}{K\nu}\right) S_{fx} \tag{6}$$

where

K = resistance coefficient

ν = kinematic viscosity

Similarly, for turbulent flow over a rough boundary, the Manning empirical resistance equation is used. Thus, b is equal to 5/3 and a_x is computed from the following expression:

$$a_x = \frac{S_{fx}^{0.5}}{n} \tag{7}$$

where

n = Manning's roughness coefficient

Rainfall distribution

In CASC2D, rainfall was analyzed using an interpolation scheme based on the inverse distances squared. This scheme approximates the distribution of rainfall intensity over the watershed:

$$i^t(j,k) = \frac{\sum_{m=1}^{NRG} \frac{i_m^t(j_{rg},k_{rg})}{d_m^2}}{\sum_{m=1}^{NRG} \frac{1}{d_m^2}} \tag{8}$$

where

$i^t(j,k)$ = rainfall intensity in element (j,k) at time t.

$i^t(j_{rg},k_{rg})$ = rainfall intensity recorded by rainfall gages located at (j_{rg},k_{rg}) at time t.

d_m = distance from element (j,k) to rainfall gage located at (j_{rg},k_{rg}).

NRG = Total number of rainfall gages.

If no raingage data is available, rainfall is assumed to be uniform over the watershed.

Channel flow

The core of the model formulation is the Priessman coefficients, which represent the finite difference approximations of the temporal and spatial derivatives of the de St. Venant conservation equations of mass and momentum. The coefficients used were derived in iterative form. The quadratic convergence of the Newton-Raphson scheme results in low iteration counts. In fact, there is little gain in solution accuracy in going from two to three iterations.

Channel conveyance data are represented in analytical form using a trapezoidal cross-section approximation. From the trapezoidal geometry, the channel conveyance with respect to depth is computed.

Picatinny Arsenal contains four ephemeral first order streams. Each of these ephemeral streams presents a problem for double-sweep channel routing as the implicit method cannot handle zero flow depths (dry-bed). Several approaches have been applied in the past to enable continuous implicit channel routing in dry-bed situations (Cunge, et al. 1980; Fread 1988). The dry-bed solution method by Meselhe and Holly (1993) was chosen for use because of its relative ease of programming and small effect on the total discharge at the basin outlet. This method requires three operations when the flow depth falls below a user specified level: (1) the inertial terms of the de St. Venant equations are suppressed; (2) the friction slope is changed to depend solely on upstream conditions; and (3) a minimum depth is maintained in the channel at all times. Any flow added to prevent dry-bed conditions in the first order streams can be removed as seepage loss in higher order streams.

The upstream boundary condition on all first order streams is a constant discharge, representing the minimum discharge to prevent dry-bed oscillations. This discharge depends on the channel cross-section properties and slope. There are also locations within the network topology where the de St. Venant equations are locally non-applicable. Internal boundary conditions are applied in these situations, such as: low weirs, culverts, reservoir water surface elevations, scheduled reservoir releases, and emergency spillway flows. Low weirs are modeled using the procedure presented in Cunge, et al. (1980, pg. 180), with linearization to avoid problems when the weir is flooded and the water levels are nearly equal upstream and downstream of the weir. Linearization is necessary because the partial derivative of discharge with respect to the difference in upstream and downstream water surface elevations approaches infinity as the water levels deviate from equality.

Culvert flow conditions considered include inlet and backwater control. The height of the roadway above the culvert must be specified, and if overtopping occurs, a composite weir/culvert internal boundary condition is employed. As a first approximation a wide rectangular weir of user specified width is used to simulate the flow over the roadway.

Flow is not routed through reservoirs. Instead, the linear reservoir approximation is made based on the reservoir storage curve. The reservoir water surface elevation provides an internal boundary condition for all links which feed the reservoir. Design spillway parameters and scheduled releases provide a Q(t) internal boundary condition at the outlet of dams.

The channel routing scheme presented herein represents the combination of several recent advances in implicit finite-difference de St. Venant channel routing. The methodology is general, in that it considers the most frequently encountered internal and external boundary conditions. This channel routing method allows fully-distributed physically-based hydrologic simulations on basins which are larger than those for which most current channel routing techniques are applicable.

Infiltration

The first step in simulating a rainfall-runoff event on a watershed is to determine the excess rainfall. An infiltration scheme must accommodate both spatial variations due to soil texture changes, and temporal variations due to the time-variant nature of both rainfall and soil infiltration capacity. Additionally, the fact that rainfall history affects the infiltration rate at the present time has to be accounted for in the infiltration scheme. Ideally, the scheme should also rely on physically measurable soil infiltration parameters. The Green-Ampt infiltration equation adequately satisfies these requirements and is therefore well-suited for distributed watershed modeling.

The Green-Ampt infiltration scheme has gained considerable attention in the past decade, partially due to the ever growing trend towards physically-based hydrologic modeling. The parameters of the Green-Ampt equation are based on the physical characteristics of the soil and therefore can be determined by field measurements or experiments. The Green-Ampt equation may be written as:

$$f = K_s \left[1 + \frac{H_f M_d}{F} \right] \quad (9)$$

where

f = infiltration rate

K_s = hydraulic conductivity at normal saturation

H_f = capillary pressure head at the wetting front

M_d = soil moisture deficit equal to $(O_c\text{-}O_i)$

O_c = effective porosity equal to $(P\text{-}O_r)$

P = total soil porosity

O_r = residual saturation

O_i = initial soil moisture content

F = total infiltration depth

The head due to surface depth has been neglected as H_f easily overpowers shallow overland depth. Rawls et al. (1983) provided sets of average values of total porosity, effective porosity, capillary pressure head, and hydraulic conductivity based on soil texture class (see Table 17).

Data Requirements

Elevation grids

The elevation data was generated by the Geotechnical Lab at WES from contour maps. In order for CASC2D to simulate correctly, the elevation map had to be smoothed slightly in order to remove any artificial depressions.

Table 17
Green-Ampt Parameters Based on Soil Texture

Soil Texture	Total Porosity	Effective Porosity	Wetted Front Capillary Head (cm)	Hydraulic Conductivity (cm/h)
Sand	0.437	0.417	4.95	11.78
Loamy Sand	0.437	0.401	6.13	2.99
Sandy Loam	0.453	0.412	11.01	1.09
Loam	0.463	0.434	8.89	0.34
Silt Loam	0.501	0.486	16.68	0.65
Sandy Clay-Loam	0.398	0.330	21.85	0.15
Clay Loam	0.464	0.309	20.88	0.10
Silty Clay-Loam	0.471	0.432	27.30	0.10
Sandy Clay	0.430	0.321	23.90	0.06
Silty Clay	0.479	0.423	29.22	0.05
Clay	0.475	0.385	31.63	0.03

Source: Green and Ampt parameters (CASC2D User's Manual).

Once the elevation grid was smoothed, a channel network was created which indicated which grid cells were overland routing cells and which grid cells were channel routing cells.

From the three equations of continuity and momentum, five hydraulic variables need to be determined. Therefore a resistance law should be established to relate flow rate to depth and to other parameters. A general depth-discharge relationship may be written, in the x-direction for example, as:

$$q_x = a_x h^b \tag{5}$$

where a_x and b are parameters which depend on flow regime; i.e., laminar or turbulent. For laminar flow in the x-direction, the value for b is taken to be 3, and the following expression gives a_x:

$$a_x = \left(\frac{8g}{K\nu}\right) S_{fx} \tag{6}$$

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Similarly, for turbulent flow over a rough boundary, the Manning empirical resistance equation is used. Thus, b is equal to 5/3 and a_x is computed from the following expression:

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where n is Manning's roughness coefficient.

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In CASC2D, rainfall was analyzed using an interpolation scheme based on the inverse distances squared. This scheme approximates the distribution of rainfall intensity over the watershed:

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where

f = infiltration rate

K_s = hydraulic conductivity at normal saturation

H_f = capillary pressure head at the wetting front

M_d = soil moisture deficit equal to $(O_c\text{-}O_i)$

O_c = effective porosity equal to $(P\text{-}O_r)$

P = total soil porosity

O_r = residual saturation

O_i = initial soil moisture content

F = total infiltration depth

The head due to surface depth has been neglected as H_f easily overpowers shallow overland depth. Rawls, et al. (1983) provided sets of average values of total porosity, effective porosity, capillary pressure head, and hydraulic conductivity based on soil texture class (see Table 17).

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Soils grids (soils parameters)

The soil texture map was generated by the Geotechnical Lab at WES from SCS county maps. From the soil texture classifications, a hydraulic conductivity grid, an initial soil moisture grid, a porosity grid, and a wetted front capillary head grid was generated. Table 17 shows the relative relationship between soil texture and the above mentioned soil properties.

Precipitation

An SCS Type-II 24 hr distribution was used to simulate the frequency rainfall for the 1, 2, 10, 25, 100, and 500 year storms. The total rainfall amounts for the different frequency storms, Table 18, was taken from the 1961 U.S. Weather Bureau TP-40 maps. Since there were no rain gages available within or near the watershed that could be used for estimating spatial distribution, the rainfall was applied uniformly over the entire watershed.

Table 18
24 Hour - Duration Rainfall Data

Frequency (Flow)	1	2	10	25	100	500
Depth (in.)	3.00	3.50	5.00	6.00	7.50	8.35

Landuse grids

The landuse grid was generated by the Geotechnical Lab at WES. From this grid, a Manning's roughness grid was generated for use in the overland routings. The following is a list of the roughness coefficients used for the various landuse types.

Table 19
Overland Roughness Coefficients

Landuse Classification	Manning's 'n'
Urban Areas	0.020
Golf Courses and Baseball Fields	0.060
Meadows and Fields	0.070
Forested Areas	0.140

Channel cross-sections

Surveyed cross-sections were used for the main stem of Green Pond Brook below the outlet of Lake Picatinny. The tributaries and channels above Lake Picatinny were measured using a weighted tape in order to get rough channel dimensions. Manning's roughness coefficients ranged from 0.034 to 0.045 for the mainstem of Green Pond Brook.

CASC2D Modeling/ Simulation Philosophy

Based upon the above geological description, soils were assumed to consist of moderately to well drained sands and gravels having high infiltration rates or low runoff potential. Due to the lack of recorded rainfall data, spatial variation or time distribution analyses for storms could not be performed. Therefore the standard SCS 24 hr rainfall distribution was assumed for the study. Peak rainfall intensities for the SCS distribution occur near the middle of the storm period. The explicit solution technique used in CASC2D requires a very small computational time step especially when using the small grid cell size of 30 m. For these reasons, only the central portion of the storm from 7.5 to 15 hr was simulated. This was sufficient to catch the peak flow rates and flood depths and greatly reduced the computer simulation time. The initial soil moisture deficit parameter in CASC2D was assumed to be zero for the 1, 2, and 10 year events and 30 percent for the 25, 100, and 500 year events.

Discussion of Simulation Results

A Log-Pearson frequency analysis of the peak discharges recorded at the USGS gaging station (see Table 20) located near the lower end of the Picatinny Arsenal watershed was performed used the HEC-FFA computer program and the results are shown in Table 21.

Table 20
Peak Discharge Data at USGS Gage

Rank	Peak Flow (cfs)	Date
1	572	04-05-84
2	344	05-17-90
3	332	09-14-87
4	229	05-17-89
5	194	01-26-86
6	186	09-27-85
7	178	03-29-93
8	163	06-06-92
9	141	12-04-90
10	97	10-28-87

Table 21
Peak Flow (CFS) Comparison

Return Period Years	HEC-FFA Log-Pearson Frequency Analysis			CASC2D Simulation
	Computed	Expected Probability	Upper Confidence Limit .05	
1	83	70	118	208
2	205	205	271	261
10	423	473	726	472
25	--	--	--	729
100	874	1,440	2,260	1,120
500	1,350	3,670	4,520	1,337

Note: HEC-FFA does not compute a frequency flow for the 25 year return period.

Since the period of record was only 10 years, the computed discharges for the higher return periods are somewhat questionable. Peak runoff magnitudes for the 1, 2, and 10 year return periods estimated with the CASC2D model appear to be very reasonable when compared to the estimated values computed from the log-pearson analyses of the gaged data. As can be seen from the dates of occurrence, the larger events predominately occurred in the spring. This seems to verify our assumption of less soil storage available for the larger return period events since snowmelt during the spring would tend to increase the antecedent moisture conditions.

Summary

Based upon the analyses performed with CASC2D on this watershed, the model appears to be a valid simulation tool giving results that were reasonable when compared to the gage record. Although all the parameters assumed in CASC2D for simulation purposes could not be calibrated or verified, they appear to be reasonable since the computed peak flows were within the 95 percent confidence limits. Output from the CASC2D model consists primarily of composite maps generated for maximum flood depths within all grid cells during the synthetic/hypothetical storm events. However, it is also possible to generate other data such as flow or stage hydrographs or velocities at selected points within the basin if needed.

6 Threatened and Endangered Species

Task Four, Characterization of Threatened and Endangered Species, was initiated in June 1993. The habitat characterization portion of the study has focused on the assimilation and review of information pertaining to the life history, ecology, habitat requirements, and management of select target species. A list of ten target species was compiled by WES researchers in December 1993 and approved by Picatinny personnel in January 1994. Species selected for inclusion in the study include three federally protected species and seven locally sensitive species (as classified by the state of New Jersey and the U.S. Fish and Wildlife Service).

Species chosen for study include: the bald eagle (*Haliaeetus leucocephaluss*), the peregrine falcon (*Falco peregrinus anatum*), the Indiana bat (*Myotis sodalis*), the bog turtle (*Clemmys muhlenbergii*), the timber rattlesnake (*Crotalus horridus horridus*), the long-tailed shrew (*Sorex dispar*), the cerulean warbler (*Dendroica cerulea*), the eastern woodrat (*Neotoma floridana magister*), the New England cottontail (*Sylvilagus transitionalis*), and the long-tailed salamander (*Eurycea longicauda longicauda*).

Species accounts/profiles have been completed for the bald eagle, the peregrine falcon, the Indiana bat, the timber rattlesnake, and the New England cottontail. Work on the remaining species is ongoing. Species accounts/profiles include information on the life history, ecology, habitat requirements, and management of each species, as well as a comprehensive bibliography of the recent scientific/technical literature.

Information on the habitat requirements of each target species is was evaluated to develop habitat assessment criteria that can be applied to existing habitat on the arsenal to provide a qualitative assessment of current and future habitat conditions/suitability.

The substantial length of the report of the investigation of threatened and endangered species at Picatinny Arsenal necessitated publication of this volume as a separate volume. Volume II of this report contains the results of the investigation of threatened and endangered species.

7 Geographic Information System

A Brief History of GIS

In order to look at the historical development of the Geographic Information System (GIS), it is first necessary to look at the component parts of a GIS.

A GIS was defined by Antenucci as: "...a computer system that stores and links, non geographic attributes or geographically referenced data with graphic map features to allow a wide range on information processing and display operations, as well as map production, analysis and modeling."

Possibly the most important part of a modern GIS is the computer, the development of the systems that we would recognized as a GIS are closely linked to the development of the computer. Quite possibly the most important factor that has been responsible for the remarkable growth of the GIS industry has been the decrease in computer hardware and software prices while the relative performance of the parts has increased, dramatically. It would be possible to trace the development of GIS technology back to the development of the first Cartesian grids that permitted navigation. The development of computer technology has been well documented from the first massive computers, that were developed following the second world war onwards, filling large rooms with row upon row of valves, to the latest very powerful Unix workstations with Reduced Instruction Set Computing (RISC) computer chips that have the capacity to carry out the intensive computing that is used in a current GIS.

One of the most important pieces of software produced during the mid 60's was SYMAP, developed by Howard Fisher. During the 1970's most of the GIS development took place for a specific application and system. One of the key players, at this time was M&S Computing which later became Intergraph. They were responsible for the development of systems for the Army Missile Command as well as for the Nashville TN local government.

During the early 1980's several hardware advances, other than the obvious computing advances, affected the evolution of the technology. Three of these advances are: (1) Display devices evolved from storage tubes to refresh graphics and from the vector mode to the lower-resolution but higher-speed raster mode of operation, (2) Color graphics displays contributed the important ability to differentiate among types of features or attribute values, and they also provided a more appealing display in general, and (3) Electrostatic and Ink Jet plotters have become popular printing devices, the former especially useful when fast, inexpensive plots are required or when production volume calls for high speeds.

GIS Types

The vector based methods of data storage and retrieval attempt to represent objects as accurately as possible. This is carried out by using a series of points, lines, and areas or regions. The data is stored as x, y coordinates allowing all positions, lengths and dimensions to be defined precisely. One example of the use of vector data would be the storage of a road network. This network would not only include road attributes but also directional movement along the network. The raster based method of data storage and retrieval is based on the simplest data structure - the grid cell, or pixel. Each cell is referenced by a row and column number and it contains a number representing the type or value of the attribute being mapped. This data structure means that the two dimensional surface upon which the geographical data are represented is not continuous but quantified. Raster represents the geographical space as though it were a flat Cartesian surface. The raster method is of course the method of choice when representing remotely sensed data, such as aerial photography or satellite imagery. These grid cells can then be stored in either run length codes, block codes, or quadtrees.

Both systems are as good as their specific tasks allow. Vector methods have a compact data structure, whereas raster methods have a simple data structure. As a consequence raster based databases contain large amounts of graphic data, as opposed to the vector equivalent which has a compact data structure. The main difference between them is the quality and type of map they are capable of producing. The two clear advantages of the vector system over raster is the ability to represent well defined phenomenological data structures, as well as accurate graphics depictions. The main advantage of raster is the capability to easily permit simulations because each grid cell is the same size.

Picatinny Arsenal's GIS Background

The construction of the Geographic Information System (GIS) for the area owned by Picatinny Arsenal began as this overall scope of work was initiated. The GIS was not looked upon only as a way to store and archive collected data but as a new way of examining the data. Several layers in the GIS, such as the geology and soils, were used constantly throughout the project to aid in the development of new layers. The hope of this team is that the digital data layers delivered with the end of the project become the starting point for the construction of a new total management effort.

Decisions were made early on in the development of the GIS which shaped the construction throughout its growth. Among these decisions were coordinate systems and the arsenal boundary which would be used. The majority of existing data was in the New Jersey Stateplane Coordinate System. The system is very transportable between platforms because of its rectangular grid layout. The final platform to be used by Picatinny Arsenal in its daily production work was unknown at the beginning of this project, therefore transportability was considered to be of importance. These facts combined with the overall satisfactory representation the Arsenal displayed in this coordinate system gave reason to choose the New Jersey Stateplane Coordinate System as the system in which all data would be developed.

The decision by the Army Environmental Center (AEC) to build the GIS using Arc/Info proved useful throughout this scope of work. Silicon Graphic workstations were used to manipulate Arc/Info. Arc/Info is binary compatible between platforms, therefore many contractors and agencies can have immediate access to the finished database. The decision for Picatinny Arsenal to continue operating with Intergraph hardware/software configurations will involve minimum conversion time.

Database Description

The database as mentioned earlier is in the New Jersey Stateplane Coordinate System (SPCS), Zone 4701, with units measuring in feet. The horizontal datum in use is the North American Datum 1927. The New Jersey Stateplane Coordinate System is described by Arc/Info in the following paragraph.

> The SPCS is not a projection. It is a coordinate system that divides all fifty of the United States, Puerto Rico and the U.S. Virgin Island into over 120 numbered sections, referred to as zones. Depending on its size, each state is represented by anywhere from one to ten zones. The shape of the zone then determines which projection is most suitable. Three projections are used: the Lambert Conic Conformal for zones running east and west, the Transverse Mercator for zones running north and south, and the Oblique Mercator for one zone only, the panhandle of Alaska. Each zone has an assigned United States Geological Survey (USGS) code number,

each having a designated central origin which is specified in degrees.

New Jersey has one zone which uses the Transverse Mercator projection. The USGS number is 4701, the National Ocean Service (NOS) number is - 2900. This is the same for both NAD27 and NAD83.

All layers in the GIS conform to these standards. All layers presently existing in the GIS are shown in Table 22. Each data layer has a history of origin and techniques used to produce a useable database layer. This information will be explained in detail here layer by layer. The data file attribute descriptions however are shown as Appendix X for ease of use.

The theme of the data collection efforts during this project seemed to be "The older, the better." The first set of data given to WES by Picatinny Arsenal was a set of Intergraph Design Files depicting Arsenal roads, structures, and topology. Warnings were given to WES as to the validity of this data by Picatinny Arsenal. This survey apparently done in 1989 proved to geographically and spatially unusable. The basis for the needed surface features was taken from the ortho-corrected photographs. Control for these photos (discussed in detail later) was taken from a 1948 topographic survey.

Table 22
G.I.S. Data Layers

Layer Title	Source	Source Year
Bedrock Geology	USGS	1981
Boundary	USGS	1983
Floodplain, 1 Year	Developed	Compilation
Floodplain, 2 Year	Developed	Compilation
Floodplain, 10 Year	Developed	Compilation
Floodplain, 25 Year	Developed	Compilation
Floodplain, 100 Year	Developed	Compilation
Floodplain, 500 Year	Developed	Compilation
Geomorphology	Developed	Compilation
Historical Sites	Picatinny Arsenal/Developed	Compilation
Hydrology	Developed	1994
NWI Wetlands	National Fish and Wildlife	1993
Ortho-Photography	Developed	Compilation
Road	Developed	Compilation
Soils	SCS/Developed	1972
Structures	Developed	Compilation
Surficial Geology	USGS	1989

Topography	Developed	1948
Vegetation	Picatinny Arsenal	1980's
Vegetation Stands	Picatinny Arsenal	1980's
Wetlands	Developed	1994

Bedrock geology

The Bedrock geology digitized directly from the X map. The original source scale was 1:2400. This map showed no registration problems when being digitized into the system. The map is however missing data along the north-west edge of the Arsenal.

Boundary

The boundary of the Arsenal seems to be one of the most controversial layers. Maps were gathered from the early 1900's to the late 1900's. The map which showed actual survey coordinates was the find dated the earliest. This map, however, showed two different sets of survey coordinates, apparently taken by different surveyors. These two sets of coordinates were off as much as thirty feet toward the northern boundary of the Arsenal. The USGS Digital Line Graphs (DLG) aligned with the southern section of the early Arsenal map while varying around thirty feet with the northern section. The USGS data, although not designed to be reproduced at a scale of 1:6000, was chosen because of its general agreement with other sources and it consisted of one complete set of data.

Floodplains

The floodplain maps contained in this GIS do not simply indicate outer boundaries of floodplain delineations, but show the depth-to-surface measurements inside the floodplain region. The floodplain maps (this includes the 1, 2, 5, 10, 50, 100, and 500 year maps were developed using a GIS format called GRASS. GRASS is a raster based GIS developed by the Corps of Engineers. A raster based GIS differs from a vector based GIS in that data is represented as rectangular pixels, as opposed to points, lines, and polygons. The pixel size, or the cell size, was calibrated to be 100 ft wide by 100 ft high. These GRASS GIS files were converted to an Arc/Info polygonal coverage for full GIS integration. These files were examined and determined to be awkward to use because of the rectangular patterns indicative to raster representations. These layers were then hand contoured to produce a more useable format. The GIS contains both the original rectangular files and the hand contoured files.

Geomorphology

Initial geomorphology was delineated through the comparison of other layers in the GIS. Four major layers in the initial development of the geomorphology included the surface contours, the surficial geology, the soils, and the ortho-corrected photography. These first delineations were hand drawn and then digitized in through regular means encountered no problems. Final corrections to this layer were made on a graphics workstation overlaying many types of coverages to arrive at the final polygonal features.

Historical sites

The historical sites consist of three important features. These features are historical locations, as best known, areas of confidence for each site, and surveyed areas. Historical sites are often difficult to describe as exact coordinates. Great effort was given, however, to assign coordinates to these points with the highest possible degree of confidence. Each point does have associated with it a area of confidence. It should be understood that the historical site's exact location will lie inside this area of confidence. The last feature in this layer is termed "surveyed areas." These are broad areas on which extensive studies have been performed which would have revealed any historical artifacts.

Hydrology

The hydrology layer was derived from two data sources. The first data source is the ortho-corrected photography. Major hydrology, such as lakes and ponds, were digitized from the photography. Other smaller and/or new features were delineated along with the Wetland coverage as discussed later. Efforts have been made to impose this layer into each of the physical database layers.

NWI wetlands

The National Wetland Inventory (NWI) maps were one of the only map sets obtained in digital format. These maps came from the National Fish and Wildlife Association and are presented in the GIS unchanged from the original source. The source data was produced at a scale of 1:24000.

Ortho-photography

Ortho-photography, or ortho-rectified photography, is a term given to aerial photographs which have undergone topographic correction. The major need for this rectification lies in the inability of aerial photography to represent every point of the photograph as if the aircraft was position directly overhead. To perform this correction digitally, four pieces of information are needed: (1) scanned aerial photography, (2) a detailed digital topographic survey, (3) surveyed location descriptions and coordinates, and (4) a camera calibration report. The aerial photos, which were flown in 1992 at a scale of 1:9600, were easily scanned in 24-bit full color at 250 dots per in. A detailed topographic survey was found in a 1948 survey of the Arsenal. The closer the date of the survey to the date of the photography the better, but this was the best that could be located. A detailed description of how this survey was digitized is given later. The camera calibration report was acquired from the contractor which flew the mission. Survey markers were laid out at the time of the aerial survey, and each markers locational description was carefully recorded, but the markers were never surveyed. Locational monuments were identified off of the

1948 topographic survey. This left room for error, considering the scale of the original survey along with digitization and scanning errors. However, the aerial photographs in most cases rectified and matched together with very few problems. The aerial photographs had sixty percent horizontal overlap. It was determined that the rectification of every other photograph would prove sufficient in producing a corrected mosaic. The photograph numbered "eleven" proved to be challenging to rectify. Many variations were run on this photograph and on the photographs to the immediate left and right of photograph eleven, numbers ten and twelve. This photograph, unfortunately, makes up the majority of Picatinny Lake and north of the lake as well. As this photograph blends in to surrounding photographs seems can be found. Roads and buildings are the most evident physical feature to be effected by this problem.

Roads

Base map production was not included in the scope of work for this project. The basemap used was to be provided by Picatinny Arsenal. This map, as discussed earlier, showed errors exceeding exceptable tolerances. A basemap containing accurately placed and easily locatable physical features was needed to perform many aspects of field work. The coverage containing road features has been digitized completely from the 1992 ortho-rectified aerial photography. The roads should be accurate over most of the arsenal's area with the exception of the area surrounding and north of Picatinny Lake. This problem is a result of the difficulty encountered with photograph eleven. The roads are depicted on the accompanying plates as two parallel lines with a filled dash in the center. This line symbol is not to misconstrued as the width of the road. The roads are represented in the coverage as single arcs and not as polygons.

Soils

The soils coverages was used by many team members during the course of this project. The source for this coverage was the 1972 Soils Survey by the Soil Conservation Service (SCS) produced at a scale of 1:20000. This source seemed to be the most challenging to integrate into the GIS. Coordinate marks along the edges of each of the numerous maps which made up Picatinny Arsenal's land were placed as general guides and were not intended to be used as geographic control points. The control points used for the transformation into the GIS were gathered from physical features found on the photo-base of the soils maps. The northern boundary seemed to be the most difficult to georeference; this was probably due to differences in control gathered by the SCS and control used to produce this GIS. Please reference the suggestion concerning control later in the portion of the report. The polygons gained from the SCS maps were reviewed and approved for use by WES personnel.

Structures

Again, base map production was not included in the scope of work for this project. The basemap used to be provided by Picatinny Arsenal. This map, as discussed earlier, showed errors exceeding exceptable tolerances. A basemap containing accurately placed and easily locatable physical features was needed to perform many aspects of field work. The coverage containing structure, mostly building, features has been digitized completely from the 1992 ortho-rectified aerial photography. Like the roads, the structures should be accurate over most of the arsenal's area with the exception of the area surrounding and north of Picatinny Lake. This problem is a result of the difficulty encountered with photograph eleven. The structures are represented in the database as polygons.

Surficial geology

This coverage was digitized from the USGS 1:24,000 geologic map. The source scale was 1:24000. This was the first map which was entered into the system and proved to be one of the most used. Attempts were made to make the color codes for the surficial geology on the accompanying plates match the original source map.

Topography

The topography required for this project needed to be of as high resolution as possible. As previously discussed, the 1989 digital survey of Picatinny Arsenal proved to be questionable and did not contain the needed detail. Stereo plotting with the aerial photography was a solution to this need, but would have been very time consuming and costly. Field work required the use of this layer as soon as possible. Mr. Vern Shankle located a set of seven survey maps of Picatinny Arsenal dated 1948. These maps were scanned by Picatinny and sent via network to WES.

Once at WES, efforts were focused on vectorizing these images and combining them to produce a seamless vector topographic survey. The images were vectorized using Integraph's product I-VEC. The method used to convert these intensive maps was a batch process. Variables were set and the computer vectorized everything it could find. A centerline was placed where ever possible but occasionally linework became dense or faded and a polygon was placed around these patterns. Each of the seven original scanned maps were vectorized separately because of hardware and software restrictions. Each vectorized map was then georeferenced using Integraph's product Projection Manager (MSPM). After all were georeferenced using coordinates taken directly from the source images, all files were combined in Arc/Info to produce one large topographic coverage.

This coverage was then used on initial field maps. The numbers on the contour lines, structures, and roads were preserved from the batch vectorizing.

This type of map served its purpose for initial field investigations, but was useless for any type of digital querying. The contour lines needed much more refinement and they also needed attributing with the correct elevation. Most of the refinement was performed because of the scale at which the original maps were drawn. Around areas of great relief, contour lines ran together and essentially became on line. Linework for each five foot contour had to separated and attributed. This was done in large part by what is called "heads-up" digitizing. The lines were separated digitally while sitting in front of a graphics workstation. After each contour line was separated and labels, buildings, and road were stripped out of the file, each contour line was selected and labeled with its correct elevation value.

Further work which was performed with the resulting data was the construction of a digital surface for the use in ortho-correcting the photography and for producing needed slope maps. This was accomplished by the creation of a Triangular Irregular Network (TIN) model which consist of all points along the contour lines linked together in three dimensions by a set of triangular patterns. This TN model can be used in future applications to predict such things as surface run-off or to gain a better understanding of how a particular site looks.

Vegetation and vegetation stands

Two sets of vegetation maps were acquired from Picatinny Arsenal both at scales of about 1:10000. Both were digitized through regular means incountering no problems. The first came as hardcopies of labeled polygons drawn on the Intergraph design file basemaps. The overall spatial correctness of these maps was found to correspond with the aerial photography, but the only attribute information given for each polygon was a vegetation type label located inside each polygon.

The second vegetation map came as vegetation stand polygons hand-drawn on a base map. Apparently, these were maps generated in the field. Many folders of attribute information were retained for each polygon. The spatial correctness of these polygons, however, was found to be very inadequate. At the time of the report field work is continuing in this area. Field work will be combined with both sets on maps to produce a realistic digital representation of the vegetation at Picatinny Arsenal. Hopefully, most of the tabular data from the vegetation stand map will be preserved.

Wetlands

The wetland map stored in the GIS was developed solely from field work done by WES. Preliminary field investigations in this area, however, did utilize hydric soils and vegetation information already existing in the GIS, to help identify area of interest. Several sets of twenty-seven maps were generated at the scale of 1:2400. These were used in the field to delineate different wetland types. The wetland type "Non-Wetland" was delineated solely for the purpose of separating different wetland types. As the field maps were finished, each was digitized and joined to the others to produce new updated versions of field work.

Applications and Recommendations

This GIS is being delivered as more than was originally anticipated. An accurate basemap was begun with the development of a topographic surface and the unexpected roads and building coverages. All data has been, as carefully as possible, entered into the system with minimal distortions and in many instances more accurate than the proposed 1:6000 scale. If future plans at Picatinny Arsenal call for the development of base data at a scale greater than presented here, it would be strongly advised that the development begin with a high resolution survey of the entire Arsenal, especially the northern third.

During the course of development of the Picatinny Arsenal GIS, a question was raised concerning a possible application of this GIS to solve a problem under consideration. The task was to find a possible site for a soil staging area on Picatinny Arsenal. There were several conditions which had to be met, involving many different layers, to provide the solution to the task. These conditions were: (1) the area had to be within 400 ft from any road, (2) the slope of the entire staging area had to be less than seven percent, (3) the surficial geology of the site must be classified as Till, (4) the site must be further than 500 ft away from any water body, (5) the site must be further than 400 ft from any wetland, (6) any known archeological site must be greater than 400 ft from the staging area, and (7) the site must be 40,000 sq ft or larger.

A "buffer" operation is performed when distance-to or distance-from an object is desired. For example, this type of operation, for condition four, placed a 500 ft buffer around all polygonal and linear water features. The zones created from this buffer were then used as a means of canceling out possible staging areas located too close to the water bodies. No new intermediate layers were created for conditions such as condition three. This information is contained in the surficial geology layer. After all new buffer layers were created and queries, or database comparison conditions, were written, the resultant map was produced. The time used to create the resultant map was around four hours; this included planning time. Following are the graphical steps and results from this study.

This GIS was a new type of challenge. Many different types of data were gathered and used in conjunction with one another. The GIS should prove to be useful in many future projects at Picatinny Arsenal. It should be remembered that a strong GIS is one that is not only nurtured and maintained but used and pushed to new limits.

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Appendix A
Site Characterization Sheets
Geomorphological Investigations

Appendix B
Soil Descriptions at Field Investigation Sites

Appendix C
Cover Type Photographs and Corresponding Distribution Maps

Appendix D
Wetlands Baseline Map

Appendix E
Plant List

Appendix F
Field Data Sheets

Appendix G
G.I.S. Data Layer Information