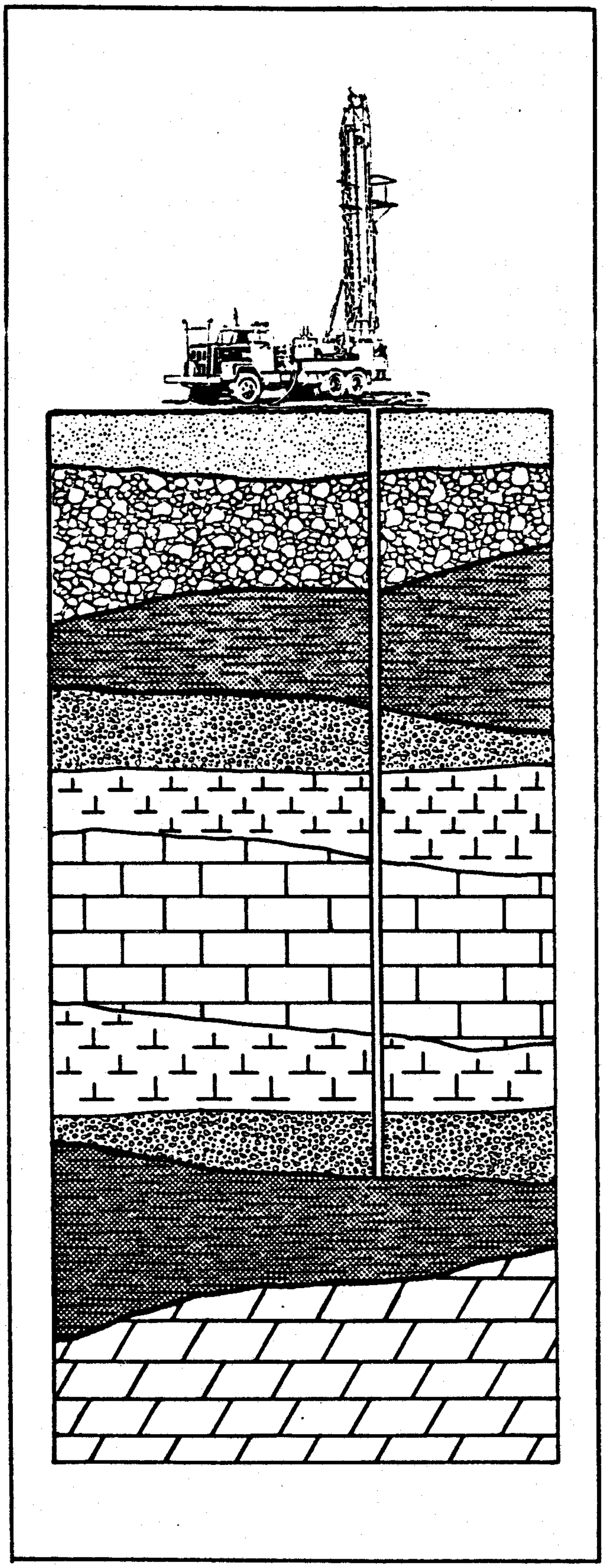


GROUND WATER RESOURCES OF THE FOUR CITIES AREA, VIRGINIA

NORFOLK **PORTSMOUTH**
VIRGINIA BEACH **CHESAPEAKE**

By

Eugene A. Siudyla
Anne E. May
Dennis W. Hawthorne

TIDEWATER REGIONAL OFFICE

COMMONWEALTH OF VIRGINIA

STATE WATER CONTROL BOARD

BUREAU OF WATER CONTROL MANAGEMENT

Richmond, Virginia

Planning Bulletin 331

November 1981

GROUND WATER RESOURCES OF THE FOUR CITIES AREA, VIRGINIA

NORFOLK
VIRGINIA BEACH
PORTSMOUTH
CHESAPEAKE

By

Eugene A. Siudyla
Anne E. May
Dennis W. Hawthorne

TIDEWATER REGIONAL OFFICE

COMMONWEALTH OF VIRGINIA

STATE WATER CONTROL BOARD

BUREAU OF WATER CONTROL MANAGEMENT

Richmond, Virginia

Planning Bulletin 331

November 1981

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF PLATES

LIST OF PLATES (continued)

LIST OF TABLES

ACKNOWLEDGEMENTS

Appreciation is extended to the citizens of the Cities of Chesapeake, Norfolk, Portsmouth and Virginia Beach for permitting water samples to be collected from their wells and for supplying much of the well information contained in this report. Representatives of area industries, military facilities, and municipal water supplies served by ground water were most helpful in supplying information on their systems. The Virginia Division of Mineral Resources, the United States Geological Survey, Wiley and Wilson, Inc., Geraghty and Miller, Converse Ward Davis Dixon, Inc., and the Virginia Department of Health supplied valuable information on wells in the study area. Well drilling contractors who have been especially cooperative in supplying information include Gildersleeve Pump and Well Company, Groundwater Development Company, and Sydnor Hydrodynamics. Special thanks go to the City of Virginia Beach Public Utilities Department and Groundwater Development Company for their assistance with aquifer tests included in this report.

This report was prepared by Eugene A. Siudyla, Regional Geologist, Tidewater Regional Office, with the assistance of Anne E. May, Technician, and Dennis W. Hawthorn, Specialist. Many other State Water Control Board personnel made this report possible, some of which are mentioned below. Larry S. McBride, Director, Tidewater Regional Office, Remo A. Masiello, Director of the Division of Water Control Management, and Albert H. Giles, Geologist, Bureau of Water Control Management, thoroughly reviewed this report and provided many helpful comments. Rick F. Bower, and P. J. Smith, Geologists, Bureau of Surveillance and Field Studies, coordinated the drilling of research stations and John P. Creason, Water Well Driller, and Dwight A. Oakes, Driller's Assistant, constructed these stations. Sherry C. Hunt patiently typed the several drafts of the report and the appendices. Melvin N. Friedman, Drafting Supervisor, provided guidance and assistance in regard to drafting and printing.

FOREWORD

This report is one of a series intended to inventory the ground water resources of each county and city in the Commonwealth. The purpose is to provide all ground water users, including private citizens, developers, inventors, well-drilling contractors, government officials, professionals,and consultants with an overview of the ground water situation as it presently exists throughout Virginia and more specifically in the Four Cities Area.

Prospective ground water users and others interested in the development and protection of ground water hopefully will gain insight into the opportunities and advantages inherent in this invaluable natural resource and the need for its careful management.

The State Water Control Board remains available for information, assistance,and governmental action.

EXECUTIVE SUMMARY

The Four Cities area is located in Southeastern Virginia and includes the Cities of Chesapeake, Norfolk, Portsmouth and Virginia Beach. The area is within the outer portion of the Coastal Plain physiographic province and is contained within the Atlantic and Gulf Coastal Plain Groundwater Region.

Moderate supplies of fresh ground water and large supplies of brackish ground water are available in the Four Cities area. The four major aquifers include the water table, the Yorktown, the Eocene-Upper Cretaceous, and Lower Cretaceous aquifers. Current ground water use from these aquifers is approximately 11 MGD[1]. Ground water development is projected to increase substantially due to increases in municipal, industrial, ground water heat pump, and lawn watering demand.

Small supplies of fresh, non-potable water for residential lawn watering and similar purposes can be developed from the water table aquifer. This aquifer consists of highly variable sand units or sand lenses generally found at depths above forty feet. The water quality of the aquifer is highly variable with the major limitations being a low pH and a high iron content. Waste disposal practices can influence the local quality of the aquifer. Water table levels change with the seasonal variations in rainfall but show no steady yearly declines. Locally, where high density water table aquifer use takes place, water level declines below shallow

---

[1] For English to metric conversion table see Appendix A

well pump capability may take place in the future.

The Yorktown aquifer is the major potable aquifer in the area. The aquifer, generally occupying the zone ranging from 50 to 150 feet deep, consists of several thin sand and shell units or sand and shell lenses separated by silt and clay units. Aquifer productivity is variable with most larger production wells limited to yields of about 50 to 75 gallons per minute. Larger development of this aquifer would have to consist of many widely scattered well fields made up of a number of wells having a 50 to 75 gpm capacity. Although water obtained from the Yorktown aquifer generally contains less iron than the water table aquifer, commonly the concentration of iron is high enough to require treatment. In many places the lower portions of the aquifer are brackish so that care must be taken in production well design to prevent upconing of brackish water into the freshwater portion of the aquifer. Water levels in the Yorktown aquifer have varied similarly to those of the water table aquifer with water levels showing no steady yearly declines due to pumping. Localized water level interference problems may take place as increased ground water development occurs.

Moderate supplies of brackish ground water are available from the Eocene-Upper Cretaceous aquifer in most of the study area. The aquifer is found at a depth of about 500 feet in the western part of the study area to depths of about 1000 feet in the eastern part. The aquifer usually consists of one or two glauconitic (dark green) sand beds. Currently the only user of the aquifer is one small industrial user in southeastern Chesapeake. Water levels in several test wells tapping the Eocene-Upper Cretaceous aquifer were much higher than the Lower Cretaceous water levels. These wells flow naturally when not being pumped. Water levels in the aquifer have shown no yearly declines.

Fresh water development in the Lower Cretaceous aquifer is limited to the northwestern part of the study area where moderate supplies are available. Wells tapping the fresh water portion of the aquifer range from 600 to 800 feet. Individual well yields for major fresh water production wells were high with the highest well yield being around 750 gpm. Major water quality limitations of the freshwater portion of the aquifer include a high fluoride and sodium content. Although saltwater intrusion in the Lower Cretaceous aquifer has been estimated to be occurring at the rate of about 30 feet per year, existing observation wells are not located close enough to the interface to detect the rate of movement. Water levels in the Lower Cretaceous aquifer are currently declining several feet per year due to intensive pumping located primarily to the west in Isle of Wight County and the City of Suffolk. The potential for future development of the freshwater portion of the aquifer is limited by the potential for lateral and vertical saltwater intrusion and steadily declining water levels.

CHAPTER I

INTRODUCTION

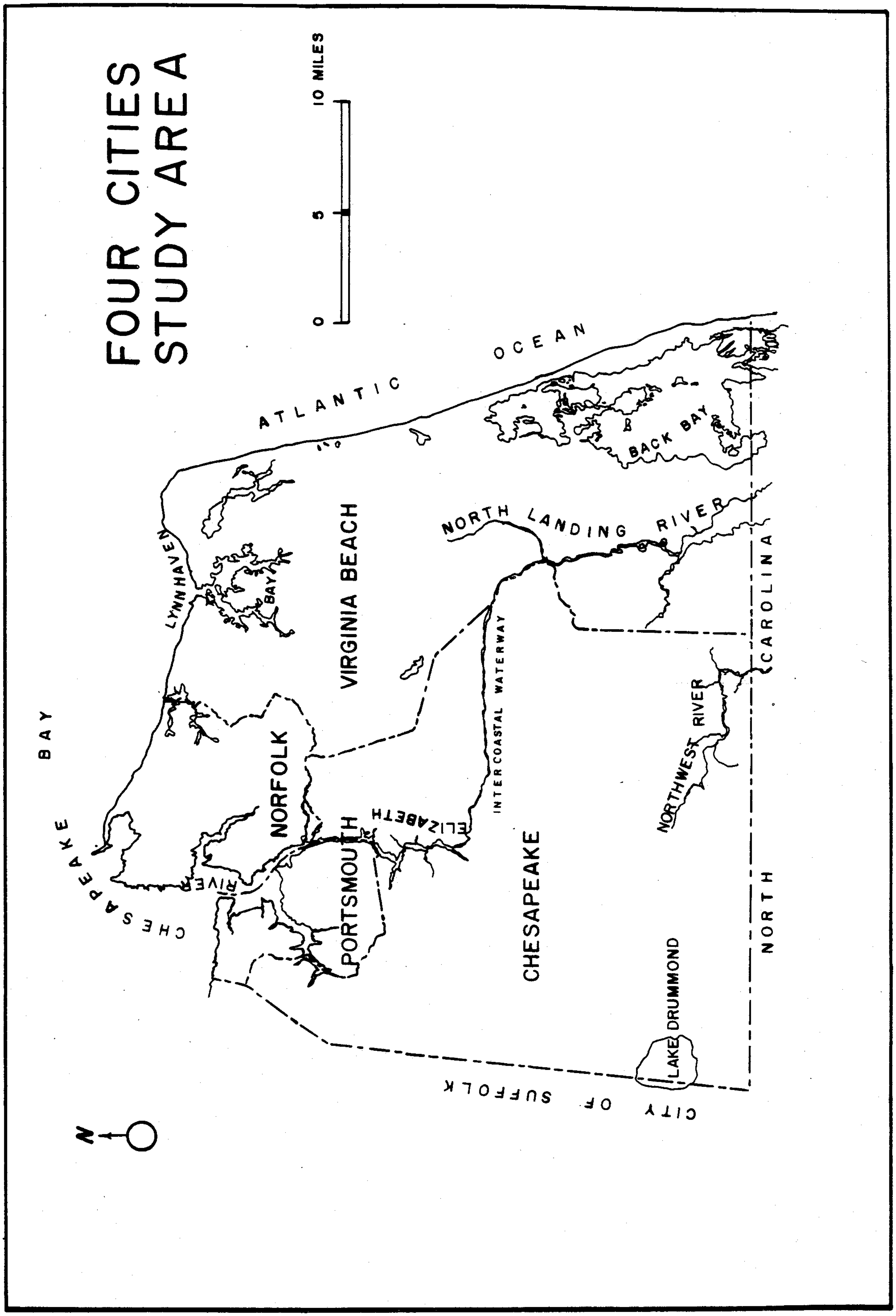
Purpose and Scope of Report

This report is intended to acquaint the public with the ground water resources in the Cities of Chesapeake, Norfolk, Portsmouth and Virginia Beach. In addition to providing general information about the area, the report introduces new hydrogeologic data collected by the State Water Control Board and compiles previous geologic and hydrologic investigations carried out under the auspices of the Board and other agencies. The report is intended to be a planning and management reference for citizens, government officials, professionals and those in the business sector. This report is intended to serve as a framework for formulation of future plans for ground water development in the study area, including small domestic supplies and large industrial or municipal well fields.

Location and Background Information

The Four Cities Study Area is located in the southeastern portion of Virginia (Plate 1), bounded on the east by the Atlantic Ocean, on the north by the Chesapeake Bay and the James River, on the west by the City of Suffolk, and on the south by North Carolina (Currituck and Camden Counties).

Land area as well as population data for the four cities in the study area is given in Table 1. Total land area is 702 square miles. The Cities of Chesapeake and Virginia Beach rank as two of the largest cities in the United States with land areas of 361



SOURCE: SWCB-TRO 1979

PLATE NO. 1

Table 1. LAND AREA AND POPULATION OF THE FOUR CITIES AREA

City	Total Population (1970 cases)*	Projected Population (2000)**	Land Area (square miles)	Population Density (per square mile)
Chesapeake	89,580	154,910	361	248
Norfolk	307,951	293,324	53	5,810
Portsmouth	110,963	121,773	29	3,826
Virginia Beach	172,106	359,326	259	665
Totals	680,600	929,333	702	2,637 (ave.)

* Source: Virginia Division of State Planning and Community Affairs " Data Summaries " for each City, (1973)

** Source: Hampton Roads Water Quality Agency (1978) square miles and 259 square miles respectively. Currently the City of Chesapeake ranks as the thirteenth largest city in land area in the United States.

The 1970 census population for the Four Cities area was 680,600. As shown in Table 1, in 1970 Norfolk was the most populated and Chesapeake the least populated. The average population density in the study area is 2,637 persons per square mile. The Hampton Roads Water Quality Agency (1978) has projected that by the year 2000 the City of Virginia Beach will be the most populated and the City of Portsmouth will be the least populated. The total population for the study area is projected to be 929,333 by the year 2000.

The major sources of employment in the area are government, wholesale and retail trade, services, and manufacturing in that order. The outstanding harbor of Hampton Roads has a significant positive impact on the economy of the area. The Portsmouth-Norfolk area is the center of the world's largest concentration of Naval activities including the Naval Supply Center, the Naval Air Station, and the Naval Shipyard.

Previous Investigations

A number of recent reports have addressed the geology of the Four Cities Area. Oaks and Coch (1973) and Barker and Bjorken (1978) studied the post-Miocene geology of the area. Brown, et al (1973) investigated the structural geology, stratigraphy, and relative permeability of strata in the North Atlantic Coastal Plain. Teifke (1973) and Onuschak (1973) presented the results of investigations of stratigraphy, paleogeology and environmental geology of the Coastal Plain of Virginia.

Although many reports have been written on the ground water resources of Southeastern Virginia, very few of these emphasized the ground water resources in the study area. Sanford (1913) briefly summarized the geology and ground water conditions in the area. Cederstrom (1945), the Virginia Division of Water Resources (1970), Lichtler and Wait (1974), and the Virginia State Water Control Board (1974) emphasized ground water conditions in the Cretaceous or Principal Aquifer of Southeastern Virginia. Geraghty and Miller (1979a) studied ground water availability and management in Southeastern Virginia for the Virginia State Water Study Commission. Lichtler and Walker (1974) discussed the hydrology of the Dismal Swamp of Virginia and North Carolina. Geraghty and Miller (1978) investigated the occurrence and availability of ground water in the City of Virginia Beach.

Method of Investigation

This study is based on an evaluation of available reports and data and new data derived from field tests. Field tests included installation of nine ground water research stations using the State Water Control Board drilling rig from which three aquifer tests were conducted. It also consisted of measuring water levels in available wells and obtaining water quality samples from selected wells and conducting one additional aquifer test at a privately-owned well field.

Some of the information on well construction and ground water quality was obtained from other agencies, although the majority of it has been collected by the State Water Control Board (SWCB). Static water level measurements were obtained from both SWCB observation wells and wells owned by various entities (i.e., private, industrial, and agricultural). Driller's notes, logs, and well yield tests were obtained from the files of area drillers. Pumpage reports and ground water use surveys submitted to the SWCB also were utilized within this report. Water quality data from select wells were used to determine the distribution of various chemical parameters within the major aquifers. The most recent of this quality information was obtained by the SWCB staff.

Water Well Numbering System

The State Water Control Board's Bureau of Water Control Management maintains such water well information as well size and depth, yield, and other pertinent data in a computerized system at the Board Headquarters in Richmond. Also, information on water quality and water level changes is maintained in Richmond by the Board's Bureau of Surveillance and Field Studies. Retrieval of this information for specific wells is possible by utilizing the water well numbering system.

This system is comprised of two sets of numbers. The first set is a county or city identity number (City of Chesapeake is 234) and the second number is a sequential listing of wells in the city. For example, well number 234-11 refers to a specific well in the City of Chesapeake. The data presented in this report reflects information from more than 423 wells which were identified and on file for this area. When citing specific wells in this report, the well number will be given in parentheses with the city identification number. For example, Reliance Fertilizer No. 1 well would be denoted as (234-17). Well numbers may be cross referenced with various plates and Appendices B through E for additional information.

CHAPTER II

PHYSICAL SETTING

Physiography

The Four Cities Area lies within the outer part of the Atlantic Coastal Plain Physiographic Province. The generalized physiography of the area is typical of the Atlantic Coastal Plain, which is known for its "stair-step" appearance, consisting of wide, gently eastward sloping plains separated by linear, steeper, eastward facing scarps. The plains become successively lower in elevation and less dissected from the western to the eastern portion of the study area. The plains slope eastward at less than two feet per mile, whereas the scarps have slopes of as much as 50 to 450 feet per mile through short distances.

The outer coastal plain is characterized by low elevations and relief. Although dunes at Cape Henry are as high as 85 feet above mean sea level (msl), usually only a few places are above 25 feet. Relief of as much as 20 feet occurs locally along the James River. Several flat areas up to five miles across, with less than five feet of relief and little natural drainage, form poorly drained areas between major streams.

Depositional topography predominates in the area but fluvial erosion has destroyed large portions of the original depositional surfaces of the inner coastal plain. Overall, the topography has a north-south trend that is closely related to the depositional morphology of ancient barrier and lagoonal environments. Several major stream valleys cut across this regional trend, but most streams follow original depositional lows parallel to the regional trend. The stream valleys are partially filled by fluvial and fluvial-estuarine sediments which have flat surfaces and locally form terraces along major streams.

Oaks and Coch (1973) subdivided the study area into major morphologic subdivisions. The following subdivisions were adopted for the area: Churchland flat, Dismal Swamp, Deep Creek swale, Fentress rise, Hickory scarp, Mount Pleasant flat, Oceana ridge, Diamond Springs scarp, and the Sand-ridge and Mud-flat complex. "Plain" and "flat" refer to broad undissected areas of low relief that are, respectively, eastward-sloping and virtually horizontal. "Rise" refers to a westward-sloping surface. A swale is a linear low. "Ridge" and "scarp" distinguish the morphology of steep-sided features that separate plains, flats, and rises lying at different elevations.

Drainage

Four major drainage systems are found in the area including the James River, Chesapeake Bay, Currituck Sound and Albemarle Sound. Short northward-flowing streams emptying into the James River or Chesapeake Bay characterize the northern part of the area and include the Elizabeth River, Little Creek, and Lynnhaven River, respectively, from west to east. Southward-flowing streams are longer and can be grouped into rivers which discharge to Currituck and Albemarle Sounds. The main drainage features are as follows: (1) West Neck Creek, North Landing River, Northwest River and its tributaries from the Dismal Swamp, and minor drainage into Back Bay, all of which empty into Currituck

Sound; (2) Dismal Swamp drainage into Albemarle Sound via the Pasquotank River, Little River, and Indiantown Creek. The closest opening to the sea for the southern drainage is Oregon Inlet, 56 miles south of the Virginia-North Carolina boundary.

Climate

The climate of the Four Cities area is classified as oceanic i.e., it is moderated by the proximity of the Atlantic Ocean and Chesapeake Bay.

The average annual temperature is approximately 60°F. Extremes have been recorded as high as 105°F and as low as 2°F. Rainfall is adequate and well distributed throughout the year. Long periods of drought seldom occur. The average annual precipitation is 44 inches. The driest year on record was 1915 when 23.22 inches of rainfall was reported at the Cape Henry weather station in Virginia Beach. The wettest year was 1889 when 70.72 inches of rainfall was reported at the Norfolk weather station.

Soils

Soils of the area have been surveyed. Simmons and Shulkcum (1945) completed a soil survey for Princess Anne County which is now the City of Virginia Beach. Henry et. al. (1958) surveyed the soils of Norfolk County which now includes the Cities of Chesapeake, Norfolk, and Portsmouth. Currently an updated soil survey is being prepared for the City of Virginia Beach by the Virginia Polytechnic Institute and State University.

Shulkcum (1945) grouped the soils in the Virginia Beach area into five categories on the basis of drainage as follows: (1) well-drained soils, (2) imperfectly-drained soils, (3) light-colored, poorly-drained soils, (4) dark-colored, poorly-drained soils, and (5) miscellaneous land types. The well-drained soils, the most highly valued soils, are found through the area. The largest areas of these soils are found north of the Virginia Beach Expressway in Virginia Beach and in the Great Bridge area. The imperfectly-drained soils are also found in all parts of the study area, in most places in small, individual areas separating the well-drained and the poorly-drained soils. The light-colored poorly-drained soils are the most extensive soils group in the area. Under natural conditions these soils are permanently wet. Water stands on the surface for long periods. The dark-colored, poorly-drained soils are located on flat relief in most places at elevations of less that 15 feet. The water table stands at the surface most of the year, and during wet periods, many areas are submerged. Where the poorly-drained soils have been drained artifically, they can be used for crops and other purposes. The miscellaneous land types, the second most abundant soil group in the area, includes coastal beach and dune sand, tidal marsh, marsh, and swamp. None of the miscellaneous land type soils are suitable for farming. The dune types are suitable for timber and homes. Drainage conditions range from excessive for dune soils to submerged for the marsh and swamp soils.

Land Use

The major uses of land within the Four Cities area include urban use, farming, and forestry. Urban use includes commercial, institutional, light industrial, heavy industrial, low-density residential, and high-density residential use. The major urban areas are Norfolk, Portsmouth, the northern one-third of Virginia Beach, and the South Norfolk, Great Bridge, and Deep Creek areas of Chesapeake. The agriculture of the area is based on the growing of corn and soybeans and, to a lesser extent, on vegetable crops and strawberries. Livestock, including beef cattle, dairy cattle, hogs, and poultry, are raised extensively. When Virginia was first settled, the area was densely forested. The forests apparently consisted of a mixture of hardwoods such as poplar, beech, hickory, red maple and species of oak and gum. At present most of the forests have been cut. Many areas either have receded to sweetgum or to other hardy, less desirable species or have been covered by dense strands of wax myrtle, gallberry, greenbriar, and reeds.

CHAPTER III

HYDROGEOLOGY

Summary of Stratigraphy

The Four Cities area is underlain by several thousand feet of unconsolidated deposits of gravel, sand, and clay, ranging in age from Lower Cretaceous to Holocene, resting on bedrock basement of Precambrian and Triassic/Jurassic age. These deposits dip and thicken gently eastward with thickness ranging from 2000 feet in the western part of the study area to over 4000 feet in the southeastern part. Teifke (1973) divided these deposits into six geologic units (Table 2). From oldest to youngest, they are the Patuxent Formation,"transitional beds", the Mattaponi Formation, the Calvert Formation, the Yorktown Formation, and the Columbia Group. The Nanjemoy Formation of Eocene age, although found in most of the Virginia Coastal Plain, is absent in the study area. An indication of the depth and thickness of the units is given by the geologic logs of two wells in Table 3. It should be noted that the Virginia Division of Mineral Resources currently is conducting a detailed study of the stratigraphy of the Virginia Coastal Plain which will update it by 1981.

The Patuxent Formation of Early Cretaceous age overlies the "basement". The Patuxent is an alternating sequence of beds of fine gravel, coarse sand, and silty and sandy clay. Sand within the Patuxent is mainly tan, gray,or white and is characteristically felthspathic.

In Southeastern Virginia transitional beds of early Cretaceous age are found above the Patuxent Formation. The transitional beds

TABLE II - STRATIGRAPHIC AND HYDROGEOLOGIC UNITS - SOUTHEASTERN VIRGINIA

SYSTEM	SERIES	NORTH CAROLINA STRATIGRAPHIC UNITS	NORTH CAROLINA HYDROGEOLOGIC UNITS		VIRGINIA STRATIGRAPHIC UNITS		VIRGINIA HYDROGEOLOGIC UNITS	DESCRIPTION OF HYDROGEOLOGIC UNITS
QUATERNARY	RECENT PLEISTOCENE	POST-MIOCENE (UN-DIFFERENTIATED)	WATER TABLE OR QUATERNARY AQUIFER		RECENT COLUMBIA GROUP		WATER TABLE OR QUATERNARY AQUIFER	Unconsolidated sand, silt, and some gravel. Sand units yield quantities adequate for domestic and small industrial demands, used extensively for lawn watering. Unconfined aquifer.
TERTIARY	MIOCENE: UPPER, MIDDLE	YORKTOWN PUNGO RIVER	TERTIARY AQUIFER SYSTEM	SAND AQUIFER	CHESAPEAKE GROUP	YORKTOWN	YORKTOWN AQUIFER	Sand and shell beds main water-bearing units. Adequate for moderate public and industrial supplies. Artesian
						CALVERT	CONFINING UNITS	Silt and clay predominant, minor sand lenses.
	EOCENE	CASTLE HAYNE LIMESTONE		LIMESTONE AQUIFER	NANJEMOY		NOT FOUND IN STUDY AREA	
	PALEOCENE	BEAUFORT			MATTAPONI		EOCENE-UPPER CRETACEOUS AQUIFER	Glauconitic sand and interbedded clay and silt. Infrequently used as a water supply. Yields adequate for moderate supplies. Brackish in most of area. Artesian
CRETACEOUS	UPPER	PEEDEE BLACK CREEK	CRETACEOUS AQUIFER SYSTEM	UPPER UNIT	LOWER CRETACEIOUS	TRANSITIONAL BEDS	LOWER CRETACEOUS	Interbedded gravel, sand, silt, and clay. Yields are adequate for large industrial use. Brackish in most of area. Artesian
	LOWER	UNNAMED		LOWER UNIT		PATUXENT		

Table 3. GEOLOGIC FORMATIONS PENETRATED BY WELLS 220-3 AND 217-6

	Elevation at top (ft-msl)	Thickness (ft)
Virginia Chemical Company Well 220-3 (N.W. Part of Study Area)		
Columbia	10	± 40
Yorktown	-30	± 290
Calvert	-320	120
Mattaponi	-440	70
"transitional beds"	-510	120
Patuxent	-630	370
Moores Bridges Well 217-6 (N. Central Part of Study Area)		
Columbia	10	± 100
Yorktown	Not determined	± 310
Calvert	-400	210
Mattaponi	-610	67
"transitional beds"	-677	105
Patuxent	-782	1,796

Adapted from Teifke, 1973

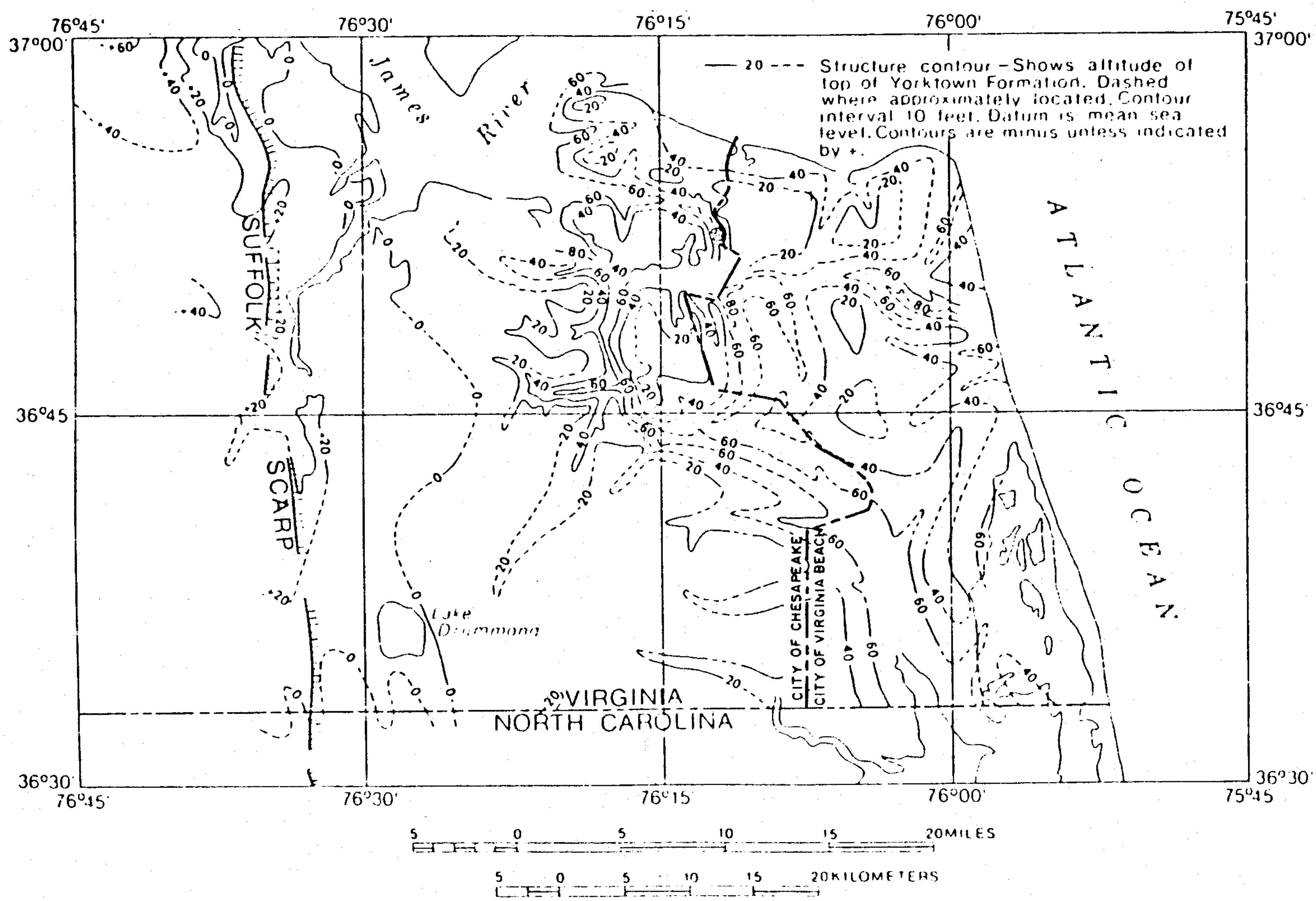
consist of sand,silt, and clay. These beds are either intermediate in composition and texture or comprise alternations of lithotypes characteristic of the Patuxent and Mattaponi Formations.

The Mattaponi Formation is of Upper Cretaceous (?), Paleocene, and Eocene age. This formation of marine origin is characterized by beds of quartz-glauconite sand, glauconitic clay, and shell. Abundant autochthonous (formed in place) glauconite is the principal lithologic criterion used to identify the formation (Teifke, 1973).

The Calvert Formation of Miocene age, which is commonly consolidated consists largely of clay and silty clay. A basal sand member consisting of medium-to-coarse sand may be present in the Calvert Formation along with some beds or lenses of phosphatic clay.

The Yorktown Formation consists of more abundant and markedly coarser sand and gravel beds and more abundant and thicker shell beds than the underlying Calvert Formation. The Yorktown is also lighter in color than the upper member of the Calvert. Plate 2 shows the topography of the top of the Yorktown Formation (Oaks and Coch, 1973).

The uppermost geologic unit, the Columbia Group, is characterized by beds of light-colored clay, sand and silt. The average thickness of the unit ranges from about 20 feet in the western part to 50 feet in the eastern part of the area. In the Four Cities area the Columbia group has been subdivided into six smaller units which, from oldest to youngest, are the Great Bridge Formation, the Norfolk Formation, the Kempsville Formation, the Londonbridge Formation, the Sand Bridge Formation and the undivided sediments (Oaks and Coch, 1973). The Division of Mineral Resources is currently updating the stratigraphy of the Columbia Group.



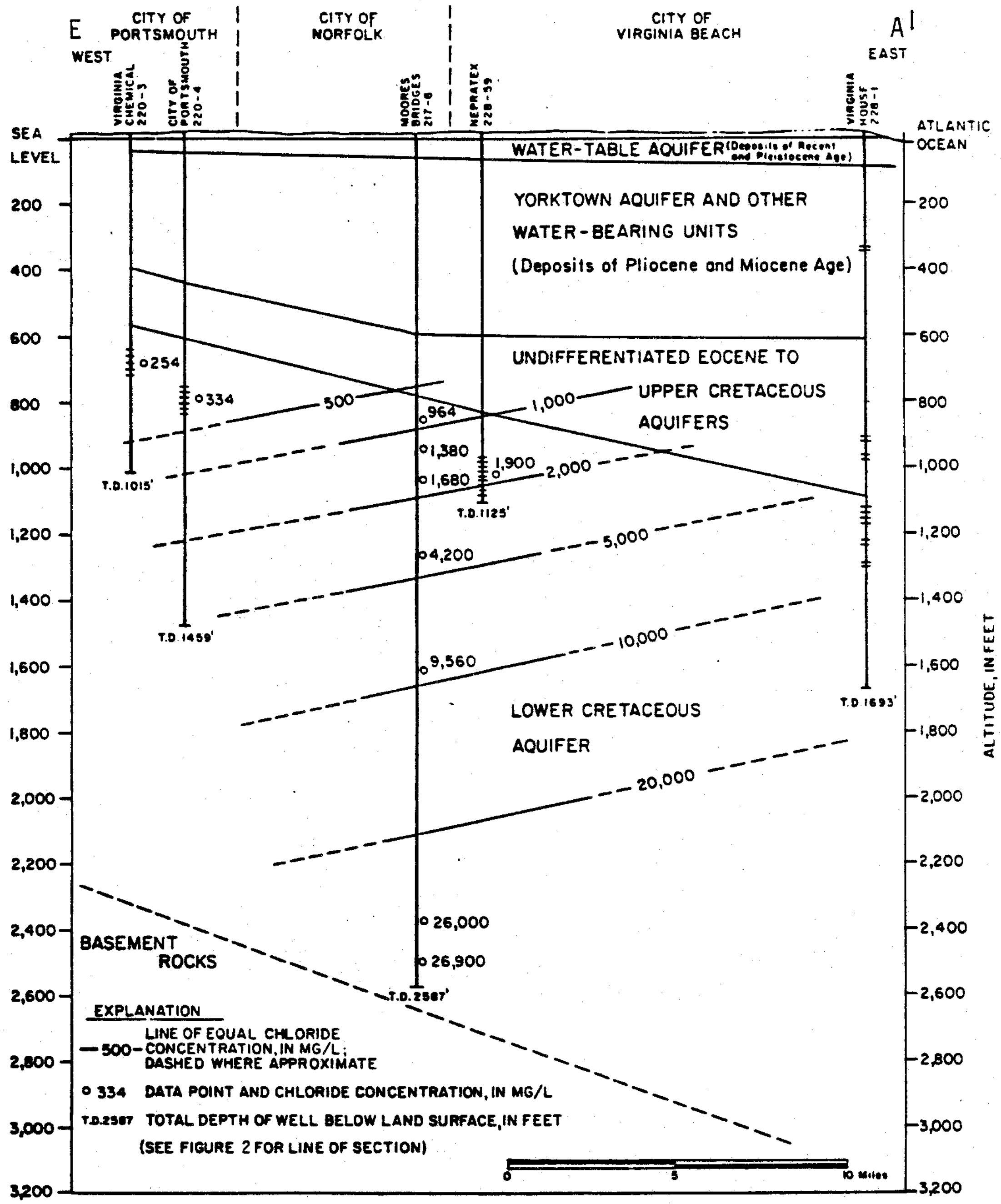
Topography of top of Yorktown Formation in the Study Area and adjoining areas. (Adapted from Oaks and Coch, 1973 and Geraghty and Miller, 1978)

Plate 2

Description of Aquifers

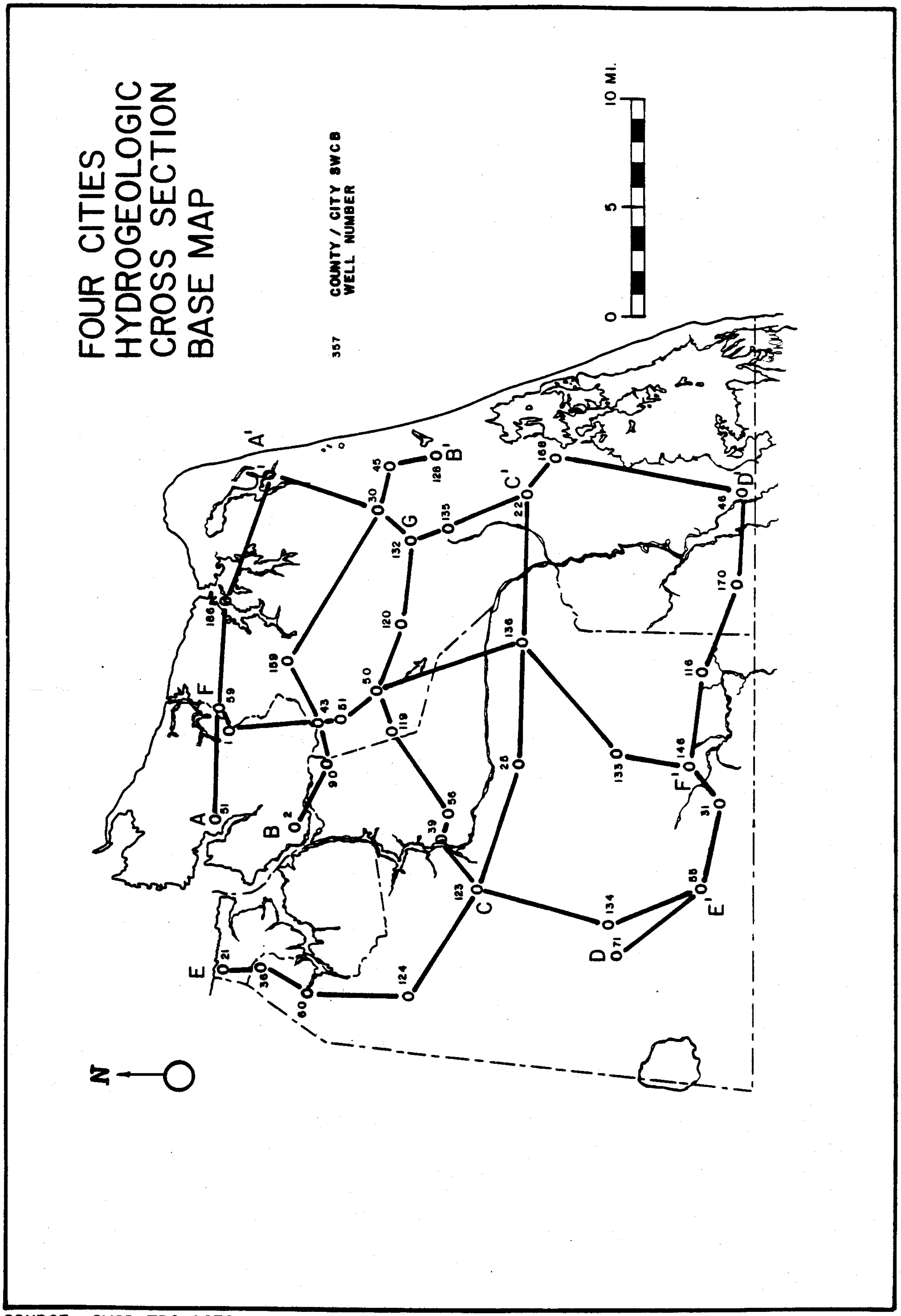
Four aquifers, one unconfined and three confined, underlie the study area. These aquifers and their geologic equivalents are as follows: 1) the water table aquifer (mostly the Columbia Group); 2) the Yorktown aquifer (upper part of the Yorktown Formation); 3) the Eocene-Upper Cretaceous aquifer (lower part of the Calvert and the Mattaponi Formation); 4) and the lower Cretaceous aquifer (the Potomac Group). Confining beds between and within the aquifer retard but do not prevent vertical movement of ground water. Overall, the water-bearing units comprise a leaky-aquifer system with the Lower Cretaceous aquifer exhibiting the most confinement. Cross section E-A', an east-west cross section which runs through the northern part of the study area, shows the four aquifers (Plate 3). The location of this cross section is shown in Plate 4.

Water Table Aquifer - The water table aquifer consists of beds and lenses of sand and some gravel, shell beds, silt, sandy clay, and clay. The sand and shell beds and sand and shell lenses, the major water-bearing strata, are very heterogeneous and discontinuous due to the complex marine estuarine environments in which they were deposited. Eight cross sections showing the major sand and shell beds in the water table and the Yorktown aquifer systems were developed by correlating the resistivity, gamma, and geologic logs of selected wells (Plates 4, 5, 6, 7 and 8). The geophysical and geologic logs indicate that the typical sand bodies in the water table aquifer consist of one or two beds or lenses of medium-to-coarse sand 5 to 10 feet thick. Although these cross sections are



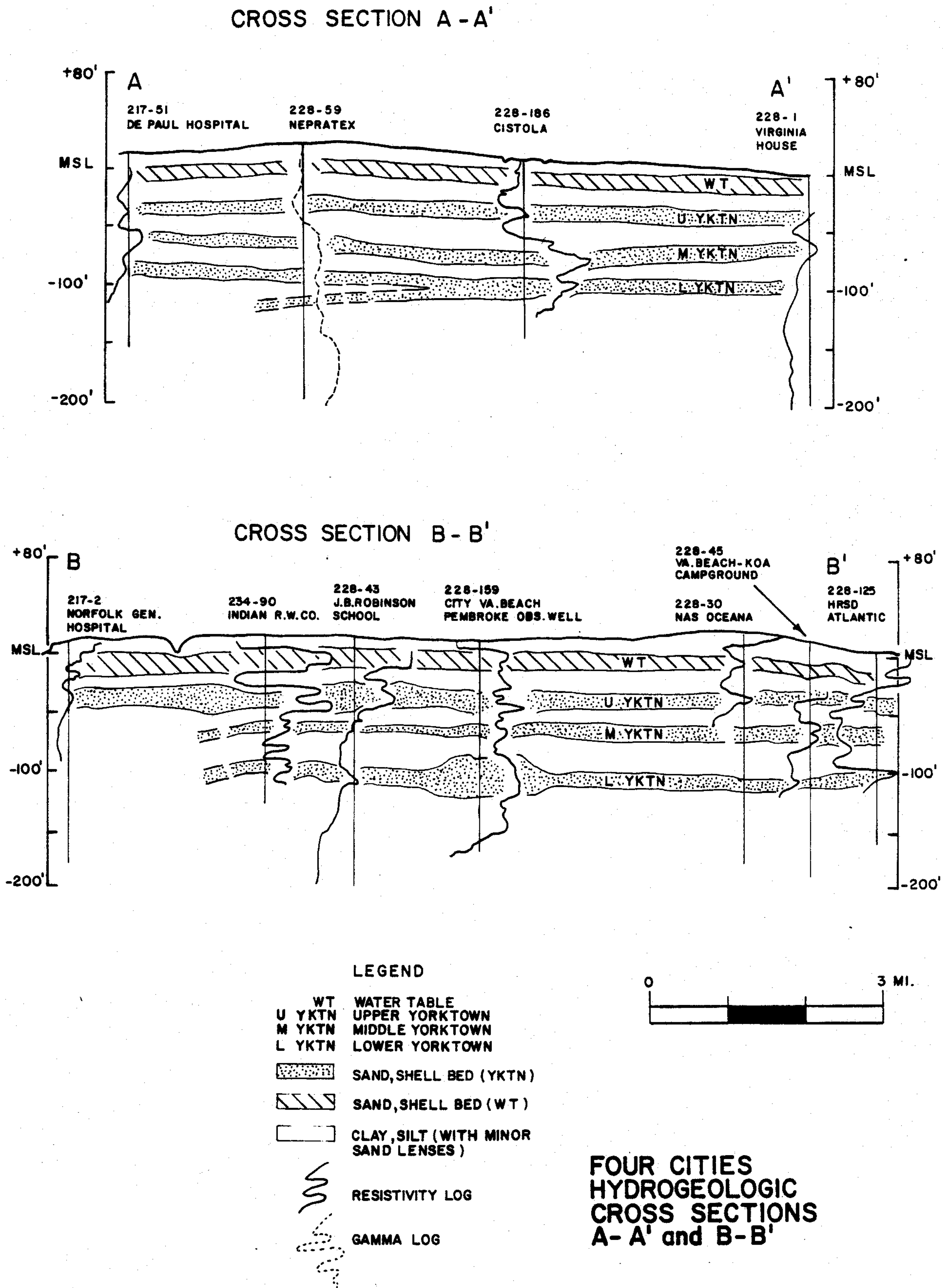
Hydrogeologic cross-section E-A[I] showing vertical distribution of brackish and salty ground water in the Lower Cretaceous Aquifer. (Adapted from W. R. Lichtler and R. L. Wait, 1974 and Geraghty and Miller, 1978)

Plate 3



SOURCE: SWCB-TRO 1979

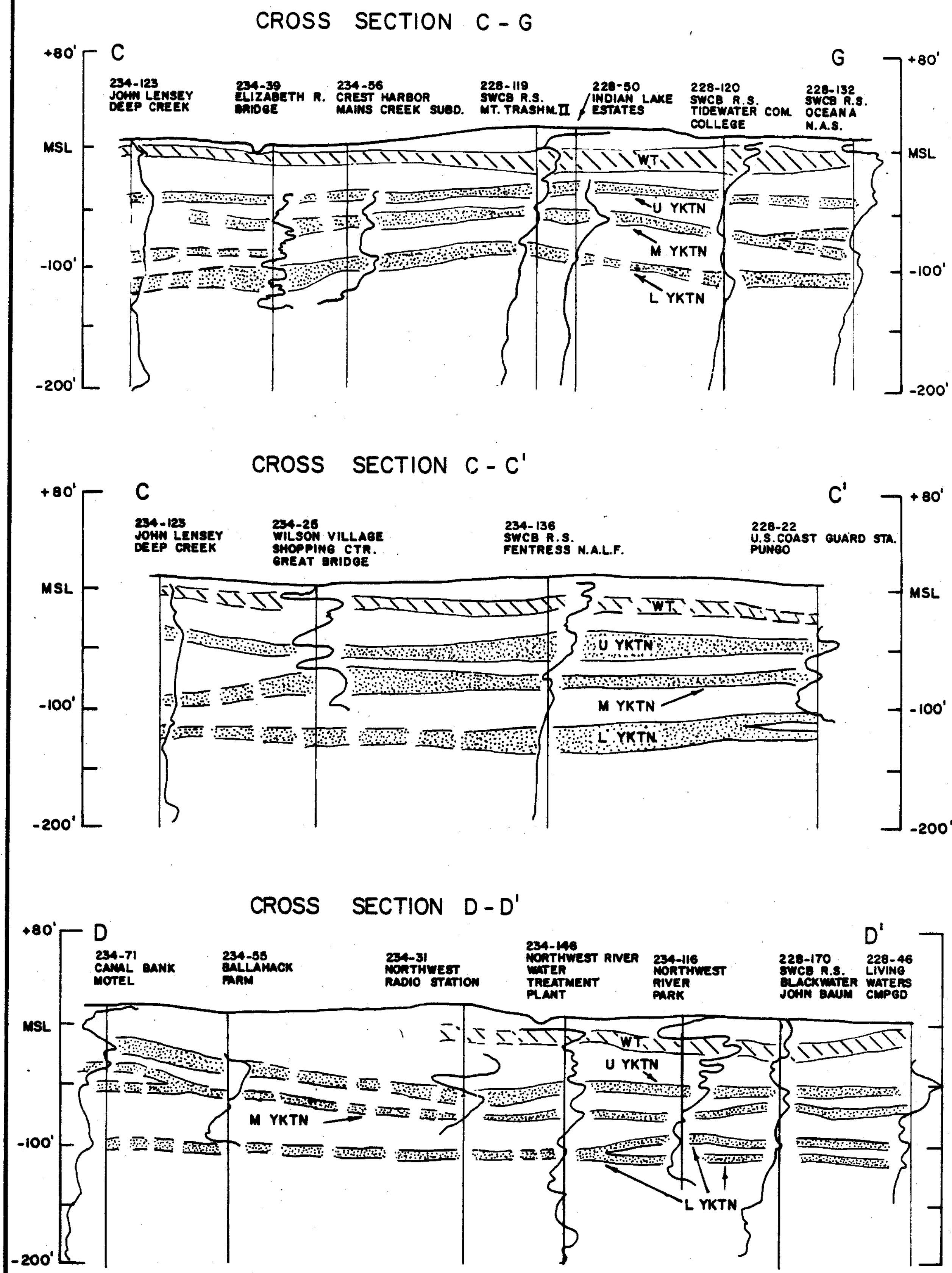
PLATE NO. 4



FOUR CITIES HYDROGEOLOGIC CROSS SECTIONS A- A' and B-B'

SOURCE: SWCB-TRO 1979

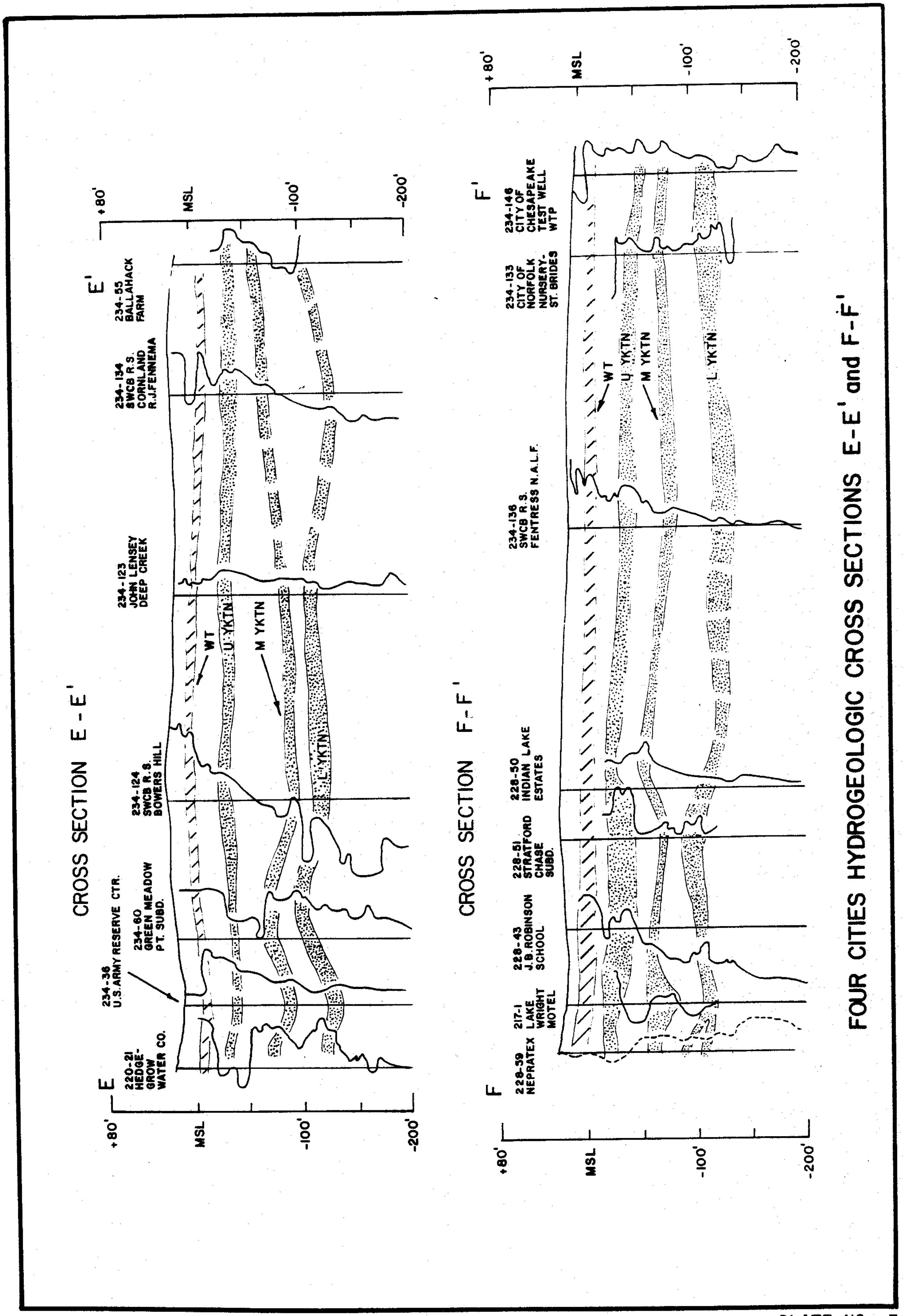
PLATE NO. 5



FOUR CITIES HYDROGEOLOGIC CROSS SECTIONS C-G, C-C' and D-D'

SOURCE: SWCB-TRO 1981

PLATE NO. 6

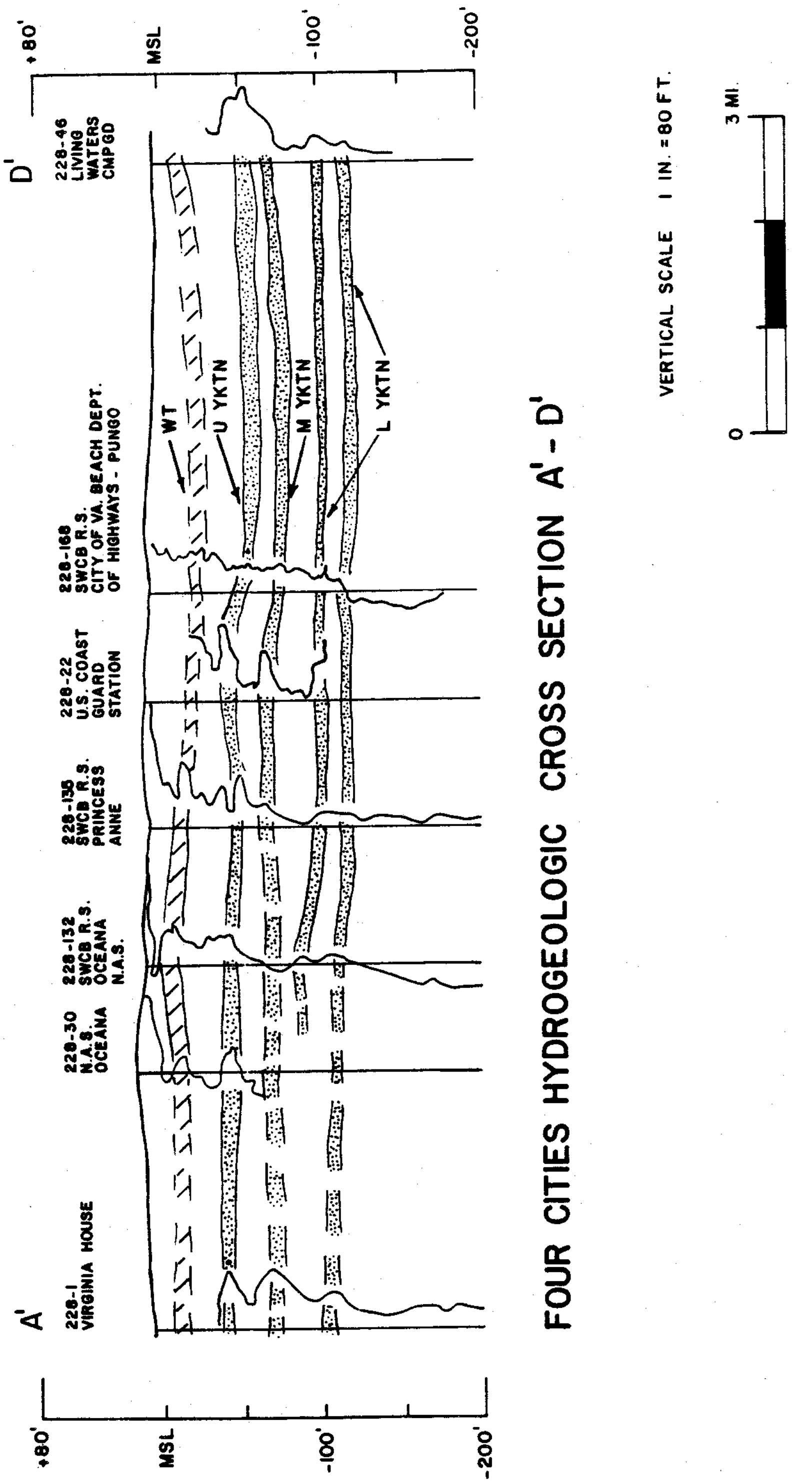


FOUR CITIES HYDROGEOLOGIC CROSS SECTIONS E-E' and F-F'

SOURCE: SWCB-TRO 1981

PLATE NO. 7

CROSS SECTION A' - D'



FOUR CITIES HYDROGEOLOGIC CROSS SECTION A' - D'

SOURCE: SWCB-TRO 1981

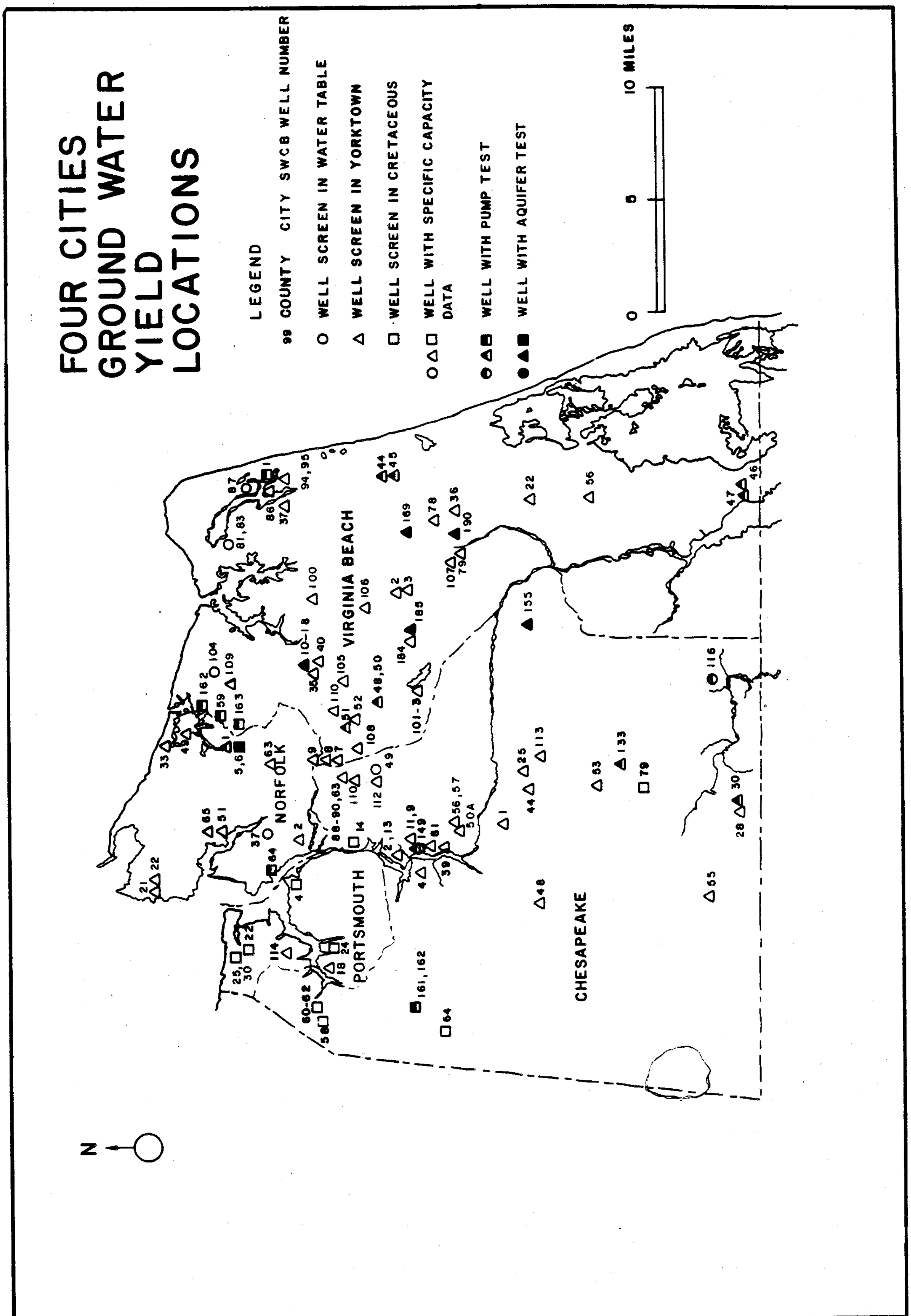
PLATE NO. 8

very generalized and so do not reflect the frequent variations between data points, they demonstrate the consistent occurence of the major sand bodies in both the water table and Yorktown aquifer system.

Recent dune sand, which was deposited by wind and wave action, occurs along the coast in a number of places. There it constitutes a part of the water table aquifer. The thickest dune sands are located at Cape Henry in the northeastern part of the study area.

Limited well yield and specific capacity data records are available for the water table aquifer (Plate 9 and Appendix B). Individual well yields range from 5 to 50 gpm and specific capacities range from about 1 to 2 gpm/ft (gallons per minute per foot of drawdown). In the 1930's and 1940's, a number of well fields consisting of batteries of small diameter wells obtained water from the water table aquifer (Cederstrom, 1945). These systems typically consisted of 10-20 wells which produced a total of between 50 and 200 gpm. Most, if not all, of these have been shut down due to increasing urbanization or substitution of city water. Cederstrom also reports that batteries of 2-inch well points about 15 feet deep yield as much as 150 gpm from dune sand at Cape Henry in northeastern Virginia Beach.

Yorktown Aquifer - Although the Yorktown Formation is 300 to 400 feet thick, the major water-bearing zones comprising the Yorktown aquifer are found in the upper 50 to 100 feet of the Yorktown Formation. The Yorktown aquifer generally is separated from the overlying water table aquifer by beds of silt, clay and sandy clay about 20 to 40 feet thick (Plates 4, 5, 6, 7, and 8). The Yorktown aquifer is separated from the underlying Eocene-Upper Cretaceous aquifer by several hundred feet of silt and clay, 350 feet thick



SOURCE: SWCB-TRO 1980

PLATE NO. 9

in the western study area to over 750 feet thick in the eastern study area.

The major water-bearing zones in the Yorktown aquifer, generally found at depths ranging from 50 to 150 feet, are composed of beds of fine-to-coarse sand, gravel, and shells generally 5 to 20 feet thick (Plates 4, 5, 6, 7 and 8). These eight cross-sections show that three major sand units, referred to as the upper, middle and lower units, comprise the Yorktown aquifer in the Four Cities area. The units are separated by silt and clay beds. Even though geophysical and geologic logs indicate that these three sand units generally are continuous throughout most of the area, the thickness, permeability, and coarseness of the units vary considerably from one data point to another. Usually one unit generally predominates in productivity from one place to another. An example can be seen by observing geophysical log correlations from well 234-136 to well 234-25 in cross section C-C' (Plate 6). The resistivity log deflection at 234-136 indicates that the upper unit predominates, whereas the deflection of the resistivity log at 234-25 indicates that the middle unit is more predominant.

Available well yield and specific capacity data for the Yorktown aquifer was limited generally to 85 larger diameter wells (6 inch or greater in diameter) used for public, commercial, or industrial supply (Plate 9 and Appendix B). Well yields for these wells range from 12 to 304 gpm with an average of about 87 gpm. Specific capacities range from 0.5 to 14.4 gpm/ft with an average of 5 gpm/ft. Area well drillers indicate that smaller diameter (1 1/4 inch to 2 inch) domestic well yields range from 5 to 50 gpm.

Eocene-Upper Cretaceous Aquifer - This aquifer is found at a depth of about 500 feet in the western part of the study area to depths of about 1000 feet in the eastern part (Plate 3). The aquifer generally consists of one or two fine-to medium-grained glauconitic sand beds 10 to 30 30 feet thick interbedded with silt and clay.

Very few wells have tapped the Eocene-Upper Cretaceous aquifer in the study area. Most deep wells go beyond the Eocene-Upper Cretaceous aquifer in order to tap the more productive Lower Cretaceous aquifer. Only six wells (all in the City of Chesapeake) are known to have tapped the Eocene-Upper Cretaceous aquifer. These wells include the abandoned Canal Bank Motel well near Cornland (234-71), the SWCB Research Station at Cornland (234-135), the City of Chesapeake test well near Saint Brides (234-146), the Oak Manor Farm well near Fentress as discussed by Cederstrom (1945), the SWCB Research Station at Fentress Naval Air Station (234-66) and the Tidewater Chemical well at Saint Brides (234-79). Only one of these wells, the Tidewater Chemical well, has well yield data; it yielded 150 gpm with a specific capacity of 2.5 gpm/ft (Plate 9 and Appendix B).

Lower Cretaceous Aquifer - The Lower Cretaceous aquifer is composed of interbedded gravel, sand, silt, and clay. Generally, it is separated from the Eocene-Upper Cretaceous aquifer by clay and silt units 50 feet or more thick. Beds of clay divide the aquifer into several permeable zones. The top of the aquifer ranges from 600 feet below land surface in the northwestern study area to about 1100 feet in the eastern part (Plate 3). The bottom of the aquifer rests on basement rocks at a depth of 2000 feet in the west, to about 4000 feet in the east.

The majority of wells drilled in the Lower Cretaceous aquifer are found in northwestern Chesapeake, in Portsmouth, and in western Norfolk where the aquifer contains fresh or slightly brackish water. Well yields for this aquifer range from 200 to 1000 gpm and specific capacities range from 2.9 to 30.8 gpm/ft (Plate 9 and Appendix B).

CHAPTER IV

HYDROLOGY

In this chapter, the hydrology of each of the major aquifers is discussed including recharge, water levels, and hydraulic characteristics determined by constant rate pumping tests and aquifer tests. The major aquifers discussed here will be the 1) water table, 2) Yorktown, 3) Eocene-Upper Cretaceous, and 4) Lower Cretaceous.

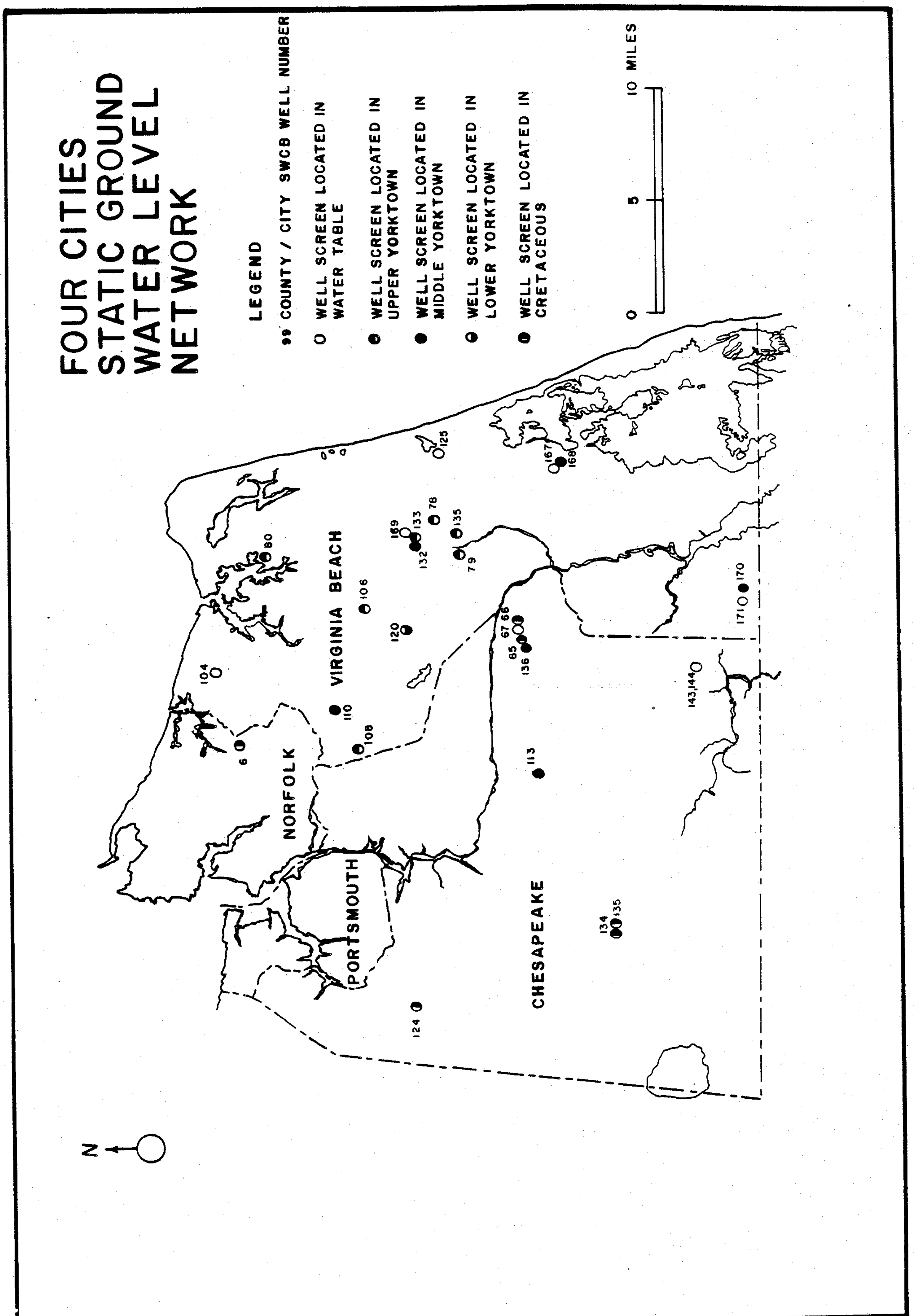
Water Table Aquifer

Recharge - Precipitation, the principal source of recharge in the Four Cities area, is fairly well distributed throughout the year and averages about 44 inches per year. A part of the precipitation runs off in streams, part is returned to the atmosphere by evapotranspiration, and part moves down through the soil zone and replenishes the water table aquifer. The recharge rate to the water table aquifer is not known precisely but is estimated to be about 30 to 50% of the annual precipitation or about 12 to 20 inches per year. This is equivalent to about 0.6 to 1 MGD or about 220 to 365 million gallons per year per square mile.

In the water table aquifer, water moves slowly under the influence of gravity to areas of discharge such as streams, lakes and other surface water bodies or to pumping wells and active borrow pits which are being dewatered. Part of the water also percolates down slowly into the underlying artesian (confined) aquifers.

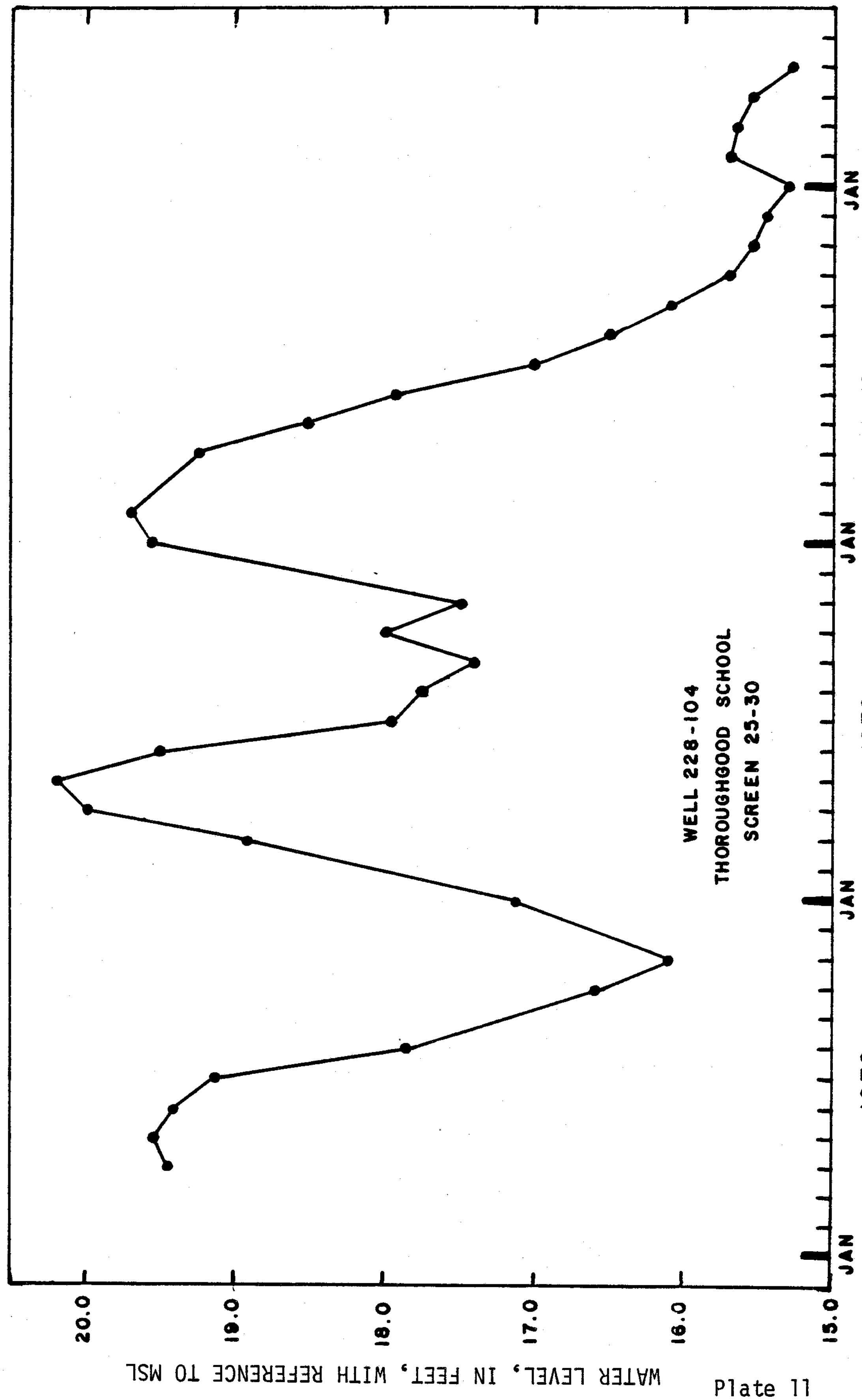
Water Levels - The altitude and configuration of the water table, or top of the zone of saturation in the aquifer, more or less is reflected by the topography, that is, the altitude is highest beneath topographic highs and lowest at the shoreline and stream beds. Thus, flow of ground water in the water table aquifer is from topographic high to topographic low except where modified locally by pumping of wells and dewatering of borrow pits. Seven wells tapping the water table aquifer are included in the SWCB static ground water level network (Plate 10). Water levels in the network wells were measured monthly beginning in 1978. The water table aquifer wells indicate that the highest and lowest altitudes of the water table during this period were 12 to 18 feet and 2 to 5 feet respectively, above mean sea level. The depth of the water table varies from less than a foot to 4 to 8 feet. The well hydrograph shown in Plate 11 indicates that in the Thoroughgood area of Virginia Beach the water table over the last three years has fluctuated 3 to 4 feet annually due to seasonal variations. The hydrograph also shows the effect of the 1980-81 drought which started in July 1980. Seasonal highs occur in April or May and seasonal lows generally occur from August through November.

Hydraulic Characteristics - Very little data are available on the hydraulic characteristics of the water table aquifer, such as transmissivity and storage coefficient. Transmissivity was determined for one water table aquifer well using a constant rate pumping test and a recovery test analysed by the Cooper-Jacob modified non-equilibrium method. The transmissivity values for this well (234-116) at Northwest River Park in Chesapeake ranged from 2,600 gpd/ft (gallons per day per foot) for the pumping test to 1,400 gpd/ft for the recovery test. The location of this well is shown in Plate 9 and the semi-log plots and calculations of transmissivity are given in Appendix C.



SOURCE: SWCB-TRO 1979

PLATE NO. 10



Composite hydrograph showing water-level trend in well screened in water table aquifer.

Plate 11

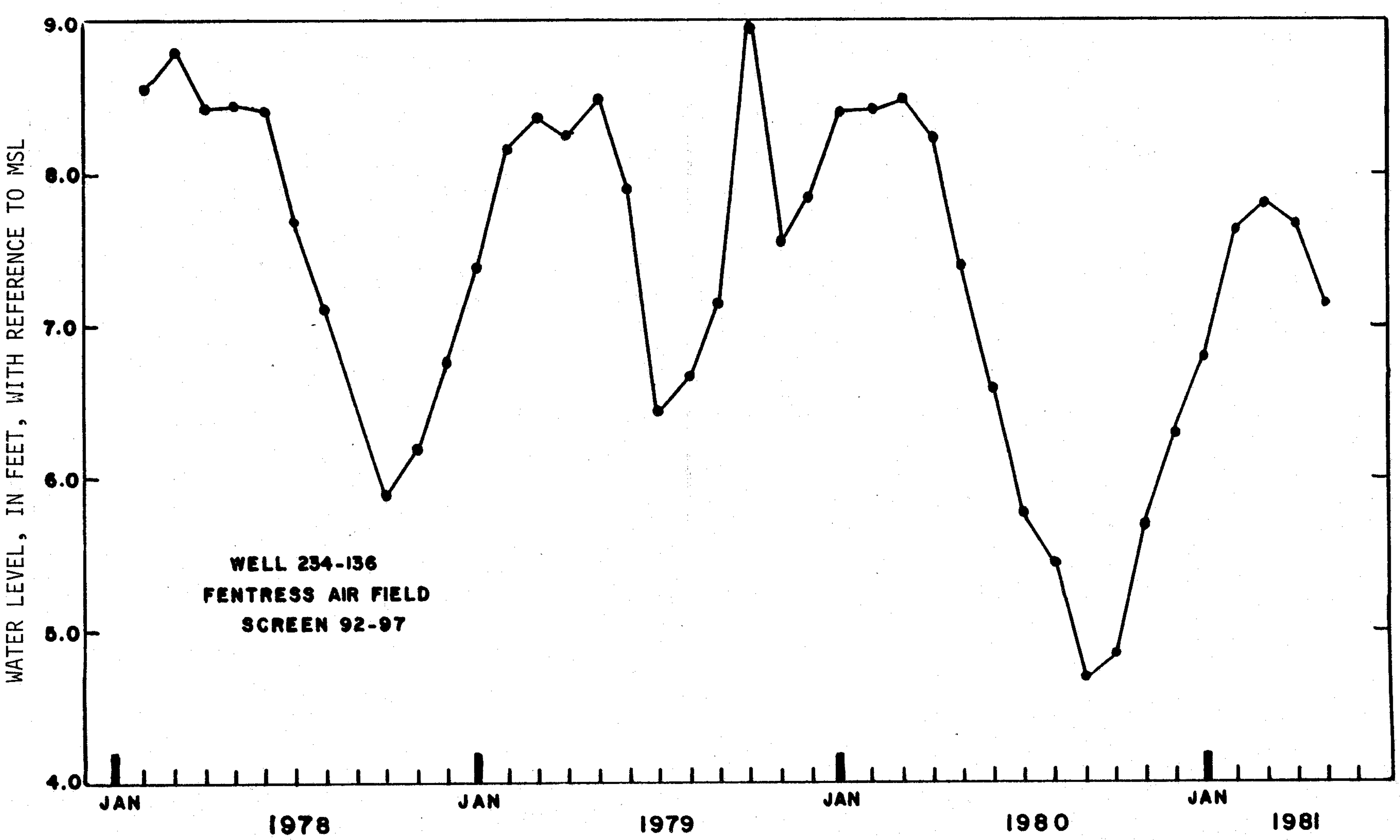
Yorktown Aquifer

Recharge - The Yorktown aquifer contains water confined under artesian pressure; the confining materials, consisting of clay, marl and sandy clay, are generally 20 to 40 feet thick. Water enters the Yorktown aquifer mainly by downward leakage from the water table aquifer where head relationships favor such movement and to a lesser extent by lateral flow from the west.

Water levels observed at the Oceana Air Station research station wells (228-132, 133, 169) and the Fentress Naval Air Station research station wells (234-136, 67) indicate that water table aquifer levels are 3 to 4 feet higher than levels in the Yorktown aquifer (Plate 10). Therefore, flow in those areas is from the water table aquifer vertically downward to the Yorktown aquifer. Water levels of Oceana Naval Air Station wells (228-133 and 132) screened in the upper and middle Yorktown aquifer units show that the Middle Yorktown well is consistently about one foot lower in head than the Upper Yorktown were. Therefore, vertical flow in that area is from the water table aquifer downward to the Middle Yorktown aquifer (screened at 97-102 feet). Water levels to the south at the Pungo research station wells (228-167,-168) and the Blackwater research station wells (228-171,-170) indicate that the Yorktown aquifer water levels are slightly higher than the levels in the water table aquifer. This indicates that the Yorktown aquifer is under water table or semi-unconfined conditions and that there may be a slight vertical flow from the Yorktown aquifer vertically upward into the water table aquifer in those areas.

Water Levels - Fourteen wells, including the wells discussed above, constitute the static water level network for the Yorktown aquifer (Plate 10). Well hydrographs of one of these wells is shown in Plate 12. Average water levels in this well ranged from about 5 to 9 feet above mean sea level. Hydrographs for the other Yorktown observation wells have a similar shape with precipitation events or lack of precipitation being the main factor in influencing the shapes of the hydrographs. The Yorktown aquifer hydrograph is similar to the water table aquifer hydrograph showing the influence of precipitation and subsequent water table aquifer water levels on the water levels in the Yorktown aquifer. The Yorktown aquifer hydrograph has shown about 2.5 to 4 feet of seasonal variation per year since 1978. Detectable trends of water level decline in the Yorktown aquifer are not indicated by the water level network wells at the present time. An accurate potentiometric water level map of the Yorktown aquifer can not be drawn at the present time due to the lack of sufficient data points. However, based on the existing ground water level network, it appears that water levels in the Yorktown aquifer generally follow the topography similarly to water levels in the water table aquifer except where significant pumpage occurs.

Hydraulic Characteristics - Transmissivity for 16 Yorktown aquifer wells was determined using the Cooper-Jacob modified non-equilibrium method for constant-rate pumping and recovery tests. The location of the wells is shown in Plate9 and the transmissivity values are summarized in Table 4. The calculated transmissivity values range from 1,600 to 66,000 gpd/ft with an average of 15,000 gpd/ft.



Composite hydrograph showing water-level trend in well screened in Yorktown aquifer.

Plate 12

TABLE 4
SUMMARY OF TRANSMISSIVITY DETERMINATIONS
USING THE SEMI-LOG METHOD FOR CONSTANT
RATE PUMP TESTS AND RECOVERY TESTS

Well No.	Description	Transmissivity (gpd/ft) Pump Test[a]	Recovery Test[a]
WATER-TABLE AQUIFER			
234-116 (Ches)	Northwest River Park	2,600	1,400
YORKTOWN AQUIFER			
217-1 (Norfolk)	Lake Wright Golf Course	15,100	17,900
228-12 (Va. Bch)	Pembroke #3	36,000[b]	38,000[b]
228-44	Rudee Campgrounds	12,800	-
228-45	Virginia Beach Campgrounds	-	5,800
228-46	Living Water Campgrounds	-	5,800
228-47	Living Water Campgrounds	3,000	1,600
228-48	Indian Lakes Estates	-	2,200
228-50	Indian Lakes Estates	-	2,700
228-51	Stratford Chase	-	3,500
228-132	SWCB Well A, Oceana NAS	24,600[c]	24,900[c]
228-184	SWCB Well C, Tidewater Com. Col.	15,000[c]	15,000[c]
228-190	SWCB Well B, Princess Anne	7,100[c]	7,200[c]
234-30 (Ches)	Northwest Radio Station, Well 2A	5,600	-
234-133	City of Norfolk Nursery	66,000	66,000
234-149	Smith Douglas #3	25,300	23,800
234-155	Fentress NAS	3,000[c]	2,600[c]
LOWER CRETACEOUS AQUIFER			
217-64 (Norfolk)	J. H. Miles Co.	37,800	-
228-1 (Va. Bch)	Virginia House	65,700[d]	-
228-59	Nepratex Industries	15,000[e]	-
228-162	Ferry Slip Test Well	19,000[e]	31,000[e]
228-163	Burton Station	38,000[e]	33,000[e]
234-161 (Ches)	City of Chesapeake-Bowers Hill	153,000[f]	157,000[f]

Explanations
- a - semi-log plots of data and calculations given in Appendix C except where noted below.
- b - production well of Pembroke aquifer test, included in Geraghty and Miller (1979b).
- c - production well of an aquifer test included in the study, plots in Appendix D.
- d - calculated by Sydnor Hydrodynamics, Richmond, Virginia.
- e - from Geraghty and Miller (1979c).
- f - semi-log plots not included in the Appendix since aquifer test was completed during final phase of study.

Semi-log plots of time-drawdown or time-recovery data for these wells, not included in previous studies and not part of the aquifer tests discussed below, are found in Appendix C.

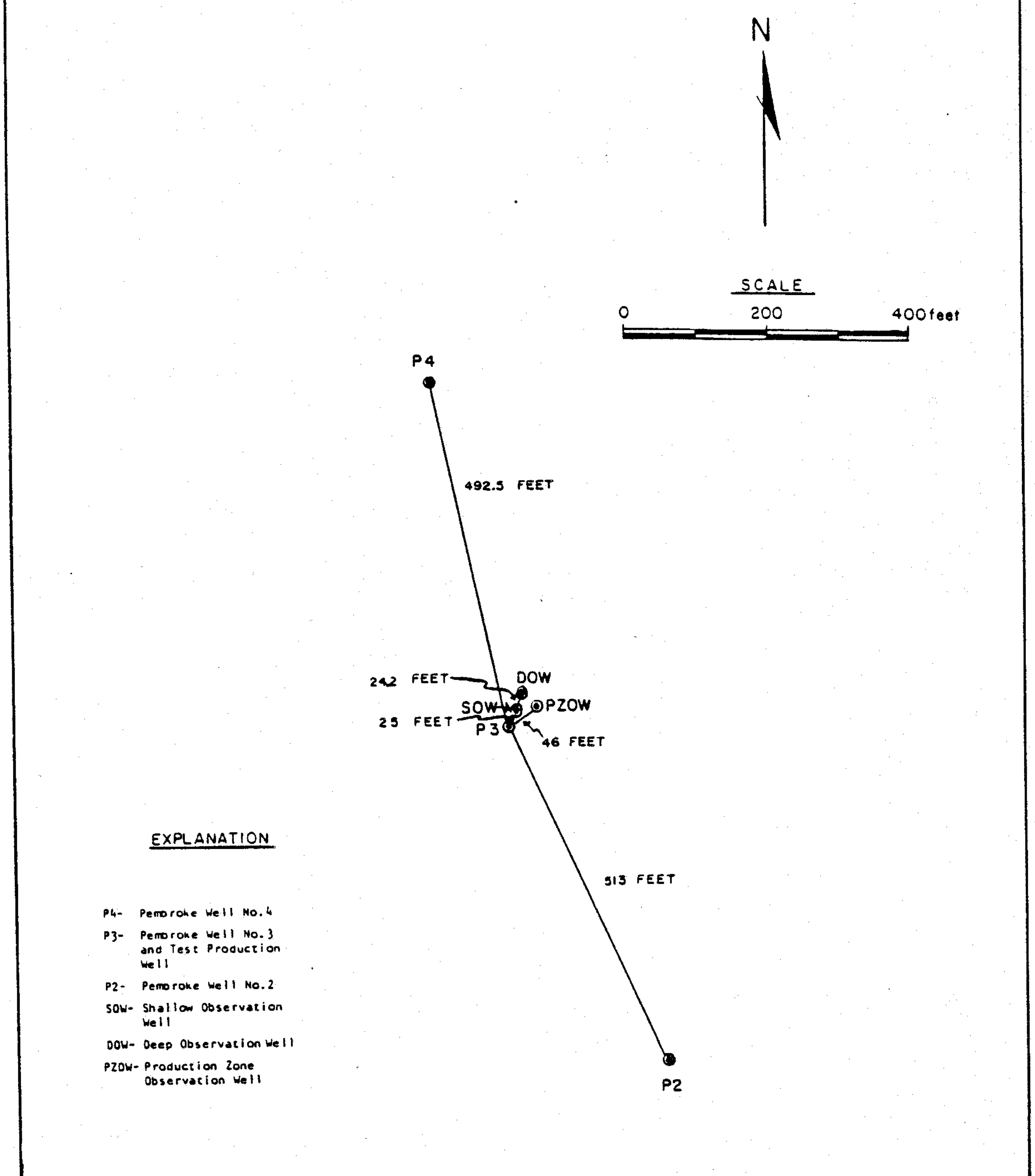
Five aquifer tests of the Yorktown aquifer have been conducted in the Four Cities Area (Plate 9). The Pembroke well field aquifer test was completed by Geraghty and Miller (1979b) in April 1979. The Fentress Naval Air Station aquifer test was completed by Ground Water Development Company and the SWCB in November 1979. The aquifer tests at Oceana Naval Air Station research station, the Tidewater Community College research station and the Princess Anne Courthouse research station were conducted by the State Water Control Board in December 1979, January 1980, and August 1980, respectively. A constant-rate pumping test and a recovery test were conducted during each aquifer test. The collected data were analyzed using several analytical techniques to determine values of aquifer transmissivity, storage coefficient, and leakance (see glossary). The primary methods used included the Hantush-Jacob method for leaky aquifers, the Cooper-Jacob modified non-equilibrium method, the distance-drawdown method, and the Theis recovery formula (Lohman, 1972). Aquifer test location maps are shown in Plates 13-17. A summary of aquifer test results is found in Tables 5-10, and the graphs and calculations for the SWCB aquifer tests are included in Appendix D.

The log-log plots of observation wells for the Pembroke well field, the Fentress NAS, the Tidewater Community College, and the Princess Anne aquifer tests were matched to the type curve for leaky artesian aquifers (Lohman, 1972), and the data indicate that the aquifer behaves like a leaky artesian aquifer. At the Oceana NAS the standard flow equations, including the Theis non-equilibrium formula and the leaky artesian equations, could not be applied because the aquifer tapped by the production well was discontinuous and, therefore, did not meet the assumption of the standard flow equations.

The pumping well for the Pembroke well field aquifer test was Pembroke production well #3 (228-12), which is screened in the Upper, Middle and Lower Yorktown units (52-120 ft.) (cross section B, B', Plate 5). Five observation wells were used nearby, three of which were screened in the same zones as the production well, one of which was screened in the water table aquifer (25-30 ft) and one was screened in a sand zone below the production zone (150-160ft) (Plate 13). The constant-rate pumping test started at 5:10 p.m. April 6, 1979, and continued for 66 hours at a pumping rate of 148 gpm. After about 2,500 minutes of pumping, the aquifer had reached equilibrium or steady-state conditions. That is, leakage and lateral flow balanced or equaled pumpage, and hence the cone of depression stabilized. The recovery test was conducted for 11 hours.

A summary of the results of the analyses for the Pembroke aquifer test is shown in Table 5. The values of aquifer transmissivity range from a high of 46,000 gpd/ft to a low of 34,000 gpd/ft. The values of storage coefficient range from 1.4×10^{-3} to 6.3×10^{-3}. Values of leakance range from 2.2×10^{-4} day^{-1} for wells P_2 and P_4 to 3.5×10^{-3} day^{-1} for the production zone observation well. Approximate permeability of the confining units, based on a confining unit thickness of a 100 ft. and the above leakance values, ranged from 0.2 ft/day

WELL LOCATIONS FOR PEMBROKE AQUIFER TEST



Source: GERAGHTY AND MILLER, INC. 1979b

PLATE NO. 13

Table 5 - SUMMARY OF AQUIFER HYDRAULIC CHARACTERISTICS
Pembroke Well Field (Adapted from Geraghty and Miller, 1979b)

Well	Type of Data Analyzed	Method of Analysis	Transmissivity (gpd/ft)	Leakance (Day-1)	Storage Coefficient (dimensionless)
Pumping Well (P3)	Drawdown	Cooper-Jacob	46,000	-	-
Pumping Well	Recovery	Residual Drawdown-t/t'	38,000	-	-
Production Zone Obs. Well (r=46 ft)	Drawdown	Cooper-Jacob	36,000	-	0.006
	Drawdown	Hantush-Jacob	34,000	3.5×10^{-3}	0.0063
Production Zone Obs. Well	Recovery	Residual Drawdown-t/t'	35,000	-	-
Observation Well P4 (r=492.5 ft)	Drawdown	Hantush-Jacob	40,000	2.2×10^{-4}	0.0014
Observation Well P2 (r=513 ft)	Drawdown	Hantush-Jacob	43,000	2.2×10^{-4}	0.0015

for wells P_2 and P_4 to .35 ft/day for the production zone observation well.

Water levels in the deep observation well at Pembroke immediately declined when pumping was commenced in well P_3 indicating that the production zone is hydraulically connected to deeper portions of the Yorktown aquifer. This is significant because the deeper portions contain water having significantly higher concentrations of total dissolved solids and the hydraulic connection is likely to allow the high-TDS water to rise up into upper parts of the aquifer when they are pumped. At the end of the pumping portion of the test the total drawdown in the deep observation well was about 2 feet. The water levels in the shallow observation well also declined due to pumping from well P_3 indicating a hydraulic connection between the shallow water table aquifer and the production zone. The shallow observation well did not respond as much as the deep observation well and only began to show a drawdown after 100 minutes of pumping (only about 0.3 of a foot).

The production well (234-155) for the Fentress Naval Air Station aquifer test was screened in the Middle Yorktown Unit (cross section C-C', Plate 6). Five observation wells were used; two were screened in the same zone as the production well (observation wells A and B), one well was screened in both the Upper Yorktown and Middle Yorktown units (observation well C; 234-136), one was screened in a lower sand unit and one was screened in the water table aquifer (Plate 14). The constant-rate pumping test started on November 20, 1979 at 10:00 a.m. and continued for 24 hours at a pumping rate of 65 gpm. Steady-state

WELL LOCATIONS FOR AQUIFER TEST AT FENTRESS NAVAL AIR STATION

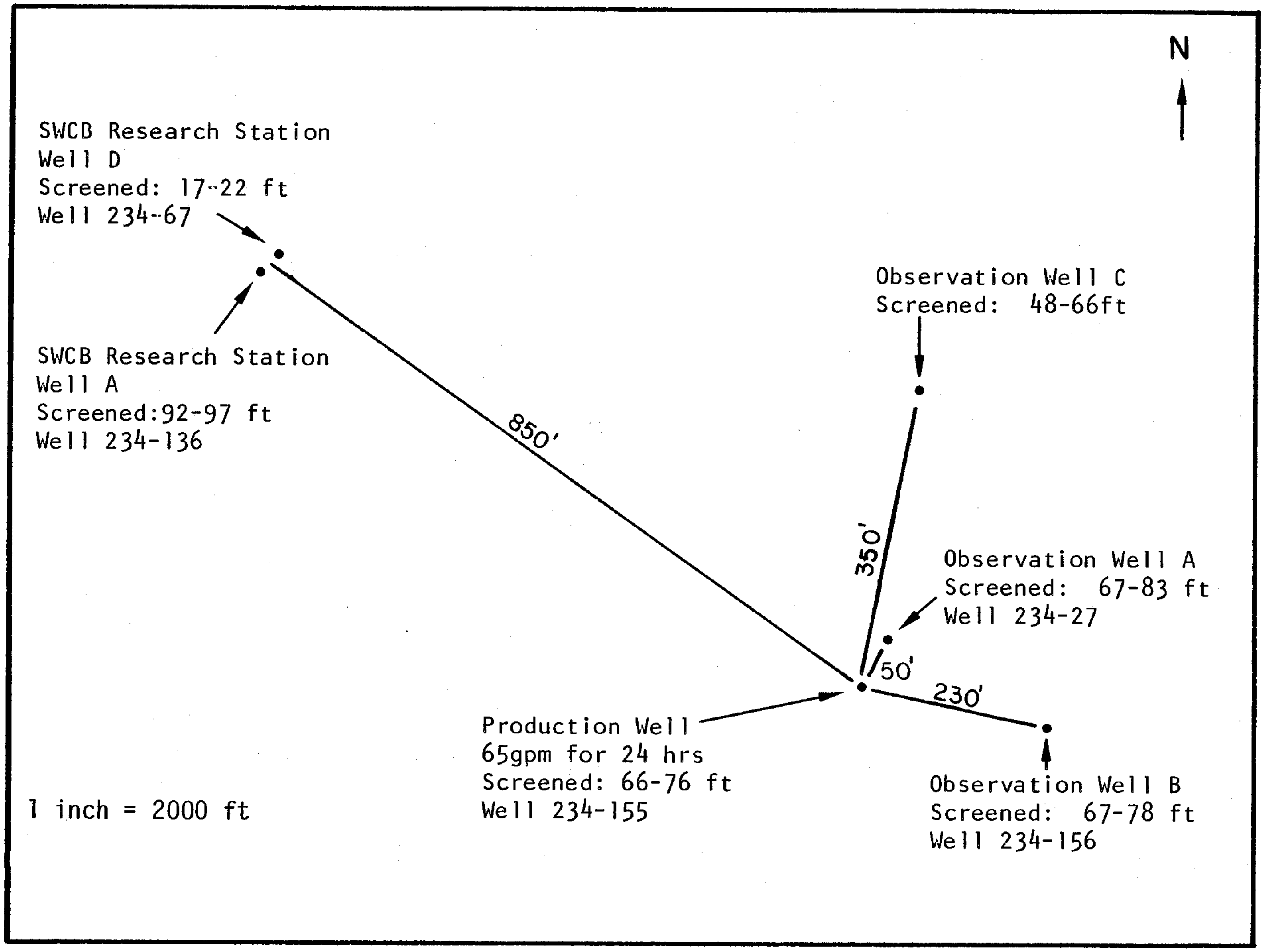


Plate 14

conditions were not reached after 24 hours. The recovery test was run for two hours.

A summary of the aquifer charactertics for the Fentress Naval Air station aquifer test is given in Table 6. Plots of drawdown and recovery data and examples of the analytical techniques used can be found in Appendix D. The values of aquifer transmissivity range from a high of 3,300 gpd/ft to a low of 1,800 gpd/ft. The values of storage coefficient range from 1.1×10^{-4} to 7.7×10^{-4}. Values of leakance range from 1.8 x 10-3 day-1 for observation well A to 1.3×10^{-4} day-1 for observation well B. Approximate permeability of the confining unit, which is the confining unit thickness (50 ft.) multiplied by the leakance value, ranged from 0.09 ft/day for observation well A to 0.006 ft/day for observation well B.

Water levels in observation well C, an abandoned production well, declined when pumping commenced in the production well but only declined a total of 1.7 ft. in 24 hours. Prior to the test, it was thought that observation well C was screened solely in the production zone but because of the small decline observed, it appears that the well is screened in both the production zone and in the Upper Yorktown unit. The water table aquifer well and the lower sand unit well showed no detectable decline at the end of 24 hours. This was expected because of the substantial distance between these observation wells and the production well (Plate 14).

A production well and three observation wells were constructed by the State Water Control Board for the aquifer test at the Tidewater Community College research station. The production well and

Table 6 - SUMMARY OF AQUIFER HYDRAULIC CHARACTERISTICS
Fentress Naval Air Station

Well	Type of Data Analyzed	Method of Analysis	Transmissivity (gpd/ft)	Leakance (Day-1)	Storage Coefficient (dimensionless)
Pumping Well (234-155)	Drawdown	Cooper-Jacob	3,000	-	-
Pumping Well	Recovery	Theis Recovery Formula	2,600	-	-
Observation Well A (234-27); r=50 ft	Drawdown	Cooper-Jacob	2,300	-	.00066
Observation Well A	Recovery	Theis Recovery Formula	2,200	-	-
Observation Well A	Drawdown	Theis-(early time)	2,600	-	.00050
Observation Well A	Recovery	Theis-(early time)	2,000	-	.00059
Observation Well A	Drawdown	Hantush-Jacob	1,800	1.8×10^{-3}	.00077
Observation Well B (234-156); r=220 ft	Drawdown	Cooper-Jacob	3,300	-	.00010
Observation Well B	Drawdown	Theis-(early time)	3,000	-	.00013
Observation Well B	Recovery	Theis-(early time)	3,100	-	.00011
Observation Well B	Drawdown	Hantush-Jacob	2,500	1.3×10^{-4}	.00014
Observation Wells A & B	Drawdown	Distance-Drawdown	3,200	-	.00012

the observation wells were screened in the Lower Yorktown unit (Plates 6 and 15). The constant rate pumping test started on January 16, 1980 at 10:15 a.m. and continued for 24 hours at a rate of 62.6 gpm. Steady-state conditions were not reached after 24 hours of pumping. The recovery test was conducted for 27 hours at which time the production well was 98.8 per cent recovered, and the observation wells were 94 to 96 per cent recovered.

A summary of the results of the analyses for the Tidewater Community College aquifer test is shown in Table 7. Plots of drawdown and recovery data and examples of the analytical techniques used can be found in Appendix D. The values of aquifer transmissivity range from a high of 22,000 gpd/ft to a low of 12,000 gpd/ft. The values of storage coefficient range from 2.2×10^{-4} to 5.8×10^{-4}. Values of leakance range from 1.2×10^{-2} day^{-1} for observation well B to 4.1×10^{-3} day^{-1} for observation well D. Approximate permeability of the confining unit, assuming a confining unit thickness of 150 ft., ranged from 1.8 ft/day for observation well B to 0.61 ft/day for well D.

The production well (228-190) and four observation wells for the aquifer test at the Princess Anne Courthouse research station were screened in the upper Yorktown unit (Plates 8, 9, and 16). The production well (well B) and observation wells A and C were constructed by the State Water Control Board and observation wells D and E were abandoned supply wells currently used in the SWCB static water level network. The constant rate pumping test started in August 14, 1980 and continued for 24 hours at a pumping rate

WELL LOCATIONS FOR AQUIFER TEST
AT TIDEWATER COMMUNITY COLLEGE RESEARCH STATION

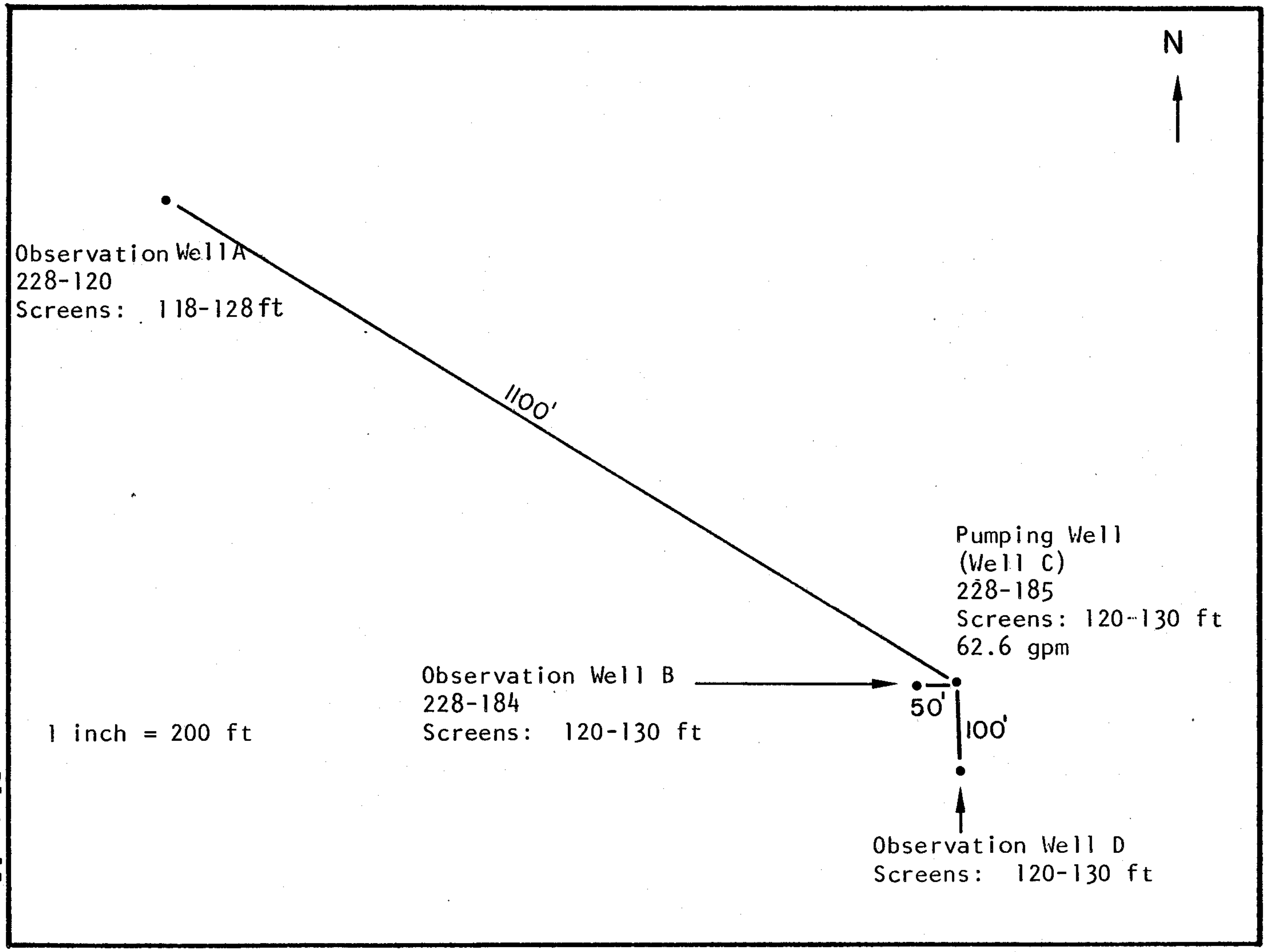


Plate 15

Table 7 - SUMMARY OF AQUIFER HYDRAULIC CHARACTERISTICS
Tidewater Community College Research Station

Well	Type of Data Analyzed	Method of Analysis	Transmissivity (gpd/ft)	Leakance (Day-1)	Storage Coefficient (dimensionless)
Pumping Well (228-185)	Drawdown	Cooper-Jacob	15,000	-	-
Pumping Well	Recovery	Theis Recovery Formula	15,000	-	-
Observation Well B (228-184); r = 50 ft	Drawdown	Cooper-Jacob	20,000	-	-
Observation Well B	Recovery	Theis Recovery Formula	19,000	-	-
Observation Well B	Drawdown	Hantush-Jacob	12,000	1.2×10^{-2}	.00041
Observation Well D	Drawdown	Cooper-Jacob	22,000	-	-
Observation Well D r = 100 ft	Recovery	Theis Recovery Formula	19,000	-	-
Observation Well D	Drawdown	Hantush-Jacob	16,000	4.1×10^{-3}	.00022
Observation Well B, D, A	Drawdown	Distance-Drawdown	15,000	-	.00058

WELL LOCATIONS FOR AQUIFER TEST
AT PRINCESS ANNE RESEARCH STATION

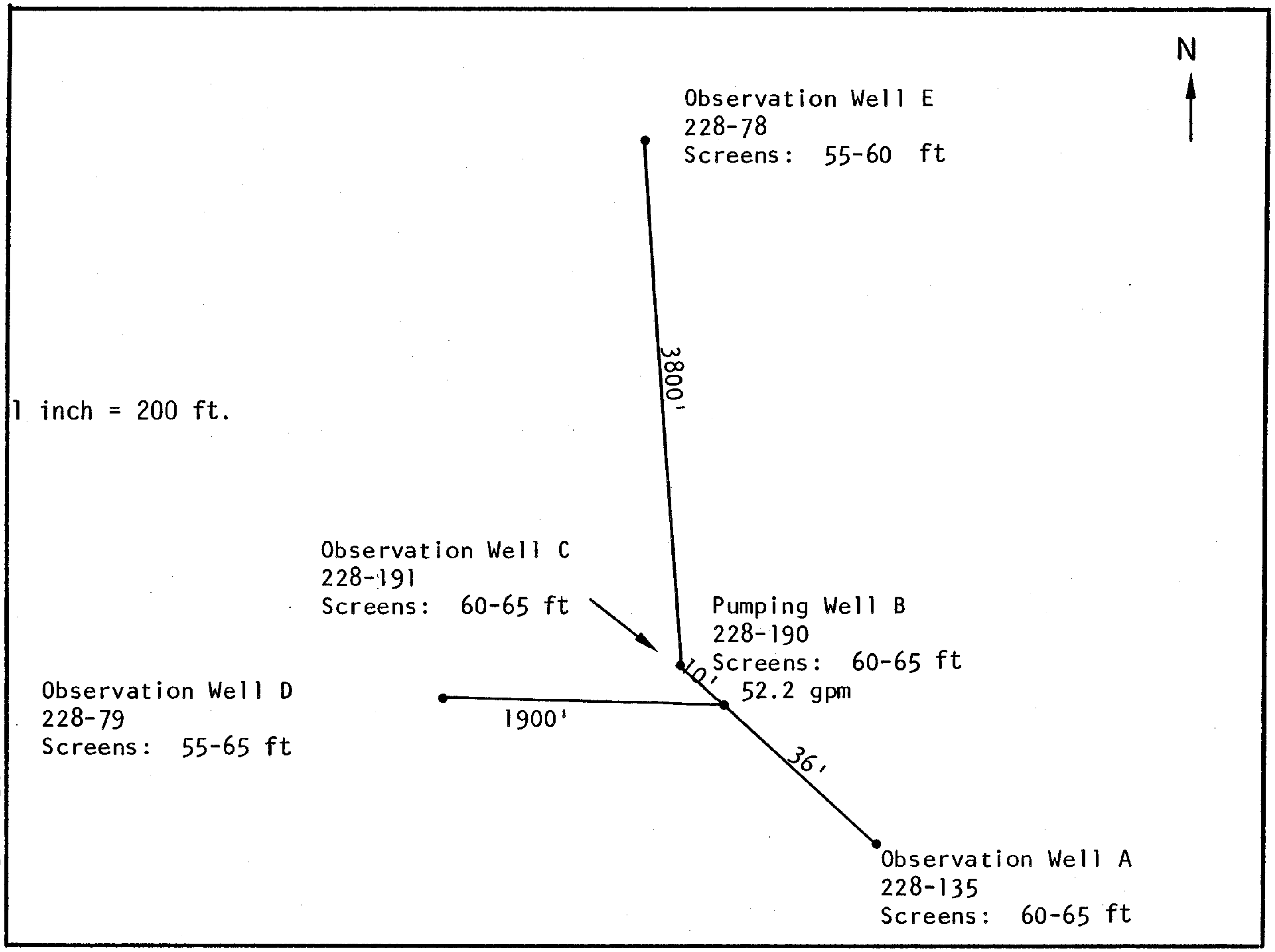


Plate 16

of 52.2 gpm. Steady-state conditions were not reached after 24 hours of pumping. The recovery test lasted 23 hours at the end of which time 99 per cent to 99.5 percent recovery had taken place.

A summary of the results of the analyses for the Princess Anne Courthouse research station aquifer test is shown in Table 8. Graphs of drawdown and recovery data and examples of the analytical techniques can be found in Appendix D. The values of aquifer transmissivity range from a high of 7,200 gpd/ft to a low of 3,900 gpd/ft. The values of storage coefficient range from 1.2×10^{-4} to 7.2×10^{-4}. Values of leakance range from 7.6×10^{-1} day^{-1} for observation well C to 6.7×10^{-2} day^{-1} for observation well A.

A production well and four observation wells constructed by the SWCB were used in the aquifer test at the Oceana Naval Air Station research station. The production well (well A) and observation wells C and E were screened in a sand-and-shell unit which was grouped into the Lower Yorktown unit (Plates 8, 9, and 17). Observation well B was screened in the Upper Yorktown unit and observation well D was screened in the water table aquifer. The constant rate pumping test started on December 17, 1979 and continued for 42 hours at a pumping rate of 84 gpm. The well screened in the Upper Yorktown unit and the water table aquifer showed no detectable response to pumping. The recovery was conducted for 52 hours at the end of which time recovery was over 90 per cent.

Production zone observation wells E and C responded sluggishly to pumping. Inspection of semi-log time versus drawdown plots in Appendix D indicate that it took about ten minutes for observation well E (r=10 ft.) and about 60 minutes for observation well C (r=100 ft.) to respond. This sluggish response indicates that

Table 8 - SUMMARY OF AQUIFER HYDRAULIC CHARACTERISTICS
Princess Anne Courthouse Research Station

Well	Type of Data Analyzed	Method of Analysis	Transmissivity (gpd/ft)	Leakance (Day-1)	Storage Coefficient (dimensionless)
Pumping Well B	Drawdown	Cooper-Jacob	7,100	-	-
Pumping Well	Recovery	Theis Recovery Formula	7,200	-	-
Observation Well C (r=10 ft)	Drawdown	Cooper-Jacob	7,100	-	.00072
Observation Well C	Recovery	Theis Recovery Formula	7,200	-	-
Observation Well C	Drawdown	Hantush-Jacob	3,900	7.6×10^{-1}	.00072
Observation Well A (r=36 ft)	Drawdown	Cooper-Jacob	6,300	-	.00064
Observation Well A	Recovery	Theis Recovery Formula	6,000	-	-
Observation Well A	Drawdown	Hantush-Jacob	4,400	6.7×10^{-2}	.00014
Observation Wells C, A, D	Drawdown	Distance-Drawdown	6,600	-	.00012

WELL LOCATIONS FOR AQUIFER TEST AT
OCEANA NAVAL AIR STATION RESEARCH STATION

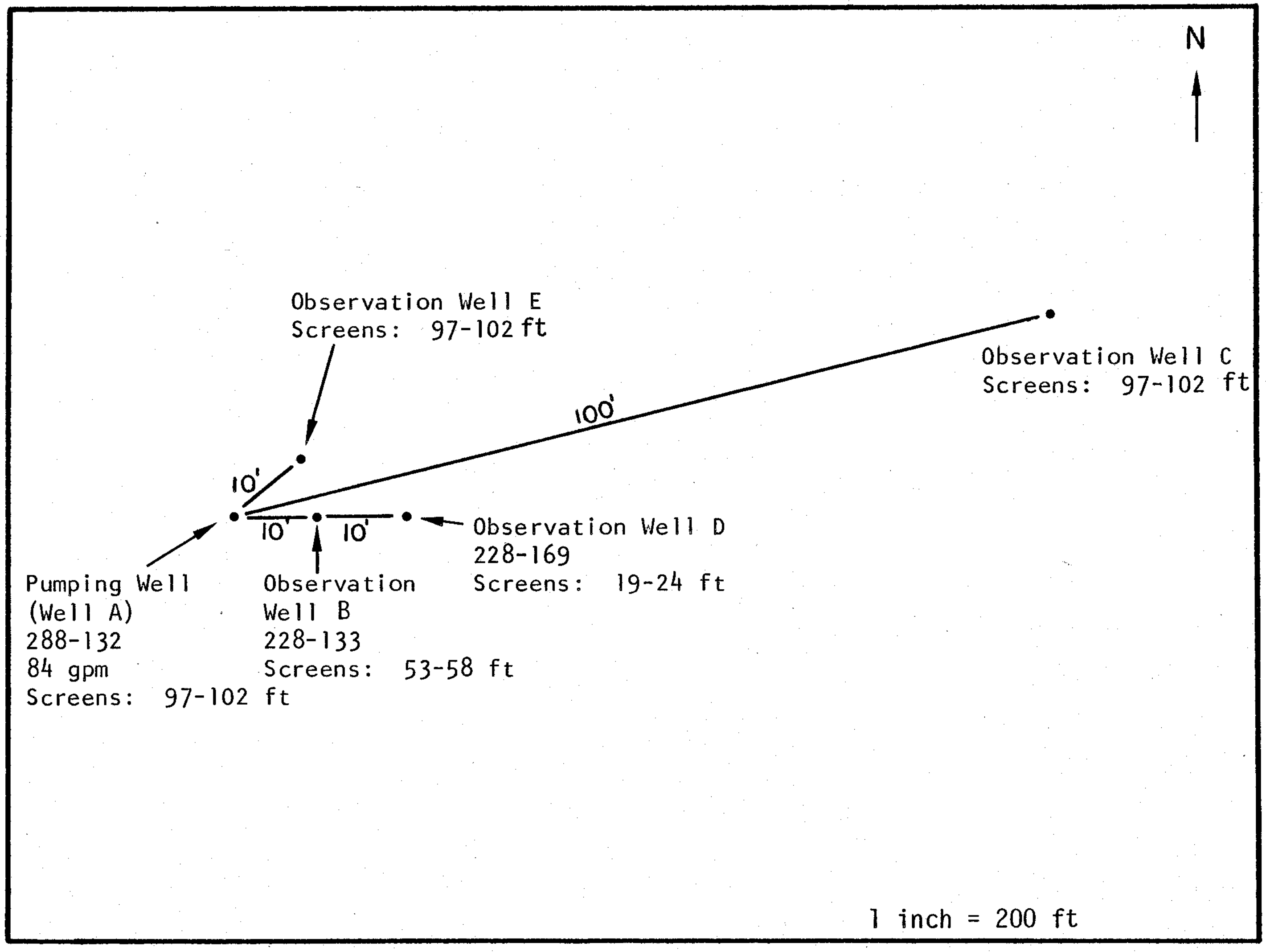


Plate 17

hydrogeologic conditions at the Oceana NAS aquifer test site did not obey the assumptions upon which the aquifer test flow equations are based. The most important assumptions that were not obeyed were the presence of a homogeneous, isotropic aquifer at least within the cone of depression of the pumping well (Ferris, et al, 1962). Therefore, accurate aquifer parameters could not be calculated using the standard methods of analysis used in the previous four aquifer tests. Apparently the aquifer tapped was a localized shell-and-sand bed whose permeability decreased rapidly in the direction of observation wells C and E.

An attempt was made to calculate approximate transmissivity values using the methods applied in the previous tests. The results, which are shown in Table 9, indicate a rapid decrease in transmissivity from the production well toward the farthest observation well (well C). This rapid decrease in transmissivity is consistent with the sluggish response of the observation wells. Graphs of drawdown and recovery data and examples of the analytical techniques used can be found in Appendix D. Storage coefficients calculated were extremely variable and not consistent with the local hydrogeology and, therefore, are not shown in Table 9.

Semi-logarithmic distance-drawdown graphs developed for each aquifer test can be used in the conceptual design of major well fields and for estimating effects of different pumpages. The plots were prepared from the last drawdown measurement taken from each observation well (Appendix D). From these graphs drawdown at various distances from the production well at the aquifer test

Table 9 - SUMMARY OF AQUIFER HYDRAULIC CHARACTERISTICS
Oceana Naval Air Station Research Station

Well	Type of Data Analyzed	Method of Analysis	Transmissivity (gpd/ft)	Leakance (Day-1)	Storage Coefficient (dimensionless)
Pumping Well	Drawdown	Cooper-Jacob	24,600	-	-
Pumping Well	Recovery	Theis Recovery Formula	24,900	-	-
Observation Well E r=10 ft	Drawdown	Cooper-Jacob	9,100	-	-
Observation Well E	Recovery	Theis Recovery Formula	9,700	-	-
Observation Well E	Drawdown	Theis-(early time)	9,400	-	-
Observation Well C r=100 ft	Drawdown	Theis-(early time)	5,100	-	-
Observation Well C	Drawdown	Hantush-Jacob	6,800	-	-

pumping rate can be determined. Table 10 summarizes the distance-drawdown results for the five aquifer tests of the Yorktown Aquifer. Drawdowns at the various distances vary with transmissivity and pumping rate at each test site. The distance-drawdown graph for the Tidewater Community College is considered average for the area since the transmissivity at this site is very close to the mean for the Four Cities area.

The distance-drawdown graph for the aquifer test considered to be most appropriate for the area to be studied can be used to prepare distance-drawdown graphs at different pumping rates and for different pumping durations (Johnson, 1966). Drawdown predictions can then be made for the design pumping rate. Well spacing and well field configuration can then be estimated. On site test drilling and aquifer tests would then follow to delineate specific parameters and yields.

Eocene-Upper Cretaceous Aquifer

Recharge - Water in the Eocene-Upper Cretaceous aquifer is confined. In the northwestern part of the study area where this aquifer contains fresh water, the primary recharge is a slow downward leakage of fresh water from the overlying Yorktown aquifer through the confining units. In the rest of the study area where the Eocene-Upper Cretaceous aquifer contains brackish water, the primary source of recharge is from slow movement of brackish water from the east and possibly by slow downward leakage of brackish water from the lower portions of the Yorktown aquifer and confining units where local head conditions permit such movement. The six wells on record which tap only the Eocene-Upper Cretaceous aquifer are brackish-flowing wells in the City of Chesapeake. Water levels in the

TABLE 10 - SUMMARY OF DISTANCE-DRAWDOWN DATA FOR AQUIFER TESTS OF THE YORKTOWN AQUIFER

Aquifer Test	Hydraulic Characteristics of Aquifer	Drawdown at Various Distances from Production Well, in feet: 100	300	500	1000	Distance to 0 Drawdown in Feet
Pembroke Well Field t = 3440 min Q = 148 gpm T = 39,000 gpd/ft	Above average Transmissivity	2.8	2	1.7	1.2	5,600
Tidewater Comm Coll. t = 1440 min Q = 62.6 gpm T = 17,000 gpd/ft	Average Transmissivity	3.2	2.2	1.7	1	2,800
Princess Anne Courthouse t = 1440 min Q = 65 gpm T = 6,200 gpd/ft	Slightly Below Average Transmissivity	5.8	3.7	2.7	1.4	2,200
Fentress NAS t = 1440 min Q = 84 gpm T = 2,600 gpd/ft	Below Average Transmissivity	15	10	7.7	4.7	2,800
Oceana NAS t = 2540 min Q = 84 gpm Variable T	Lense-Like Aquifer Not considered typical drawdown	1.7	0	0	0	300

aquifers where these wells are located indicate that vertical movement of ground water would be from the Eocene-Upper Cretaceous aquifer slowly upward toward the Yorktown aquifer and also downward into the Lower Cretaceous aquifer. Discharge therefore takes place by slow lateral movement toward heavy pumping to the west centered in Franklin Virginia, and by leakage into the Yorktown and Lower Cretaceous aquifers.

Water Levels - Both the Fennema research station at Cornland and the Fentress Naval Air Station research station have separate wells which tap the Eocene-Upper Cretaceous aquifer and the Lower Cretaceous aquifer (Plate 10). These two research stations show that the water levels are much higher in the Eocene-Upper Cretaceous aquifer than in the Lower Cretaceous aquifer, 58 feet higher at the Fennema research station (234-135, 134) and 33 feet higher at the Fentress research station (234-66, 65). These distinctly separate water levels indicate a hydrologic separation between the Eocene-Upper Cretaceous aquifer and the Lower Cretaceous aquifer. The presence of this separation is primarily why the Eocene-Upper Cretaceous aquifer is considered as a distinct aquifer separate from the Lower Cretaceous aquifer.

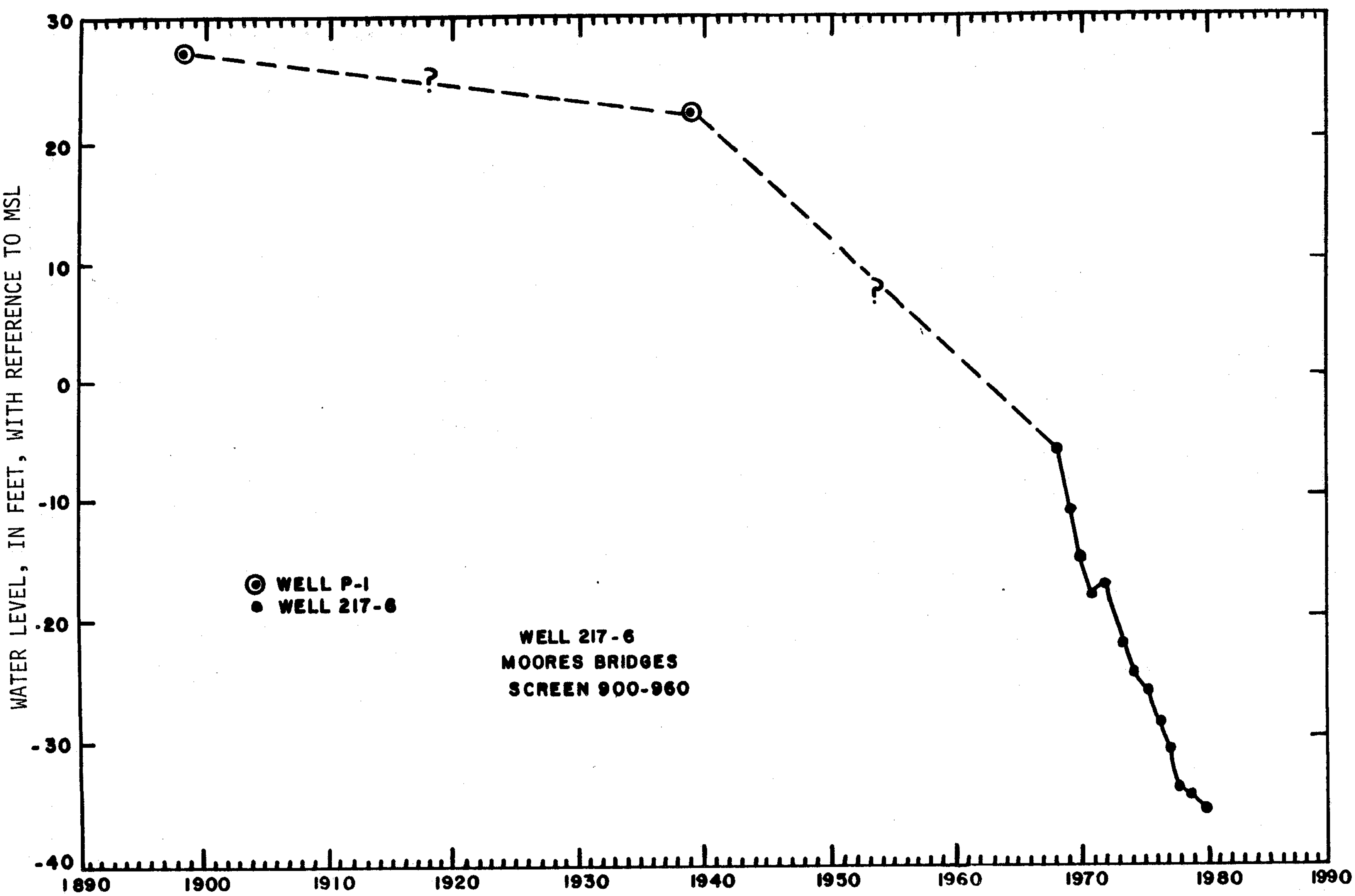
The water levels in the Lower Cretaceous aquifer prior to heavy pumpage in the west probably were similar to the present water levels in the Eocene-Upper Cretaceous aquifer. The heavy pumpage to the west accounts for the declining water levels in the Lower Cretaceous aquifer as discussed in a later section of this chapter. The three years of data available for the Eocene-Upper Cretaceous aquifer wells indicate no apparent declining water-level trend.

Hydraulic Characteristics - Constant-rate pumping tests or aquifer tests, which can be used to calculate hydraulic parameters, have not been conducted for the Eocene-Upper Cretaceous aquifer. Based upon limited specific capacity and well yield data, it is estimated that transmissivities are in the 5000 to 10,000 gpd/ft range.

Lower Cretaceous Aquifer

Recharge - Water in the Lower Cretaceous aquifer is also confined. The primary source of recharge is slow downward leakage of water from overlying aquifers and confining units and by slow movement of brackish water from the east. Discharge takes place by slow lateral movement toward centers of nearby pumping areas to the west and by light pumpage in the Four Cities area.

Water Levels - Lower Cretaceous ground water levels in the Four Cities area are measured primarily by the four wells shown in Figure 10; 234-124, 234-134, 234-65 and 217-6. The potentiometric surface of the aquifer has been declining regionally since about 1943 due to heavy pumping mainly centered at Franklin, Virginia. Plate 18 is a composite hydrograph for an abandoned well and well 217-6 at Moores Bridges. The potentiometric surface at this site has declined approximately 64 feet from the early 1900's to 1980. Figure 19 shows the regional cone of depression in the potentiometric surface of the aquifer in Southeastern Virginia. The rate of water level decline at the Bowers Hill research station (234-124) increased from 0.5 feet per year in 1978 and 1979 to about three feet a year in 1980 due to drought-emergency pumping starting about July 1, 1980. Similarly, the rate of water level decline at the Fennema research

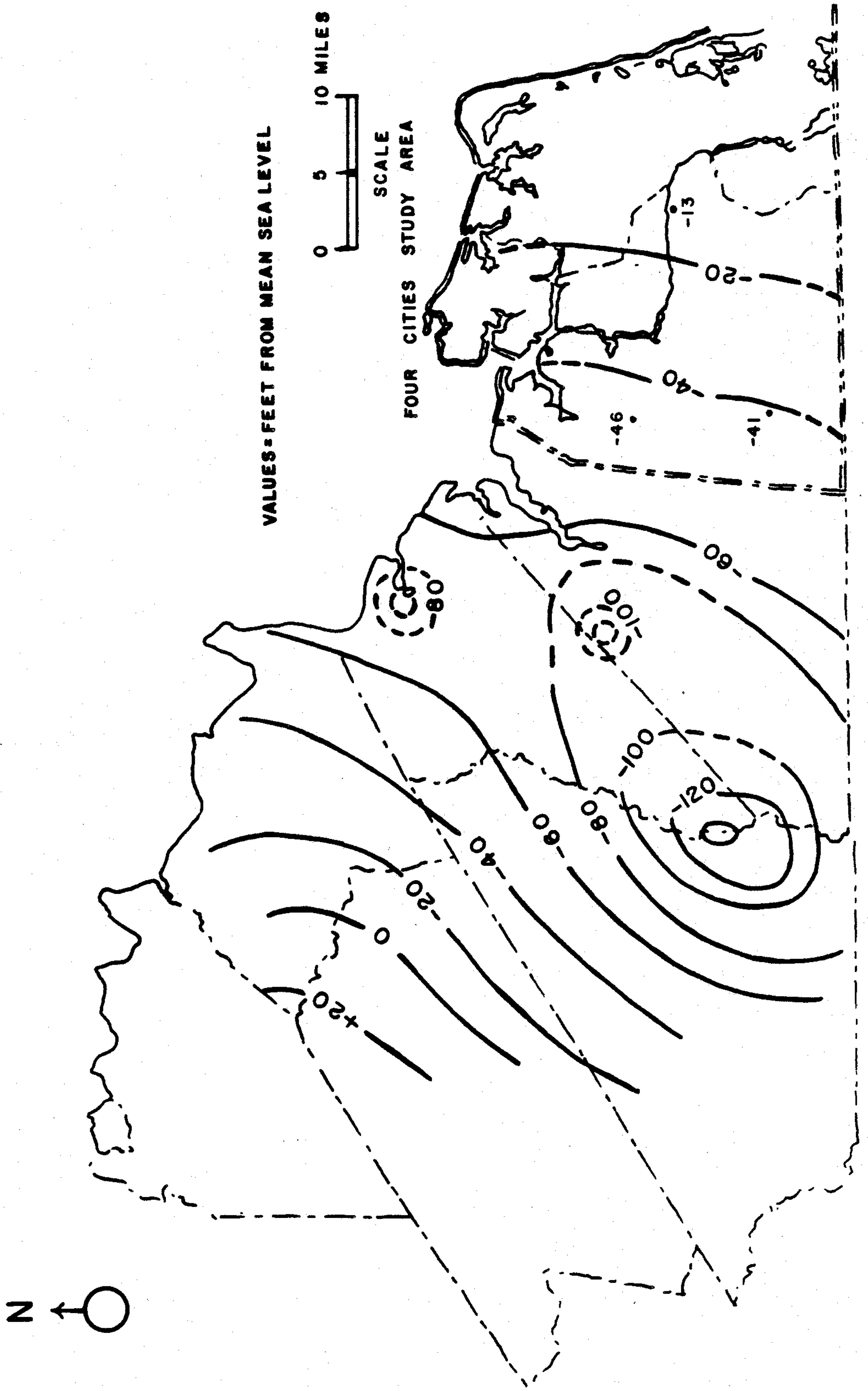


Composite hydrograph showing water-level trends in Wells P-1 and 217-6, screened in the Lower Cretaceous Aquifer. (Modified from Geraghty and Miller, 1978)

Plate 18

WATER LEVELS IN THE LOWER CRETACEOUS AQUIFER - SOUTHEASTERN VIRGINIA

SEPTEMBER 1980



SOURCE: SWCB-TRO 1981

PLATE NO. 19

station (234-134) increased from 0.2 feet in 1978 and 1979 to about 2.8 feet in 1980. The Fentress NAS research station has shown no trend of water level decline to date.

Hydraulic Characteristics - Transmissivity was determined for 6 Lower Cretaceous aquifer wells using the Cooper-Jacob modified non-equilibrium method for constant-rate pumping and recovery tests. Locations for these wells are given in Plate 9 and a summary of transmissivity values obtained is shown in Table 4. The transmissivities obtained ranged from a low of 15,000 gpd/ft at Nepratex Industries to a high of about 157,000 gpd/ft at the City of Chesapeake production well at Bowers Hill. The semi-log plot of time-drawdown data for the J. H. Miles pump test and calculations of transmissivity are shown in Appendix C.

The U.S. Geological Survey had conducted aquifer tests in the Lower Cretaceous aquifer at Moores Bridges near the Norfolk-Virginia Beach boundary (wells 217-5,6). Zones from a depth of about 900 to 990 feet were tested (Brown and Silvey, 1977). Aquifer test analyses could not be obtained by conventional aquifer test analysis methods because of recharge boundary conditions. Using a digital model of the well field, a transmissivity of 62,100 gpd/ft and a storage coefficient of 1.5×10^{-4} was obtained.

Sydnor Hydrodynamics, Inc. conducted an aquifer test in February 1981 on the City of Chesapeake new production well at Bowers Hill (well 234-161). The production well was screened in the Lower Cretaceous aquifer at several intervals between depths of 714 and 992 feet. The observation well (234-162), located 62 feet from the production well, was screened at several intervals between depths of 710 and 797 feet. The production well was pumped at a constant rate of 754 gpm for 48 hours. The recovery test was run for ten hours.

The aquifer test data was analyzed by the State Water Control Board using several analytical techniques. Using the Cooper-Jacob modified equilibrium method, transmissivities were calculated to be 153,000 gpd/ft for the production well and 133,000 gpd/ft for the observation well. Transmissivities were also calculated by the Theis recovery formula to be 157,000 gpd/ft for the production well and 133,000 gpd/ft for the observation well. The Hantush-Jacob method for leaky aquifers was used for determining the transmissivity and storage coefficient for the observation well, which were found to be 104,000 gpd/ft and .0005, respectively. Since these aquifer test data were not received until the later stages of this study, graphs for this aquifer test are not included in this report.

CHAPTER V

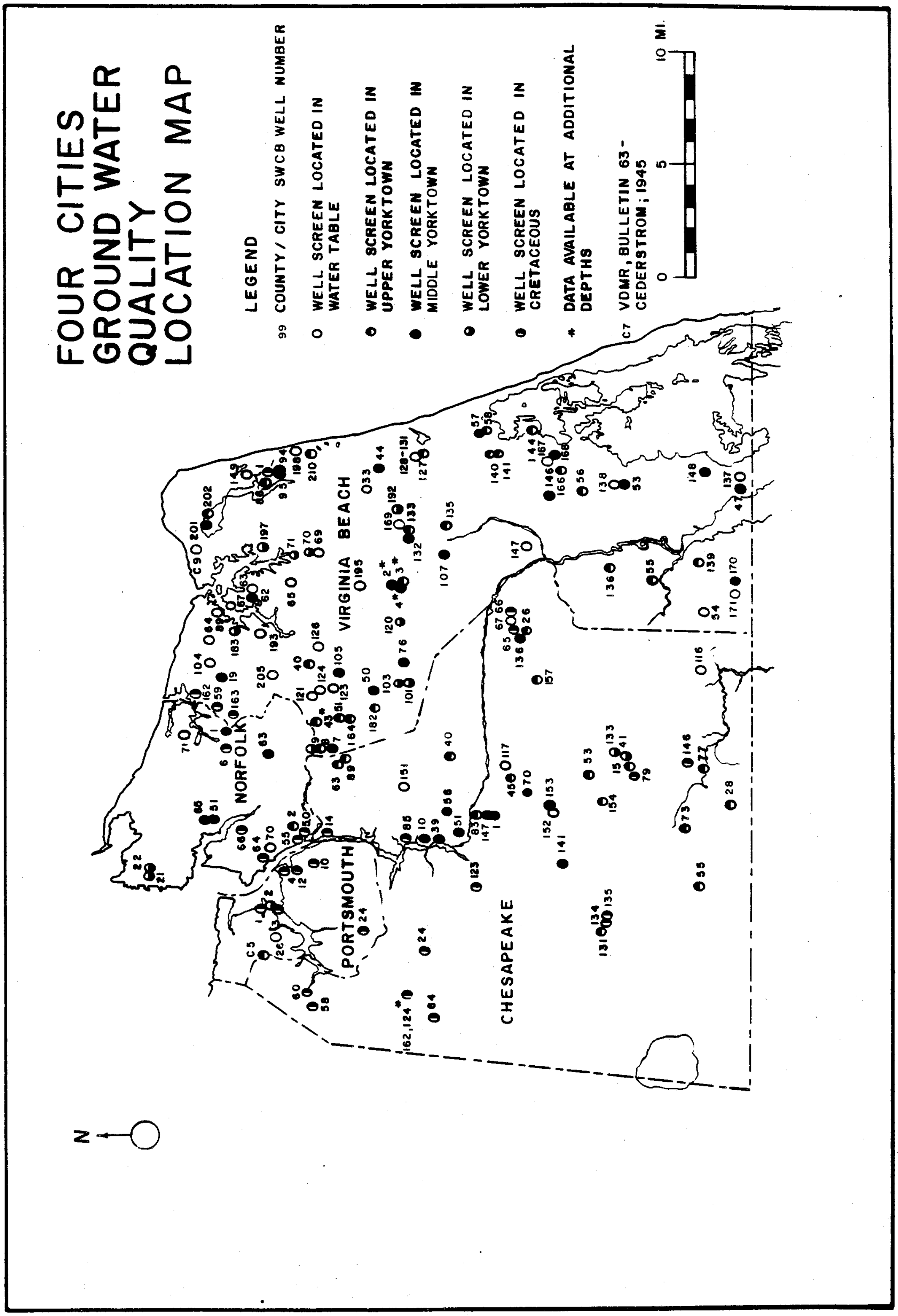
GROUND WATER QUALITY

The chemical characteristics of ground water by aquifer are discussed in this chapter. Wells with ground water quality data are located in Plate 20. Water quality analyses for these wells are listed in Appendix E. Average values for the major chemical parameters, by aquifer, may be found in Table 11.

Water Table Aquifer

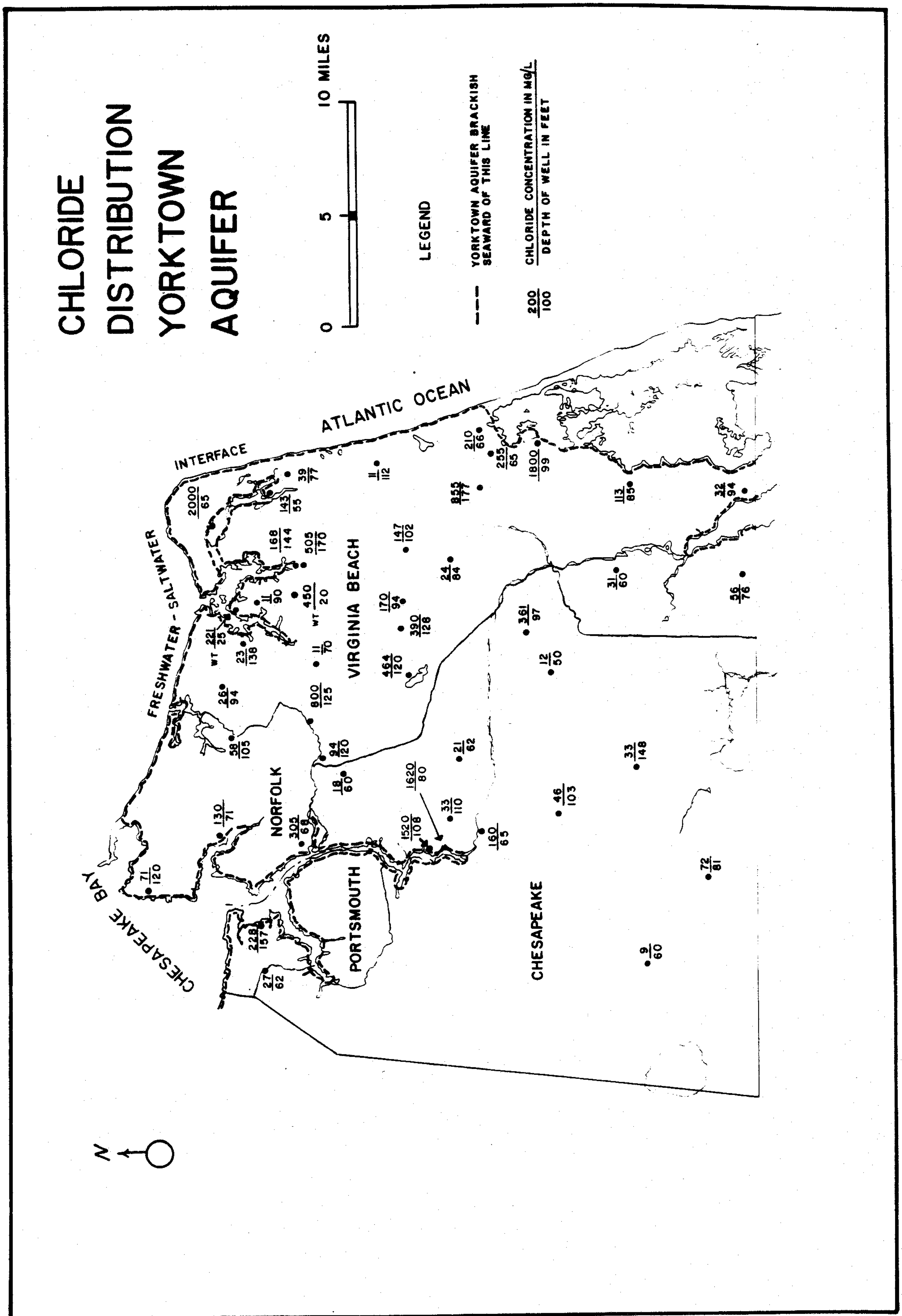
Water quality in the water table aquifer is generally suitable for some uses such as lawn watering and occasionally for domestic supply. The quality of water in this aquifer is quite variable. Water from the water table aquifer, originating from the infiltration of local precipitation, contains a low amount of dissolved solids generally ranging from 200 to 300 mg/l (milligrams per liter). Chlorides are generally low but can be high adjacent to tidal waters. This is demonstrated by wells 228-65 and 228-67 which have chlorides of 450 and 221 mg/l, respectively (Plate 21). The State Health Department limit for chloride, based on aesthetics, is 250 mg/l. Hardness generally falls into the range of hard (121-180 mg/l to moderately hard (61-120 mg/l). The most common water quality problems for the water table aquifer are low pH and high iron content.

Water contained in the water table aquifer is acidic (low pH) and, therefore, corrosive to metal well casing, plumbing and other



SOURCE: SWCB-TRO 1979

PLATE NO. 20



SOURCE: SWCB-TRO 1981

PLATE NO. 21

metal objects with which it comes in contact. The combination of abundant, free carbon dioxide and a low dissolved solids content in this aquifer is the probable cause of the acidity problems. The Ryznar stability index, which is calculated from total solids, temperature, calcium hardness, and alkalinity values for each well, is an acceptable method of classifying water in regard to scaling and corrosion (Campbell and Lehr, 1973). The Ryznar Stability Index for many of the water table aquifer wells is greater than 10, which indicates that the water will cause severe corrosion to water mains and installations.

The other major problem with the water quality of the water table aquifer is a high iron content. Upon contact with the air, the iron will precipitate as iron oxide (red stain) and cause staining of fixtures, laundry, sidewalks, lawns, automobiles, etc. Water from the majority of the water table aquifer wells exceeds the Virginia State Health Department standard of 0.3 mg/l (Appendix E and Table 11). Water with an iron content greater than the standard will cause some staining. Severe staining occurs when iron concentrations in the water table aquifer exceed about 5 mg/l, which is common. Water softeners and greensand filters can be used for iron removal where iron concentrations are moderate. The use of plastic (PVC) well casing and plumbing will minimize the iron content elevation caused by iron pipes being dissolved by the water from the aquifer. The water table aquifer can generally be used for lawn watering and other similar uses as long as the quality limitations are recognized.

Due to presence of a high water table and widespread permeable sand near the surface in the Four Cities area, land disposal of

TABLE 11. SUMMARY OF QUALITY ANALYSES FOR FOUR CITIES AREA*

AQUIFER		Depth ft	Alkalinity	TDS	Hardness	Cl	NO_2 NO_3	F	Na	Ca	Fe
Water Table	minimum	10	3	63	16	5	0.05-	0.1-	4	3	0.1-
	maximum	43	295	1178	347	1178	16.50	0.7	172	140	18.6
	mean	23	88	344	113	48	2.20	0.1	39	33	3.0
Yorktown	minimum	40	14	77	1-	6	0.01-	0.1-	4	1-	0.1-
	maximum	200	780	4110	1430	2000	6.50	3.6	1000	340	48.0
	mean	82	208	584	200	171	0.12	0.2	107	57	2.5
Eocene-Upper Cretaceous	minimum	525	705	2596	9	146	0.05-	1.5	980	11	0.1-
	maximum	780	753	5461	212	2584	1.00	2.7	1800	32	10.8
	mean	687	733	3986	117	1458	0.50	1.9	1443	19	3.6
Lower Cretaceous - Brackish	minimum	700	235	726	12	202	0.05-	0.5	59	3	0.1-
	maximum	1367	613	17858	1790	8975	1.60	4.2	4870	396	4.5
	mean	899	448	3203	168	1374	0.24	2.3	1133	40	0.7
Lower Cretaceous - Freshwater	minimum	579	238	655	8	75	0.05-	1.2	283	2	0.01-
	maximum	797	495	997	36	257	0.48	4.5	480	9	0.2
	mean	654	433	835	15	166	0.16	3.7	354	3	0.05

* All quality values are given in milligrams/liter units. Any value with a dash after the number, such as 0.1-, indicates that the value is the detectable limit for the laboratory test.

All chemical abbreviations listed in Appendix E.

SOURCE: Virginia State Water Control Board - TRO wastes impacts the quality of the water table and eventually may impact the underlying Yorktown aquifer. The Yorktown aquifer may be contaminated when additional ground water pumping centers develop in this aquifer drawing contaminated water down from the water table aquifer into the Yorktown aquifer. Typical sources of contamination are various waste lagoons, landfills, septic tanks which have been dug to below the water table, and municipal sludge application sites. Currently, the State Health Department and the State Water Control Board require above ground landfills, with liners of low permeability (10^{-7} cm/sec) placed below the landfill areas. Also, owners of landfills and major waste lagoons currently being constructed are being required to construct shallow monitoring wells around the disposal area. Because of problems such as not being able to adequately establish background ground water quality, not having enough monitoring wells at each site, and monitoring well construction and sampling problems, the extent of ground water contamination at most of these sites has not been delineated clearly.

One case of a water contamination problem in the water table aquifer that has been identified by field data is from the City of Virginia Beach landfill #2. This landfill, which is located near the intersection of Centerville Turnpike and Kempsville Road, has been in operation since 1971. At that time no stringent landfill guidelines were in effect, and hence, no low-permeability liner was placed below the landfill. The landfill site was excavated several feet below the land surface and leveled off to a depth at, or near, the seasonal water table. Landfilling then proceeded with area filling being by means of a series of lifts. Since landfilling began, eleven ground water monitoring wells were emplaced between October 1971 and August 1975. Periodic sampling of these wells for a number of chemical parameters indicates that the landfill progressively is degrading the quality of water in the water table aquifer in the vicinity of the landfill. The parameters showing the greatest increase are iron, sulfate, potassium, and sodium. An investigation is currently underway to establish the extent of the contamination plume.

Yorktown Aquifer

The water quality in the Yorktown aquifer is generally suitable for potable and most other uses. The water quality of this aquifer, as was observed for the water table aquifer, varies from place to place even in the same well field or subdivision. The major parameters vary as follows: hardness ranges from less than 1 to 1430 mg/l; iron from less than 0.1 to 48 mg/l; chloride from 6 to 2000 mg/l; and TDS from 77 to 4110 mg/l. Parameter averages found in Table 11 for the Yorktown aquifer can be compared to those of the water table aquifer. Corrosion and iron problems are generally not as severe or common in the Yorktown aquifer as in the water table aquifer. However, a number of public water supplies and domestic wells do show high iron concentrations and, therefore, require iron treatment (Plate 20 and Appendix E).

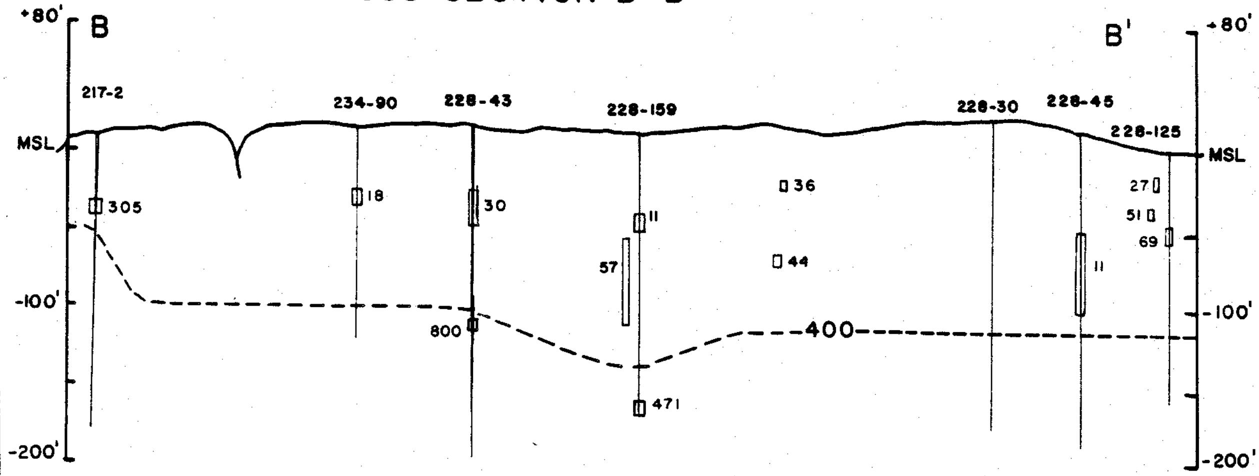
The presence of brackish water in the Yorktown aquifer locally can be a problem generally, but is predictable. Brackish water is defined as water containing greater than 250 mg/l chloride (Virginia State Health Department Standard) or greater than about 1000 mg/l TDS.

The fresh water-salt water interface of the Yorktown aquifer generally follows the Atlantic Ocean and Chesapeake Bay shoreline bending landward where tidal estuaries or bays are present, such as at the Lynnhaven River, the Elizabeth River, and Back Bay (Plate 21). Moving inland away from the interface line shown in Plate 21, the interface occurs at elevations of -100 to -120 feet mean sea level (Plates 4 and 22). The interface occurs as shallow as elevations of -50 to -60 feet mean sea level as the interface line in Plate 21 is approached. The western most extent of the interface in the Yorktown aquifer is not known since no control points are available in the western 1/5 of the study area.

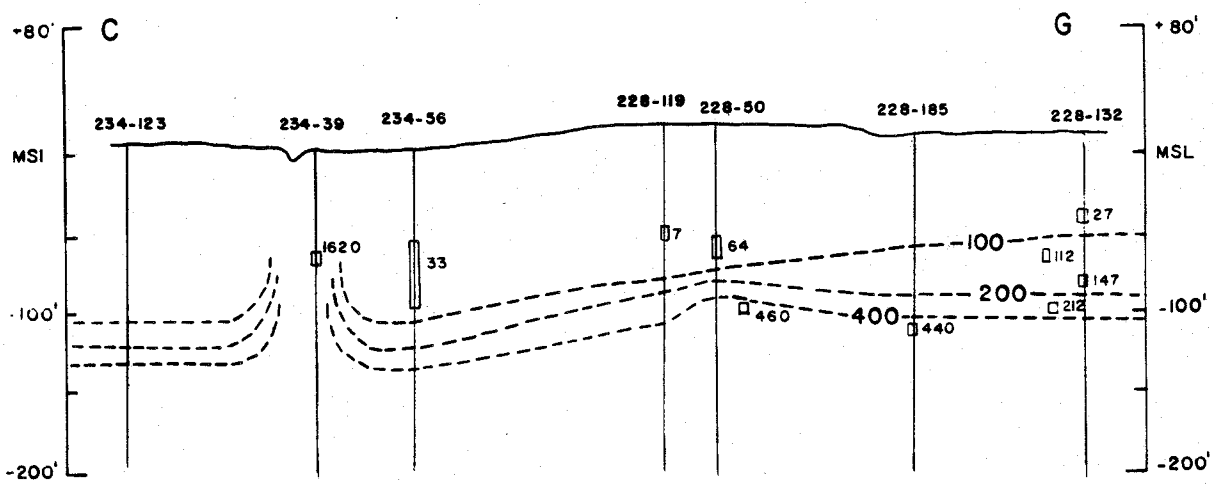
The quality of brackish ground water in the Yorktown aquifer ranges from about 250 to 2000 mg/l chloride and from 1000 to 4110 mg/l TDS (Plate 21 and Appendix E). In the northern half of the City of Virginia Beach and the northwestern part of the City of Chesapeake, the brackish water in the Yorktown aquifer ranges from about 400 to 2000 mg/l chloride and from 900 to 4100 mg/l TDS. In southeastern Virginia Beach adjacent to the western shore of Back Bay, brackish water contained in the middle or lower Yorktown units ranges from about 250 to 1800 mg/l chloride and 700 to 3700 mg/l TDS. Interpretation of a number of electric logs from wells drilled to depths of 200 feet or greater indicates a general increase in TDS content with depth in the confining units below the Lower Yorktown unit.

Invasion of brackish water into fresh water portions of the Yorktown aquifer due to pumping is a possibility. Light pumping of fresh ground water from the Yorktown aquifer at or near the fresh water-salt water interface near the Atlantic Ocean and Chesapeake Bay shoreline

CROSS SECTION B-B'



CROSS SECTION C - G



LEGEND

122 — CHLORIDE CONCENTRATION IN PARTS-PER-MILLION AT THE DEPTH INTERVAL INDICATED

--100-- — CONCENTRATION LINE IN PARTS-PER-MILLION

CHLORIDE DISTRIBUTION CROSS SECTIONS B-B' and C-G

SOURCE: SWCB-TRO 1981

PLATE NO. 22

(Plate 21) has not caused any detectable landward movement of brackish water. However, intense well field development along the shoreline would probably result in brackish water encroachment into the well fields.

Inland, the concern is upward movement or upconing of brackish water found at about -100 feet mean sea level into the fresh water portion of the Yorktown aquifer, especially where large well fields are planned. There is some existing data which indicates that some slight localized upconing may have taken place in one well field tapping the Yorktown aquifer. Water analyses of each of the seven wells in the Pembroke well field indicate that the range of chloride content approximately has doubled in all of the wells, from 11 to 50 mg/l in 1965 when the wells were first installed, to 29 to 97 mg/l in 1978 (Geraghty and Miller, 1979b). The data could indicate a slight upconing of higher-chloride waters, or it might reflect some other unknown factor.

Water quality samples taken during two constant-rate pumping tests conducted for this study indicate a slight increase in chlorides possibly due to upconing. Three water samples taken during the Tidewater Community College pumping test showed a slight increase in chlorides from 390 mg/l chloride after three hours pumping to 440 mg/l chloride after 23 hours pumping. The pumped well was screened in the brackish portion of the Lower Yorktown unit so that the slight increase in chloride content is probably due to a slight upconing from the lower portion of the Lower Yorktown sand unit or the confining unit found below the Lower Yorktown unit (Plate 22, cross section C-G).

Water samples taken during the Oceana Naval Air Station constant rate pumping test showed a total increase of 14 mg/l in chlorides from the beginning of the test until its conclusion about one day later, after which time the chloride level appeared to stabilize at about 177 mg/l (Plate 23). The slight increase in the production well, which was screened just above the fresh water-salt water interface, may indicate a slight upconing (Plate 22, cross section C-G). At the present time upconing does not appear to be a significant problem. However, when major wells or well fields are planned in the Yorktown aquifer, they should be designed to minimize upconing.

Eocene-Upper Cretaceous Aquifer

The only wells which tap the Eocene-Upper Cretaceous aquifer in the Four Cities are found in the southern half of the City of Chesapeake. Chemical data are available for only four of these wells 234-66, -79, -135 and 146 (Plate 20). The analyses indicate that the aquifer is brackish in this area. Chlorides and TDS increased in concentration from west to east; chlorides range from 146 to 2584 mg/l and TDS from 2601 to 5461 mg/l. The fluoride content decreased west to east from 2.7 to 1.5 mg/l. For more detailed information on the quality of these wells, see Appendix E. Water from the Eocene-Upper Cretaceous aquifer is expected to be brackish in other parts of the study area, except the northwestern part.

Lower Cretaceous Aquifer

Fresh ground water in the Lower Cretaceous aquifer (less than 250 mg/l chloride and 1000 mg/l TDS) is found only in the upper 200 feet of the aquifer in the northwestern part of the study area.

CHANGES IN CHLORIDE CONCENTRATION DURING AQUIFER TEST
AT OCEANA NAVAL AIR STATION RESEARCH STATION

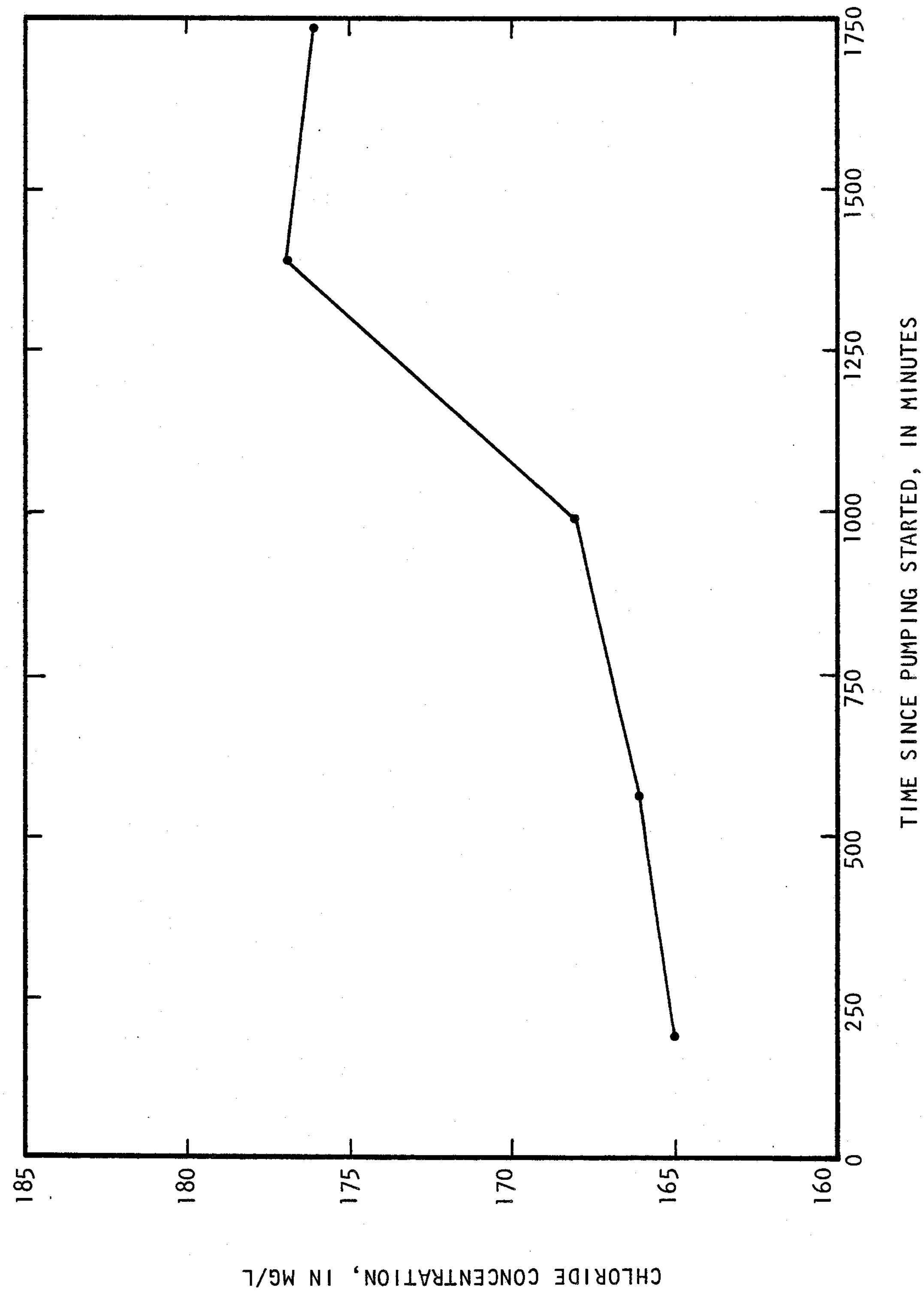


Plate 23

Plate 24 depicts the changes in TDS content in the upper 200 feet of the aquifer in the Four Cities area. In this area TDS content ranges from less than 1000 mg/l in the west to over 18,000 mg/l in the east. No data are available for the extreme southwestern part of the study area which is located in the Dismal Swamp. Plate 3, an east-west ground water quality cross-section of the Lower Cretaceous aquifer shows that the chlorides, and thus the brackishness of the water, increases west to east and with depth.

The fresh water portion of the Lower Cretaceous aquifer is suitable for potable use. The parameters range as follows: chlorides from 75 to 257 mg/l, TDS from 655 to 997 mg/l, sodium from 283 to 480 mg/l, fluoride from 1.2 to 4.5 mg/l, and iron from less than .01 to .20 mg/l (see Table 11). Heavy development of this portion of the aquifer may cause upconing of brackish water. Additional data for wells located in Plates 20 and 24 may be found in Appendix E.

To the east of the 1000 mg/l TDS line shown in Plate 24, water in the Lower Cretaceous aquifer is applied to other than potable use. This includes industrial cooling, industrial process water, and ground water heat pumps. Most of the wells which utilize the brackish portion of the Lower Cretaceous aquifer are found in eastern Portsmouth and western Chesapeake where the TDS value is between 1000 and 2000 mg/l.

Water similar in quality to that of well 228-164 (a TDS of between 5000 and 6000 mg/l) has been considered as a source of water for a Virginia Beach desalination plant. Additional water quality data for all Cretaceous wells are found in Appendix E.

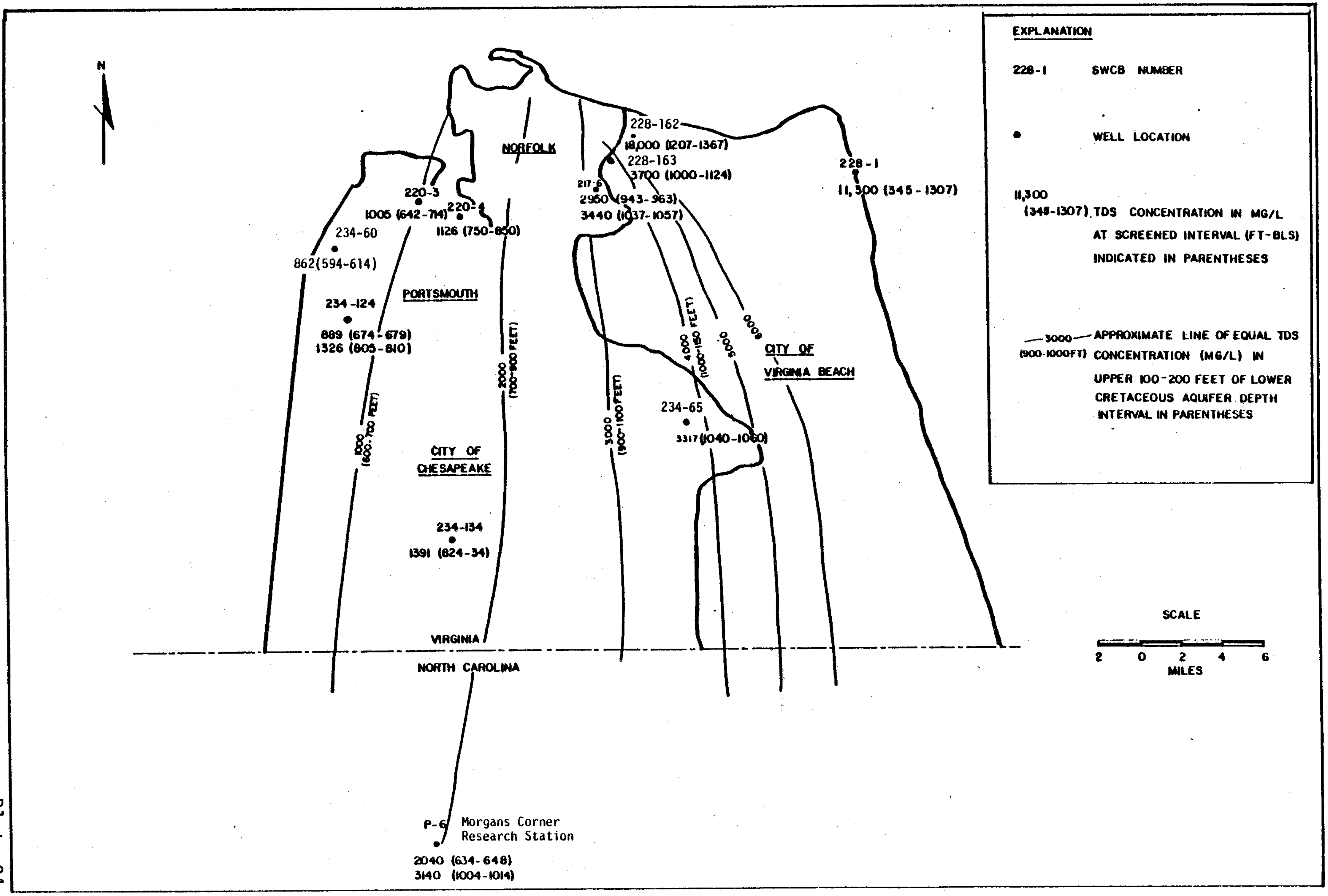


Plate 24

Approximate distribution of TDS concentrations in upper 200 feet of Lower Cretaceous aquifer in the Four Cities area (Adapted from Geraghty and Miller, 1979)

CHAPTER VI

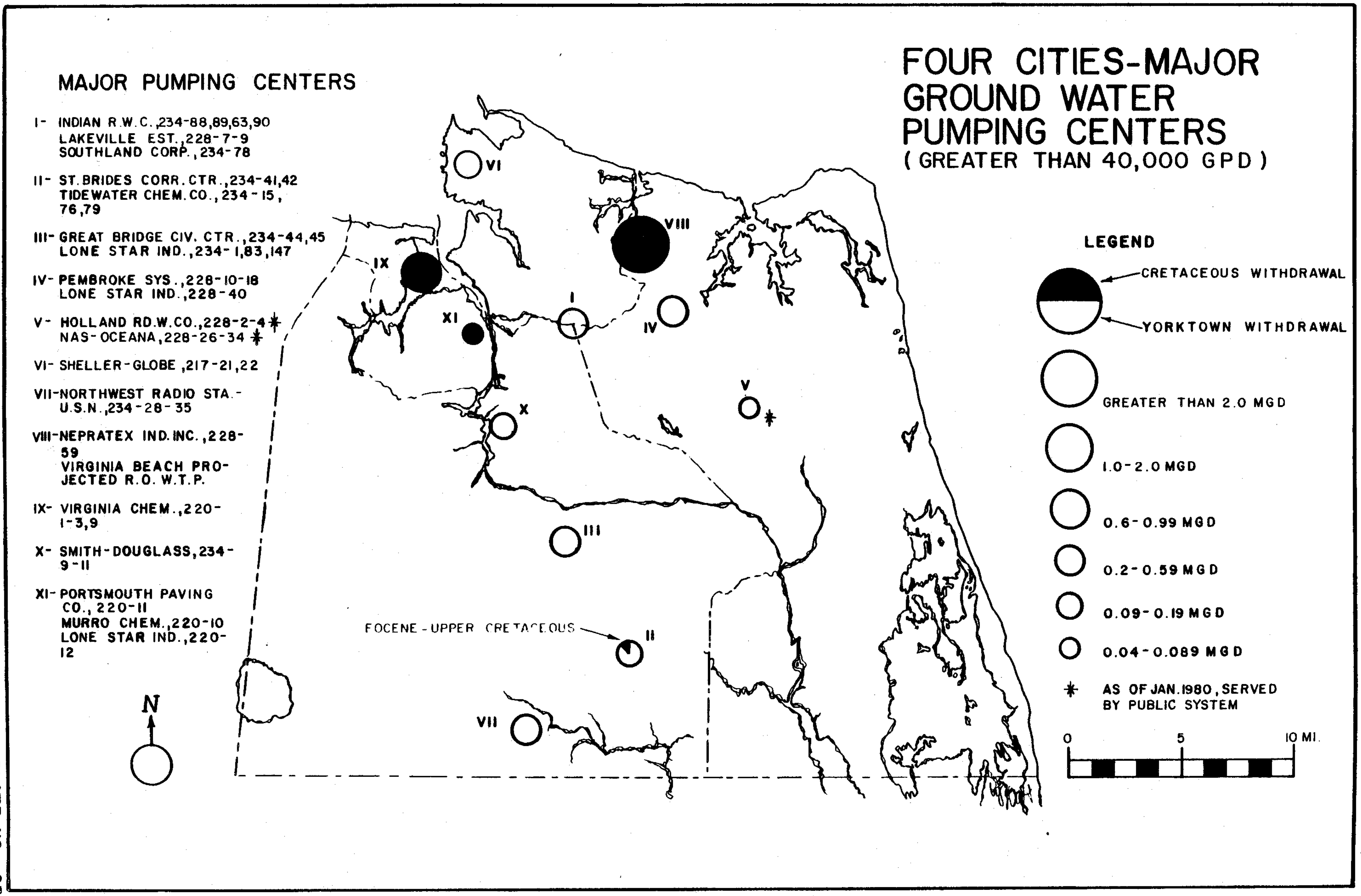
GROUND WATER DEVELOPMENT

Present Development

As mentioned previously, the Four Cities area is underlain by four aquifers of which the Yorktown aquifer is used the most. The study area has eleven pumping centers of 40,000 gpd or greater. Of these, seven pump from the Yorktown aquifer, three pump from the Lower Cretaceous aquifer and one pumps from a combination of the Eocene-Upper Cretaceous and the Yorktown aquifer (Plate 25).

Because the Four Cities area is located within the Southeastern Virginia Ground Water Management Area, industrial and commercial users of ground water in amounts of 50,000 gpd or greater, are required to hold a Certificate of Ground Water Right which stipulates the maximum amount they may withdraw. In addition, most smaller industrial users and domestic public systems report their pumpage rates every three months. The following ground water use figures were developed from the pumpage and use reports and estimates of residential well usage.

At the present time the Four Cities area, a total of approximately 11 MGD is withdrawn from the four aquifers, i.e., water table, Yorktown, Eocene-Upper Cretaceous, and Lower Cretaceous aquifers. The Yorktown aquifer supplies 84 per cent of the total use, approximately 9.3 MGD, while the Lower Cretaceous aquifer supplies approximately 1.2 MGD (10.9 per cent of total use). Water table aquifer usage, which is primarily decentralized, lawn water pumpage, is



SOURCE: SWCB-TRO 1979

PLATE NO. 25

estimated to be .55 MGD (5 per cent of total use). It should be noted that dewatering operations from sand borrow pits, which pump probably several MGD, are not included in the water table aquifer usage. Currently, the only user of the Eocene-Upper Cretaceous aquifer in the study area is the Tidewater Chemical Company located in southeastern Chesapeake, which uses about .008 MGD (0.1 per cent of total use) of brackish water for industrial processing.

The current water use of each aquifer will be described in detail in the following paragraphs.

Water table aquifer - Due to ground water quality limitations such as iron and corrosion and a low well yield potential, the water table aquifer is used generally for small scale irrigation such as residential and commercial lawn watering. The State Health Department does not allow the use of water from the water table aquifer for public water supplies. Occasionally, the aquifer is applied to individual use. In these instances, care should be taken not to locate domestic water table wells in areas of high density septic tank use or where other nearby contamination sources, such as landfills or waste lagoons, are evident. If there is a question about the water quality, the water should be analyzed for at least the following parameters, which are indicators of contamination: coliform bacteria, fecal coliform bacteria, nitrate, chloride, and total organic carbon.

Wells in the water table aquifer are generally small diameter wells which are driven, jetted, or drilled. Grouting is recommended for domestic wells. In some instances, a battery of water table aquifer wells are used where somewhat greater quantities of water are required.

Yorktown aquifer - Of the 9.3 MGD pumped from the Yorktown aquifer, approximately 8.6 MGD (93 per cent of the Yorktown use) is used by domestic and public distribution systems. Private domestic users pump about 7.6 MGD (82 per cent of the Yorktown use) and public distribution systems pump the remaining 1.02 MGD (11 percent of the total Yorktown pumpage). According to data collected between 1977 and 1979, industrial pumpage accounted for only 0.70 MGD or 7 per cent of the total Yorktown pumpage.

In addition to the above uses of the Yorktown aquifer, ground water heat pump use is rapidly becoming a major use of this aquifer in the Four Cities area since most of the heat pump systems use Yorktown water. With rising energy costs, the ground water heat pump has become competitive with the other methods of heating and cooling since about 1976. The temperature of the water of the Yorktown aquifer ranges from 61°F to 63°F, which is an ideal temperature for heat pump water. The ground water is pumped through the heat exchanger coils and returned to surface or ground water at a temperature 10° cooler or warmer than the initial temperature depending upon whether the heat pump is operating in the heating or cooling mode. A committee of Virginia regulatory officials, well drillers, and heat pump distributors, which will soon develop specific criteria for ground water heat pump construction and operation in Virginia, has made an initial recommendation that return water be reinjected into the same aquifer from which it came by means of a return well in order to conserve water and prevent salt water intrusion.

A survey of area well drillers and heat pump distributors indicate that approximately 1500 ground water heat pump units (primarily domestic units) have been developed in the area. The majority of the systems utilize the Yorktown aquifer as a source of water and return the water via a return well to this aquifer. Until recently, records on the specifics of each system installed have not been kept. Hence, it is difficult to determine a precise ground water use figure. Distributors indicate that the average heat pump unit uses about 6 to 10 gpm when the unit is in operation. Currently, the total ground water heat pump use in the Yorktown aquifer is several MGD. More precise estimates will be possible as more accurate operational data on ground water heat pump units becomes available.

Design of major production wells in the Yorktown aquifer is similar to the design used for major production wells in other unconsolidated aquifers of the Virginia Coastal Plain. A test hole is drilled and well cuttings are taken. A geophysical log of the test hole is run and correlated with well cuttings and the driller's log. The geophysical log, in combination with these other logs, is used to select one or more zones which should be screened. A small diameter test well sometimes is constructed, developed and pumped to establish well yield and water quality characteristics if they are known. If the test well is favorable, a production well of larger diameter is constructed. The production well screen slot-size and gravel pack size are designed based upon a sieve analysis of the aquifer material. The well is constructed and developed and a well yield test is conducted for 24-48 hours.

Lower Cretaceous aquifer - The Lower Cretaceous aquifer has the highest potential of the aquifers in the study area for producing large quantities of water; however, as was discussed in the previous chapter, only in the extreme northwestern part of the study area is the water suitable for potable use. In this area, in the vicinity of the Bowers Hill part of Chesapeake, approximately 0.10 MGD is pumped from the Lower Cretaceous aquifer. In the remainder of the study area, high chloride and total dissolved solids concentrations make desalting a prerequisite before potable use would be feasible. Virginia Beach had been planning to build a 2 MGD pilot reverse-osmosis desalting plant which was to use the brackish Lower Cretaceous aquifer as a feed water. However, the project has been delayed because of the lack of federal funding.

Industrial pumpage accounts for the remaining pumpage from the Lower Cretaceous aquifer and is estimated at 1.06 MGD. Once again, most of the users are located in the northwestern portion of the study area where TDS is less than 2000 mg/l. Only one large user utilizing this aquifer has been located elsewhere. This user, Nepratex, Inc., which had been located in Virginia Beach Airport Industrial Park, has recently discontinued operations. Due to the non-potable use in this case, high concentrations of chloride and TDS did not prohibit the aquifer's use.

Future Development

The intensity of ground water development in the Four Cities area is likely to increase in the future. Portsmouth, Norfolk, Virginia Beach and part of Chesapeake are served by the Norfolk and Portsmouth water systems. These obtain water primarily from surface water supplies located in the City of Suffolk and Isle of Wight County and to a lesser extent from wells tapping the Lower Cretaceous aquifer in that same area. Droughts in 1977 and 1980 caused mandatory water restrictions to be implemented. This prevented many normal uses such as car washing and lawn watering. In reaction to these restrictions, many water system customers have installed wells for lawn watering, etc.

The Cities of Virginia Beach and Chesapeake, which are directly affected by short term shortages, as well as a projected long term shortage if a major source of water is not developed soon by Norfolk and Portsmouth, also are considering development of their own supplemental ground water supplies. Therefore, the City of Virginia Beach had completed feasibility studies in regard to the development of supplemental supplies in the Yorktown aquifer as well as constructing a desalting plant which will use brackish water from the Lower Cretaceous aquifer. The City of Chesapeake is in the planning stages of developing additional ground water supplies in the Lower Cretaceous and Yorktown aquifers so that the City would have a virtually independent water system in the future. In addition, increased energy costs have triggered the installation of a rapidly increasing number of ground water heat pumps, primarily in the Yorktown aquifer.

Water table aquifer - Due to water-use restrictions, many water system customers are installing small capacity, lawn watering wells. Unfortunately, many of these wells bypass the water table aquifer because of poor quality water and are constructed in the Yorktown aquifer. It is the author's opinion that the water table aquifer should be used generally for the lawn watering or similar uses instead of the Yorktown since the water table aquifer generally is not suitable for potable use. This would leave the Yorktown aquifer water available primarily for potable use. Where the quality is favorable, the water table aquifer also could be applied to ground water heat pump use. No major problems are anticipated in regard to the development of the water table aquifer. Locally, where high density water table aquifer use takes place, water level decline below shallow well pump capability may take place.

Yorktown aquifer - The Yorktown aquifer generally contains water of good quality and is capable of supplying moderate quantities of water. The City of Virginia Beach had intended to develop a supplementary supply of water from the Yorktown aquifer to add to the centralized water system. Conceptual plans were to develop ten 1 MGD well fields within the City of Virginia Beach during the next seven years (Wiley and Wilson, 1979). Drought conditions in 1980 and 1981 had forced the City to attempt to develop these well fields more rapidly. Recently completed ground water exploration and development studies for Virginia Beach indicated that development of 10 MGD of ground water from the Yorktown aquifer was feasible (Converse Ward Davis Dixon, Inc., 1981 and Betz Converse Murdoch, Inc., 1981). Howeven, immediate development has been delayed until other alternatives have been more fully evaluated. Also, the City of Chesapeake plans to develop 10 MGD from ground water within the City, several MGD of which will probably be from the Yorktown aquifer. With adequate planning, test drilling and design, these major well fields can be constructed with minimal environmental impact.

The major potential environmental impacts of such well fields would be water well interference between wells, lateral salt water encroachment, and upconing of brackish water from underlying strata. The well interference problem can be minimized by locating well sites as far as possible from existing wells. Lateral salt water intrusion generally can be avoided by not locating well fields at or adjacent to the fresh water-salt water interface, which roughly parallels the Atlantic Ocean and Chesapeake Bay shoreline in most places (Plate 21). Upconing of brackish water can be minimized by adequate well design or by not constructing well sites in areas where brackish water is known to occur at shallower-than-normal depths such as in southeastern Virginia Beach (Plates 21 and 22).

The most favorable sites for major well fields should be selected on the basis of available ground water information. However, site selection can become complex when other factors such as land availability, land costs and a location convenient to major water lines enters into the selection process.

It is recommended that favorable sites be tested thoroughly in a fashion similar to the guidelines below:

1. Inventory existing wells in the vicinity of the proposed well field from the standpoint of useful data and potential well interference.
2. Sample existing wells and pump-test an existing well if available.
3. Drill several test wells in the area of the proposed well field. For each test well, run a suite of geophysical

logs, obtain a water sample, and perform a specific capacity pump test. Split-spoon core samples should be taken from at least the production zone to correlate with geologic and geophysical logs and to use in gravel pack and well screen design.

4. Conduct a controlled aquifer pump test on one of more of the test wells. This probably would require the drilling of one or two observation wells in the immediate vicinity of the test well. Water quality samples should be taken at several times during the pump test and analyzed for at least pH, chloride, TDS, and iron.
5. Analyze data collected and determine spacing and yield for production wells.

Ground water heat pumps also will become a major user of the Yorktown aquifer in the future. The development of guidelines for ground water heat pump construction and operation mentioned previously will probably be developed into regulations which will protect the ground water resource. One of the major potential problems facing ground water heat pump users, as well as other users of the Yorktown aquifer which use small diameter wells, is the lowering of ground water level locally below the intake of shallow well pumps. This lowering of water levels locally, due to intense use by various ground water users, is a real possibility. If the water levels stay consistently below shallow well pump intakes, larger diameter wells at least two inches in diameter would be required in order to install a deep well jet pump to obtain water from greater depths. Such an incident occurred during the summer of 1980 when various pumpages, in combination with drought conditions, lowered water levels to a depth of about 28 feet, a depth below the intake capability of most well pumps in the area. Local ordinances may eventually be necessary to avoid an increasing occurrence of such problems.

Eocene-Upper Cretaceous aquifer - No major development of this aquifer is anticipated because of the brackish water quality and its moderate yield capabilities. Industries able to use moderate quantities of brackish water could utilize this aquifer.

Lower Cretaceous aquifer - The City of Chesapeake plans to use several MGD of fresh ground water from the Lower Cretaceous aquifer in northwestern Chesapeake. A one MGD production well has been constructed. Moderate yields of several MGD of fresh ground water are possible from a well field in this part of the study area (Plate 24). Adequate test drilling should be performed to minimize upconing of brackish water.

The moderately brackish zone (1000-2000 mg/l TDS) located in eastern Portsmouth, western Norfolk, and northern Chesapeake is capable of moderate-to-large supplies of brackish water for industrial process water, industrial cooling, and large ground water heat pump installations. The more brackish ground water encountered to the east (5000 to 10,000 TDS) can be used for certain industrial uses and feedwater for desalination. Intense use of this brackish zone could also cause upconing of more brackish ground water.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Moderate supplies of fresh ground water and large supplies of brackish ground water are available in the Four Cities area. Current ground water use in approximately 11 MGD. Ground water development is projected to increase substantially in the future due to increases in municipal, industrial, ground water heat pump, and lawn watering demand. This projected demand can be met adequately without major environmental impacts as long as adequate planning, ground water testing, and well field design is completed for proposed major withdrawals of ground water.

Four aquifers have been identified in the Four Cities area. Small supplies of fresh, non-potable water for residential lawn watering and similar purposes can be developed from the water table aquifer. The Yorktown aquifer is the major potable aquifer in the area. Proposed municipal development of this aquifer include many widely scattered well fields made up of a number of wells having a 50 to 75 gpm capacity. Fresh water development in the Lower Cretaceous aquifer is limited to the northwestern part of the study area where moderate supplies are available. In the rest of the study area, the Lower Cretaceous aquifer is capable of producing large quantities of brackish ground water for desalting purposes or for the other uses where saltiness is not objectionable.

Also, moderate supplies of brackish ground water are available from the Eocene-Upper Cretaceous aquifer in most of the study area.

Recommendations

Several local environmental ground water problems have occurred in the area. They indicate the need for continued ground water monitoring, research, and subsequent regulations, if necessary. The recommendations given below generally emphasize the collection of data to understand changing ground water conditions in the study area:

(1) One contamination problem identified, which is occurring in the water table aquifer, indicates the need for a close examination of the impact of the existing waste disposal practices upon ground water quality. Ground water quality monitoring research at several waste disposal sites should be conducted in order to determine the extent and rate of contamination to the water table aquifer. These research results then can be used to develop sound waste management practices.

(2) Water level declines in the Lower Cretaceous aquifer, localized declines in the Yorktown aquifer, local water well interference problems in the Yorktown aquifer, and evidence of slight upconing in the Yorktown aquifer indicate a need for continued collection, compilation and analysis of water level, water quality and other data such as well completion reports and test drilling results. Special emphasis should be placed upon data collection and

evaluation, at or in the vicinity of, major well fields as they are constructed.

(3) Establish ground water observation wells (research stations) where existing wells do not provide adequate water quality or water level data. Currently, there is a need to establish research stations in the western part of the study area to determine the western-most extent of the fresh water-salt water interface in the Yorktown aquifer.

(4) A large number of ground water heat pumps have been and will continue to be installed in the area. Therefore, additional data on the ground water heat pumps in the area should be collected including average yearly water use, ground water temperature changes in heat pumps supply and return wells, and heat pump return water quality. Also, research should be conducted on ground water heat pump design, especially on the most effective return well design for this area. A reliable return well design will assure that the water used by the heat pump is returned to the aquifer. Many return wells have malfunctioned so that user practice is not to reinject spent heat pump water.

(5) Encourage a beneficial use such as irrigation or cooling water for the several million gallons a day of water currently being pumped out of area borrow pits for dewatering purposes.

APPENDIX A

METRIC CONVERSIONS

ENGLISH	MULTIPLY BY	METRIC
Cubic Feet (ft^3)	2.832 X 10	Liters (L)
Cubic feet per minute (ft^3/min)	2.832 X 10	Liters per minute (L/min)
Degrees Fahrenheit (^oF)	(F^o-32) .556	Degrees Celsius (^oC)
Feet (ft)	3.048 X 10^{-1}	Meters (m)
Gallons (gal)	3.785	Liters (L)
Gallons per day per foot (gpd/ft)	1.242 X 10^{-1}	Liters per day per meter (L/day/m)
Gallons per minute (gpm)	3.785	Liters per minute (L/min)
Gallons per minute per foot (gpm/ft)	1.242 X 10^{-1}	Liters per minute per meter (L/min/m)
Inches (in)	2.540	Centimeters (cm)
Miles (mi)	1.609	Kilometers (Km)
Ounces (oz)	2.8349 X 10	Grams (g)
Pounds (lb)	4.536 X 10^{-1}	Kilograms (Kg)
Square miles (mi^2)	2.590	Square Kilometers (Km^2)
Tons (T)	9.0178 X 10^2	Kilograms (Kg)
Yards (Y)	9.144 X 10^{-1}	Meters (m)

APPENDIX B
SUMMARY OF SPECIFIC CAPACITY DATA FOR THE FOUR CITIES

Appendix B contains specific capacity data on the Four Cities. Well numbers can be cross-referenced to Plate 9 for location. The data listed in Appendix B include:

State Water Control Board Number
Owner
Screen depth
Aquifer
Diameter (in.) of well casing
Test yield (gpm)
Drawdown (ft.)
Specific capacity (gpm/ft)
Duration of pump tests (hr)

Aquifer abbreviations used are:

WT -	Water Table
U Yktn -	Upper Yorktown
M Yktn -	Middle Yorktown
L Yktn -	Lower Yorktown
E, U Cret -	Eocene, Upper Cretaceous
L Cret -	Lower Cretaceous

SPECIFIC CAPACITY DATA FOR CITY OF NORFOLK

SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
217-1	Lake Wright	75-105	M Yktn	6	304	21	14.4	8
217-2	Norfolk General	63-68	U Yktn	6	30	60	.5	-
217-21	Sheller Globe	100-120	L Yktn	4	70	63	1.1	-
217-22	Sheller Globe	100-120	L Yktn	4	68	63	1.1	-
217-33	Seaview Amusement Park	60-70	U Yktn	6	65	23	2.8	-
217-37	Norfolk Contracting Co.	18-23 35-50	WT	6	45	28	1.6	-
217-49	Roosevelt Gardens	71-81	M Yktn	6	125	11	11.3	15
217-51	DePaul Hospital	66-71	M Yktn	6	35	10.5	3.3	48
217-63	Police Pistol Range	93-101	M Yktn	2	24	25	1.0	-
217-64	J. H. Miles Co.	790-890	L Cret	8	1000	71	14.1	24
217-65	National Medical Care	70-78	Yktn	4	32	13	2.5	24

SPECIFIC CAPACITY DATA FOR CITY OF PORTSMOUTH

SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
220-4	Pinners Point STP	750-850	L Cret	8	750	71	10.5	-
220-18	Julian E. Trimyer	90-95	M Yktn	2	50	14	3.6	-
220-22	Merrifield Subdivision	582-602	L Cret	6	240	66	3.6	-
220-25	Edgefield Subdivision	580-604	L Cret	6	200	96	2.1	-
220-30	Edgefield Subdivision	589-609	L Cret	6	120	40	3	-
220-24	Shared Hospital Service	638-658	L Cret	6	220	46	4.8	24

SPECIFIC CAPACITY DATA FOR CITY OF VIRGINIA BEACH

SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
228-1	Virginia House	345-350 865-875 886-896 1130-1150 1164-1174 1178-1188 1232-1242 1297-1307	L Cret below 1100 ft.	20 in to 345 8 in 300-1593 20 in gravel pack 300-1320	831	60.66	13.7	8
228-2	Cardinal Estates No. 1	62-67 90-95 115-120	Yktn	6 20 in gravel pack	51	8	6.3	8
228-3	Cardinal Estates No. 2	62-67 90-95	U, M Yktn	6 20in gravel pack	50	27.5	1.8	8
228-7	Lakeville Estates No. 1	78-98	M Yktn	6 20 in gravel pack	50	63	0.8	24
228-8	Lakeville Estates No. 2	57-62	U Yktn	6 20 in gravel pack	81	22	3.7	8
228-9	Lakeville Estates No. 3	100-120	L Yktn	6 20 in gravel pack	160	38	4.2	8
228-10	Pembroke Manor #1	59-64 88-93 117-122	L Yktn	6 20 in gravel pack	50	4	12.5	24

SPECIFIC CAPACITY DATA FOR CITY OF VIRGINIA BEACH

SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
228-11	Pembroke Manor #2	57-62 80-85 110-115	Yktn	6 20 in gravel pack	50	5	10	24
228-12	Pembroke Manor #3	52-57 82-87 115-120	Yktn	6 20 in gravel pack	50	2.6	19.2	24
228-13	Pembroke Manor #4	58-68 110-115	Yktn	6 20 in gravel pack	50	3	16	72
228-14	Pembroke Manor #5	52-57 91-96 114-119	Yktn	6 20 in gravel pack	50	3	16.6	24
228-15	Pembroke Manor #6	74-79 88-93 115-120	Yktn	6 20 in gravel pack	50	20	2.5	24
228-16	Pembroke Manor #7	55-60 69-74 112-117	U, L Yktn	6 18 in gravel pack	50	20	2.5	24
228-17	Pembroke Manor #8	52-57 63-68 115-120	U, L Yktn	6 18 in gravel pack	50	21	2.3	24

SPECIFIC CAPACITY DATA FOR CITY OF VIRGINIA BEACH

SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
228-18	Pembroke Manor #9	55-60 81-86 115-120	Yktn	6 18 in gravel pack	50	26	1.9	24
228-22	Coast Guard Radio Sta.	46-56 78-80	U, M Yktn	8	50	15	3.3	24
228-35	Kempsville School Plant	60-70	U Yktn	6	100	12	8.3	8
228-36	Seaboard Elementary	68-78	U Yktn	6	45	21	2.1	8
228-37	Linkhorn Park School	45-51	U Yktn	6	75	16	4.6	8
228-40	Southern Materials	50-70	U Yktn	6	100	52	1.9	18
228-44	Rudde Campground	62-82 102-112	M, L Yktn	6	141	29.5	4.7	8
228-45	Va. Beach Campground	72-92 116-126	M, L Yktn	6	151	44.5	3.4	24
228-46	Living Water Campground #1	58-83	U Yktn	6	80	46	1.7	24
228-47	Living Water Campground #2	69-94	U, M Yktn	6	80	54	1.5	24
228-48	Indian Lake Estates Test Well No. 1	50-60 70-80	U, M Yktn	4	32.5	35	.9	65
228-50	Indian Lakes Estates #3	74-94	U Yktn	4	45	60	0.8	8

SPECIFIC CAPACITY DATA FOR CITY OF VIRGINIA BEACH

SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
228-51	Stratford Chase	52-72	U Yktn	4	40	30	1.3	8
228-52	Stratford Chase	70-95	U Yktn	4	62	18	3.4	8
228-56	Creeds Elementary	57-62	U Yktn	6	42	19	2.2	-
228-59	Nepratex	993-1028 1049-1084 1110-1120	L Cret	12	1000	115	8.7	5
228-77	Parks & Rec. (Old Niki Site)	80-85	M Yktn	6	40	16	2.5	-
228-78	Floyd Kellam High School	55-60	U Yktn	6	30	16	1.9	-
228-79	Courthouse Elementary	55-65	U Yktn	6	60	18	3.3	-
228-81	John B. Dye Elementary #3	35-40	WT	6	50	28	1.8	-
228-83	John B. Dye Elementary #2	31-36	WT	6 10 in gravel pack	22	18	1.2	-
228-86	E. K. Wilson Birdneck Point	50-55	U Yktn	3	50	11	4.5	-
228-87	J. W. Wood	22-27	WT	6	32	19	1.7	-
228-94	Princess Anne Country Club	72-77	U Yktn	8	75	15	5	-

SPECIFIC CAPACITY DATA FOR CITY OF VIRGINIA BEACH

SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
228-95	Princess Anne Country Club	72-77	U Yktn	8	50	17	2.9	-
228-100	Princess Anne Plaza	65-75	U Yktn	6 12 in gravel pack	150	56	2.7	72
228-101	Stumpy Lake	110-120	L Yktn		40	12	3.3	-
228-102	Stumpy Lake	110-120	L Yktn	8 7 in gravel pack	85	11.5	7.4	-
228-103	Stumpy Lake	110-125	L Yktn	8 in 7 in gravel pack	210	13	16.1	-
228-104	Thoroughgood Elementary	25-30	WT	6 14 in gravel pack	32	21	1.5	-
228-105	Kempsville Meadows Elementary	74-79	U Yktn	6 in gravel pack	75	12	6.3	-
228-106	Plaza Elementary	55-60	U Yktn	6 11 in gravel pack	60	14	4.3	-
228-107	Public Safety Bldg.	64-84	U, M Yktn	6 in gravel pack	80	26	3.1	24

SPECIFIC CAPACITY DATA FOR CITY OF VIRGINIA BEACH

SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
228-108	Woodstock Elementary	68-73	U Yktn	8 7 in gra-vel pack	55	22	2.5	-
228-109	Bettie Williams Elementary	65-70	U Yktn	6 11 in gra-vel pack	50	20	2.5	-
228-110	Kempsville Elementary	61-66	U Yktn	6 11 in gra-vel pack	30	20	1.5	-
228-132	SWCB-Oceana NAS A	97-102	M Yktn	4 in	84	45.95	1.8	42
228-162	Va. Beach - Ferry Road Observation Well	1207-1229 1250-1264 1286-1306 1345-1367	L Cret	4	200	34	5.9	10
228-163	Va. Beach Burton Station Observation Well	1000-1010 1024-1068 1082-1124	L. Cret	4	200	25	8.0	16
228-184	SWCB Tidewater Community College #C	120-130	L Yktn	4	62.6	47.05	1.3	24
228-190	SWCB Princess Anne B	60-65	U Yktn	4	52.2	24.44	2.3	24

SPECIFIC CAPACITY DATA FOR CITY OF CHESAPEAKE

SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
234-1	Lonestar Great Bridge	87-92	M Yktn	6 in gravel pack	86	19	4.5	-
234-2	Southern Block and Pipe	92-112	M Yktn	6 in	226	22	10.2	8
234-4	VEPCO Gilmerton	67-72 92-97	U, M Yktn	8 22 in gravel pack	100	13.5	7.4	12
234-9	Smith Douglas	90-95 113-118	M, L Yktn	8 in gravel pack	180	41	4.3	48
234-11	Smith Douglas	56-66 97-102	U, M Yktn	8 in gravel pack	183	12	15.2	8
234-14	Citadel Cement	800 ft total depth	L Cret	6	200	36	5.5	8
234-25	Wilson Village	82-92	M Yktn	4	50	20	2.5	-
234-28	Northwest Radio Station	50-60	U Yktn	8	35	42	.8	-
234-30	Northwest Radio Station	48-59 75-86	U Yktn	6	38	35.5	1.1	24
234-39	Dept. of Highways	70-80	M Yktn	6	21	5	4.2	8
234-44	Great Bridge Civic Center	55-60 90-110	U, M Yktn	8	350	30	11.6	8

SPECIFIC CAPACITY DATA FOR CITY OF CHESAPEAKE

SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
234-48	Deep Creek Elementary	65-75	U Yktn	6	40	20	2	-
234-49	Indian River Elementary	40-45	WT	6	30	20	1.5	-
234-50A	Crestwood School	81-91	M Yktn	6	60	19	3.1	-
234-53	Hickory Elementary	55-60	U Yktn	6	20.5	47	.4	-
234-55	Bayville Farms	56-81	U, M Yktn	6	98	55	1.7	8
234-56	Crest Harbor	66-76 96-111	M, L Yktn	6	140	23	6	24
234-57	Crest Harbor	81-86 100-115	M, L Yktn	6	149	20	7.4	24
234-58	Taylorwood Estates	610-630	L Cret	4	300	20	15	-
234-60	Tidewater Co. Green Meadow Point	594-614	L Cret	6	131	44	2.9	-
234-61	Tidewater Co. Green Meadow Point	535-565	L Cret	6	330	57	5.7	-
234-62	Tidewater Co. Green Meadow Point	550-570	L Cret	6	200	50	4	-
234-63	Indian River Water Co. #4	50-60	U Yktn	6	50	12	4.1	-

SPECIFIC CAPACITY DATA FOR CITY OF CHESAPEAKE

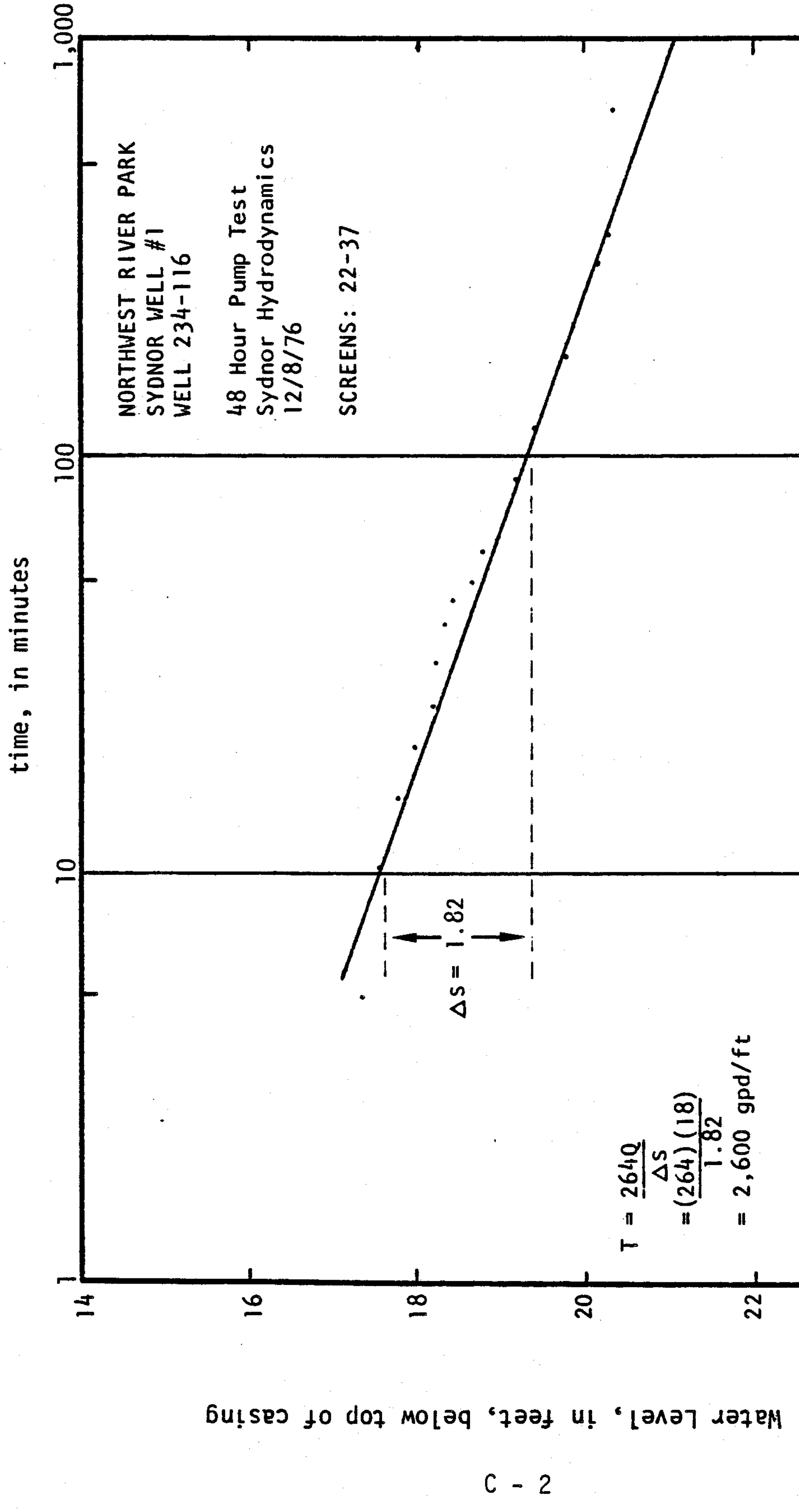
SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
234-64	Sunray Water Co.	635-645	L Cret	4	60	12	5	-
234-79	Tidewater Chemical	740-760	E, U Cret	4	150	60	2.5	6
234-81	Weaver Fertilizer	107-117	L Yktn	6	150	95	1.6	-
234-88	Indian River Water Co.	50-55 74-79	U Yktn	6	60	13	4.6	4
234-89	Indian River Water Co.	50-60	U Yktn	6	40	22	1.8	-
234-90	Indian River Water Co.	55-60 75-80	U Yktn	6	70	34	2	8
234-110	Proctor & Gamble	83-105	Yktn	8	162	71	2.2	-
234-112	Indian River Annex	60-65	Yktn	8	60	21	2.8	-
234-113	Great Bridge School	84-94	Yktn	8	160	26	6.1	-
234-114	Churchland Junior High	55-65	U Yktn	4	90	7	12.8	-
234-116	Northwest River Park	22-37	W T	6	18	12	1.5	48
234-133	City of Norfolk Nursery	118-148	L Yktn	6	200	7	28.6	24
234-149	Smith Douglas	94-114	L Yktn	8	450	58.5	7.7	24
234-155	Fentress NAS G. W. Dev. Well A	66-76	Yktn	6	65	35	1.9	24

SPECIFIC CAPACITY DATA FOR CITY OF CHESAPEAKE

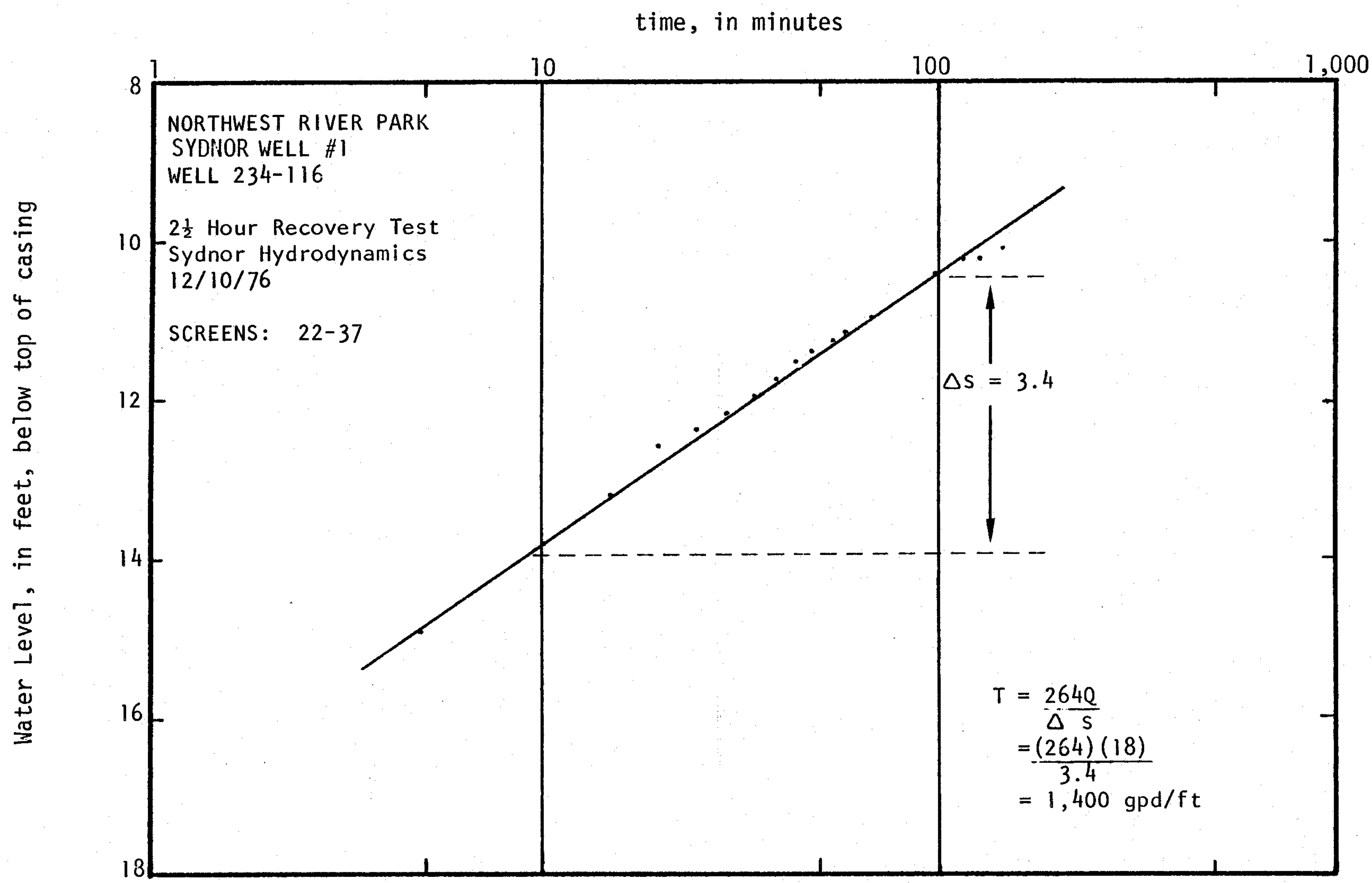
SWCB Number	Owner	Screen Depth	Aquifer	Diameter (in)	Test Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Length of Test (hr)
234-161	City of Chesapeake - Bowers Hill Prod. Well 1	714-734 738-758 786-796 833-853 898-908 930-940 982-992	L Cret	10 x 8	754	24.5	30.8	48
234-162	City of Chesapeake - Bowers Hill Observation Well	584-589 601-606 614-624 710-720 734-744 766-771 792-797	L Cret	4	94	26	3.6	8

APPENDIX C

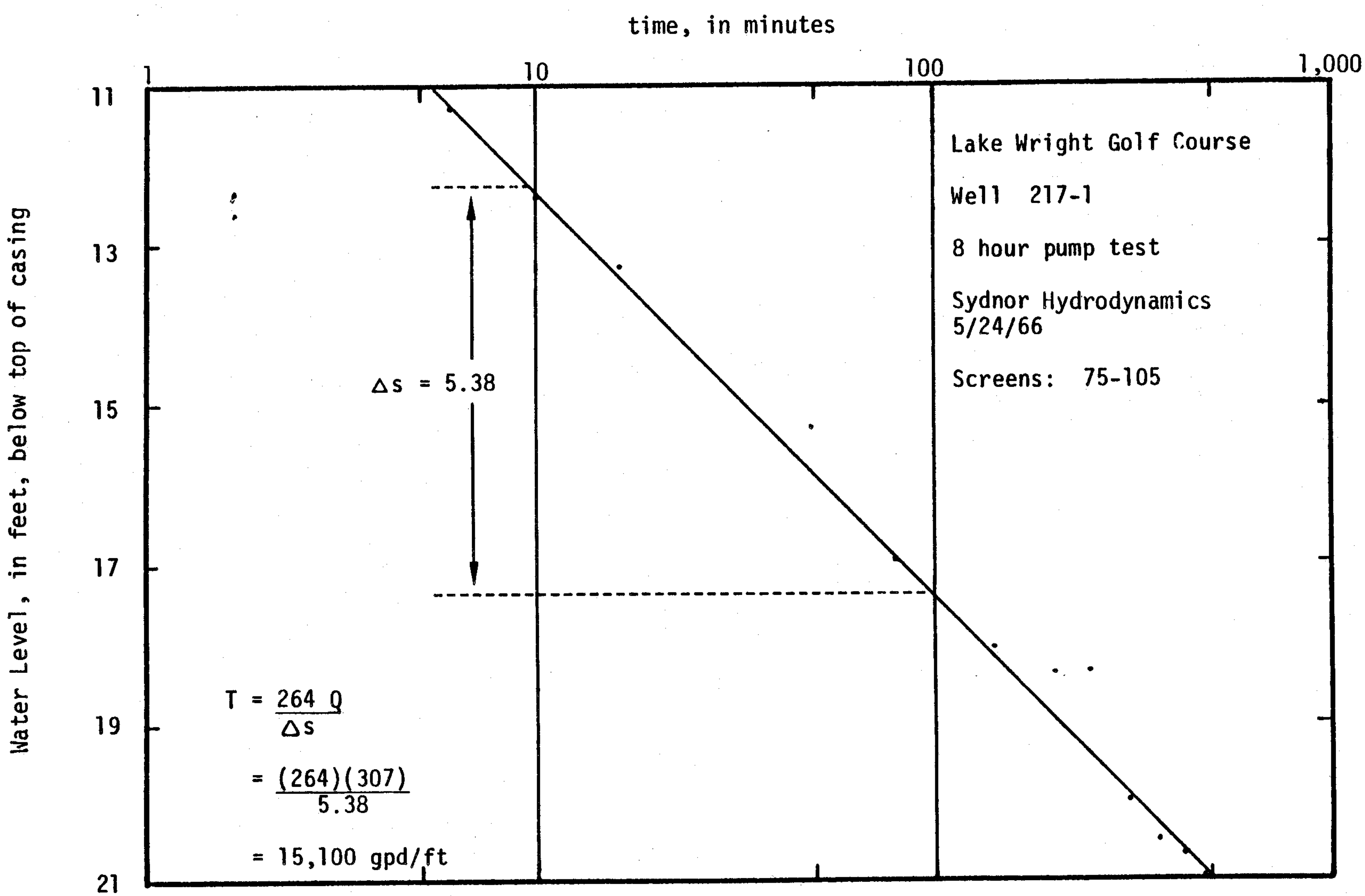
Appendix C includes semi-log plots and transmissivity calculations for wells which are summarized in Chapter 4, Table 4. See Appendix D for semi-log plots of the production wells for aquifer tests which were completed for this study.



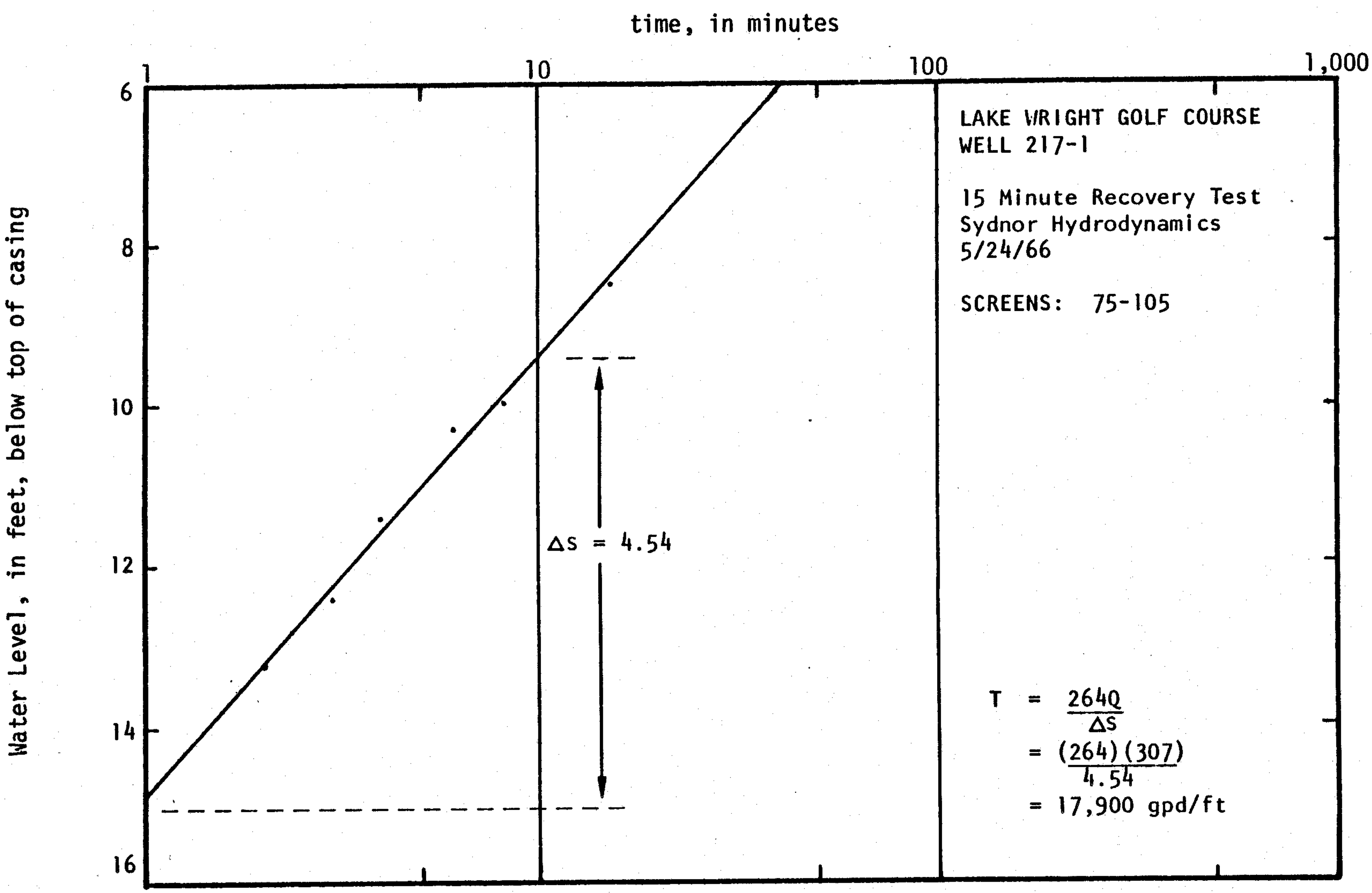
Source: State Water Control Board



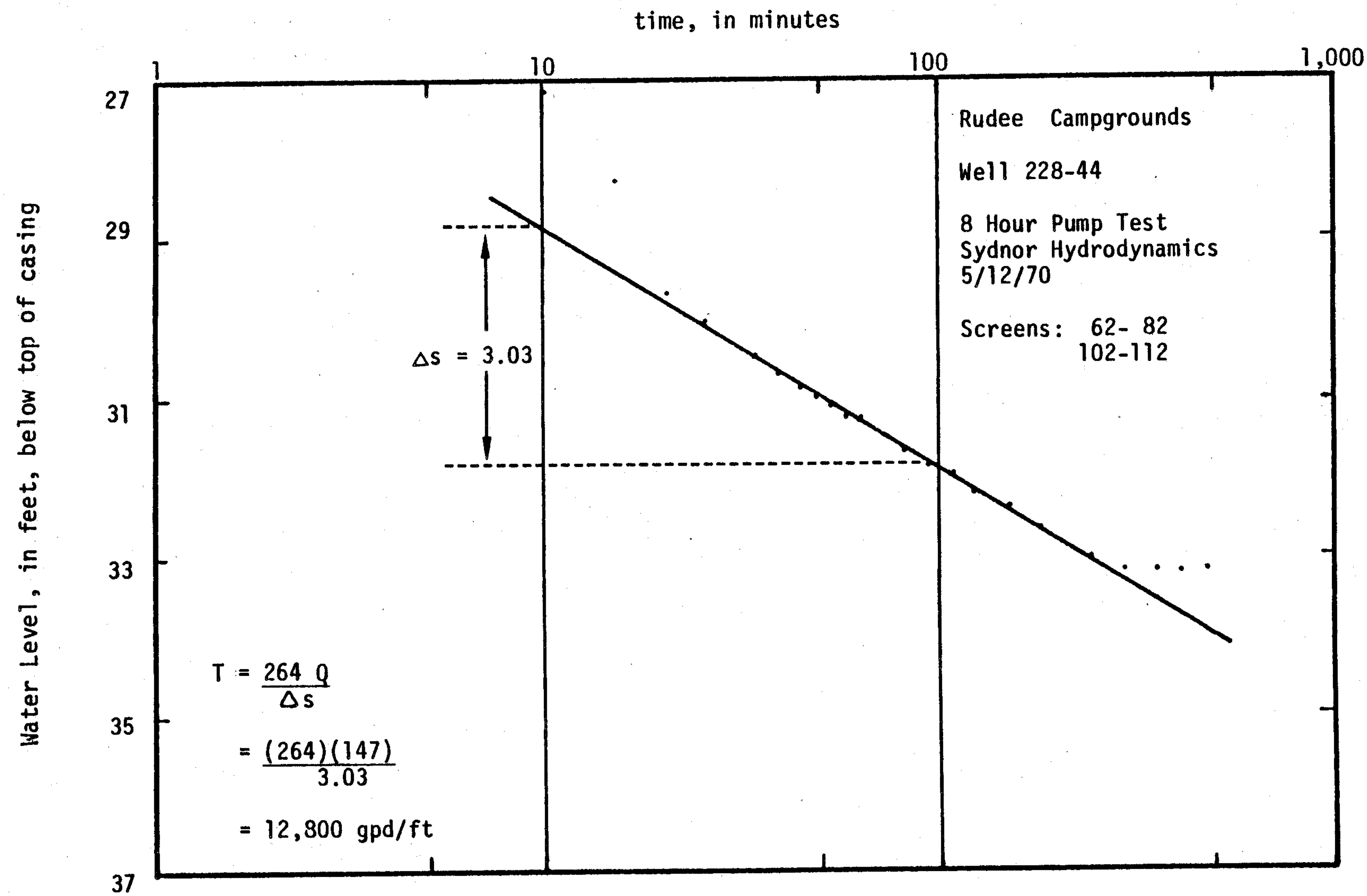
Source: State Water Control Board



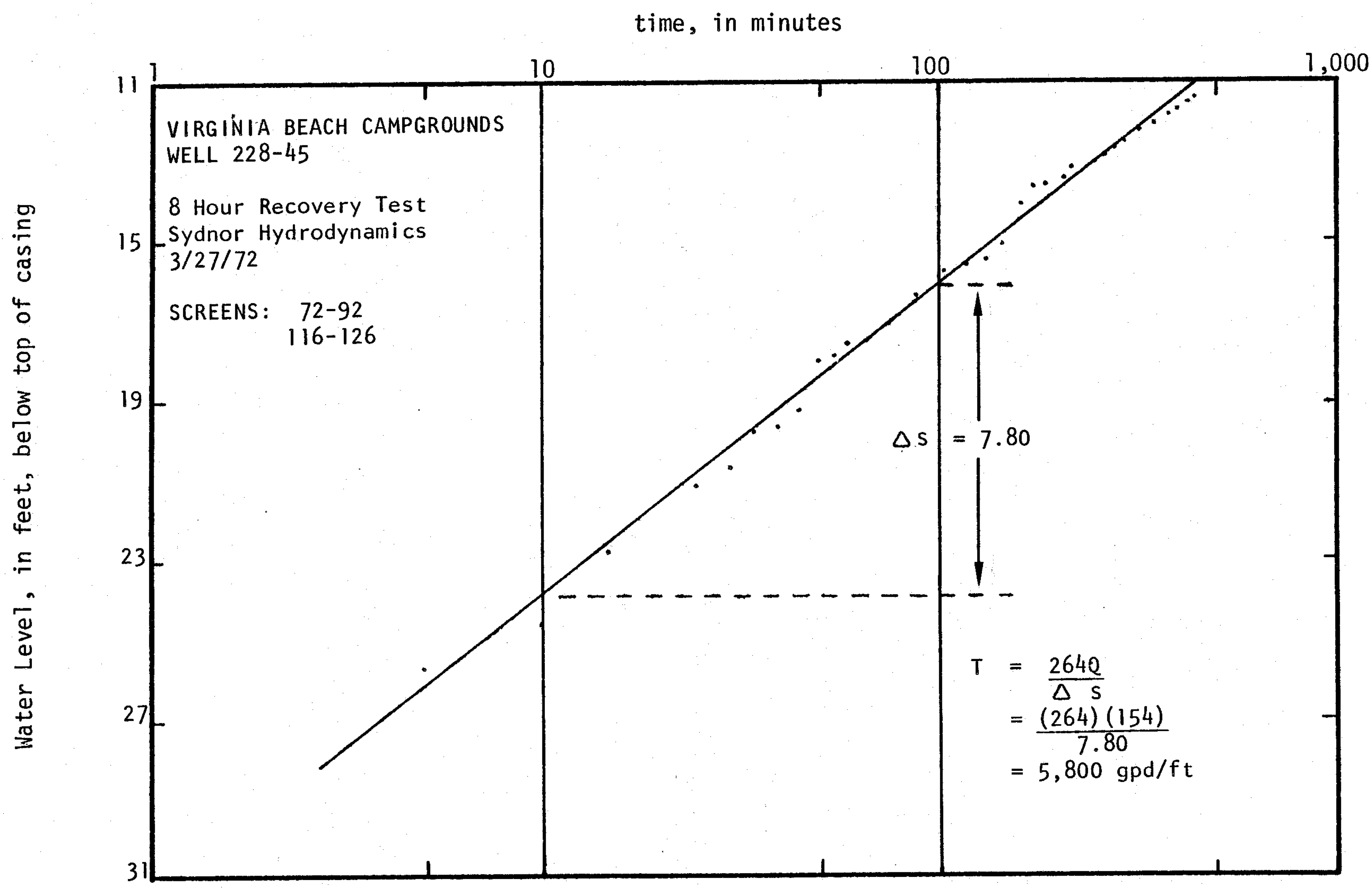
Source: State Water Control Board



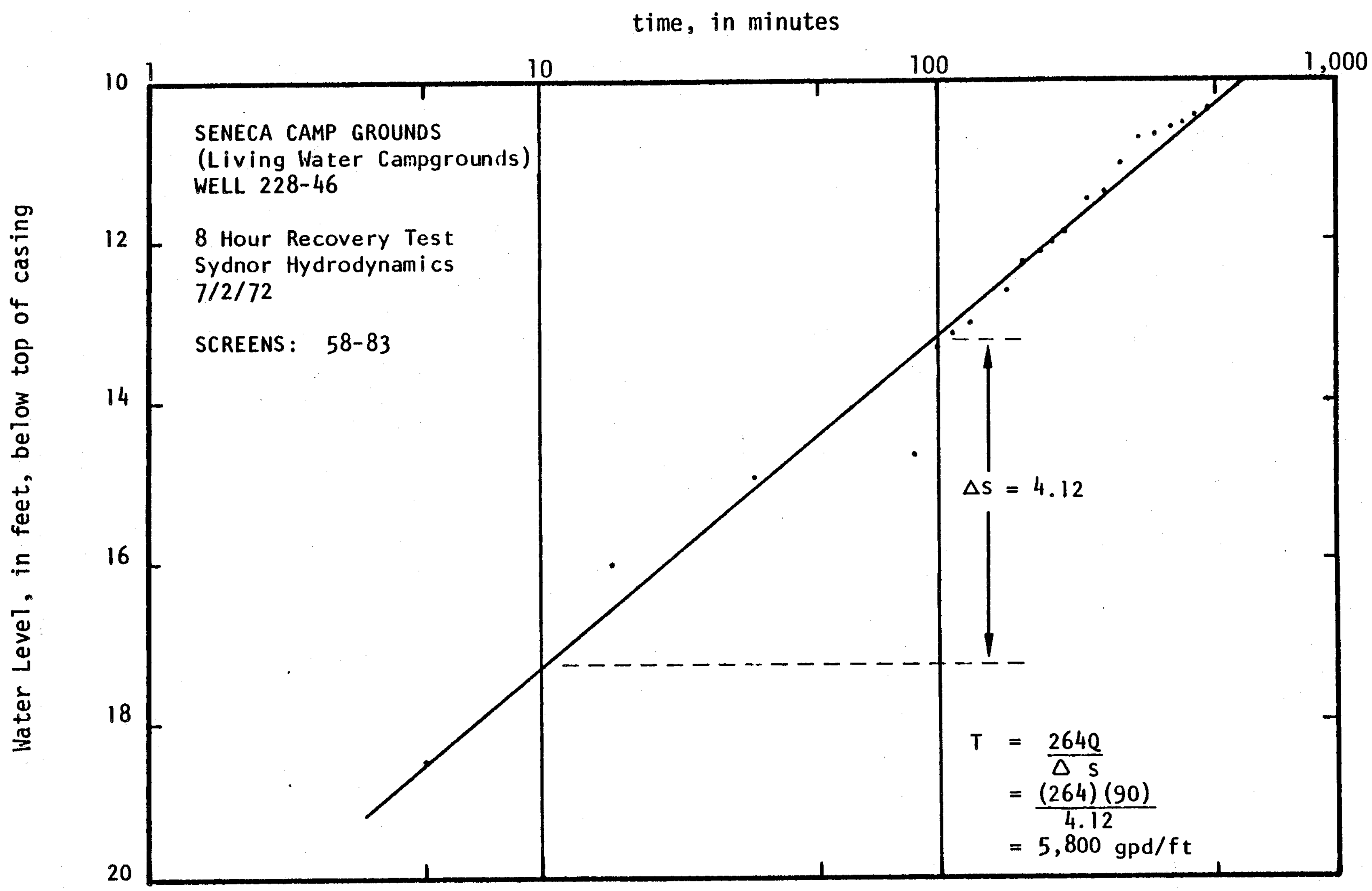
Source: State Water Control Board



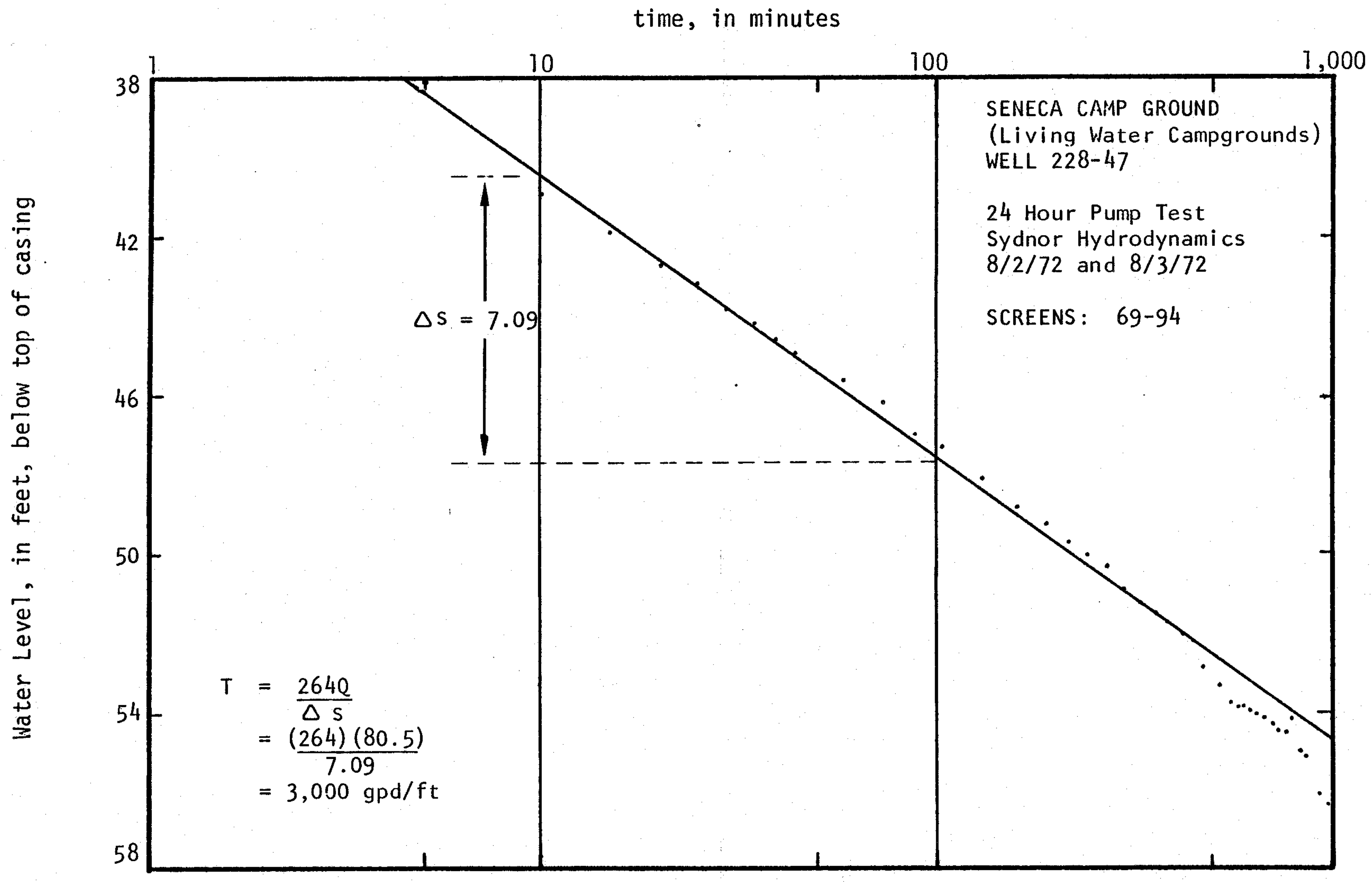
Source: State Water Control Board



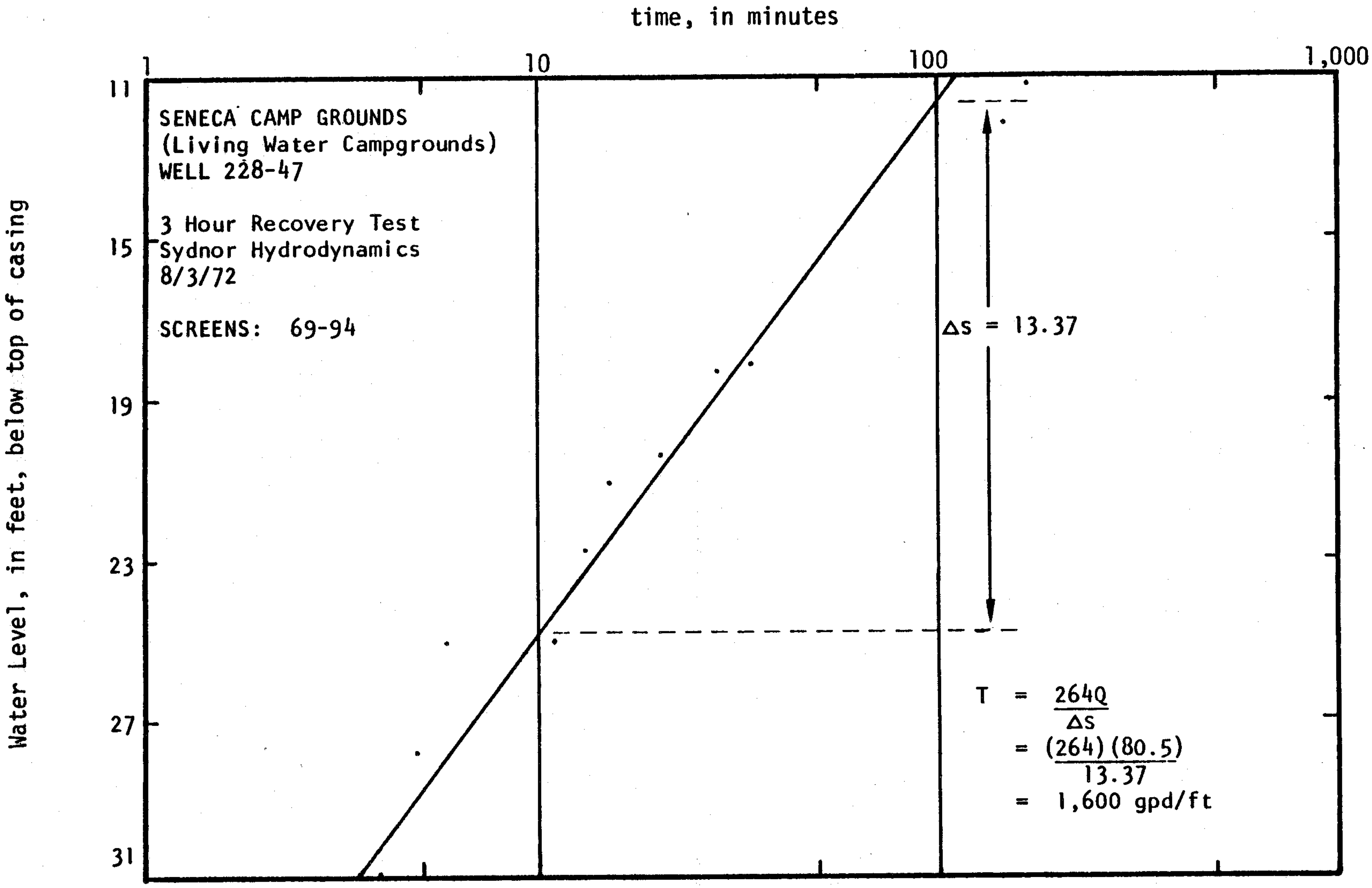
Source: State Water Control Board



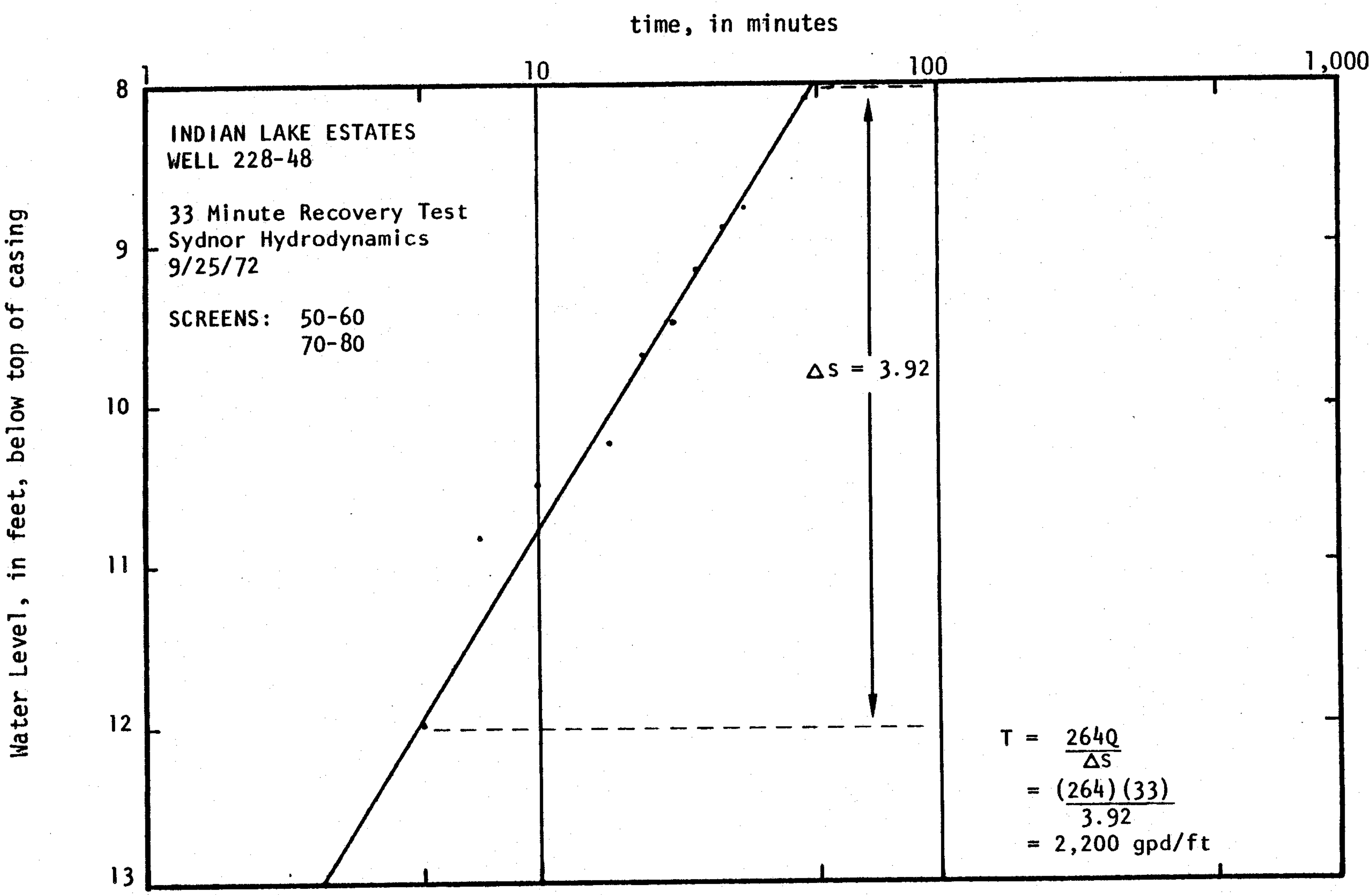
Source: State Water Control Board



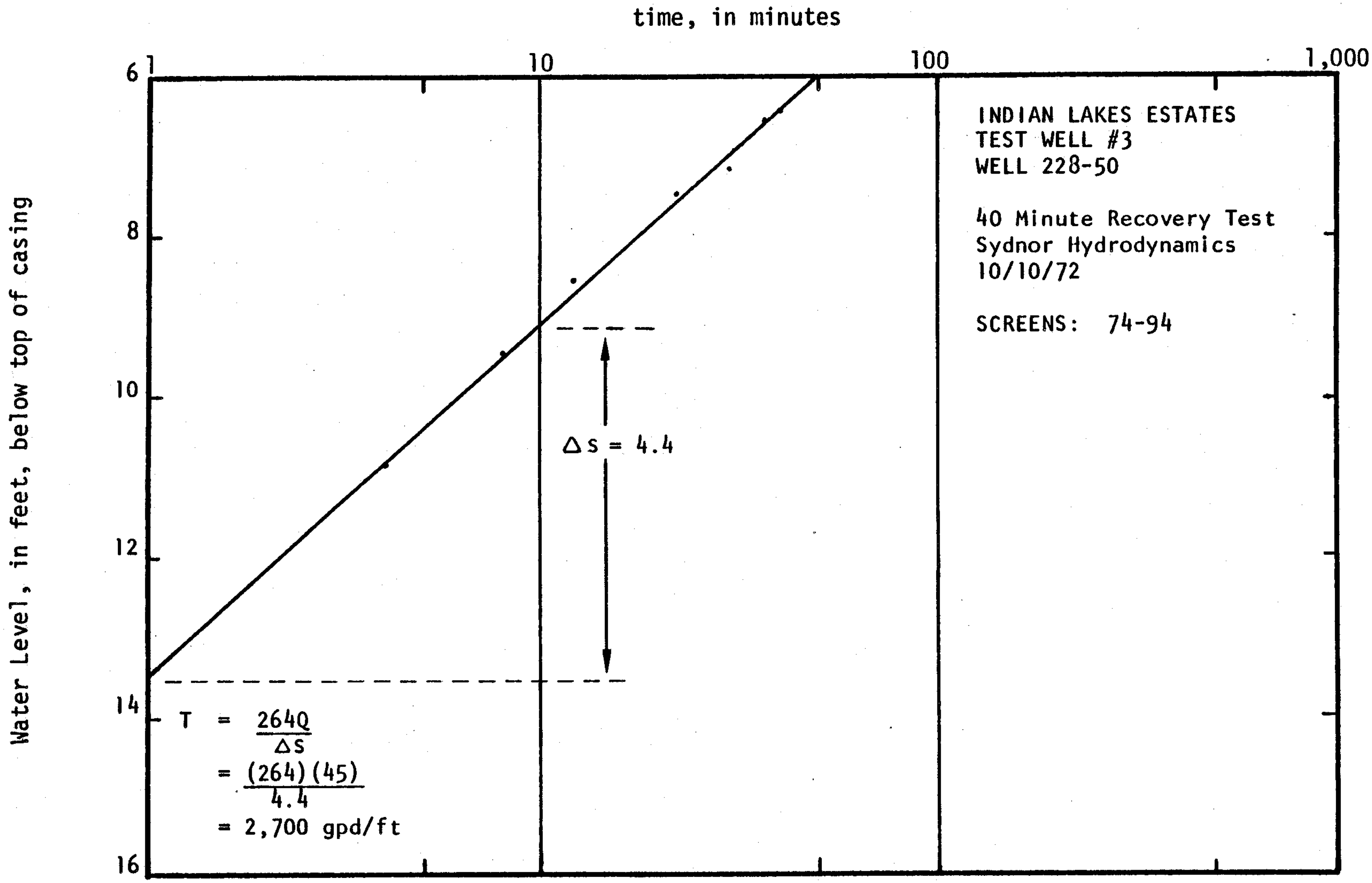
Source: State Water Control Board



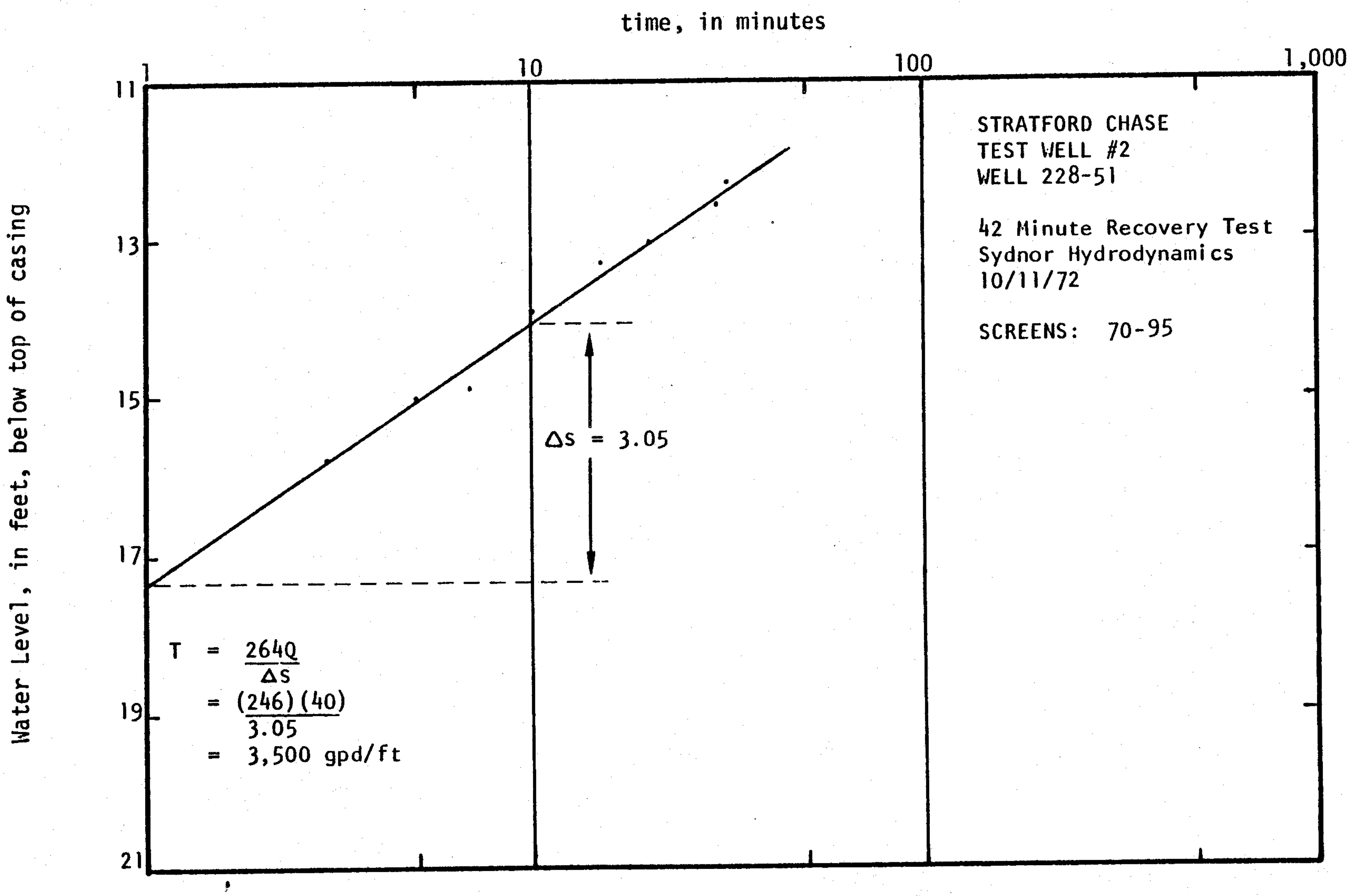
Source: State Water Control Board



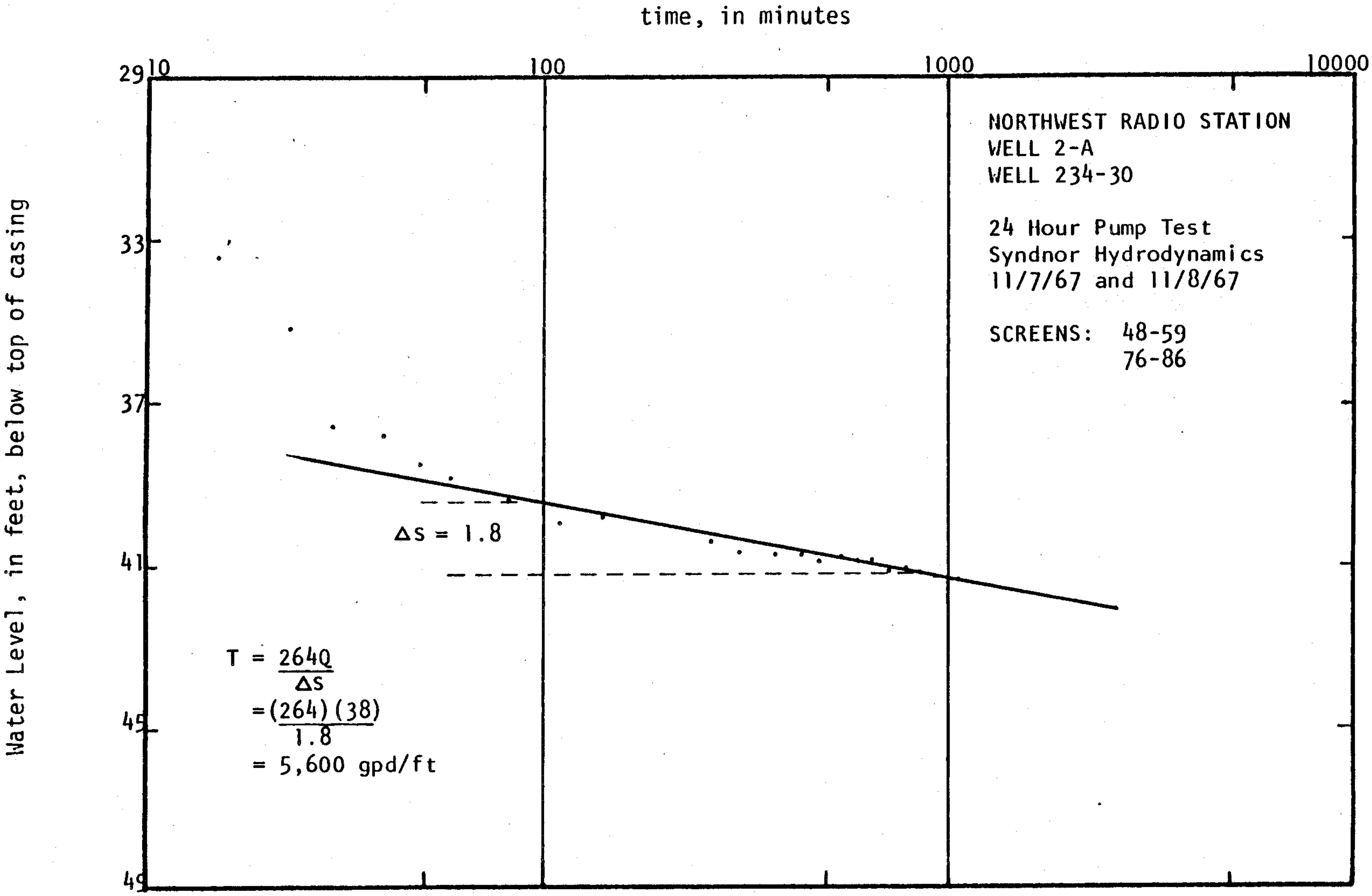
Source: State Water Control Board



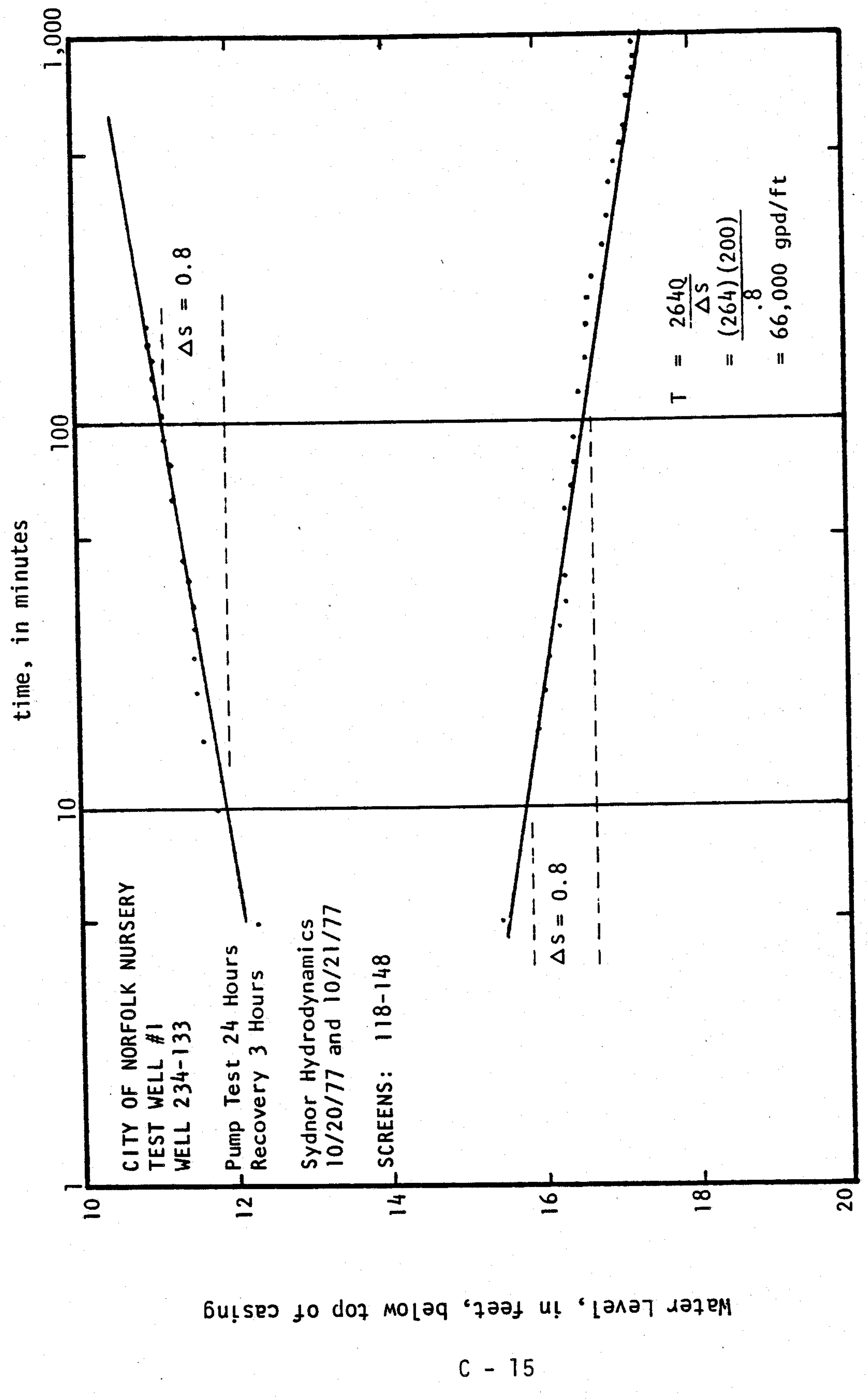
Source: State Water Control Board



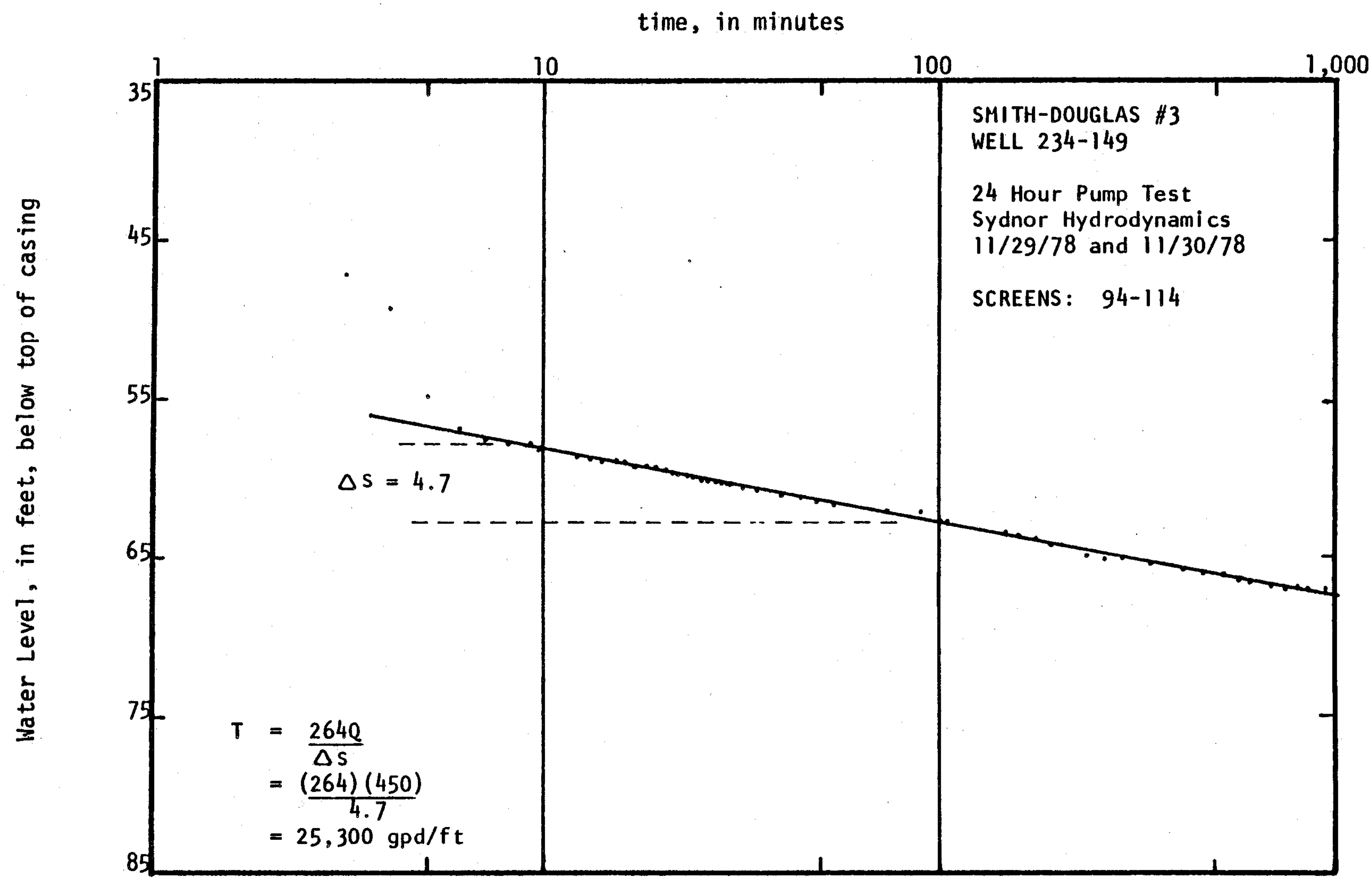
Source: State Water Control Board



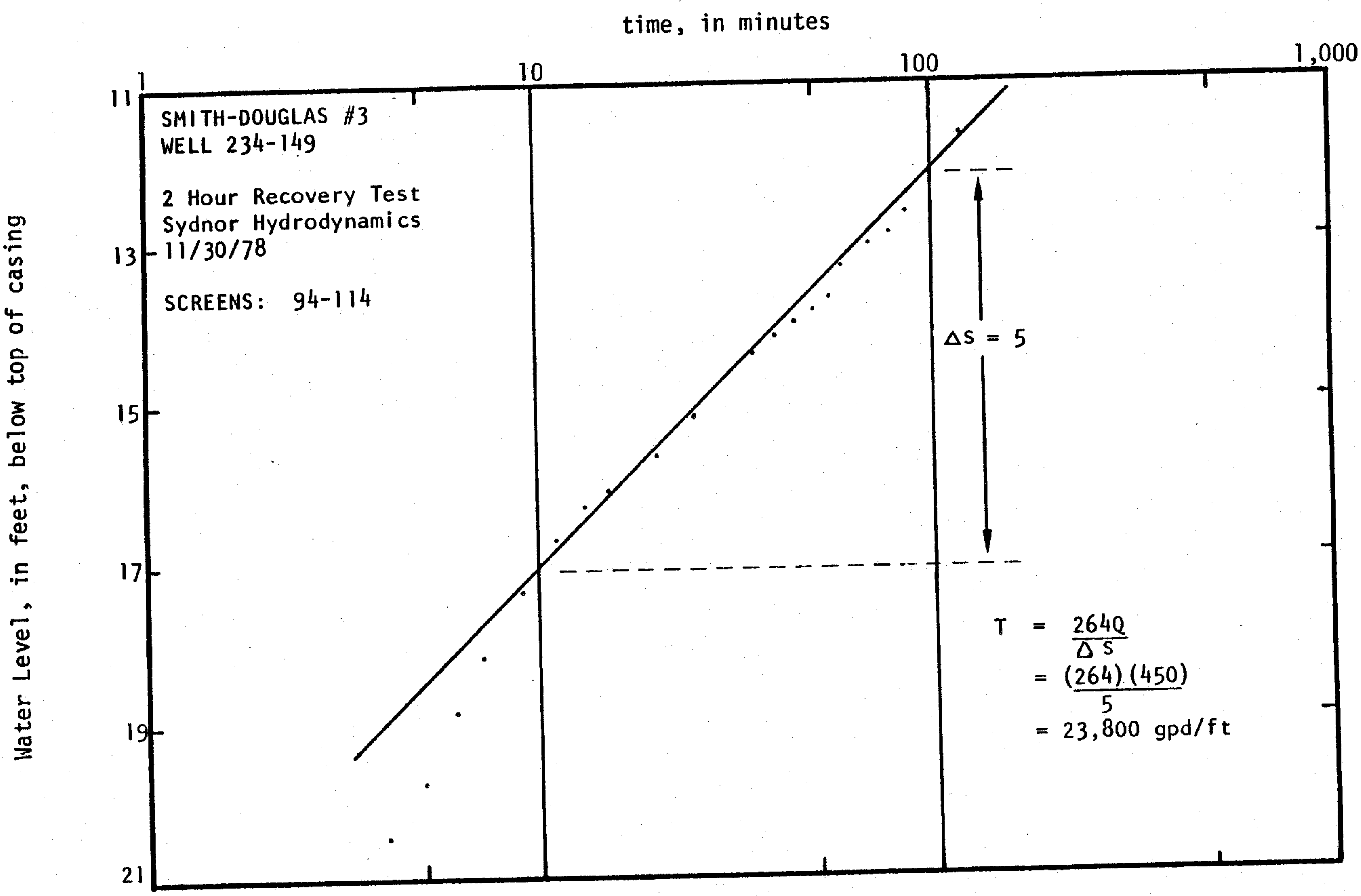
Source: State Water Control Board



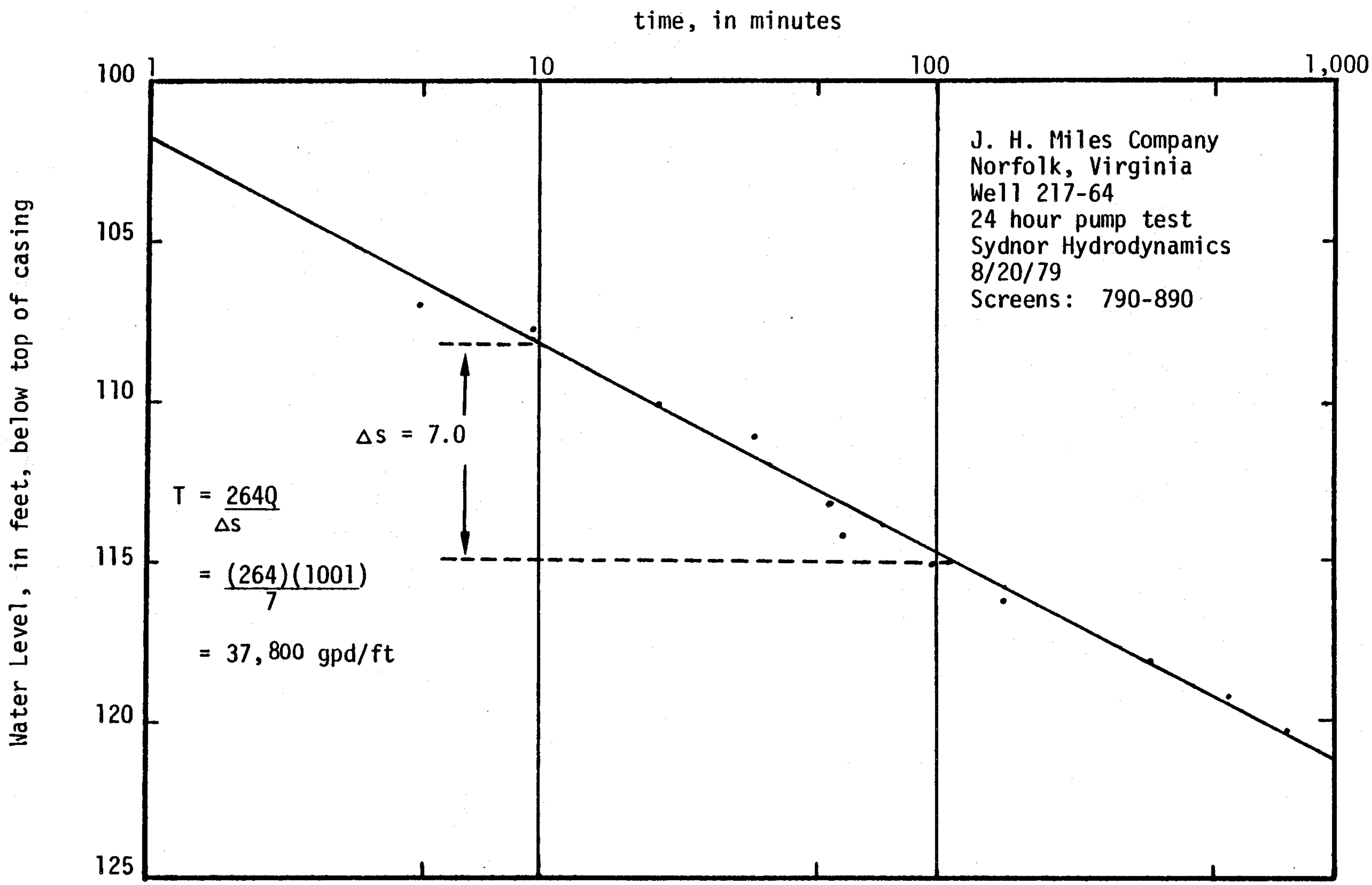
Source: State Water Control Board



Source: State Water Control Board



Source: State Water Control Board



Source: State Water Control Board

APPENDIX D

Appendix D includes examples of the graphs used to calculate transmissivity, storage coefficient, and leakance for the aquifer test at Frentress Naval Air Station, the Tidewater Community College Research Station, the Oceana Naval Air Station Research Station and the Princess Anne Courthouse Research Station. Graphs include semi-log time-drawdown, semi-log t/t' - residual drawdown, semi-log distance - drawdown, and log-log $+/r^2$ - drawdown plots. These graphs can be cross referenced with the well location maps and aquifer characteristics summary tables in Chapter IV as follows:

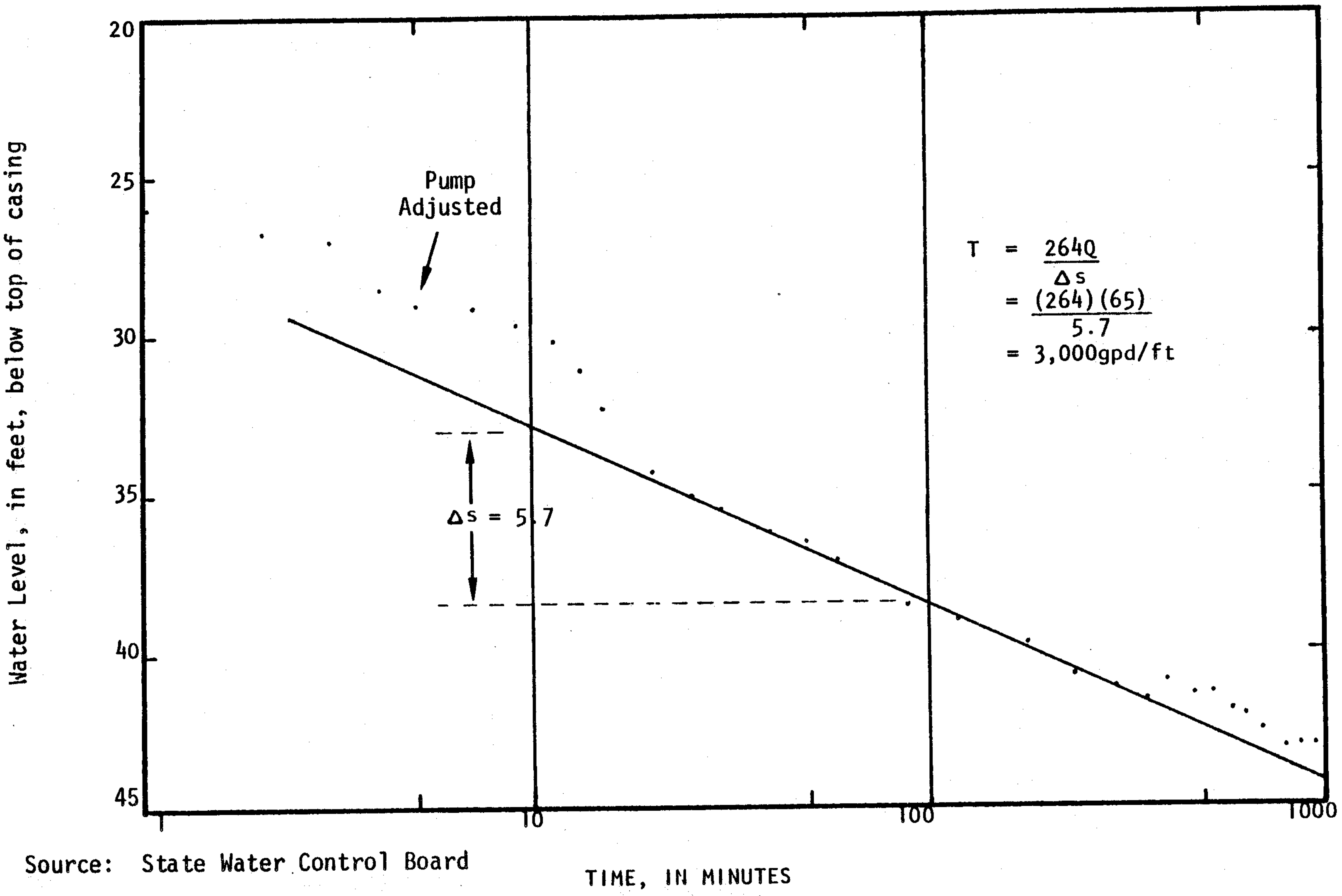
Fentress Naval Air Station Plate 15 and Table 6

Tidewater Community College Research Station Plate 16 and Table 7

Princess Anne Courthouse Research Station Plate 17 and Table 8

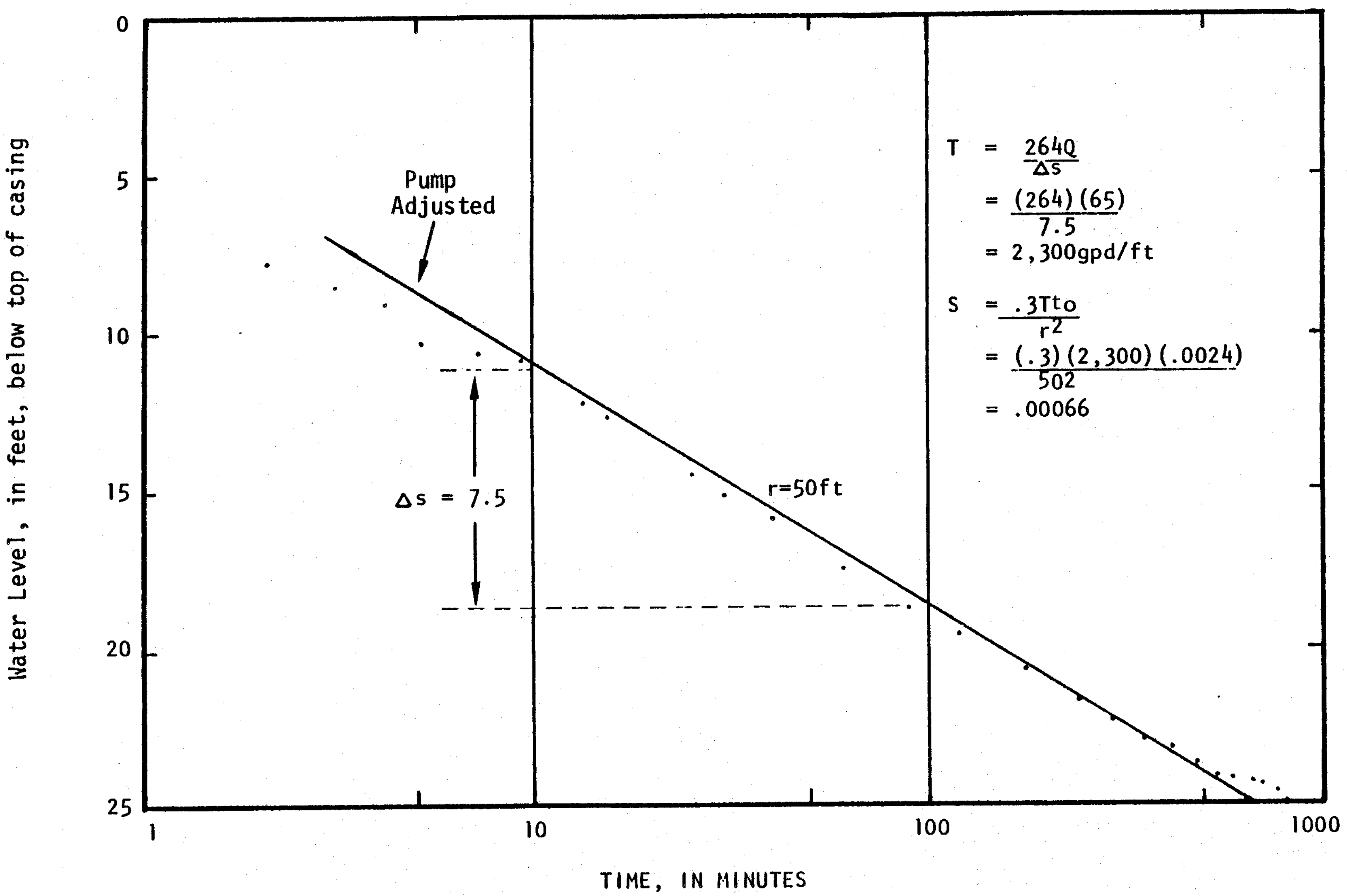
Oceana Naval Air Station Research Station Plate 18 and Table 9

SEMI-LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN PRODUCTION WELL, FENTRESS NAVAL AIR STATION



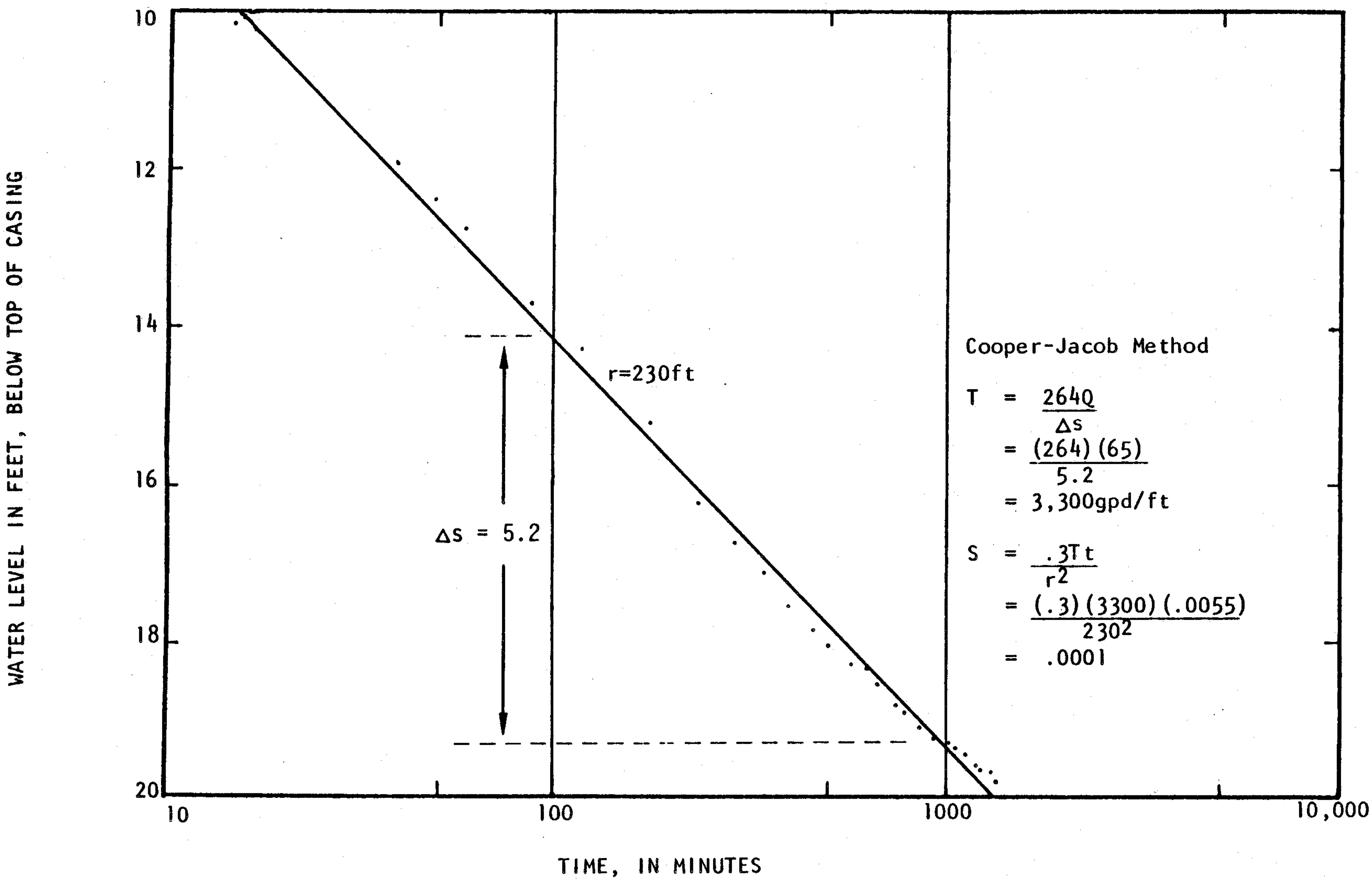
Source: State Water Control Board

SEMI-LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN OBSERVATION WELL A, FENTRESS NAVAL AIR STATION



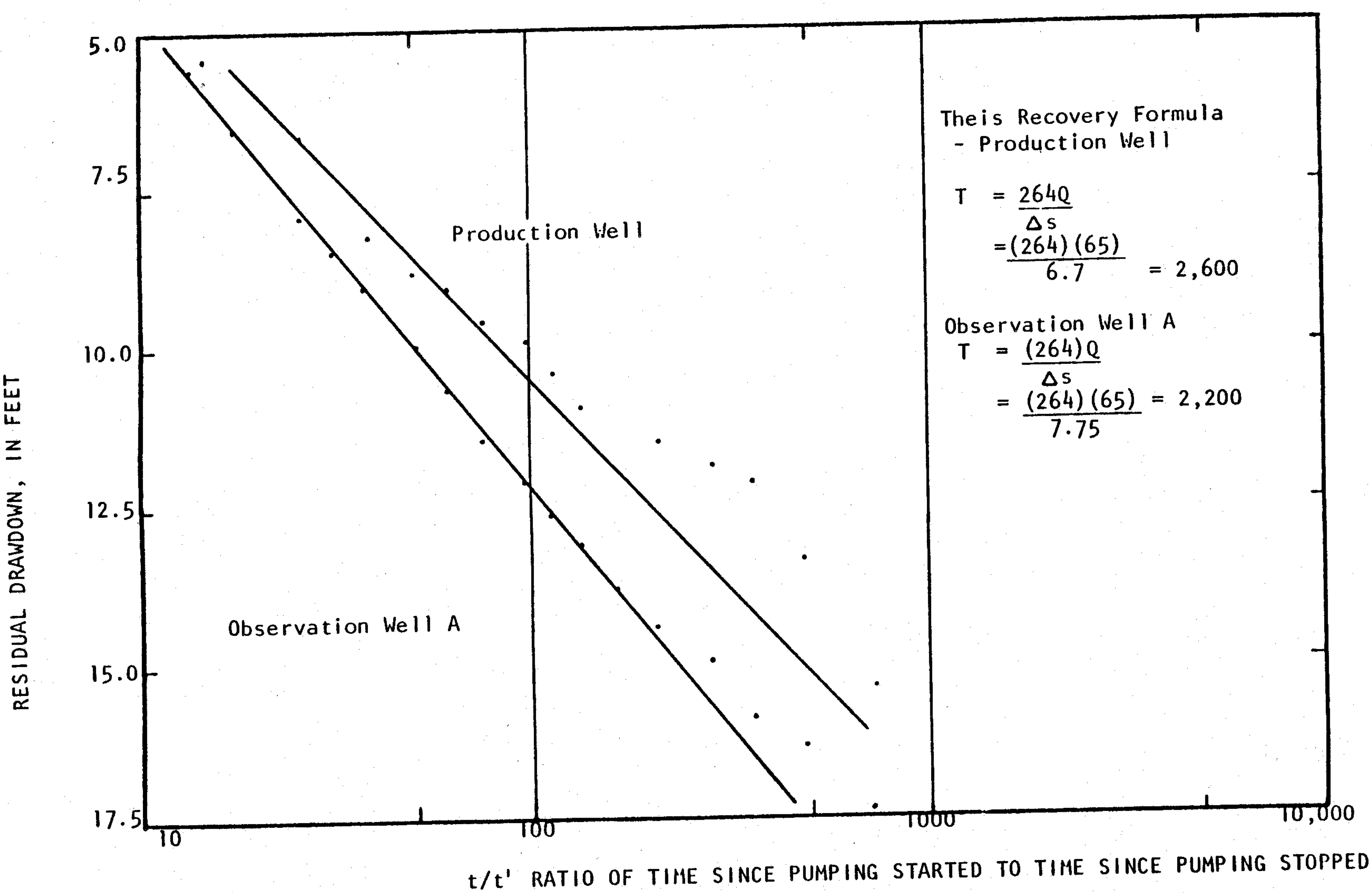
Source: State Water Control Board

SEMI-LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN OBSERVATION WELL B
FENTRESS NAVAL AIR STATION



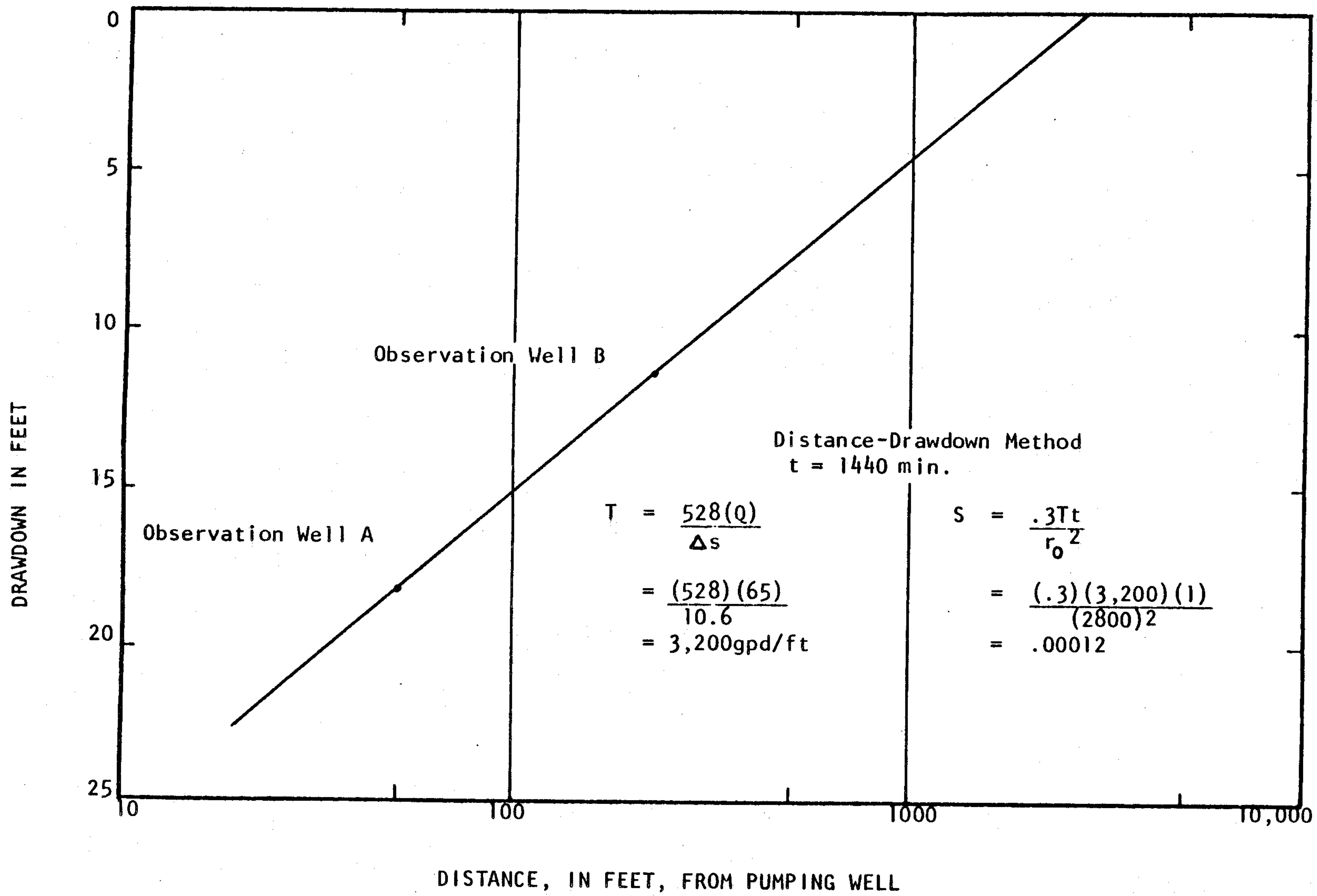
Source: State Water Control Board

SEMI-LOGARITHMIC PLOT OF WATER LEVEL RECOVERY IN THE PRODUCTION WELL AND OBSERVATION WELL A, FENTRESS NAVAL AIR STATION



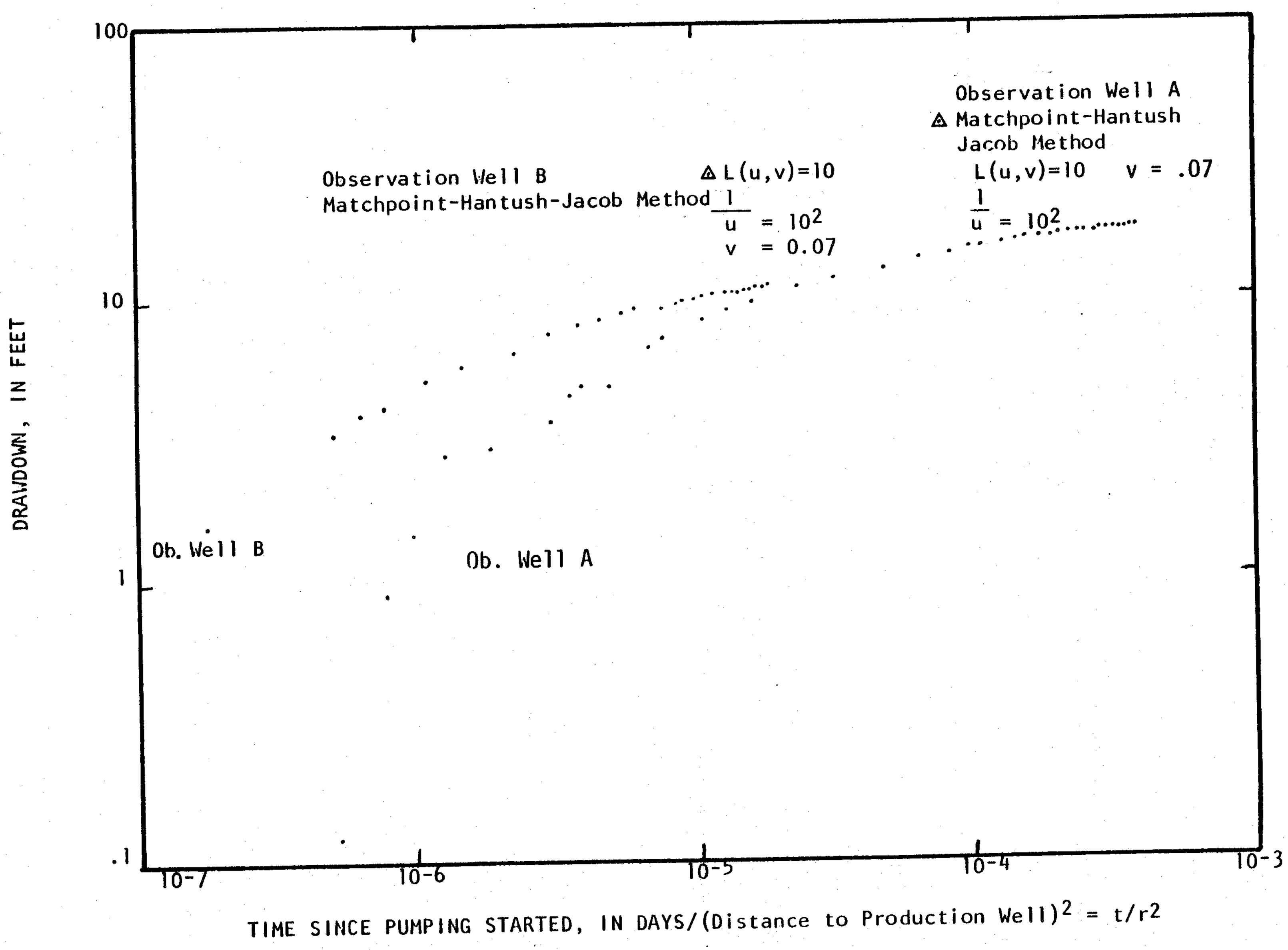
Source: State Water Control Board

SEMI-LOGARITHMIC PLOT OF DISTANCE-DRAWDOWN DATA
FENTRESS NAVAL AIR STATION

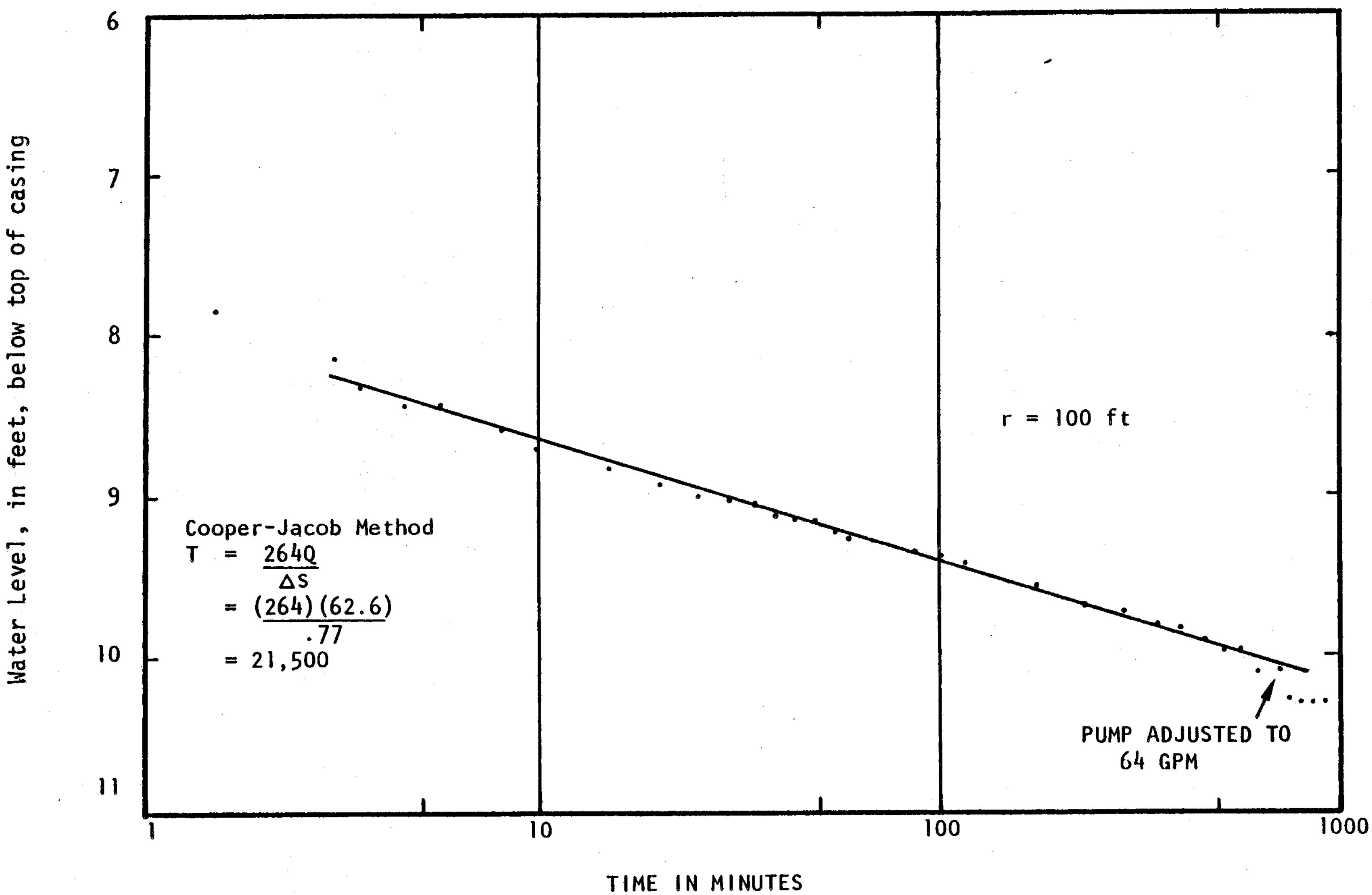


Source: State Water Control Board

LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN OBSERVATION WELLS A AND B, FENTRESS NAVAL AIR STATION

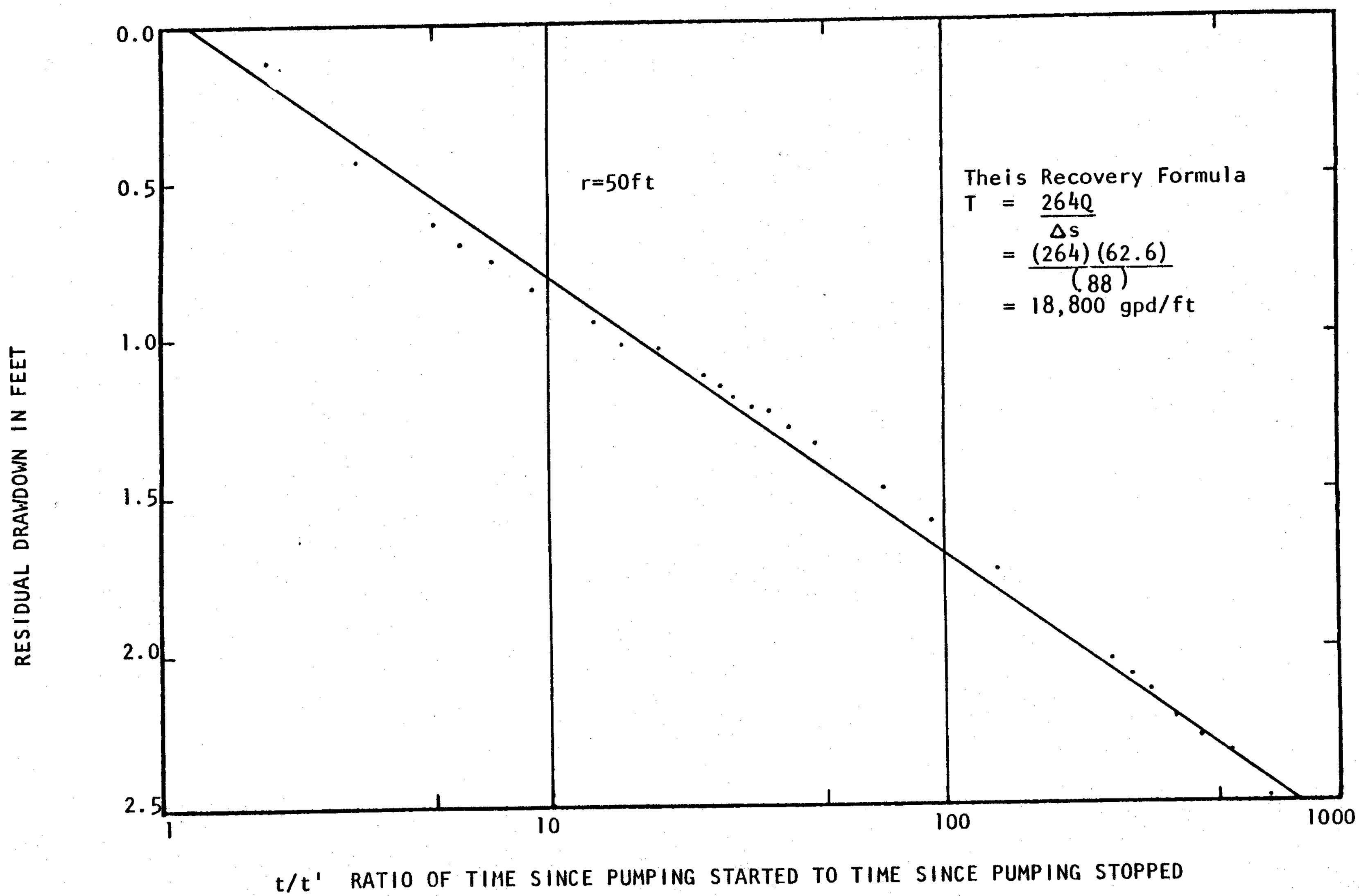


SEMI-LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN OBSERVATION WELL D,
TIDEWATER COMMUNITY COLLEGE RESEARCH STATION



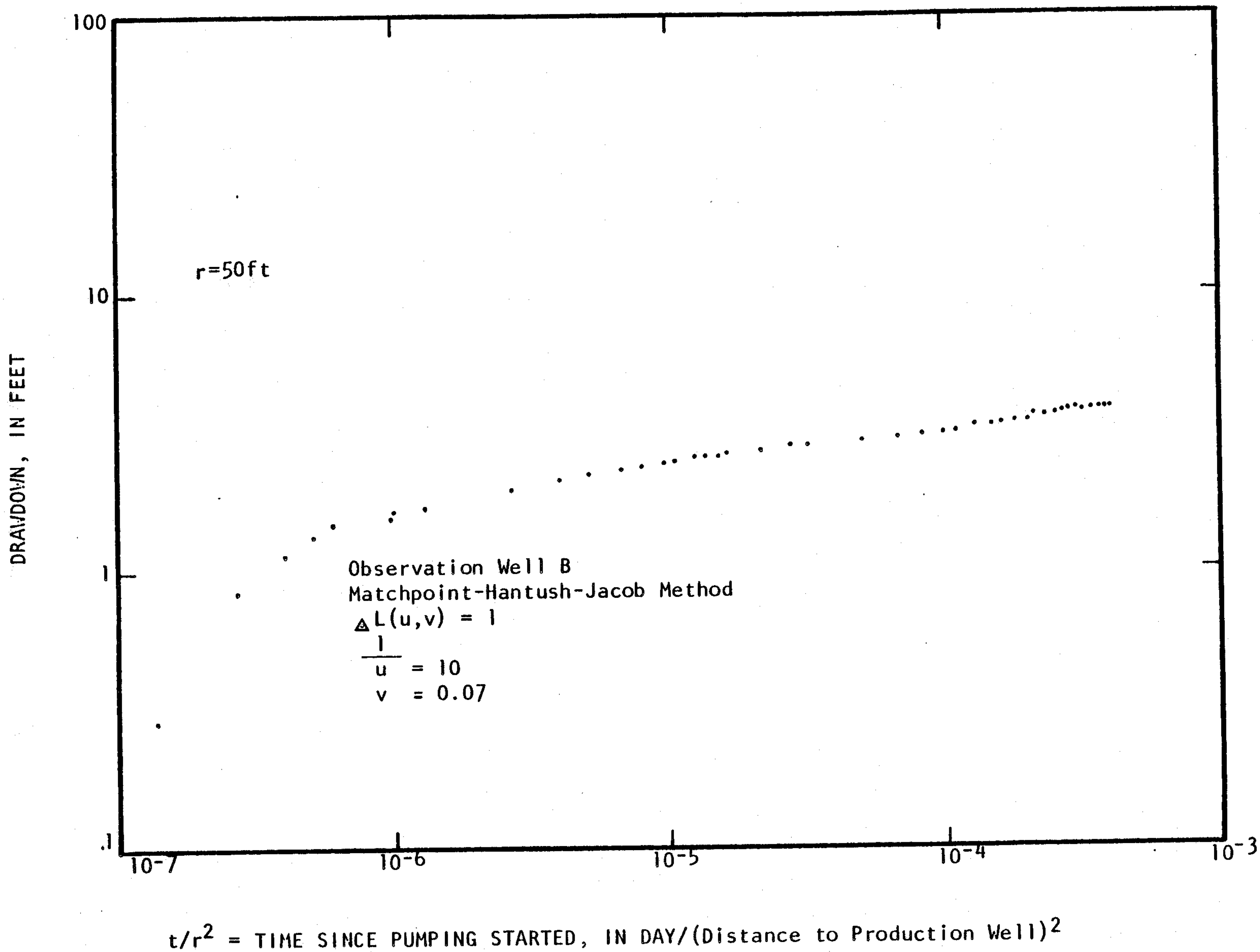
Source: State Water Control Board

SEMI-LOGARITHMIC PLOT OF WATER LEVEL RECOVERY IN OBSERVATION WELL B
TIDEWATER COMMUNITY COLLEGE RESEARCH STATION

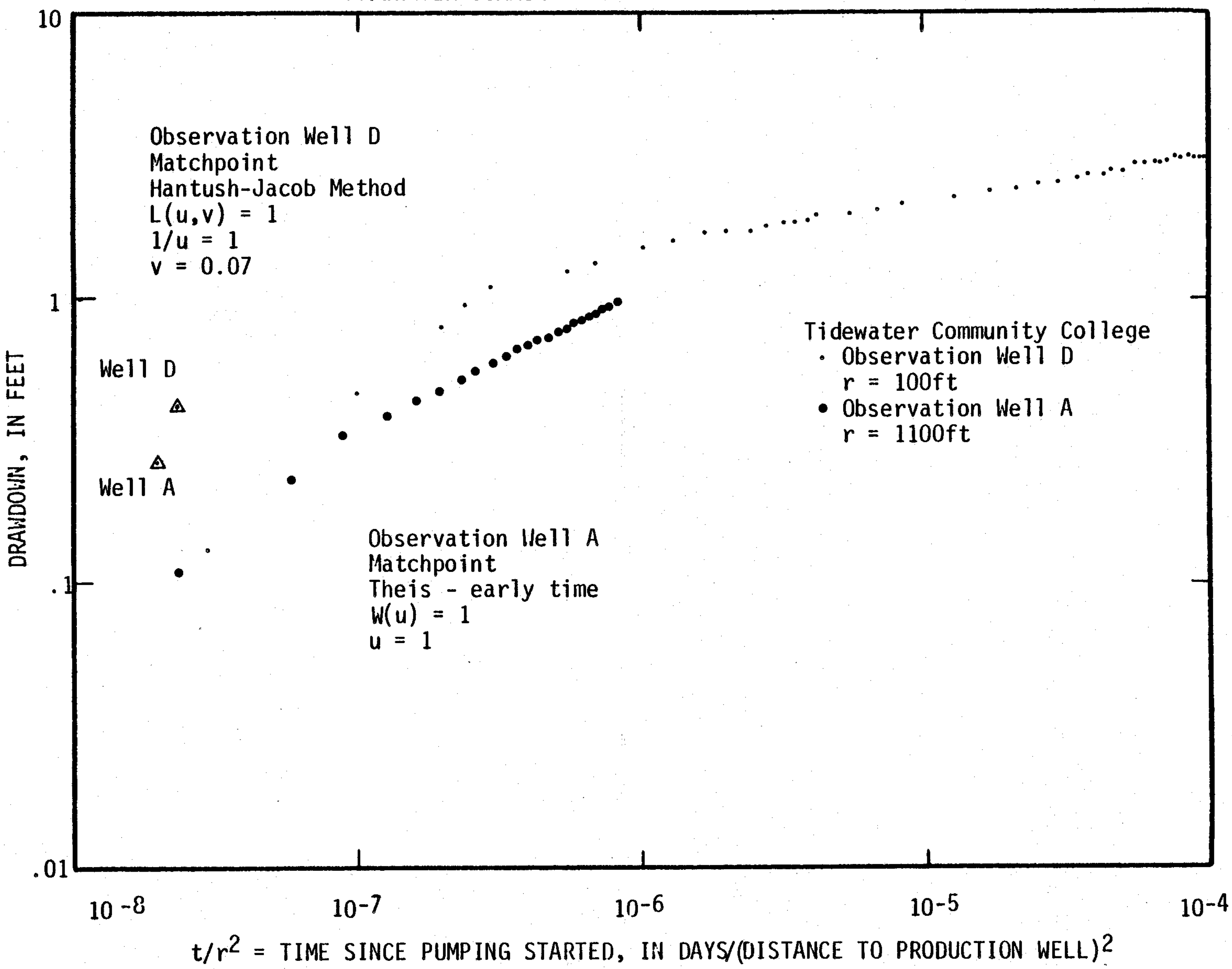


Source: State Water Control Board

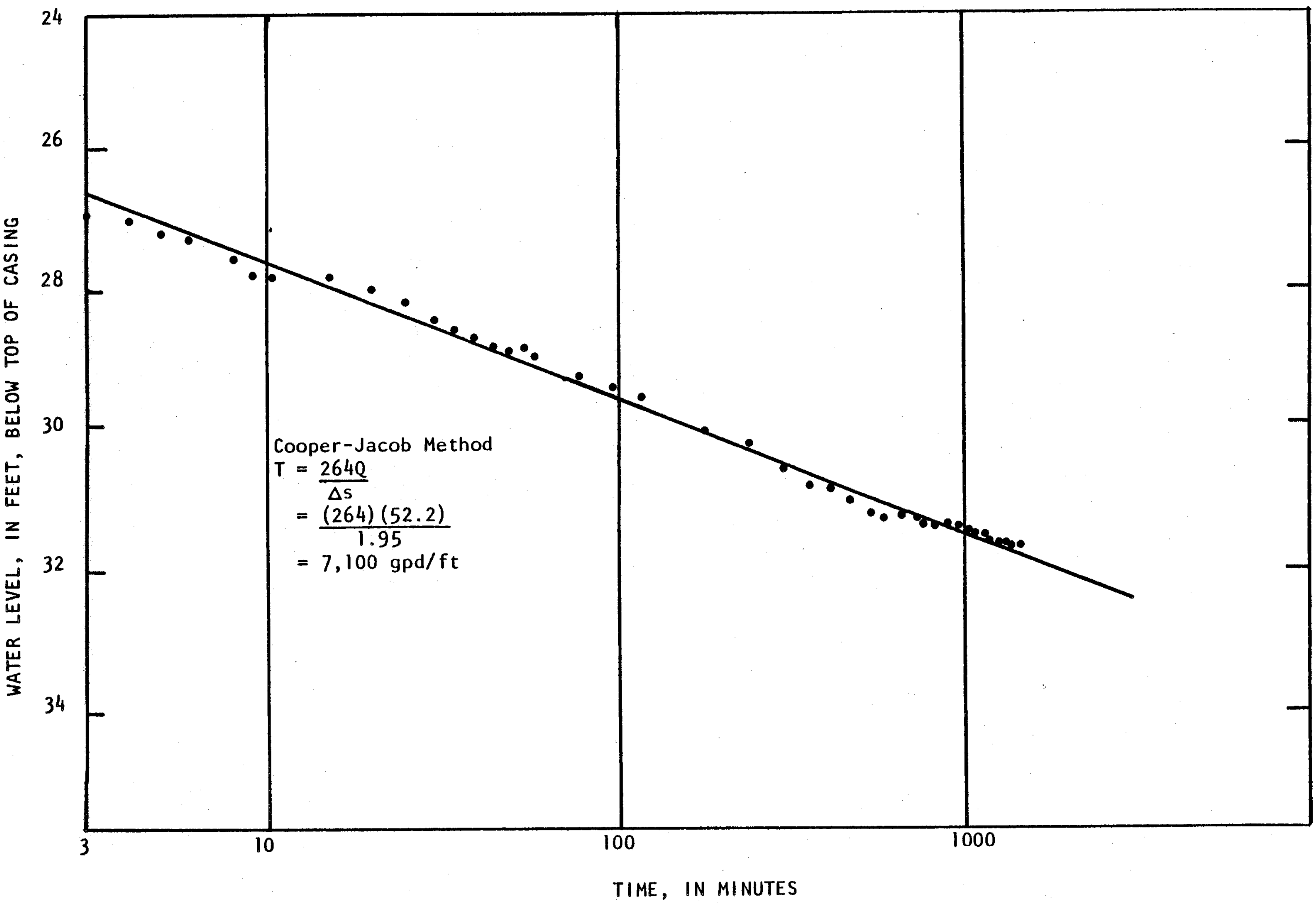
LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN OBSERVATION WELL B,
TIDEWATER COMMUNITY COLLEGE RESEARCH STATION



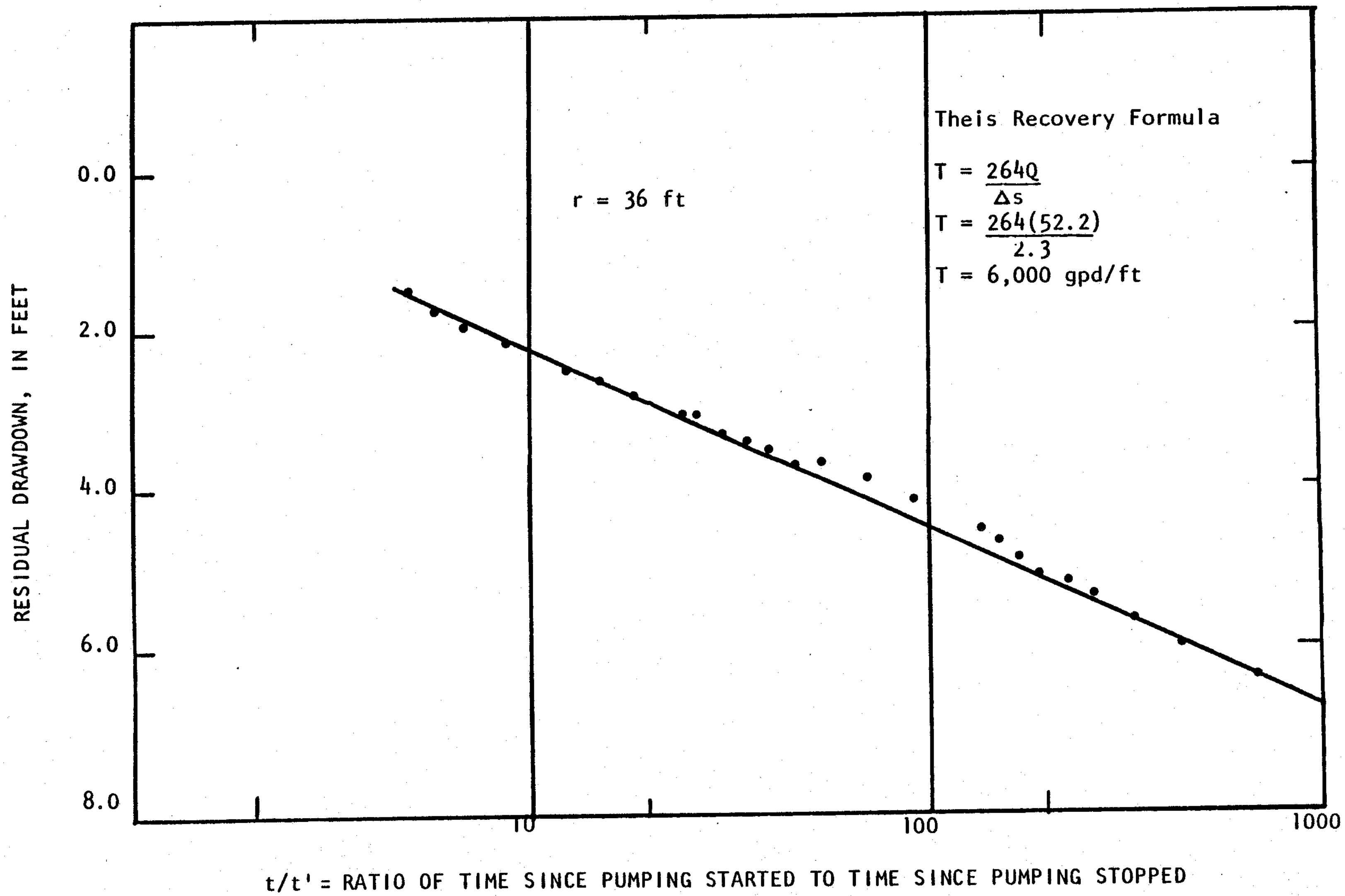
LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN OBSERVATION WELL A AND D, TIDEWATER COMMUNITY COLLEGE RESEARCH STATION



SEMI-LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN PUMPING WELL
PRINCESS ANNE COURTHOUSE RESEARCH STATION

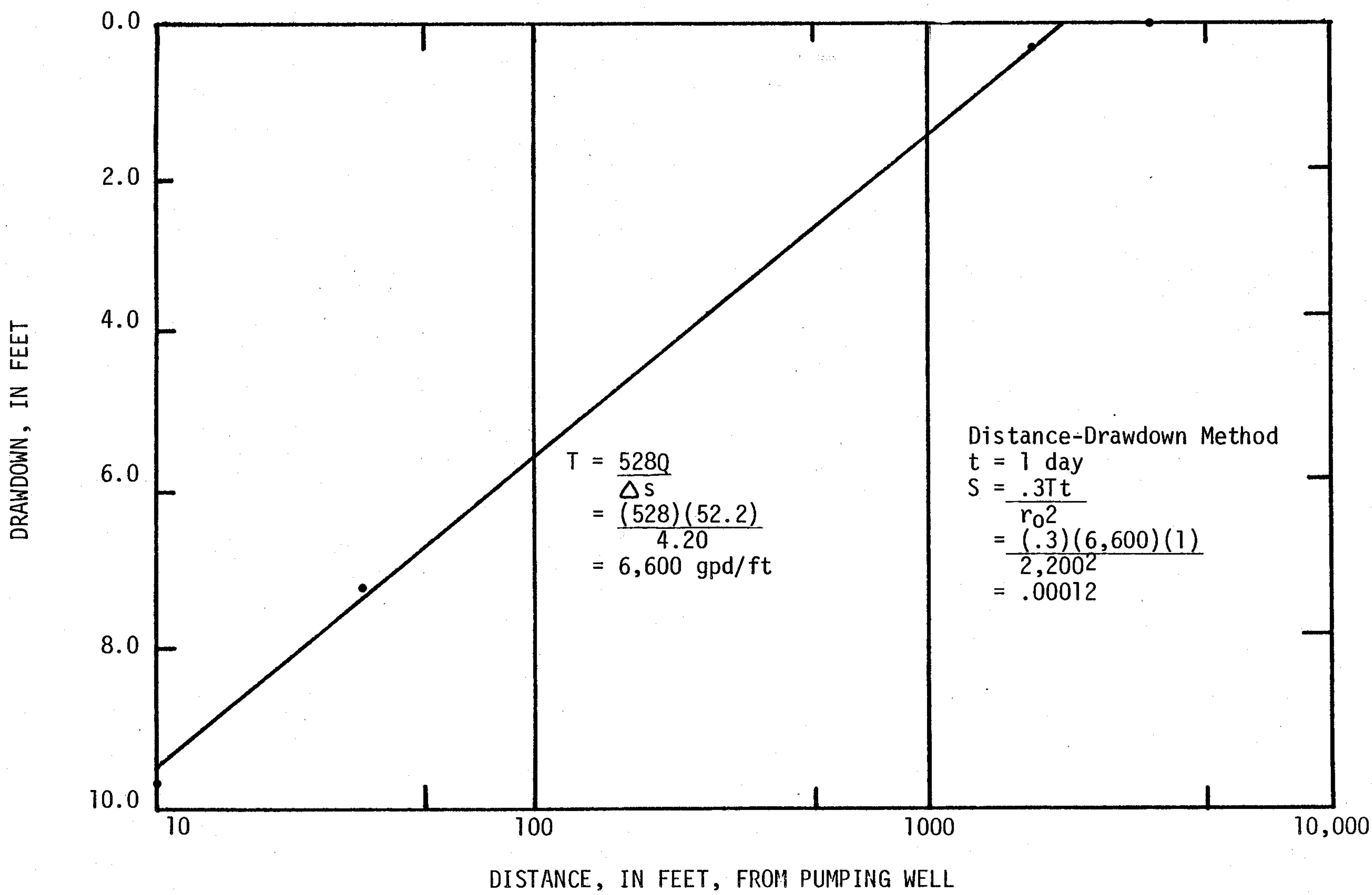


SEMI-LOGARITHMIC PLOT OF WATER-LEVEL RECOVERY IN OBSERVATION WELL A
PRINCESS ANNE COURTHOUSE RESEARCH STATION

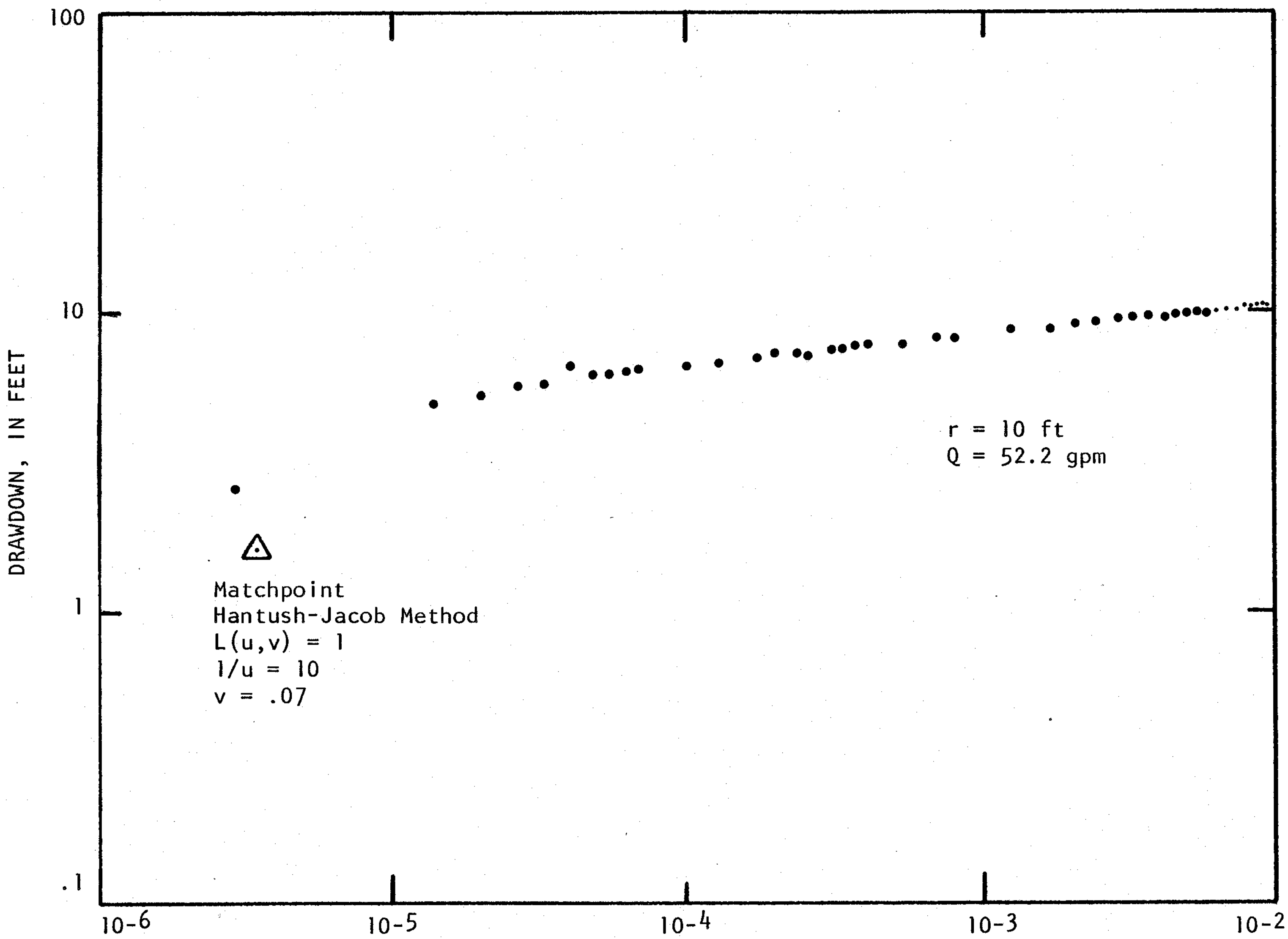


SOURCE: STATE WATER CONTROL BOARD

SEMI-LOGARITHMIC PLOT OF DISTANCE DRAWDOWN DATA
PRINCESS ANNE COURTHOUSE RESEARCH STATION

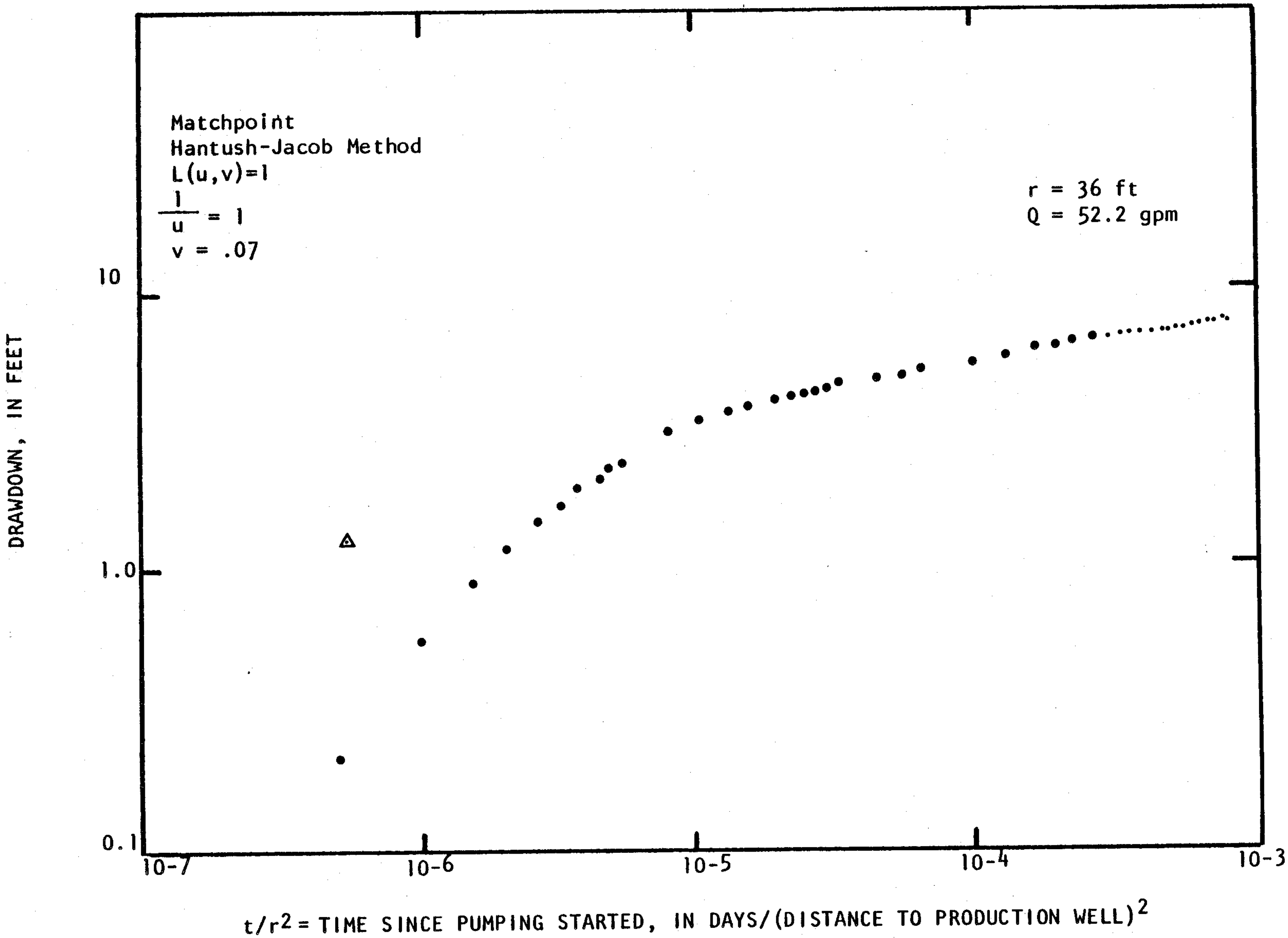


LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN OBSERVATION WELL C
PRINCESS ANNE RESEARCH STATION

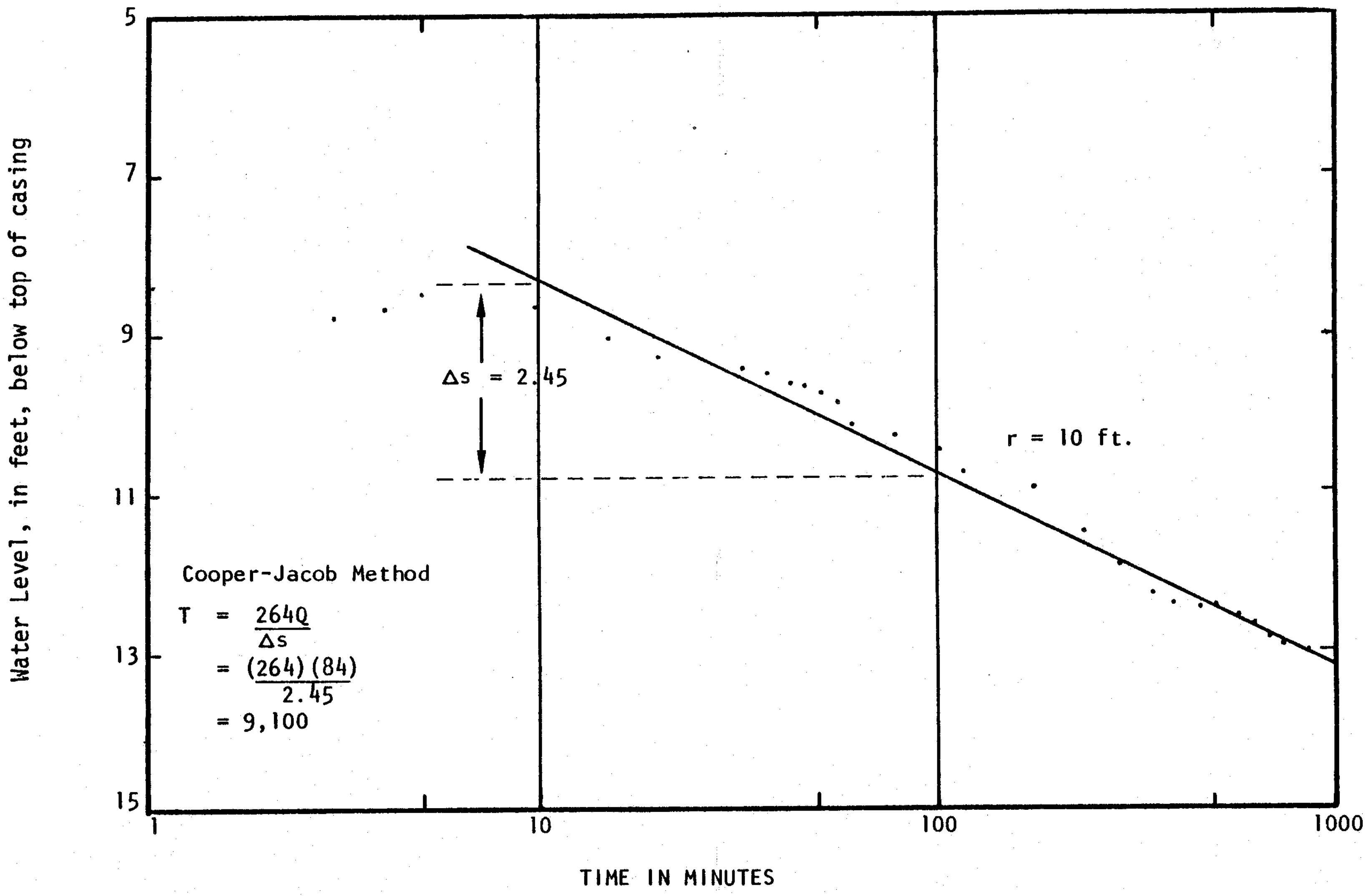


t/r^2 = TIME SINCE PUMPING STARTED, IN DAYS/(DISTANCE TO PRODUCTION WELL)^2

LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN OBSERVATION WELL A
PRINCESS ANNE RESEARCH STATION

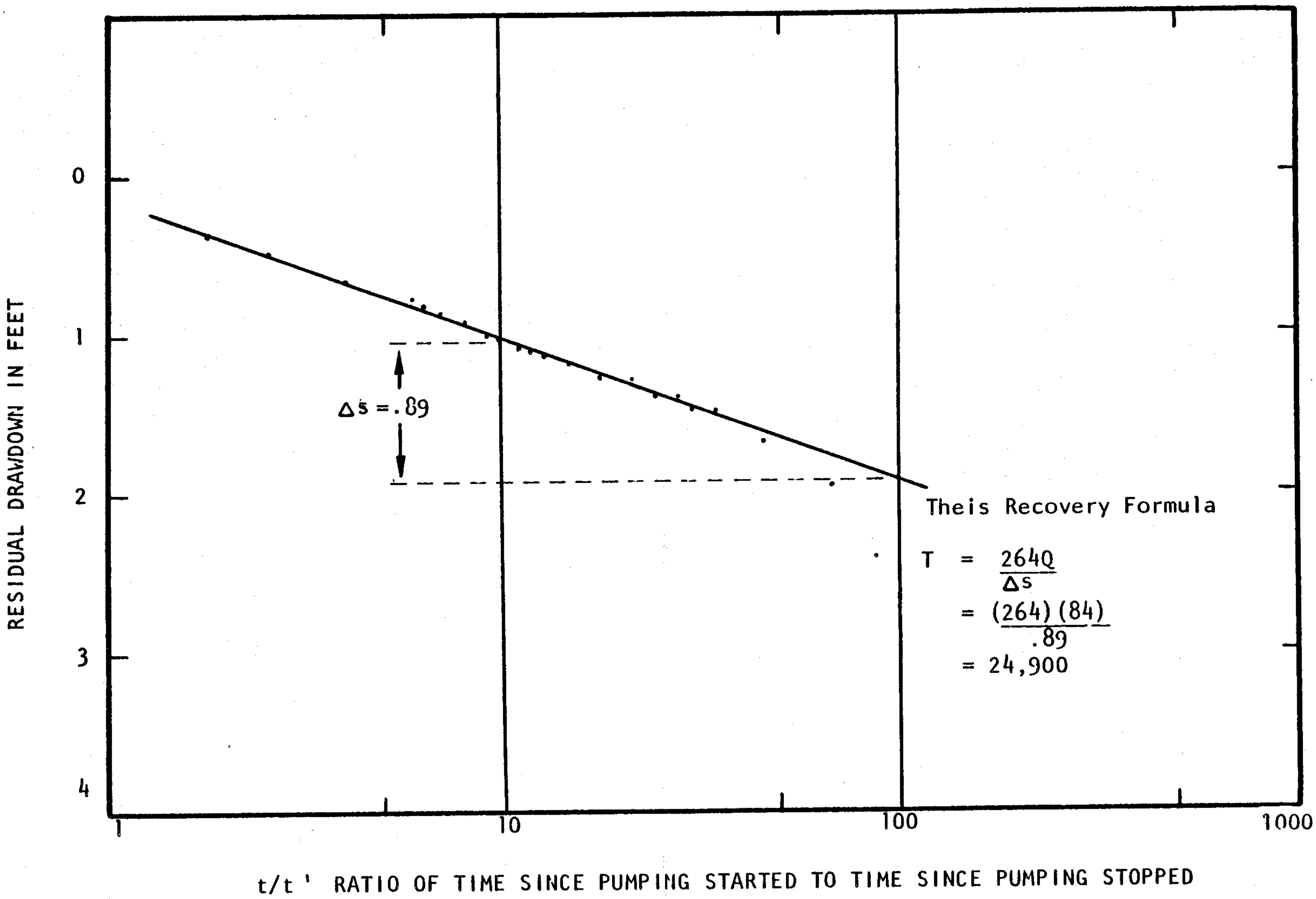


SEMI-LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN OBSERVATION WELL E, OCEANA NAVAL AIR STATION RESEARCH STATION



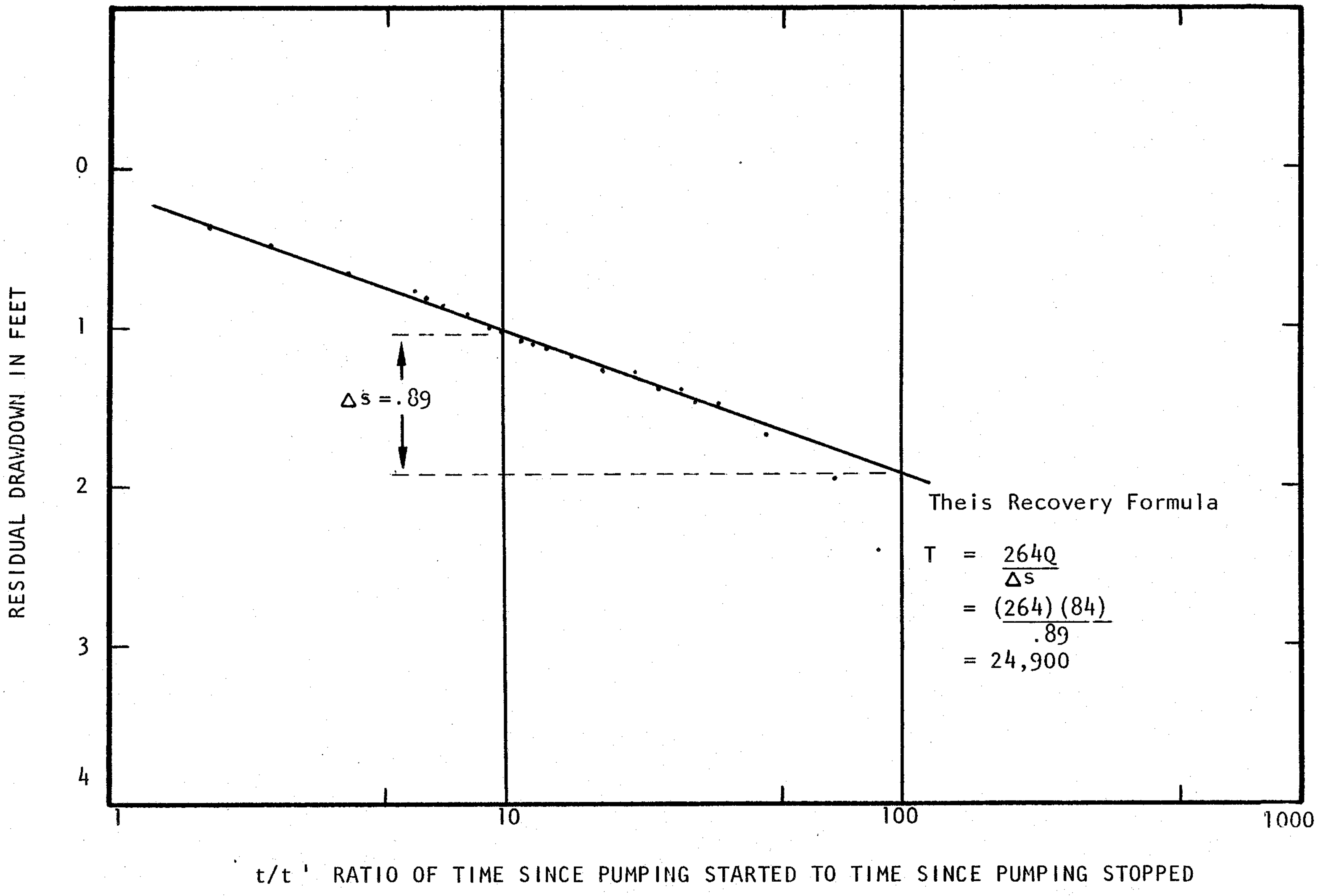
Source: State Water Control Board

SEMI-LOGARITHMIC PLOT OF WATER LEVEL RECOVERY IN PUMPING WELL, OCEANA NAVAL AIR STATION RESEARCH STATION



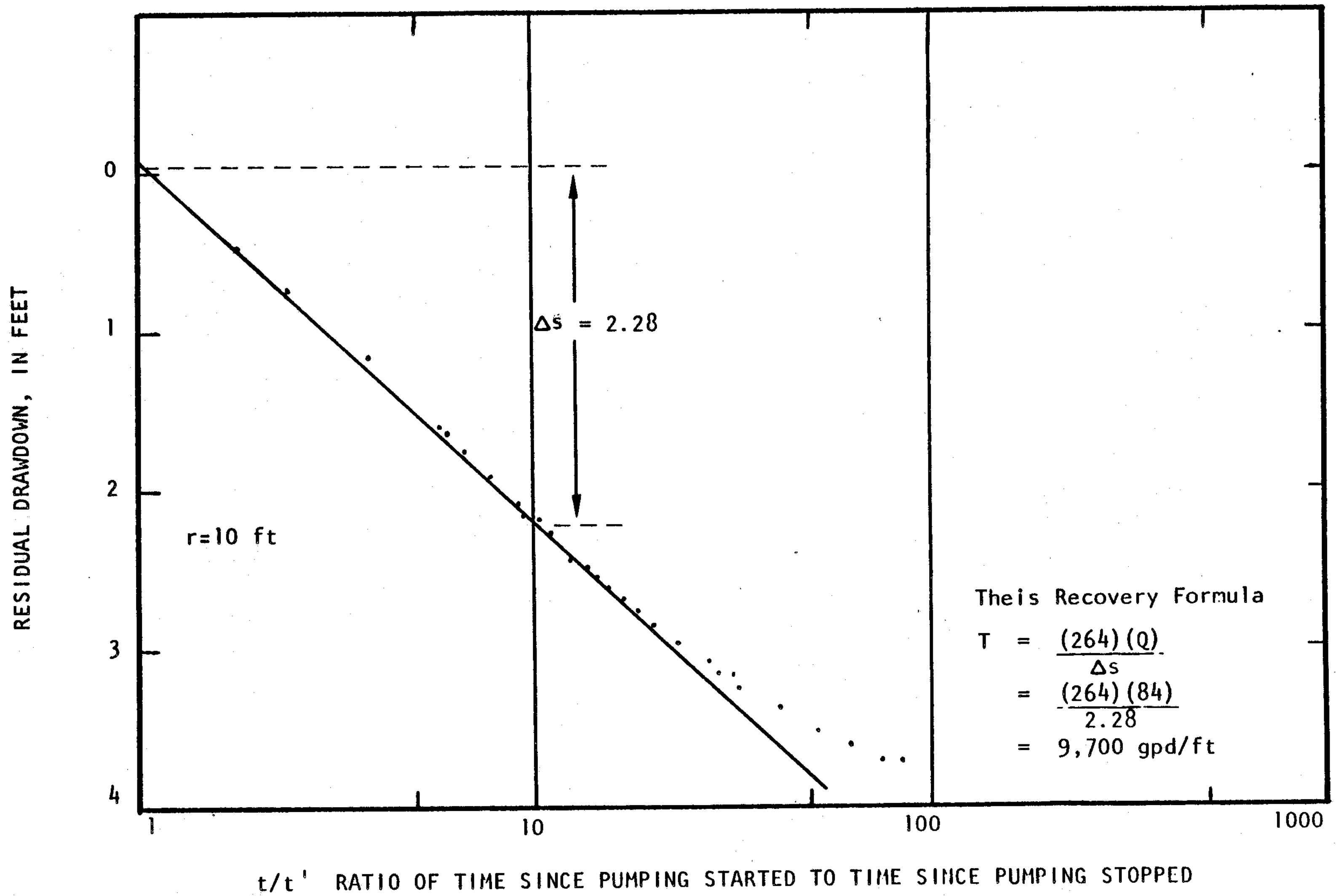
Source: State Water Control Board

SEMI-LOGARITHMIC PLOT OF WATER LEVEL RECOVERY IN PUMPING WELL,
OCEANA NAVAL AIR STATION RESEARCH STATION



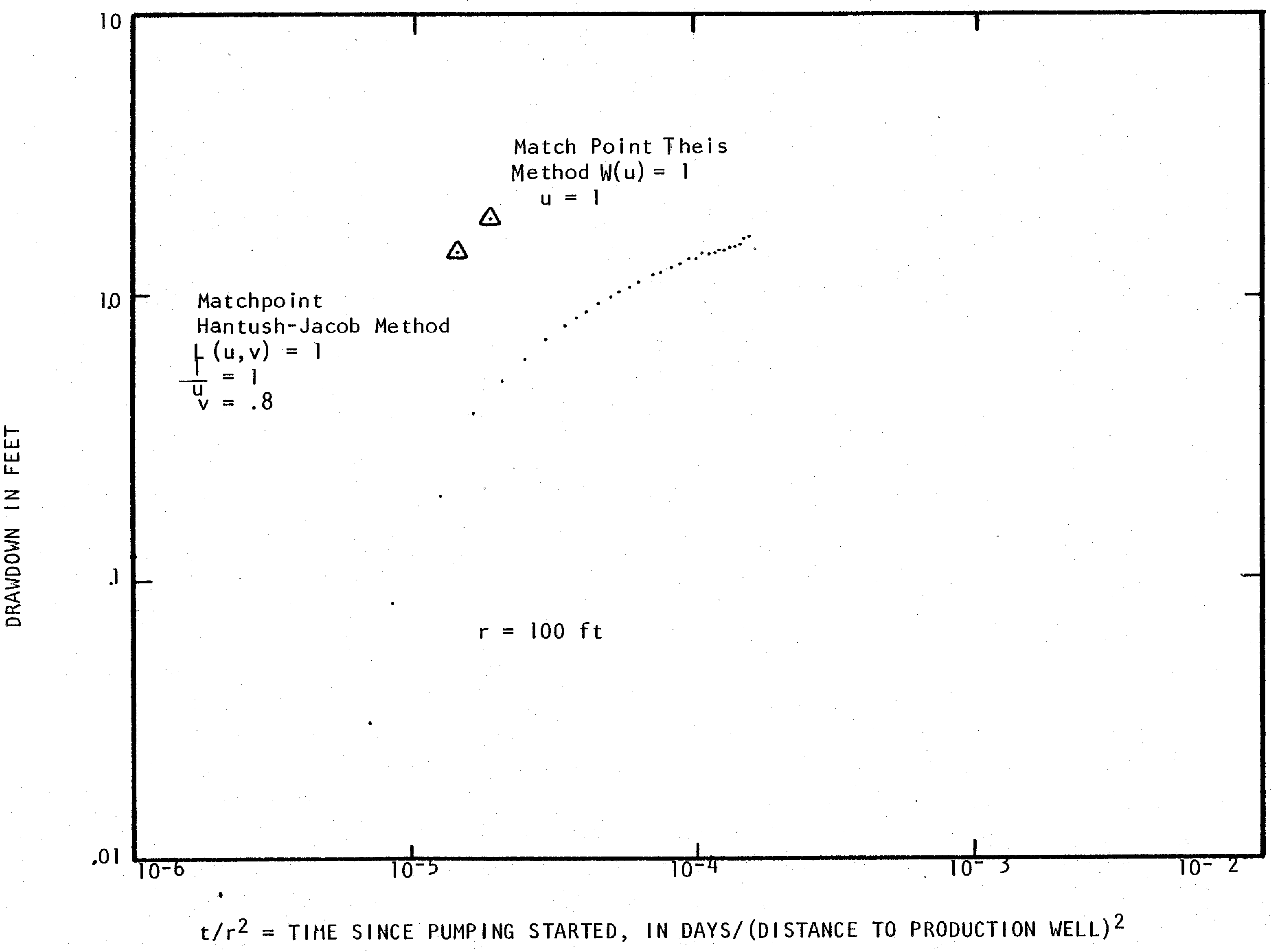
Source: State Water Control Board

SEMI-LOGARITHMIC PLOT OF WATER-LEVEL RECOVERY IN OBSERVATION WELL E, OCEANA NAVAL AIR STATION RESEARCH STATION

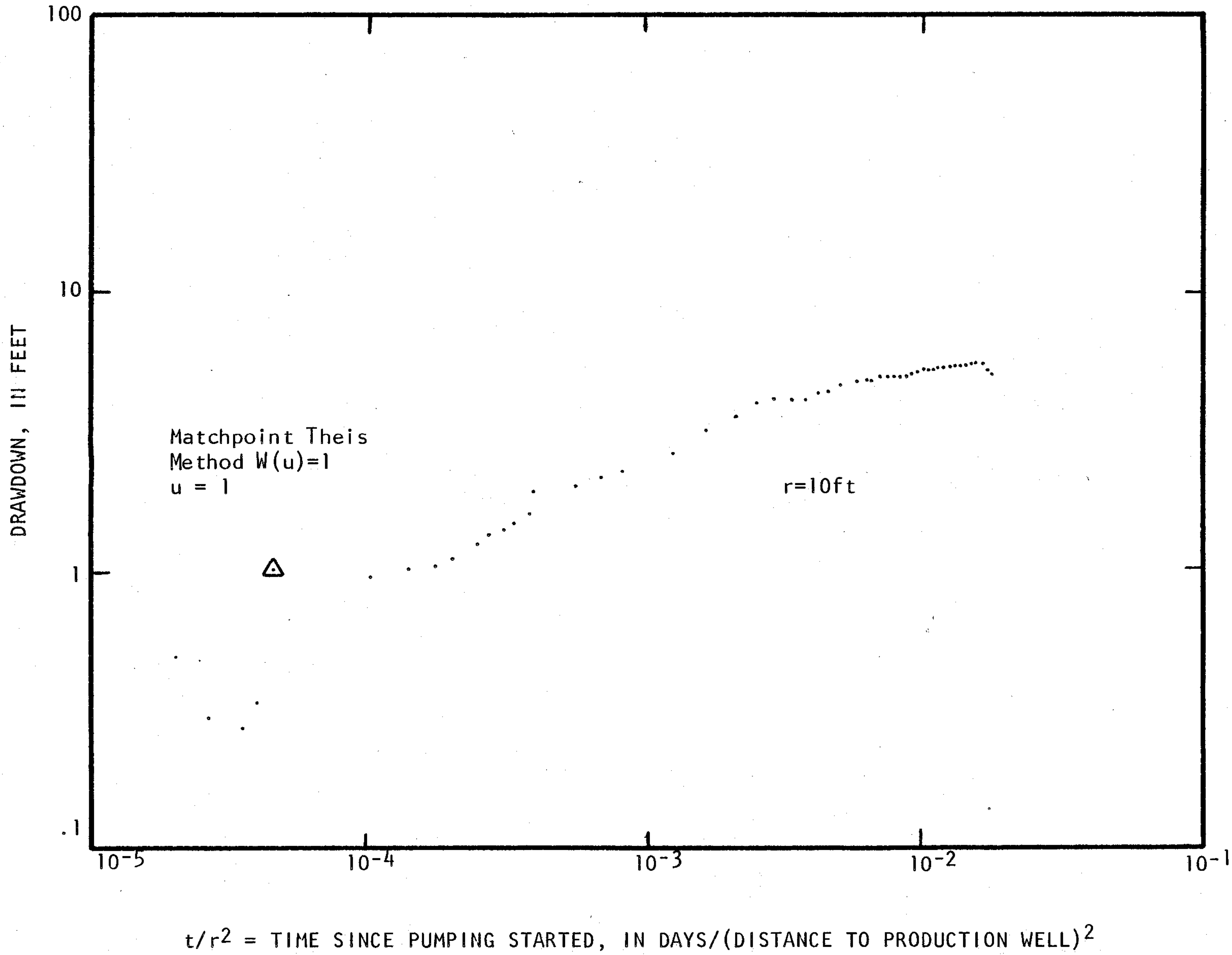


Source: State Water Control Board

LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN OBSERVATION WELL C, OCEANA NAVAL AIR STATION RESEARCH STATION



LOGARITHMIC PLOT OF WATER-LEVEL DRAWDOWN IN OBSERVATION WELL E,
OCEANA NAVAL AIR STATION RESEARCH STATION



APPENDIX E

GROUND WATER QUALITY DATA

This appendix contains chemical quality data on the ground water of the Four Cities Area. The data listed in the Table includes the following:

- State Water Control Board Number (cross reference to Figure 20)
- Owner and/or Location of the Well
- Date Sampled
- Aquifer, abbreviated as the following:
  - Water Table (WT)
  - Upper Yorktown (UYK)
  - Middle Yorktown (MYK)
  - Lower Yorktown (LYK)
  - Eocene-Upper Cretaceous (EUCR)
  - Cretaceous (CR)
  - Lower Cretaceous (LCR)
- Screens Depths in Well (feet); "I" indicates well screens at intervals between two depths shown.
- All chemical constituents in Table expressed in milligrams per liter, unless indicated otherwise:

Alkalinity	Calcium (Ca)
Dissolved Solids (TDS)	Iron (Fe)
Chloride (Cl)	Magnesium (Mg)
Hardness	Manganese (Mn)
Nitrite & Nitrate (NO_2 & NO_3)	Zinc (Zn)
Fluoride (F)	Sodium (Na)
Total Organic Carbon	Potassium (K)
Sulfate	
Specific Conductance (micro-mhos/cm)	
pH (Standard Units)	

Any value expressed with a dash after the number, such as 0.1-, indicates that the value is the detectable limit for the laboratory test.

The data is a listing of water samples collected by the State Water Control Board, other governmental agencies, and private testing laboratories.

The following page contains standards and descriptions of several of the parameters listed in the Table.

GROUNDWATER QUALITY PARAMETERS

Substance	Maximum Recommended Concentration (mg/l)*	Remarks
Bicarbonate	150	Seldom considered detrimental; lower amounts recommended for washing.
Calcium	200	Seldom a health concern; may be a disadvantage in washing, laundry, bathing; encrustations on utensils.
Chloride	**250 (Esthetics)	Taste is a major criterion; generally not harmful unless in very high concentrations, but may be injurious to suffers of heart and kidney diseases; sea water is 19,000 mg/l.
Fluoride	**1.8 (Health)	Presence of about 1.0 mg/l may be more beneficial than detrimental; more than 1.8 mg/l may mottle teeth; extreme doses (4 grams) may cause death.
Hardness (as $CaCO_3$)	0-60 Soft 61-120 Md. Hard 121-180 Hard Above 180 Very Hard	Hard waters have had no demonstrable harmful effects upon the health of consumers; major detrimental effect is economic--values above 100 mg/l become increasingly inconvenient; wastes soap and causes utensil encrustation.
Iron	**0.3 (Esthetics)	Essential to nutrition and not detrimental to health unless in concentrations of several milligrams; main problems are bad taste, staining and discoloration of laundry and porcelain fixtures.
Magnesium	150	Not a health hazard because taste becomes extremely unpleasant before toxic concentrations reached; may have laxative effect on new users.
Manganese	**0.05 (Esthetics)	Essential to nutrition but may be toxic in high concentrations; taste becomes problem before toxic concentrations reached; undesirable because it causes bad taste, deposits on cooked food, stains and discolors laundry and plumbing fixtures.

GROUNDWATER QUALITY PARAMETERS (Contd)

Substance	Maximum Recommended Concentration (mg/l)*	Remarks
Nitrate	**10 as N, 45 as NO_3	May be extremely poisonous in high concentrations; may cause disease in infants ("blue baby"); irritates bladder and gastro-intestinal tract, may cause diarrhea.
pH	5.5-8.0	Indicates whether solution will act as an acid or base; water acquires "sour" taste below 4; high values favor corrosion control; efficiency of chlorination severely reduced when pH above 7.
Potassium	1000-2000	May act as a laxative in excessive quantities.
Sodium	100	May be harmful to suffers of cardiac, circulatory, or kidney disease; concentrations as low as 200 mg/l may be injurious.
Solids (Total Dissolved)	500	Not a health hazard above 500 mg/l, but may impart disagreeable taste, corrode pipes; general indicator of how highly water is mineralized.
Specific Conductivity	1000	An indicator of the amount of dissolved solids in water; high concentrations can cause corrosion of iron and steel.
Sulfate	**250 (Esthetics)	Above 250 mg/l may act as laxative on new users; may impart foul taste and odor.

* Recommended concentrations based on current literature

** Actual limits established by the Virginia Department of Health; parentheses ( ) indicate basis for limit

Source: McKee and Wolf (1963); Virginia Department of Health

GROUNDWATER QUALITY - CITY OF NORFOLK

SWCB NUMBER	OWNER AND/OR PLACE	DATE	AQUIFER	SCREEN	DEPTH	pH (Lab)	ALKALINITY	DISSOLVED SOLIDS	CHLORIDE	HARDNESS	NITRITE & NITRATE	FLUORIDE	TOTAL ORGANIC CARBON	SPECIFIC CONDUCTANCE	SULFATE	METALS Ca	Fe	Mg	Mn	Zn	Na	K
217-1	Lake Wright Golf Course	4/17/75	MYK	75	105		176	305	58	160	1.13	0.1		500	2.0	53	0.0	6			44	5
217-2	Norfolk General Hospital	9/11/78	UYK	63	68	7.8	230	1253	86	433	.05	0.1	7	1700	14	150	3.9	25	.31	.01	180	13
		9/02/80	UYK	63	68	7.4	216	1286	445	440	.05	0.1	16	2042	20	139	5.8	27	.37		183	12
217-6	Moores Bridges - USGS Test Well	1/24/68	LCR	848	868	7.8		2300	964	54	.70	1.9		3900	102	10	0.1	7	.03	.03	818	23
		1/22/68		943	963	7.8		2950	1380	79	1.20	1.3		5080	137	15	0.9	10	.04	.04	1110	26
		1/22/68		1037	1057	7.8		3440	1680	101	1.00	1.1		5940	140	20	0.1	13	.05	.05	1290	27
		1/20/68		1257	1277	7.4		7630	4200	499	1.60	0.5		12600	242	105	1.2	58	.22	.09	2620	52
		1/17/68		1614	1634	6.9		17200	9560	2070	2.50	0.4		26400	410	480	14.0	209	1.30	.20	5280	87
		12/18/67		2370	2391	7.1		45100	26000	10280	1.15	0.5		61300	1020	2660	16.0	854	11.00	.20	12600	124
		12/16/67		2499	2520	6.4		47700	26900	10900	1.11	0.5		63800	1050	2940	16.0	846	13.00	.22	12800	123
		2/21/68		900	960	8.4		2820	1280	68	.61	1.5		4840	135	14	.05	8	.05	.04	1045	25
217-21	Sheller-Globe Corp. #1	12/21/77	LYK	100	120	7.4	180	560	49	228	.05	0.1	9	835	165	130	0.8	8	.05	.01	40	4
		12/7/78	LYK	100	120	8.0	180	848	71	353	.05	0.1	1-	854	202	130	0.1	8	.03	.01	38	4
217-22	Sheller-Globe Corps. #2	12/21/77	LYK	100	120	7.5	242	601	78	328	.05	0.1	6	926	135	120	0.8	9	.05	.01	71	5
		3/15/79	LYK	100	120	7.9	196	495	57	260	.10	0.3	7	757	90	50	0.8	7	.05	.04	31	4
217-50	Sheldon-Arcade	1/17/68	LCR	745	765				582	23					56		.02					
217-51	DePaul Hospital	11/8/77	MYK	66	71	7.4	172		130	160				550			0.3		0			
217-55	F&M Bank	8/3/78	LCR	740	773	8.4	431	1263	420	18	.15	4.2	6	2184	100	6	0.3	3	.01	.04		14
217-63	Police Pistol Range	6/18/79	MYK	93	101	7.8	220	394	77	157	.13	0.1	9	688	3	45	0.1-	100	.05	.01	81	86
217-64	J. H. Miles Co.	6/14/79	LCR	790	890	7.5	392	1136	389	16		3.2			39	3	0.3	2	.02			
217-65	National Medical Care	9/19/79	MYK	70	78	7.6			130	188		0.4				53		11			93	10
		8/24/79	MYK	70	78	7.9	214	524	140	184	.05	0.1	6	876	2	47	0.2	13	.13	.05	154	11
217-66	Compeco Cleaners	2/25/81	LCR	820	830	8.1	388	1531	520	28	.05	2.3	14	3200	70	4.4	0.1-	3	.01	.31	590	16
217-70	Werner Miller-Ellsworth	4/22/81	WT	28	43	6.7	100	212	41	112	.05	0.1	6	444	3	29	16.0	6	.37		19	4
217-71	James Williams-Roosevelt Gardens	4/23/81	WT	13		6.4	62	211	26	62	.05	0.1	11	573	98	17	14.0	4	.10		42	4

GROUNDWATER QUALITY - CITY OF PORTSMOUTH

SWCB NUMBER	OWNER AND/OR PLACE	DATE	AQUIFER	SCREEN DEPTH		pH (Lab)	ALKALINITY	DISSOLVED SOLIDS	CHLORIDE	HARDNESS	NITRITE & NITRATE	FLUORIDE	TOTAL ORGANIC CARBON	SPECIFIC CONDUCTANCE	SULFATE	METALS						
																Ca	Fe	Mg	Mn	Zn	Na	K
220-1	Va. Chemicals #1	7/19/74	LCR	579	603	8.2	377	826	211	36		1.2				9	0.1	3		.03	325	12
220-2	Va. Chemicals #2	12/21/77	LYK	137	157	8.2	380	883	228	6	.40	3.6	13	1525	38	5	0.1-	2	.01-	.04	380	12
220-3	Va. Chemicals #3	12/21/77	LCR	642	714	8.2	433	997	257	22	.05-	4.0	12	1747	38	4	0.1-	2	.01-	.03	440	14
220-4	Pinners Point	7/19/74	LCR	750	850	7.9	407	1054	334	16		1.1				3	0.1	2			450	12
		3/15/79	LCR	750	850	8.2	409	1118	328	16	.05-	3.8	6	1767	39	4	0.1	2	.02	.02	459	13
220-10	Murro Chemical Co.	3/08/78	LCR	720	760	7.9	431	1052	273	14	.05-	3.7	11			6	0.4	4	.03	.02	400	16
220-12	Lone Star - Port Norfolk	5/10/78	LCR	700		8.0	416	1077	300	14	.48	4.0	16	1821	41	4	0.3	2	.01-	.3	410	13
C-5	J. S. Wright - Churchland	8/05/39	UYK	62					27	164		0.5			36							
220-24	Shared Hospital Services	2/25/81	LCR	638	658	8.2	452	817	158	8	.05-	3.9	20	161	24	2	0.1-	1	.01-	.02	320	9
220-26	D. Kay - Churchland	6/8/81	WT	35	37	6.5	40		12	31	.05-	0.1	1	121	4	7	6.2	2	.08		4	1

GROUNDWATER QUALITY - CITY OF VIRGINIA BEACH

SWCB NUMBER	OWNER AND/OR PLACE	DATE	AQUIFER	SCREEN DEPTH		pH (Lab)	ALKALINITY	DISSOLVED SOLIDS	CHLORIDE	HARDNESS	NITRITE & NITRATE	FLUORIDE	TOTAL ORGANIC CARBON	SPECIFIC CONDUCTANCE	SULFATE	METALS						
																Ca	Fe	Mg	Mn	Zn	Na	K
228-1	Virginia House	6/19/64	CR	345I	1307	7.8	306	10792	5041	397		0.4			211	116	0.8	26	.05			
228-2	Holland Road Water Co. #1	6/19/64	MYK	62	67	7.8	418	686	96	93							1.9					
		6/19/64	MYK	93	98	7.9	395	692	112	91							2.0					
		6/19/64	LYK	115	120	8.1	400	696	134	84							1.0					
		1/30/79	YK	62I	120	7.9	287	918	340	318	.05-	.10+	9	1615	5	54	0.8	42	.03	.06	177	25
228-3	Holland Road Water Co. #2	6/30/64	MYK	58	63	7.5	285	516	131	285							1.4					
		6/30/64	MYK	76	81	7.6	289	552	137	287							1.4					
		6/30/64	LYK	112	117	7.8	305	708	209	302							1.2					
		8/02/79	MYK	62	95	8.1	292	839	264	316	.06	.10+	2	1436	3	56	2.4	45	.04	.01+	220	28
228-4	Holland Road Water Co. #3	7/18/64	MYK	63	68	7.6	265	528	131	269							1.2					
			MYK	89	94	7.7	280	624	170	288							1.0					
			LYK	115	120	7.7	296	708	212	302							1.6					
228-7	Lakeville Estates #1	12/09/80	MYK	78	98	7.4	108	193	14	114	.05-	.11	6	306	13	34	5.3	5	.11		12	3
228-8	Lakeville Estates #2	4/14/65	UYK	52	57	6.8	86	154	24	84		.1					4.6					
		3/11/80	UYK	52	57	7.1	83	139	15	72	.05-	0.1+	6	234	2	20	4.7	2	.06	.01+	12	1.4
228-9	Lakeville Estates #3	12/9/80	LYK	100	120	7.9	186	369	95	156	.05-	.14	10	712	1+	47	4.8	9	.08		73	6.4
228-19	Bradford Acres	12/10/58	MYK	84	94	6.3	28	120	26						6		9.0		.15			
228-33	Oceana Air Sta.	1/13/77	WT	35		7.5	126	206	5	120	.05-	0.2	7			34	0.2	8	.16		23	5
228-40	Southern Materials Company	2/5/79	UYK	50	70	8.0	180	264	21	176	.06	0.1	6	390	2	57	0.7	5	.07	.07	16	2
228-43	J. B. Robinson Boys Home	6/18/53	UYK	40	60	6.6	780		30	14							3.5					
		6/18/53	LYK	115	125				800								1.0					
228-44	Holiday Inn Campground	12/28/77	MYK	62I	112	7.0	80	148	11	59	.05-	0.2	5	199	3	21	0.4	6	.15	.08	13	2
228-47	Living Waters Campground	8/10/72	MYK	69	94	7.7	124	276	49	124		0			1	33	0.3	10	.14			
228-50	Indian Lakes	10/19/72	MYK	74	94	7.5	130	260	64	126		0			2	35	0.3	9	.00			
228-51	Stratford Chase	10/31/72	UYK	52	72	6.7	56	150	19	86		.02			17	28	1.6	4	.00			

GROUNDWATER QUALITY - CITY OF VIRGINIA BEACH CONTD.

SWCB NUMBER	OWNER AND/OR PLACE	DATE	AQUIFER	SCREEN DEPTH		pH (Lab)	ALKALINITY	DISSOLVED SOLIDS	CHLORIDE	HARDNESS	NITRITE & NITRATE	FLUORIDE	TOTAL ORGANIC CARBON	SPECIFIC CONDUCTANCE	SULFATE	METALS						
																Ca	Fe	Mg	Mn	Zn	Na	K
228-53	Creeds Volunteer Fire Department	4/06/78	MYK	75	85	7.2	178	331	113	183	.05-	0.2	13	729	4	60	2.3	11	.16	.18	72	9
228-54	G. Pendleton - Smith Creek	4/15/75	WT	40					64	188		0.2		560								
228-55	Parkers Trading Post	4/12/78	UYK	60		7.2	110	179	21	1-	.05-	0.1	2	278	5	1-	0.1-	1-	.01-	.04	68	1-
228-56	Creeds Elementary School	4/06/78	UYK	57	62	7.7	116	166	9	107	.05-	0.1-	6	259	4	45	0.6	2	.13	.07	9	2
228-57	Indian Cove Campground #1	4/12/78	MYK	86		7.4	250	625	209	256	.05-	0.2	11	1158	4	61	2.3	23	.22	.81	78	13
228-58	Indian Cove Campground #2	4/12/78	UYK	66		7.5	250	623	210	252	.05-	0.2	11	1167	5	46	2.2	36	.09	.55	120	23
228-59	Nepratex Industries	10/02/74	LCR	993I	1120	8.2	613	4093	1900	134		1.1						17			1700	31
		3/18/80	LCR	993I	1120	8.0	594	4298	2000	142	.05-	1.0	16	6502	170	37	0.5	17	.01	.04	1470	35
228-62	Michaelwood #1	4/12/76	MYK	90		6.2	51	123	11	25	.05-	0.1	2		12	8	5.1	2	.12		35	1
228-63	Michaelwood #2	4/12/76	WT	25		6.0	20	168	15	69	6.20	0.1-	13		37	12	1.3	12	.02		16	2
228-64	Baylake Pines	4/12/76	WT	25		5.9	24	208	34	139	6.75	0.1-	1		45	21	14.0	9	.15		23	4
228-65	Little Haven	4/12/76	WT	20		7.0	158	1178	450	347	.14	0.1-	1-		40	140	0.1	17	.02		172	3
228-67	Keeling Drain	4/12/76	WT	25		7.3	166	598	221	201	.05-	0.1-	1-			106	1.1	7	.19		112	3
228-69	Wolfsnare Plantation	4/12/76	WT	25		6.4	46	190	35	89	.05-	0.1-	3		21	14	3.4	8	.10		28	3
228-70	Wolfsnare Plantation	4/12/76	LYK	160	170	7.6	371	1214	505	333	.05-	0.1-	53		.5-	57	1.7	18	.02		450	23
228-71	Southern Points	4/19/78	LYK	136	144	7.3	260	572	168	236	.05-	0.1	10	1042	4	53	0.9	27	.03	.04	100	23
228-76	Virginia Beach Parks & Rec.	9/28/76	MYK	84	94	7.1	339	595	84	318		0.3	3	740		103	0.7	32	.37		103	5
228-86	Birdneck Point	4/20/78	UYK	50	55	7.2	65	350	143	126	.09	0.2	12	625	7	29	6.7	10	.11	.50	80	9
228-89	Bayville Farms	5/11/81	WT	33	38	5.5	7	332	36	172	16.50	0.1-	2	443	57	32	.06	20	.04		12	2
228-94	Princess Anne Country Club	4/21/78	MYK	72	77	6.5	76	154	39	90	.05-	0.1	3	281	7	29	3.7	4	.06	.05	23	2

GROUNDWATER QUALITY - CITY OF VIRGINIA BEACH CONTD.

SWCB NUMBER	OWNER AND/OR PLACE	DATE	AQUIFER	SCREEN	DEPTH	pH (Lab)	ALKALINITY	DISSOLVED SOLIDS	CHLORIDE	HARDNESS	NITRITE & NITRATE	FLUORIDE	TOTAL ORGANIC CARBON	SPECIFIC CONDUCTANCE	SULFATE	METALS Ca	Fe	Mg	Mn	Zn	Na	K
228-95	Princess Anne Country Club	4/21/78	MYK	72	77	6.4	80	166	45	94	.18	0.1	4	292	8	28	0.2	4	.06	1.60	23	2
228-101	Stumpy Lake	12/04/78	LYK	110	120	8.0	394	1239	464	290	.05	0.1	18	2205	3	61	1.2	40	.13	.01	350	29
228-103	Stumpy Lake	12/04/78	LYK	110	125	8.0	264	506	198	152	.05	0.2	10	1169	4	35	0.3	19	.08	.02	190	16
228-104	Thoroughgood Elementary	6/11/58	WT	25	30	6.2			22	51							1.8					
228-105	Kempsville Meadow Elementary	7/17/58	MYK	74	79	7.7	210	380	91								0.5					
228-107	Virginia Beach Public Safety	3/25/74	MYK	64	84	7.6	260	290	24	221		0.2		460	7	68	0.9	12	TRACE			
228-120	Tidewater Comm. College	10/13/78	LYK	118	128	7.9	380	872	283	15	.05	0.1	18		2	66	1.5	34	.18	.08	210	23
228-121	T. Berglund-Pocahontas Vlge	10/07/77	WT	17	20											9	5.8	16	.18	4.7	81	2
228-123	H. Rock - Windsor Woods	7/20/77	WT	19	22											6	11.0	5	.17	.36	26	1
228-124	E. Siudyla - Pocahontas Village	2/22/81	WT	30	34	6.7	86	200	60	88	.05	.18	15	442	2	20	13.0	5	.16	.66	40	2
228-126	D. Barham - Thalia Village	12/08/77	WT	21		7.0	211	467	59	338	.05	.14	9	740	4	73	1.4	6	.06	.22	25	3
228-127	Malbon Farm	12/28/77	UYK	50	60	7.7	255	439	69	4	.05	.16	9	690	4	1	0.1	1	.01	.04	170	6
228-128 -131	Malbon Farm	12/28/77	WT	20	30	7.0	226	370	50	206	.05	.20	11	600	4	75	6.7	12	.54	.06	40	4
228-132	Oceana Air Sta.-SWCB Res. Sta.	12/18/79	MYK	97	102	7.9	274	601	168	251	.05	.10	14	1030	2	50	0.7	30	.01	.01	113	33
228-133	Oceana Air Sta. - SWCB Res. Sta.	12/12/77	UYK	53	58	7.0	68	204	27	51	.05	.33		272	20	16	0.7	7	.20	.28	37	2
228-135	Princess Anne Courthouse - SWCB Res. Sta.	12/19/77	UYK	60	65	8.0	406	411	41	100	.05	.26				86	5.2	14	.20	.03	40	4
228-136	Gill Blackwater Grocery Store	4/06/78	UYK	50	60	5.8	14	144	31	59	6.5	.10	6	256	22	14	0.1	6	.08	.08	27	2

GROUNDWATER QUALITY - CITY OF VIRGINIA BEACH CONTD.

SWCB NUMBER	OWNER AND/OR PLACE	DATE	AQUIFER	SCREEN DEPTH		pH (Lab)	ALKALINITY	DISSOLVED SOLIDS	CHLORIDE	HARDNESS	NITRITE & NITRATE	FLUORIDE	TOTAL ORGANIC CARBON	SPECIFIC CONDUCTANCE	SULFATE	METALS						
																Ca	Fe	Mg	Mn	Zn	Na	K
228-137	T. Williams - Morse Point	4/06/78	WT	20	26	5.7	9		20	84	14.0	.10-	3	251	26	24	0.1-	7	.06	.05	8	1-
228-138	Creeds Volunteer Fire Dept.	4/06/78	WT	30		7.0	160	228	19	152	.05-	0.1	13	378	4	44	6.6	4	.17	1.30	15	1
228-139	Blackwater Fire Dept.	4/20/78	UYK	50	60	6.9	118	171	12	124	.05-	0.2	6	265	5	37	1.4	3	.07	.18	11	2
228-140	N. Bayshore Campground #1	4/21/78	UYK	60	65	7.2	245	734	255	270	.05-	0.2	13	1292	3	62	3.4	28	.13	.05	170	19
228-141	N. Bayshore Campground #2	4/21/78	UYK	60	65	7.3	250	718	261	254	.05-	0.2	10	1312	3	60	1.0	27	.11	.02	170	19
228-144	Meiggs Farm	9/13/79	UYK	50	60	8.0	228	566	102	297	.05-	0.2	4	739	3	106	1.1	18	.26	.05	30	6
228-146	Pleasant Ridge TV	4/20/78	MYK	75	80	6.9	66	164	22	116	.05-	0.1-	2	271	35	34	0.2	3	.07	.03	11	2
228-147	R. Eaton - West Landing	10/27/78	WT	20	25	6.3	14	163	22	50	8.50	0.1-	14	274	4	15	1.6	8	.07	.54	8	3
228-148	E. Garner - Creeds	10/27/78	MYK	92	102	7.7	109	195	21	100	.05-	0.1-	1	224	2	4	1.6	6	.13	.39	16	4
228-149	W. Glennon	11/28/78	WT	20	28	6.4	11	179	22	45	3.20	0.1-	5	207	37	3	0.1-	9	.08	.04	25	2
228-162	Ferry Road	5/10/79	LCR	1207I	1367	7.8	235	17858	8975	1790	.05-	0.3	3	26124	140	396	4.5	176	.71	.19	4870	88
228-163	Burton Station	5/11/79	LCR	1000I	1124	8.4	593	4334	1650	116	.05	1.2	6	6648	384	23	0.9	13	.02	.36	1350	32
228-164	D. Alder - Stratford Chase	6/28/79	UYK	60	74	6.4	44	175	14	60	.05-	.10-	6	258	40	19	11.0	39	.57	.01	12	1
228-166	Pungo Highway Shop	7/09/79	UYK	61	66	7.6	96	336	114	96	.05-	.11	4	591	7	3	0.2	8	.04	.21	79	7
228-167	Pungo - SWCB Research Sta.	7/25/79	WT	20	24	7.8	130	964	86	178	.35	.10-	4	549	1	77	6.5	7	.44	.13	55	6
228-168	Pungo - SWCB Research Sta.	6/27/79	MYK	88	98	8.2	330	3702	1823	560	.05-	.32	7	6136	82	66	1.2	880	.02	.08	1000	38
228-169	Oceana Air Sta.- SWCB Res. Sta.	?/79	WT	24		6.5			20	85												
228-170	Blackwater - SWCB Res. Sta.	7/26/79	MYK	66	76	7.9	210	374	56	195	.05-	.38	3	587	3	53	0.7	20	.05	.35	47	22
228-171	Blackwater - SWCB Res. Sta.	7/26/79	WT	20	24	7.4	67	244	16	108	.05-	.10-	2	299	43	35	2.4	7	.17	.46	19	3

GROUNDWATER QUALITY - CITY OF VIRGINIA BEACH CONTD.

SWCB NUMBER	OWNER AND/OR PLACE	DATE	AQUIFER	SCREEN DEPTH		pH (Lab)	ALKALINITY	DISSOLVED SOLIDS	CHLORIDE	HARDNESS	NITRITE & NITRATE	FLUORIDE	TOTAL ORGANIC CARBON	SPECIFIC CONDUCTANCE	SULFATE	METALS						
																Ca	Fe	Mg	Mn	Zn	Na	K
228-182	Christian Broad-casting Network	6/15/79	UYK	60	68			196	7	118	.05-	.35	4	281	1	40	0.5	74	.04	.23	15	6
228-183	C. Reid - Thoroughgood	6/29/81	LYK	130	138	7.5	88	170	26	98	.05-	.10-	3	298	8	32	0.2	2	.06		20	2
228-192	J. Vogel	11/19/80	LYK	193	200	7.5	231	326	22	224	.05-	.22	4	542	3	80	1.7	6	.06		22	2
228-193	B. Callahan - Pembroke Meadows	12/18/80	WT	18		6.2	21	270	17	117	2.40	.10-	3	482	132	25	7.2	13	.13		24	5
228-195	D. Custis - Bow Creek	4/03/81	WT	10	13	5.6	25	327	77	92	.05-	.10-	4		88	12	5.7	13	.15	.90	54	1.1
228-197	R. Larabee - Trant-wood Shores	4/07/81	LYK	125	130	7.7	190	297	39	192	.05-	0.1-	12	587	3	56	0.5	9	.05		28	6
228-198	Princess Anne Inn	4/07/81	WT	22	32	6.2	40	669	207	170	3.20	0.1-	5	1569	172	10	0.3	30	.36		131	8
228-201	John Holland - Bay Island	4/23/81	MYK	85		7.0	153	511	154	168	.05-	0.1	25	990	7	19	1.1	20	.13		89	13
228-202	Jack Holland - Bay Island	4/23/81	UYK	60	65	7.5	267	4110	2000	740	.05-	0.2	23	6660	135	98	0.1	123	.09		983	52
228-205	K. Thompson-Aragona Village	5/10/81	WT	16		4.8	3	240	36	92	.05-	0.1	3		88	10	4.9	13	.33		19	1
228-210	Southern Ice	6/01/81	UYK	55	65	6.4	109	476	151	136	.05-	0.1	6	847	34	4	0.5	1.6	.41		71	1
C9	Seashore State Park	8/30/39	WT	15				63	21	16		0.5			5	3	3.7	2.1			11	1

GROUNDWATER QUALITY - CITY OF CHESAPEAKE

SWCB NUMBER	OWNER AND/OR PLACE	DATE	AQUIFER	SCREEN	DEPTH	pH (Lab)	ALKALINITY	DISSOLVED SOLIDS	CHLORIDE	HARDNESS	NITRITE & NITRATE	FLUORIDE	TOTAL ORGANIC CARBON	SPECIFIC CONDUCTANCE	SULFATE	METALS						
																Ca	Fe	Mg	Mn	Zn	Na	K
234-1	Lone Star - Great Bridge	5/10/78	MYK	87	92	7.4	199	391	71	194	.05	0.3	5	641	15	72	0.8	6	.03	.04	57	4
234-10	Smith-Douglas #2	1/03/79	MYK	85I	108	7.2	219	4011	1520	1430	.05-	0.3	17		969	340	48.0	100	1.20	.42	250	60
234-14	Lone Star - La Farge	12/1/77 9/1/77	LCR LCR	760 760	780 780	8.5 8.5	260 410	726 1147	202 349	36 12	.41 .05-	2.6 3.3	4			9 4	1.0 0.9	2 2	.02 .03	.05 .02	410 59	12 14
234-15	Tidewater Chemical	10/28/74 1/04/79	UYK	45 45	50 50	7.7	208	360	43	192	.01-	0.3	10			67	2.4	17	.05	.08	46	8
234-24	Colony Manor	11/2/77 10/27/80	LCR LCR	684 684	704 704	8.3 8.4	490 481	924 961	234	10 12	.05- .36	4.5 3.9	10	1488	32	3 2	0.1- .04	2 1	.02 .01	.07 .06	430 363	12 11
234-26	Fentress Air Field #2	1/13/77	UYK	43	66	6.6	77	155	25	68	.05-	0.2	4			18	11.0	4	.32		63	3
234-28	Northwest Radio Station	4/10/75	UYK	50	60				25	136		0.2		270								
234-39	Elizabeth River Bridge	10/27/66	MYK	70	80	7.4	184	3398	1620	488		0			256	152	5.2	26	.20			
234-40	Field Unit #22	2/13/74	UYK	52	62	6.8	38	122	21	48	.01	0.1		172	21	11	5.6	5	.14	.03	14	2
234-41	Saint Brides Prison Farm #1	12/15/78	LYK	110	140	8.0	331	588	98	308	.05-	0.3	11	937	30	80	1.6	28	.15	.07	78	7
234-45	Great Bridge Civic Center #2	2/05/79	UYK	63	71	7.8	158	248	30	144	.05-	0.1	8	398	2	50	1.4	3	.05	.06	26	2
234-51	Crestwood Jr. High School	10/17/61	MYK	74	94	7.4		809	286	269					31	79	0.3	18				
234-53	Hickory Elem. School	1/16/79	UYK	55	60	6.8	38	221	29	85	.05-	0.1-	3	355	107	31	17.7	9	.51	.41	29	3
234-55	Ballahack Farms Inc.	12/04/78	UYK	56	81	8.0	331	546	72	290	.05-	0.2	23	821	3	110	0.3	17	.03	.02	72	5
234-56	Crest Harbor	8/73	MYK	65I	110	8.2	233	344	33	216	.03	0.2			4	73	1.5	9	.07	.02	31	4
234-58	Taylorwood Estates	7/30/68 5/13/75	LCR LCR	610 610	630 630	7.9 7.6	238	655 674	82 75	14 18		3.8 4.0	10	1020 860	17	4 2	0.2 0.1	1 12	.04		250	7
234-60	Green Meadow Point #1	1/03/77	LCR	594	614	8.4	453	882	178	10	.48	4.0	8			2	0.1	0.1	.01		480	10

GROUNDWATER QUALITY - CITY OF CHESAPEAKE CONTD.

SWCB NUMBER	OWNER AND/OR PLACE	DATE	AQUIFER	SCREEN DEPTH		pH (Lab)	ALKALINITY	DISSOLVED SOLIDS	CHLORIDE	HARDNESS	NITRITE & NITRATE	FLUORIDE	TOTAL ORGANIC CARBON	SPECIFIC CONDUCTANCE	SULFATE	METALS						
																Ca	Fe	Mg	Mn	Zn	Na	K
234-63	Indian River Water Co. #4	5/05/66	UYK	50	60	6.8	132		15	147							2.8					
234-64	Sunray Water Co.	2/18/75	LCR	635	645	8.1	480	770	100	14		4.0	16		19	3	0.1-	1	.01-		300	9
		10/27/80	LCR	635	645	8.4	495	864	221	10	.30	4.5	10	1276	20	2	.01-	1	.01-	.08	283	9
234-65	Fentress Air Field SWCB-Res. Sta.	6/06/79	LCR	1040	1060	8.5	444	3300	1555	90	.05-	1.4	2	5767	125	22	0.8	12	.03	.24	1100	3
234-66	Fentress Air Field SWCB-Res. Sta.	6/18/79	E-UCR	760	780	8.1	705	5461	2584	212	.05-	1.5	1-	9167	119	32	0.1-	350	.01	.30	1800	48
234-67	Fentress Air Field SWCB-Res. Sta.	7/26/79	WT	17	22	6.7	81	181	29	52	.05-	0.1-	2		16	12	5.4	5	22	2.80	43	3
234-70	Great Bridge Apartments	8/28/72	MYK	92	102	7.9	188		16	173	.18	0.2			1	64		3	.12		14	1
234-73	Triple R Ranch	12/4/78	UYK	50	60	8.0	273	422	58	244	.05-	0.2	17		5	97	0.4	10	.04	1.20	56	5
234-77	Southern Packing	12/4/78	UYK	50	60	8.0	316	414	139	278	.16	0.3	5	163	15	110	0.2	13	.09	.05	110	8
234-79	Tidewater Chemicals	4/10/75	EUCR	740	760				1450	96		1.5		5600								
		1/04/79	EUCR	740	760											19	1.7	20	.01-	.19	1510	4.5
234-83	Lone Star - Great Bridge	5/10/78	UYK	65		7.5	202	573	160	236	.05-	0.2	7	949	22	86	0.9	7	.03	.01	89	4
234-89	Indian River Water Co. #3	11/4/65	UYK	50	60	6.8	128	182	18	144							2.5					
234-116	Northwest River Park	2/5/79	WT	22	37	7.2	217	316	35	200	.05-	0.7	5	511	78	45	18.6	19	.49	.20	31	3
234-117	P. Laframbroise-Great Bridge	7/13/76	WT	?												68	2.0	6	.03		46	3
234-123	John Lensey - Deep Creek	5/30/75	LCR	820			605	1440	370	16	.66	2.5		2150	67	3	.03	2			550	15
234-124	Bowers Hill - SWCB Research Station	1/77		438	443	8.5	418	901	180	26	.05-	3.5		1280	34	3	2.3	2	.02		290	10
		1/77	LCR	674	679	8.5	427	889	185	10	.05-	3.5		1380	31							
		1/77	LCR	805	810	8.8	412	1326	400	64	.40	1.8		1950		11	0.3	4	.01		300	15
		1/77	LCR	1051	1056	8.4	356	2715	1270	80	.05-	0.3		4500	146	16	15.0	8	.18		650	13
234-131	R. Fennema-Cornland	12/4/78	UYK	50	60	8.0	179	236	9	168	.05-	0.2	8	365	2	67	0.1	4	.06	.07	18	2

GROUNDWATER QUALITY - CITY OF CHESAPEAKE CONTD.

SWCB NUMBER	OWNER AND/OR PLACE	DATE	AQUIFER	SCREEN DEPTH		pH (Lab)	ALKALINITY	DISSOLVED SOLIDS	CHLORIDE	HARDNESS	NITRITE & NITRATE	FLUORIDE	TOTAL ORGANIC CARBON	SPECIFIC CONDUCTANCE	SULFATE	METALS						
																Ca	Fe	Mg	Mn	Zn	Na	K
234-133	Norfolk Nursery	8/23/79	LYK	118	148	8.2	210	324	33	202	.05-	0.2	3	60	1-	69	0.7	5	.05	.33	45	3
234-134	R. Fennema-SWCB Res. Sta.	11/8/77	LCR	824	834	8.7	536	1391	392	40	.05-	2.7		2300	58	6	1.3	3	.07	.01	560	16
234-135	R. Fennema-SWCB Res. Sta.	11/8/77	EUCR	525	535	8.5	753	2596	146	9	1.00	2.7		4200	160	15	2.0	12	.03	.08	980	31
234-136	Fentress Air Field SWCB Res. Sta.	12/12/77	UYK	92	97	8.1	281	963	361	206	.05-	0.2		1725	26	73	3.2	34	.03	.03	290	25
234-141	M. McDaniel	12/8/77	MYK	75	80	7.1	370	302	21	176	.05-	0.16	8	380	22	15	3.9	6	.24	2.20	50	1
234-146	Chesapeake Water Plant	2/4/76	EUCR	630	640	8.5	741	3902	1653	150		1.9		6000		11	10.8		.45		1480	42
234-147	Lone Star - Great Bridge	5/10/78	MYK	80	85	7.5	189	296	28	174	.05-	0.2	7	442	9	60	0.9	5	.03	.01	28	2
234-151	Wilkerson - George-town Colony	3/29/79	WT	22		7.8	295	457	56	280	.05-	0.2	15		20	9	8.0	11	.17	.57	44	1
234-152	Huddleston-S.W. Great Bridge	3/29/79	WT	13		6.4	18	150	18	62	.05-	0.1-	3		54	12	8.4	6	.22	2.67	8	3
234-153	Huddleston-S.W. Great Bridge	3/29/79	MYK	95	103	8.0	242	369	46	222	.05-	0.3	10		12	23	1.5	7	.04	.26	4	4
234-154	Willow Grove Baptist Church	10/31/79	UYK	50	55	7.5	104	170	6	110	.05-	0.1-	3	250	5	44	0.3	3	.05	.04	9	1
234-157	Centerville Group Home	10/31/79	UYK	40	50	6.1	15	77	12	16	.05-	0.1-	4	97	1	4	3.0	2	.05	.03	8	1
234-162	Bowers Hill - City of Ches. Obser.	10/9/80	LCR	710	797	8.4	442	757	123	11		3.5			35	2.8	0.1	1.0	.02-			

GLOSSARY

AQUICLUDE	A formation of relatively low permeability that overlies or underlies an artesian aquifer and confines water in the aquifer under pressure. It contains little or no water and transmits essentially none.
AQUIFER	A water-bearing formation, group of formations, or part of a formation that will yield ground water in useful quantities.
AQUIFER SYSTEM	A group of inter-related aquifers.
AQUITARD	A formation that partially restricts ground water flow. It contains water, transmits it slowly, but will not yield water to a well.
ARTESIAN AQUIFER	A confined aquifer in which ground water rises in a well above the point at which it is found in the aquifer.
ARTESIAN WELL	A well in which the water rises under artesian pressure above the top of the aquifer (the well penetrates), but does not necessarily reach the land surface.
AUTOCHTHONOUS	A term applied to rocks of which the dominant constituents have been formed in the natural or original position as opposed to prior to erosion and disposition.
BEDROCK	Any solid rocks exposed at the surface or overlain by unconsolidated materials.
BICARBONATES (Metal + HCO_3 e.g. Na HCO_3)	Can raise the pH to a high concentration which may be corrosive.
CAPILLARY FRINGE	The zone of partial or complete saturation directly above the water table in which water is held in the pore spaces by capillarity.
CASING	Pipe used in water well construction generally extending from the land surface to the top of the well screen. The type and size of casing used will vary depending on well yield and other design requirements.

CHLORIDES (Cl^-)	Are indicative of concentrations of salt water, concentrations above 250 milligrams per liter (mg/l) are detectable by taste.
CLASTIC ROCK	A consolidated sedimentary rock composed of broken fragments that are derived from pre-existing rocks, e.g. sandstone, conglomerate, or shale, etc.
CLAY	The term clay as used today carries with it three implications: natural material with plastic properties, an essential composition of particles of very fine size grades, and an essential composition of crystalline fragments of minerals that are essentially hydrous-aluminum silicates or occasionally hydrous, magnesium silicates.
COLIFORM BACTERIA	A group of bacteria considered a reliable indicator of the adequacy of treatment for bacterial pathogens.
COASTAL PLAINS	Any plain which has its margin on the shore of a large body of water, particularly the sea and generally represents a strip of recently emerged sea bottom.
CONE OF DEPRESSION	A conelike depression of water table or of the (potentiometric) surface that is created in the vicinity of a well by pumping. The surface area included in the cone is known as the area of influence of the well.
CONFINED WATER	Water under artesian pressure. Water that is not confined is said to be under water table conditions.
CONFINING BED	A bed which overlies or underlies an aquifer and which, because of low permeability relative to the aquifer, prevents or impedes upward or downward loss of water and pressure.
CONSOLIDATED	A rock that is firm and rigid in nature due to the natural interlocking and/or cementation of its mineral grain components. The reverse is unconsolidated.
CROSS-SECTION	A diagram or drawing that shows features transected by a given plane; e.g. geologic feature such as geologic structure.
DISSOLVED SOLIDS	Generally noticeable in concentrations greater than 500 mg/l.

DRAWDOWN	The depression or decline of water level in a pumped well or in nearby wells caused by pumping. It is the vertical distance between the static and the pumping levels of the wells.
DRILLERS LOG	The drillers record of material drilled through in the process of drilling a well.
ELECTRIC LOG	The log of a well or borehole obtained by lowering electrodes in the hole and measuring various electrical properties of the geologic formations traversed.
EVAPOTRANSPORATION	The process by which surface water, soils and plants release water vapor to the atmosphere.
FACIES	The rock record of different sedimentary environments as distinguished by both physical and organic characters, often lateral subdivisions.
FECAL COLIFORM BACTERIA	A group of bacteria used to indicate fecal pollution.
FLOWING WELL	A well having sufficient artesian pressure head to discharge water above the land surface.
FLUORIDE	A general reference to compounds containing fluorine. Presence of about 1.0 mg/l is beneficial for reduction of dental caries. Concentrations greater than 1.8 mg/l may cause mottling of teeth.
FLUVIAL-DELTAIC	Pertaining to rivers, streams, ponds, or river deltas.
FORMATION	A unit of geologic mapping consisting of some one kind of rock material. Also a unit having lateral or vertical continuity.
GAMMA RAY LOG	A method of logging wells or boreholes by observing the natural radioactivity of rocks through which the hole passes.
GEOPHYSICAL LOG	Methods of logging by lowering a sensing device into a well to make a record which can be interpreted in terms of the rocks characteristics, of the contained fluids, and of the construction of the well.

GLAUCONITE	A green mineral, closely related to the micas and essentially a hydrous potassium iron silicate. Commonly occurs in sediments of marine origins.
GRAVEL PACK	Gravel placed around the outside of the well screen to increase the effective diameter of the well and therefore well efficiency.
GREENSAND	A sand rich in glauconite grains.
GROUND WATER	Water beneath land surface in the zone of saturation and below the water table.
HARDNESS	Quality of water that prevents lathering because of calcium and magnesium salts which form insoluble soaps.
HYDRAULIC GRADIENT	The gradient or slope of the water table or of the potentiometric surface, in the direction of the greatest slope generally expressed in feet per mile.
HYDROGEOLOGY	The science of the natural laws that control occurence and movement of ground water. Geology as affected by hydrology.
HYDROLOGY	The science that relates to water movements and physical characteristics.
IGNEOUS ROCKS (Basement Rocks)	Rocks formed by the cooling and crystallization of molten or partly molten material.
IMPERMEABLE	Having a texture which does not allow perceptible movement of water through rock.
INDURATED	Rendered hard.
INFILTRATION	The flow of water through the soil surface into the ground.
INTERSTICES	The opening or pore spaces in a soil or rock formation. In an aquifer, they are filled with water.
LEAKANCE	The ratio K'/b', in which K' and b' are the vertical hydraulic conductivity and the thickness respectively of the confining beds; this term is used in the flow equations for leaky aquifers with vertical movement.
LEAKY AQUIFER	An aquifer bounded above and below by a semi-pervious layer so that water from this layer flows or leaks into the aquifer.
LITHOLOGY	The large scale physical characteristics of rocks/sediments.

METAMORPHORIC ROCKS	Rocks altered from pre-existing rocks by changes in temperature, pressure, and chemical environment.
NITRATES (NO_3)	A salt or ester of nitrous acid (concentrations greater than 45 parts per million (ppm) can be toxic).
NONFLOWING ARTESIAN WELL	An artesian well in which the head is not sufficient to raise water to the land surface at the well site.
pH	The negative logarithm of the hydrogen ion activity--measured 1 through 14 with 7 being neutral, 1 being indicative of highest acidity and 14 indicative of highest alkalinity.
PALEONTOLOGY	The study of fossil animal and plant remains (to determine past environments).
PERCOLATION	Movement under hydrostatic pressure of water through the interstices of rocks or soils, except movement through large openings such as solution channels.
PERMEABILITY	The ability of a rock to transmit water per unit of cross-section.
PIEZOMETRIC SURFACE	An imaginary surface that everywhere coincides with the static level of water in an artesian aquifer.
POROSITY	The ratio of the volume of the openings in a rock to the total volume of the rock.
POTENTIOMETRIC SURFACE	Synonymous with piezometric surface.
PUBLIC SUPPLY	As defined by the Virginia Department of Health, a water system serving 25 individuals or more than 15 residential connections.
PUMPING LEVEL	Depth to water in a well when the well is being pumped.
PUMPING TEST	Pumping of a well at a constant rate in order to obtain information about the performance of the well or to provide data from which the principal factors of aquifer performance can be calculated. A test set up for the second purpose is call an "aquifer test".

RECHARGE	The addition of water to an aquifer by natural infiltration or artificial means. Injection of water into an aquifer through wells is one form of artificial recharge.
RECOVERY	The residual drawdown after pumping has stopped.
RUNOFF	That part of precipitation that flows in surface streams. Ground water recharge is that part of runoff which has existed as ground water since its last precipitation.
SALT WATER INTRUSION	The phenomenon occurring when a body of salt water, because of its greater density, invades a body of fresh water. This may be caused by a loss of pressure in a fresh water aquifer.
SEDIMENT	Material borne and deposited by water.
SEDIMENTARY ROCKS	Usually stratified formations consisting of products of weathering by actions of water, wind, ice, etc.
STATIC WATER LEVEL	The level of water in a non-pumping or non-flowing well.
STRATIGRAPHY	The relationship of the formation composition, sequence and correlation of layered rocks or sediments.
STORAGE COEFFICIENT	Volume of water contained in an aquifer which is related to porosity. Expressed as an absolute value normally from 0.00001 to 0.002 for artesian aquifers and from 0.02 to 0.35 for water table conditions.
TERRACE DEPOSITS	Deposits of alluvium (sand, gravel, cobble or clay) which occurs along the margin and above the level of a body of water, marking a former water level.
TOPOGRAPHY	The relief and form of a land surface.
TRANSMISSIVITY	The capacity of an aquifer to transmit water in gallons per unit of time per section 1 foot wide by aquifer thickness. Expressed as gallons per day per foot (gpd/ft) normally ranging from 1000 to 1,000,000 gpd/ft.
UNCONFINED AQUIFER	Water not under artesian pressure. Generally applied to denote water below the water table.

UNCONSOLIDATED	A sediment that is loosely arranged or unstratified, or whose particles are not cemented together.
UPCONING	The phenomenon of salt water beneath a well rising and entering the well when water is pumped from wells that are too close to the fresh water - salt water interface.
WATER TABLE	The upper, unconfined surface of the zone of saturation. The surface in water table aquifer at which the water level stands.
WATER-TABLE AQUIFER	An aquifer which is not confined above, in which the water level in a well indicates the water table.
WATER WELL	An artificial excavation (pit, hole, tunnel) generally cylindrical in form and often walled in, sunk (drilled, dug, driver, bored, jetted) into the ground to such a depth as to penetrate water-yielding rock and to allow water to flow or to be pumped to the surface.
WELL INTERFERENCE	The situation when the pumping of one well causes drawdown in another well so that the second well has difficulty in pumping water for some time period.
ZONE OF AERATION	The zone in which the open spaces in soil or in a rock formation contain air and water.
ZONE OF SATURATION	The zone in which the open spaces in the rocks are completely filled with water.

REFERENCES

Barker, W. J. and Bjorken, E. D. Geology of the Norfolk North Quadrangle, Virginia. Virginia Division of Mineral Resources Publication 8, 1978.

Barker, W. F. and Bjorken, E. D. Geology of the Norfolk South Quadrangle, Virginia. Virginia Division of Mineral Resources Publication 9, 1978.

Betz Converse Murdoch, Inc. Development of 10 MGD Fresh Ground Water Supply for Virginia Beach. Betz Converse Murdoch, Inc. Vienna, Virginia, 1981

Brown, D. L. and Silvey, W. D. Artificial Recharge to a Freshwater-Sensitive Brackish - Water Sand Aquifer. Norfolk, Virginia. United States Geological Survey, Professional Paper 796, 1972.

Bouwer, H. Groundwater Hydrology. McGraw-Hill Book Company, 1978.

Campbell, M. S. and Lehr, J. H. Water Well Technology, McGraw-Hill Book Company, 1973.

Cederstrom, D. J. Chloride in Groundwater in the Coastal Plain of Virginia. Virginia Geological Survey Bulletin 58, 1943.

Cederstrom, D. J. Geology and Ground-Water Resources of the Coastal Plain in Southeastern Virginia. Virginia Geological Survey Bulletin 63, 1945

Cederstrom, D. J. Chemical Chapter of Groundwater in the Coastal Plain in Southeastern Virginia. Virginia Geologic Survey Bulletin 63, 1945.

Coastal Plain Regional Commission. Groundwater in the Coastal Plains Region - A Status Report and Handbook. Coastal Plains Regional Commission, Charleston, South Carolina, 1979.

Converse Ward Davis Dixon, Inc. Report of Hydrogeologic Investigation Ground Water Development Phase Virginia Beach Fresh Ground Water Project for City of Virginia Beach, Virginia. Converse Ward Davis Dixon, Inc. Caldwell, New Jersey, 1981.

Denning, G. W. Economics of Groundwater in Virginia. Virginia State Water Control Board Planning Bulletin 308, 1977.

Ferris, J. G. and Knowles, D. B. Brown, R. H., and Stallman, R. W. Theory of Aquifer Tests. U. S. Geological Survey Water Supply Paper 1536-E, 1962.

Geraghty and Miller, Inc. Availability of Ground Water for Public Supply in the City of Virginia Beach. Geraghty and Miller, Inc. Tampa, Florida 1978.

Geraghty and Miller, Inc. Availability of Ground Water in the Southeastern Groundwater Management Area. Prepared for the Virginia State Water Study Commission by Geraghty and Miller, Inc., Annapolis, Maryland, 1979a.

Geraghty and Miller, Inc. Evaluation of Pumping Test on Yorktown Aquifer, City of Virginia Beach, Virginia. Geraghty and Miller, Inc., Annapolis, Maryland, May, 1979b.

Geraghty and Miller, Inc. Evaluation of Availability of Brackish Ground Water for Desalination in the City of Virginia Beach. Geraghty and Miller, Inc., Annapolis, Maryland, 1979c

Hampton Roads Water Quality Agency. Hampton Roads Water Quality Management Plan, Public Hearing Draft, 1978.

Harris, W. H. and Wilder, H. B. Geology and Ground Water Resources of the Hertford-Elizabeth City Area, North Carolina. North Carolina Department of Water Resources Ground Water Bulletin No. 10, 1966.

Hem, John D. Study and Interpretation of the Chemical Characteristics of Natural Water. United States Geological Survey, Water-Supply Paper 1473, 1970.

Henry, E. F., Chudoba, J. and Porter, H. C. Soil Survey of Norfolk County, Virginia. United States Department of Agriculture in Cooperation with the Virginia Agricultural Experimental Station, 1958.

Johnson, E. E. Inc. Ground Water and Wells. Johnson Division, Universal Oil Products Company, 1966.

Kruseman, G. P. and DeRidder, N. A. Analysis and Evaluation of Pumping Test Data. International Institute for Land Reclamation and Improvement, 1970.

Lichtler, W. F. and Wait, R. L. Summary of the Ground Water Resources of the James River Basin, Virginia. United States Geological Survey, Open File Report 74-139, 1974.

Lichtler, W. F. and Walker, P. N. Hydrology of the Dismal Swamp, Virginia-North Carolina. U. S. Geological Survey Open File Report 74-39, 1974.

Lohman, S. W. Ground Water Hydraulics. U. S. Geological Survey Professional Paper 708, 1972.

Norfolk District, Corps of Engineers. Flood Plain Information, Coastal Flooding, Virginia Beach, Virginia, 1969.

Norfolk District, Corps of Engineers. Flood Plain Information, Coastal Flooding, Norfolk, Virginia, 1970.

Norfolk District, Corps of Engineers. Flood Plain Information, Coastal Flooding, City of Chesapeake, Virginia, 1972.

Norfolk District, Corps of Engineers. Flood Plain Information, Coastal Flooding, Portsmouth, Virginia, 1973.

North Carolina - Virginia Groundwater Subcommittee. Groundwater Management in Southeastern Virginia and Northeastern North Carolina. Prepared for the North Carolina-Virginia Water Resources Management Committee, 1975.

Oaks, R. Q., Jr. and Coch, N. K. Post-Miocene Stratigraphy and Morphology, Southeastern Virginia. Virginia Division of Mineral Resources Bulletin 82, 1973.

Omuschak, E. Jr. Pleistocene-Holocene Environmental Geology, in Geologic Studies, Coastal Plain of Virginia. Virginia Division of Mineral Resources Bulletin 83, Part 3, 1973.

Peek, H. M. Groundwater Conditions in Northeastern North Carolina. Groundwater Section, Division of Environmental Management, North Carolina Department of Natural Resources and Community Development, Report of Investigations No. 15, 1977.

Russnow-Kane and Associates, Inc. Results of Chemical Analyses and Geophysical Survey, Virginia Beach Landfill #2. Russnow-Kane and Associates, Inc., Newport News, Virginia , 1979.

Russnow-Kane and Associates, Inc., Evaluation of Chemical Analyses and Ground Water Quality, Virginia Beach Landfill #2, Russnow-Kane and Associates, Inc., Newport News, Virginia, 1977.

Sanford, S. The Underground Resources of the Coastal Plain Province of Virginia. Virginia Geological Survey Bulletin 5, 1913.

Simmons, C. S. and Shulkcum, E. Soil Survey of Princess Anne County, Virginia. U. S. Department of Agriculture, 1945.

Teifke, R. H. Stratigraphic Units of the Lower Cretaceous through Miocene Series, in Geologic Studies, Coastal Plain of Virginia, Virginia Division of Mineral Resources Bulletin 83, Parts 1 and 2, 1973.

U. S. Environmental Protection Agency. Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities. U. S. Environmental Protection Agency Manual (SW-616), 1977.

U. S. Geological Survey. Water Resources of Northeast North Carolina. U. S. Geological Survey Water Resources Investigations 77-81, 1978

VanNieuwenhuise, R. E. et al. Multiple Land-Use Study Criteria: Evaluation for Urban Coastal Plains Environments. Prepared by the Department of Geophysics and Geophysical Sciences, Old Dominion University, Technical Report POSTR-GE 76-27, 1976

Virginia Division of State Planning and Community Affairs. Data Summary Chesapeake City, 1973.

Virginia Division of State Planning and Community Affairs. Data Summary Norfolk City, 1973.

Virginia Division of State Planning and Community Affairs. Data Summary Portsmouth City, 1973

Virginia Division of State Planning and Community Affairs. Data Summary City of Virginia Beach, 1973.

Virginia Division of Water Resources. Ground Water of Southeastern Virginia. Virginia Department of Conservation and Economic Development Planning Bulletin 261, 1970.

Virginia State Department of Health. Water Regulations, Public Drinking Water Supply. Bureau of Water Supply Engineering, 1977.

Virginia State Water Control Board. Groundwater of Southeastern Virginia. Planning Bulletin 261-A, 1974.

Walton, W. C. Groundwater Resource Evaluation. McGraw-Hill, Inc. 1970.

Wiley and Wilson, Inc. Virginia Beach Water Resources Study Phase II Report Engineering Study. Wiley and Wilson, Virginia Beach, Virginia 1978.

Wiley and Wilson, Inc. City of Virginia Beach Department of Public Utilities Comprehensive Potable Groundwater Report. Wiley and Wilson, Virginia Beach, Virginia, 1979