DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PRELIMINARY DELINEATION OF SALTY GROUND WATER IN THE NORTHERN ATLANTIC COASTAL PLAIN

By Harold Meisler

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ABSTRACT

Salty ground water underlies freshwater in the eastern part of the northern Atlantic Coastal Plain. The transition zone between freshwater and saltwater is represented in this report by a series of maps showing the depths to chloride concentrations of 250, 1,000, 10,000, and 18,000 milligrams per liter. The maps are based on chloride concentrations obtained from self-potential (SP) logs as well as from water-quality analyses.

Depths to the designated chloride concentrations generally increase inland from the coast except in New Jersey where they are greatest along the coast and in North Carolina where depths to the 10,000 and 18,000 milligrams per liter concentrations are greatest beneath Pamlico Sound. The transition zone between 250 and 18,000 milligrams per liter of chloride is generally 1,500 to 2,300 feet thick except in part of North Carolina, where it is less than 1,000 feet.

Depths to 250 and 1,000 milligrams per liter of chloride are probably controlled by the natural flow pattern of fresh ground water. Areas where these concentrations are relatively shallow generally coincide with areas of natural ground-water discharge. Depths to 10,000 and 18,000 milligrams per liter of chloride, and the occurrence offshore of ground water that is fresher than seawater, is attributed to long-term hydrologic conditions during which sea level fluctuations of a few hundred feet recurred several times. The origin of ground water that is saltier than seawater is attributed to the leaching of evaporitic strata beneath the Continental Shelf and Slope followed by westward movement of the brines during periods of sea-level rise.

INTRODUCTION

Purpose and Scope

Salty ground water underlies freshwater in the eastern part of the Atlantic Coastal Plain. At some locations shallow salty ground water, in hydraulic connection with salty surface water, may overlie the freshwater. This report defines, using a series of maps, the transition zone between the deepest known fresh ground water and the underlying saltwater, from North Carolina to New Jersey. Within this transition zone, salinity generally increases with increasing depth. Contour maps were constructed showing the depth below National Geodetic Vertical Datum of 1929 (NGVD of 1929)[1] to water containing chloride concentrations of 250, 1,000, 10,000, and 18,000 mg/L. Chloride rather than dissolved solids was used to delineate the transition zone because sodium bicarbonate water that contains dissolved solids in excess of 1,000 mg/L occurs in the freshwater zone and does not indicate the transition zone. The 250-mg/L chloride concentration was selected because it is used as a potable water standard. The 18,000-mg/L concentration was selected because it is the approximate chloride concentration of seawater, a possible source of the salty ground water.

This report is part of a U.S. Geological Survey 5-year study entitled, "Regional aquifer system analysis of the Northern Atlantic Coastal Plain."

Previous Investigations

Saltwater in the Atlantic Coastal Plain has been studied for many years. Sanford (1910, p. 77-86) summarized data collected by the U.S. Geological Survey on saltwater and the distribution of strata yielding saltwater. He found that areas of saltwater are numerous, that they occur in low ground and are generally near the ocean or some large body of saltwater. He concluded that "finding freshwater is better to the west rather than the east of any particular saltwater well."

Barksdale (1958, p. 110-111) delineated the boundary between saltwater and freshwater in the Raritan and Magothy Formations of New Jersey and Delaware. The delineation was largely theoretical, based on freshwater heads and the specific gravity of saltwater rather than chemical analyses. Perlmutter and others (1959) and Lusczynski and Swarzenski (1966) defined a body of salty ground water in southwestern Long Island by detailed subsurface exploration that included chemical analyses.

Back (1966) delineated two saltwater-freshwater interfaces (one in Cretaceous sediments and one in Tertiary sediments) from New Jersey to Virginia. He showed also a three-dimensional

[1] In this report the datum will be referred to as "sea level."

distribution of the major ions on a series of fence diagrams. Upson (1966) studied the relation of freshwater to salty ground water from Long Island to Maryland. Manheim and Horn (1968) showed the distribution of salinity in a series of wells along the Atlantic Coast from Long Island, N.Y. to Key West, Fla.

Contour maps showing the depths to water of specified chemical quality appear in several reports. Cushing and others (1973) delineated the base of freshwater, defined as less than or equal to 1,000 mg/L dissolved solids, on the Delmarva Peninsula. Heath, Thomas, and Dubach (1975, fig. 8.20) contoured the depth to water containing 250 mg/L of chloride in the coastal plain of North Carolina. The Commonwealth of Virginia, State Water Control Board (1978, p. 44 and 1979, p. 57) contoured the depth to "the 250 mg/L salt concentration" in southeastern Virginia.

Water fresher than seawater was discovered beneath the submerged Continental Shelf from Maryland to Massachusetts as a result of test drilling on Nantucket Island, Mass. (Kohout and others, 1976; 1977) and the Atlantic Margin Coring Project (Hathaway and others, 1976; 1979).

Acknowledgments

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METHODS OF STUDY

Figures 2 - 5 show depths below sea level to selected chloride concentrations. They are based on chloride data from; (1) chemical analyses of water from wells, (2) analyses of pore fluids from cores of the Atlantic Margin Coring Project (Manheim, written commun., 1980; Hathaway and others, 1976), and (3) chloride concentrations interpreted from calibrated self-potential (SP) logs.

Graphs showing the relation of chloride concentration to depth were constructed for more than 70 wells. Each well has chloride data for several depths. Selected graphs are shown in figure 1.

Depths to chloride concentrations for the maps were obtained from the graphs either directly or by extrapolation of the known chloride-depth relation. Chloride analyses from several hundred wells, each having analytical data from one depth, were also used to construct the maps. Some of these data were extrapolated to the selected chloride concentrations using the chloride-depth graphs of nearby wells. The chloride and depth data for all wells used in this report are given in table 1.

Depths to chloride concentrations of 10,000 (fig. 4) and 18,000 mg/L (fig. 5) are based on chemical analyses of water from wells, SP logs, and chemical data from the Atlantic Margin Coring Project. In some wells chemical data were extrapolated from a few thousand to 10,000 and 18,000 mg/L using chloride-depth graphs of nearby wells.

Depths to chloride concentrations of 250 (fig. 2) and 1,000 mg/L (fig. 3) are based on chemical analyses of water from wells or the extrapolations from them. In a few areas, where saltwater is deep and analyses are not available, the depths to 250 and 1,000 mg/L were estimated from much greater chloride concentrations determined from SP logs.

The computation of chloride concentrations from SP curves is based largely on the theory and procedures outlined in Schlumberger (1972 and 1978). The relation of the SP curve to resistivity of the ground water is given by the equation (Schlumberger, 1972, p. 78):

$$SP = -K \log \frac{Rmfe}{Rwe}$$

where

SP is the deflection, in millivolts, of the SP curve from the shale baseline,

K is a constant approximated by 60 + 0.133T, where T is the formation water temperature in degrees fahrenheit,

Rmfe is the equivalent resistivity of the drilling mud filtrate in ohm-meters,

Rwe is the equivalent resistivity of the ground water in ohm-meters.

Rmfe was obtained by using the equation (Schlumberger, 1978, p. 6): Rmfe = 0.85 Rmf where Rmf is the resistivity of the drilling mud filtrate in ohm-meters. Rwe was obtained from the first equation above and converted to Rw, formation water resistivity, using graph SP-2 in Schlumberger (1978, p. 7) or figure 13.3 in Schlumberger (1972, p. 79). Graph SP-2 was used for water which has an Rwe of less than 0.8 ohm-meters and is considered to be a predominantly sodium chloride type. Figure 13.3 was used for water which has an Rwe of 0.8 ohm-meters or greater and is believed to contain significant concentrations of sodium bicarbonate. Rw was converted to specific conductance. Chloride concentrations were estimated from a graph of chloride versus specific conductance developed using chemical analyses of ground water in the study area.

OCCURRENCE OF SALTY GROUND WATER

Description

The transition zone between freshwater and salty ground water is depicted by a series of maps (figs. 2-5) showing the depth to chloride concentrations of 250, 1,000, 10,000, and 18,000 mg/L.

Brackish water (250 and 1,000 mg/L of chloride) generally deepens away from the coast from Delaware to North Carolina (figs. 2 and 3). In New Jersey brackish water is deep near the coast and shallow westward. The contours in figures 2 and 3 delineate large mounds or ridges of brackish water in five locations: (1) Delaware Bay and adjacent southwestern New Jersey and eastern Delaware; (2) Lower Chesapeake Bay and adjacent parts of the York-James peninsula and the Middle Peninsula of Virginia; (3) Albemarle Sound to the Pamlico River of North Carolina; (4) Cape Fear River, North Carolina; and (5) along the eastern coast of the Delmarva Peninsula and extending northeastward off the coast of New Jersey. In addition a small, well defined, mound of brackish water occurs adjacent to the northeastern shore of Chesapeake Bay.

Saltwater (10,000 and 18,000 mg/L of chloride) generally deepens westward in Virginia, Maryland, and Delaware (figures 4 and 5). In New Jersey, it is deep near the coast and shallow westward and forms a large mound under Delaware Bay and adjacent parts of Delaware and New Jersey. Similarly, in North Carolina, saltwater is deep near the coast, particularly in the vicinity of Pamlico Sound. It is shallower westward, forming a prominent ridge, then deepens westward from the ridge. A small mound of saltwater adjacent to Cape Fear River in North Carolina has chloride concentrations greater than 10,000 mg/L (fig. 4) but less than 18,000 mg/L (fig. 5).

Ground water containing less than 10,000 mg/L chloride (fig. 4) extends as much as 70 miles off the New Jersey Coast in the form of an eastward thinning wedge the base of which becomes shallower eastward. The wedge narrows southward towards southern Virginia as the depth to saltwater (fig. 4) decreases along the coast. Its extent east of the North Carolina Coast is not known, but a borehole located 45 miles off of Cape Hatteras contains no water that is fresher than seawater.

No saltwater is shown in figures 2-5 north of southeastern New Jersey as the deep aquifers in east-central New Jersey and western and central Long Island contain freshwater. The saltwater in the Magothy aquifer in southwestern Long Island is underlain by freshwater in the Lloyd aquifer (Perlmutter and others, 1959).

Lusczynski and Swarzenski (1966, p. 1) considered this saltwater to represent an extension "from a main body of salty water that lies seaward of the barrier beaches." The present author believes that the saltwater in southwestern Long Island is in hydraulic connection with Jamaica Bay and is unrelated to the regional saltwater delineated in the present study.

Saltwater occurs also in parts of the glacial aquifer and the Magothy aquifer in the Forks of eastern Long Island. Investigators have inferred that the underlying Lloyd aquifer also contains saltwater (Nemickas and Koszalka, 1980). No reliable analyses are available to substantiate this, however. The configuration of the base of freshwater (250 mg/L of chloride) on the South Fork delineated by Nemickas and Koszalka (1980) suggests hydraulic connection with surrounding seawater. The present author believes that the salty ground water is probably unrelated to the regional saltwater body delineated in the present study.

The thickness of the transition zone between 250 and 18,000 mg/L of chloride can be determined from the maps in figures 2-5. In most of the study area the zone ranges in thickness from about 1,500 to 2,300 feet. It is thicker along the coast than near the western boundary of the 18,000 mg/L concentration. The thinnest zone of transition in the study area, less than 1,000 feet, coincides with the prominent saltwater ridge in North Carolina.

The thickness of the transition zone from freshwater to saltwater in the study area contrasts with that of two documented areas. In the Biscayne aquifer in Miami, Fla., the transition zone from 250 to 18,000 mg/L of chloride is about 50 feet thick (Kohout, 1960, fig. 4). In the Magothy aquifer in southwestern Long Island, New York the transition zone from 40 to 15,000 mg/L (concentrations as high 18,000 mg/L are not reported) is generally 100 to 200 feet thick (Lusczynski and Swarzenski, 1966, plates 2 and 3). Transition-zone thickness greater than that in the study area is found in the Southeast Georgia Embayment. Manheim and Paull (unpublished data, 1980; fig. 3) show a vertical distance of about 3,000 feet between dissolved-solids concentrations that correspond roughly to chloride concentrations of 500 and 18,000 mg/L.

Origin of the Saltwater

Additional data collection and analysis are needed for a thorough explanation of the origin and occurrence of salty ground water in the northern Atlantic Coastal Plain. A complete analysis should attempt to explain: (1) the relation of brackish water and saltwater mounds and troughs to the natural ground-water flow system and sea-level fluctuations; (2) the offshore occurrence of ground water that is fresher than seawater; (3) the origin of brines; and (4) the relatively thick transition zone from freshwater to saltwater. The maps in this report suggest generalized explanations for these characteristics.

The brackish water mounds shown on the 250 and 1,000 mg/L maps (figs. 2 and 3) and cited earlier in this report probably coincide with areas of major ground-water discharge and are probably in equilibrium with the natural freshwater flow system. Earlier investigators reached similar conclusions. Back (1966, p. 40) stated that the position of the deep saltwater (350 mg/L of chloride) "is determined by the relative head distribution in the freshwater and in the saltwater." Upson (1966, p. C242) concluded that the circulation pattern of the fresh ground water, particularly the location of the discharge zones, controls the locations of saltwater (250 mg/L of chloride) boundaries.

The location of saltwater shown on the 10,000 and 18,000 mg/L maps (figs. 4 and 5) is probably influenced by long-term hydrologic conditions rather than by predevelopment conditions. Predevelopment water levels do not appear to be high enough to account for the great depths to saltwater, especially along the coasts of New Jersey and North Carolina and farther inland in Maryland. The offshore wedge of ground water containing chloride concentrations of much less than 10,000 mg/L is probably relict water from periods of lower sea level. That this water is not in equilibrium with the predevelopment freshwater flow system is indicated by the low predevelopment water levels in the aquifers along the coast and by the lack of freshwater offshore. A minimum chloride concentration of 230 mg/L was found about 9 miles from the Delaware coast, and 820 mg/L was found about 7 miles from the New Jersey coast. Typical chloride concentrations are greater than 3,000 mg/L.

The occurrence of the offshore wedge of ground water is probably related to a longer period than the Pleistocene glacial maximum and associated low sea-level stand of about 15,000 years ago as proposed by Hathaway and others (1979, p. 523). This is suggested by the location of shorelines 9,000 and 13,000 years ago (Dillon and Oldale 1978, fig. 1). The shoreline 13,000 years ago was almost as far offshore from the present southern Virginia coast as from the present New Jersey coast. The shoreline 9,000 years ago was even closer to New Jersey. Yet, as seen on figures 4 and 5, the wedge extends much farther offshore from New Jersey than from Virginia. The size of the wedge is dependent, however, on factors in addition to shoreline position. Higher heads and aquifer permeabilities in New Jersey and Long Island could account for its greater extent in that area. Nevertheless, the presence of both the offshore wedge and the deep saltwater along the coast and the occurrence of shallow saltwater in the vicinity of Delaware Bay suggests that the shoreline from New Jersey to Maryland has generally been farther east than at present and that Delaware Bay has been an area of ground-water discharge for a long time.

The origin of brines in the coastal plain is discussed by Manheim and Horn (1968, p. 229-233). They describe two possible sources: leaching of evaporitic strata and concentration of dissolved solids through membrane filtration. They conclude that leaching of evaporitic strata along with updip movement of the brines account for the present distribution of highly saline water and "that membrane - filtration phenomena do not play an important role in the formation of concentrated brines in the Atlantic Continental Margin." Drilling and geophysical data (Hathaway and others, 1979, p. 529) have indicated the presence of evaporitic strata beneath the Continental Shelf and Slope. On the other hand, there is no evidence that membrane filtration has taken place in the Atlantic Coastal Plain.

After formation, the brines could migrate westward as sea level rises and the Continental Shelf becomes inundated by seawater. Seawater intrusion into the aquifers would also take place. Conversely, flushing of the brines and the intruded seawater would take place as the sea level declines and the Continental Shelf becomes exposed to the atmosphere. This back and forth movement of freshwater and salty ground water probably caused the thick transition zone between freshwater and saltwater. Cooper (1964, p. C6-C10) states that freshwater-saltwater mixing and dispersion can be caused by "the reciprocative motion of the saltwater front resulting from ocean tides and from the rise and fall of the water table..." He states also that dispersion rates are much larger in aquifers of alternating beds of high and low permeability than in homogeneous aquifers. Upson (1966, p. C242) also concluded that the thick transition zones result partly from tidal fluctuations and partly from sea-level changes.

CONCLUSIONS

Salty ground water underlies freshwater in the eastern part of the Atlantic Coastal Plain from New Jersey to North Carolina. Salinity generally increases with depth within a transition zone between the deepest freshwater and the underlying saltwater. The zone from 250 to 18,000 mg/L of chloride is generally 1,500 to 2,300 feet thick and is caused by the back and forth movement of freshwater and salty ground water as sea level fluctuates.

Depth to brackish water (250 mg/L and 1,000 mg/L of chloride) generally increases westward from the coast, except in New Jersey where the greatest depths are along the coast. Areas of shallow brackish water coincide with areas of fresh ground-water discharge. The brackish water is probably in equilibrium with the natural freshwater flow system.

Depth to saltwater (10,000 mg/L and 18,000 mg/L of chloride) generally increases westward in Delaware, Maryland, and Virginia. It is greatest near the coast in New Jersey and North Carolina. A large area of shallow saltwater underlies Delaware Bay and adjacent parts of Delaware and New Jersey. Ground water containing less than 10,000 mg/L of chloride extends as much as 70 miles from the New Jersey coast and is believed to be relict water emplaced when sea level was low. The position of the saltwater, both onshore and offshore, is probably influenced by long-term average hydrologic conditions rather than by predevelopment conditions or the last low sea level during the Pleistocene. Depths to saltwater, therefore, suggest that the shoreline from New Jersey to Maryland has generally been east of its present location and that Delaware Bay has functioned as an area of fresh ground-water discharge.

Leaching of evaporitic strata is believed to form brines having dissolved-solids concentrations greater than that of seawater. The brines move westward when sea level rises and tend to be flushed when sea level declines.

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TABLE 1.-- DATA USED FOR CONSTRUCTION OF CHLORIDE - DEPTH MAPS

E FIRST NUMBER IS THE IDENTIFICATION NUMBER APPEARING ON THE MAPS.
E NUMBER BEFORE THE SLASH (/) IS THE CHLORIDE CONCENTRATION IN MG/L.
E NUMBER AFTER THE SLASH(/) IS THE DEPTH BELOW SEA LEVEL AT WHICH THE
LORIDE CONCENTRATION OCCURS. MOST DEPTHS ARE ESTIMATED FROM REPORTED
REEN SETTINGS OR AQUIFER DEPTHS. SOME DEPTHS ARE ESTIMATED FROM REPORTED
SING AND WELL DEPTHS. THE LETTER (Q, SP, E, R) REFERS TO THE SOURCE
THE CHLORIDE VALUE AS FOLLOWS: Q, CHEMICAL ANALYSIS; SP, SELF-POTENTIAL
G; E, ESTIMATED FROM DISSOLVED SOLIDS CONTENT OR SPECIFIC CONDUCTANCE;
RESISTIVITY LOG.

CONTINENTAL SHELF

. Q 16200/103	16200/241	E 8000/306	Q 820/305	1800/337
Q 1600/460	1000/523	1160/585	1350/648	2090/710
Q 8100/802	2720/895	E 1800/926		
. Q 14950/154	12800/211	10900/240	4020/272	
. Q 17000/213	18200/243	11260/273	6340/304	5140/335
Q 3700/335	3790/429	3520/460	3170/460	3390/491
Q 3530/522	3770/554	4830/616	4960/647	5640/709
Q 7330/771	6190/832	9070/926	7210/1018	10970/1081
Q 14270/1112				
. Q 17600/276	15800/335	14000/397	15500/522	14600/585
Q 13900/772	13400/832	13200/957	13500/1019	13400/1081
Q 14100/1144	18000/1237			
. E 17600/1001	18000/1013	18400/1028	18100/1072	18000/1196
E 18000/1258	18200/1414	18000/1502	18000/1634	18000/1728
E 18200/1821				
. Q 14800/98	13500/128	8600/158	4500/188	230/259
Q 1500/304	E 200/335	Q 880/366		
. Q 19000/892	19500/928	18500/990	19200/1051	19500/1236
Q 20100/1298	19900/1352	18600/1391	19300/1453	19200/1579
Q 19200/1640				
. E 20000/308	15800/364	13300/426	13200/457	13900/488
E 14800/519	15100/582	15400/645	16400/707	17000/766
E 17800/829	18000/891	17500/986	18400/1018	17000/1049
. E 20600/262	19000/290	20500/321	20000/352	18200/415
E 19700/477				

DELAWARE

. Q 212/80	2. Q 38/88	3. Q 6/550	4. Q 19/170	
. Q 300/640	SP 1100/725	2100/910	3000/1000	2200/1080
SP 3600/1180	7900/1340	8800/1560	10000/1750	13200/1860
SP 9000/2040	14200/2160	12400/2200		
. Q 20/113	7. Q 1070/1100	8. Q 7/450		
. Q 64/480	535/640	541/780	10. Q 168/560	266/700
1. SP 1400/800	1000/1090	1200/1540	1800/1610	2800/1750
SP 3500/1820	6000/1860	6800/1960	7400/2250	11200/2340
SP 15400/2480				
2. Q 37/248	13. Q 29/350	14. Q 33/300	15. Q 21/290	

MARYLAND

SP 1000/1190 1200/1240 1500/1330 2800/1450 1500/1620
SP 1800/1710 4300/1940 9000/2100 8000/2220 14000/2510
SP 17500/2720 17500/2920 19000/3050 17500/3190 16000/3350
SP 38000/3460 37000/3750
Q 18/590 3. Q 5/600 4. Q 13/665
Q 1000/550 R 500-1500/970 6. Q 16/440 R 1-20/1360
Q 2/215 R 1500-4000/1500 8. Q 47/635 R 50-500/1230
Q 32/1450 10. Q 3/480 473/1140 2580/1340 11. Q 1/684
. Q 2/830 13. Q 2/1040 14. Q 1/780 15. Q 5/1730
. Q 10/1013 R 1-20/1760 17. Q 13/2550 18. Q 2/1350
. Q 2/850 20. Q 2/1120 21. Q 6/530 22. Q 31/1150 23. Q 61/750
. Q 2/1000 25. Q 1/860 26. Q 1/1032 27. Q 1/830 28. Q 2/580
. Q 2/590 30. Q 2/680 31. Q 2/530 32. Q 2/1260 1/1300
. Q 59/390 34. Q 2080/400 35. Q 65/480 36. Q 170/300 580/540
. Q 195/500 38. Q 1200/1000 39. Q 250/670 40. Q 242/730
. Q 5/910
. Q 33/1040 42/1130 110/1280 41000/3800 42000/4000 42000/4200
SP 800/1520 1500/1880 2100/1930 6100/2020 4500/2250 5100/2390
SP 5500/2490 10000/2770 16000/3820 31400/3920 29000/4200
. Q 439/400 44. Q 326/500 45. Q 52/300
. SP 3200/1270 2500/1430 3000/1700 3700/1830 4000/2160
SP 4200/2240 14200/2370 14800/2460 21000/2750 36000/2960
SP 43000/3280 45700/3580 48700/3840 57400/4210 52000/4540
SP 55800/4640 47. Q 60/140 48. Q 47/160
. SP 1100/1700 3200/1910 7000/2140 9000/2230 10000/2350
SP 12000/2630 22000/2840 24500/2990 24500/3100 26000/3320
. Q 170/420 296/460 2710/700

NEW JERSEY

Q 118/80 307/100 2. Q 275/225 3. Q 165/320 4. Q 122/220
Q 216/240 6. Q 155/210 7. Q 150/200 8. Q 223/330 9. Q 139/200
. Q 138/500 176/610 11. Q 188/590 12. Q 210/640
. Q 32/90 700/330 1900/700 14. Q 142/610 15. Q 4/720 283/1330
. Q 6/390 780/2730 SP 1100/2740 2700/2860 5400/3030 7000/3090
SP 7000/3170 11300/3370 11300/3480 17. Q 39/800 325/1250
. Q 11000/1980 12000/2490 18000/3010 22000/3180 27000/3310
SP 600/860 3300/1230 8000/1480 8700/1840 11600/2410
SP 12400/2660 16700/2940 25900/3030 27400/3110 27400/3240
. Q 200/880
. SP 1300/1840 1500/2100 6400/2210 10300/2420
SP 10300/2580 11600/2690 21000/3010 28800/3110 28800/3680
SP 32200/3910 38100/4360 22100/5200 22100/5380

NEW YORK AND MASSACHUSETTS

Q 5/1240 2. Q 14/1910 3. Q 13/1670 4. Q 1200/1400

08. Q 758/370 109. Q 113/100
10. Q 123/190 3200/570 13000/860 16000/1280
11. Q 490/90 112. Q 244/260 1410/330
13. Q 9950/860 11400/1180 15500/1400
14. SP 2000/700 2700/870
SP 2700/970 4800/1070 5000/1150 3500/1370 6000/1450
SP 3000/1780 3300/1880 3000/2030
15. SP 7800/1270 6800/1350 16000/1850 19000/1860 23500/1920
SP 21000/2130 21000/2180 23500/2570 28000/2590 23500/2660
SP 34000/2730 38000/2830 38000/2900 42000/3010 42000/3080
SP 42000/3170 42000/3270 42000/3610 116. Q 101-250/125
17. Q 111/400 118. Q 85/420 119. Q 10/200 120. Q 28/430
21. Q 30/300 122. Q 1-10/300 123. Q 101-250/350 124. Q 11-25/240
25. Q 26-100/360 126. Q 8/320 320/570 127. Q 1-10/360
28. Q 1-10/250 129. Q 34/450 130. Q 11-25/370 131. Q 15/450
32. Q 11/270 133. Q 101-250/310 134. Q 101-250/360 135. Q 101-250/380
36. Q 101-250/380 1-10/430 137. Q 110/250 138. Q 57/300
39. Q 26-100/370 140. Q 12/510 67/640 141. Q 222/660 470/820
42. Q 10/240 840/360 4100/550 143. Q 8/190 144. Q 15/380
45. Q 386/370 765/400 6720/540 146. Q 19/210 147. Q 28/250
48. Q 168/300 820/360 2460/400 3540/460 149. Q 65/220
50. Q 98/200 186/260 151. Q 226/280 1500/470 152. Q 270/270
53. Q 382/260 154. Q 155/400 748/600 155. Q 780/420
56. Q 200/310 2960/460 9700/900 157. Q 120/300 158. Q 212/130
59. Q 308/100 160. Q 240/150 1625/680 7150/850 17000/1240
61. Q 44/80 SP 12800/1520 10600/1760 26000/2310 26000/2360
SP 34000/2450 26000/2550 31500/2620 38000/2720 31500/3330
SP 34000/3400
62. SP 2500/510 7800/790 10300/840 12800/1140
SP 14800/1220 12800/1280 13200/1550 13600/1680 21000/1790
SP 13600/1960 14800/2060 19000/2150 19000/2560
63. SP 3300/950 5000/990 9500/1090 6800/1500 14200/2280
SP 12000/2320 15400/2410 38000/2490 34000/2560 34000/2590
64. SP 6200/970 6100/1000 8800/1790 12000/2330 17500/2390
SP 23500/2540 19000/2580 16800/2630
65. SP 11000/2390 11600/2540 13600/2620 13600/2730 16000/2830
SP 14200/3370 26000/3440 28000/3510 31000/3600 28000/3750
SP 26000/3880 28000/4040 31000/4260 31000/4410 34500/4640
66. SP 3800/420 3900/560 5000/730 4700/970 5100/1010 6900/1280
SP 7000/1320 8200/1960 12000/2820 15400/2910 14200/3050
SP 23500/3240 31500/3890
67. Q 14/135 88/320 1240/460 1360/490 1540/540 3325/620
Q 3360/680 3593/750 168. Q 36/550 169. Q 3/400 170. Q 10/470
71. Q 15/240 260/290 1260/420 1340/520 4160/650
72. Q 9/400 173. Q 3/140
74. Q 42/770 175. Q 20/230 319/350 176. Q 25/280 302/420
77. Q 7/170 1100/320 1020/460 178. Q 202/620 1600/790
79. Q 380/310 510/360 180. Q 79/320 618/860
81. Q 350/130 300/190 680/280
82. Q 6/120 183. Q 170/440 1700/600 184. Q 6/200 185. Q 12/200
86. Q 6/180 120/340 1200/450 10400/730
87. Q 125/550 1370/720 15400/960
88. Q 19/360 189. Q 150/400 190. Q 16/210 191. Q 1070/360

92. SP 9000/1520 10000/1570 9500/1650 9800/1780
SP 9500/1950 9300/2240 9800/2300 23500/2390 13600/2470
SP 13600/2580 13200/2690
93. SP 10000/1600 12800/1620
SP 17500/1640 16800/1680 21000/1860 23500/1910 21000/2040
SP 16800/2080 14800/2380 12400/2490 34000/2550 38000/2580
SP 31500/2690 28000/2820 28000/3230 34000/3300
94. SP 3800/1510 3000/1600 17500/1720 19000/1810 16800/1930
SP 19000/2020 21000/2070 21000/2180 23500/2420 42000/2640
SP 34000/2690 34000/2820 21000/3070 21000/3270 31500/3360
SP 48000/3410 42000/3450
95. SP 2200/1800 5000/1880 9200/1930
SP 9000/2050 9500/2280 11300/2630 13600/2810 9800/3120
SP 8800/3340 12000/3590 14200/3630
96. SP 9000/1780 9200/1910
SP 9200/2010 12000/2090 12000/2130 12000/2280 12400/2630
SP 16000/2810 28000/2900 28000/3270
97. SP 2000/1080 3000/1150 8200/1820 10000/1960 10000/2010
SP 14200/2110 16800/2180 16800/2270 15400/2320 21000/2660
SP 26000/2740 23500/2980
98. SP 1500/1030 3100/1180 8400/1870 8400/2010 16800/2230
SP 13200/2360 21000/2710 34000/2090 38000/3210 38000/3380
99. SP 8800/1930 13200/2080 14800/2200 16800/2330 19000/2420
SP 16800/2750 21000/2790 38000/2850 28000/2950 19000/3060
SP 34000/3290 34000/3410 42000/3460
00. SP 5300/1740 2800/1850 9000/2400 28000/2510 14200/2590
SP 28000/2850 34000/2880 34000/2920
01. SP 1400/890 1300/1030 4300/1250 9300/1350 9000/1410
SP 8500/1550 17500/1680 13600/1800 12400/1980 13200/2040
SP 14200/2210 23500/2350
02. SP 4000/1560 6700/1770 13000/2040 12000/2100 13600/2210
SP 16700/2520 11600/2760 15000/3060 16000/3140 15000/3250
03. SP 6200/1440 8500/1490 8500/1560 7000/1610 14800/2250
SP 21000/2460 16800/2600 16800/2740 38000/3280 34000/3500
04. Q 3/400 205. Q 3/150 206. Q 7/180 207. Q 12/140 208. Q 12/200
09. Q 44/350 210. Q 8/410 211. Q 15/350 212. Q 180/420
13. Q 10/250 214. Q 8/330 215. Q 43/220 216. Q 17/180
17. Q 165/300 218. Q 5/400 219. Q 370/300 220. Q 4/160 221. Q 26/500
22. Q 30/150 223. Q 2450/550 224. Q 74/350 225. Q 47/120
26. Q 35/280 227. Q 19/140
28. SP 600/670 600/770 700/790 1800/970 2700/1110 3000/1200
29. SP 1100/840 600/900 1500/1050 2000/1150 4000/1210 2600/1260
SP 4000/1310 3800/1430 3200/1460
30. SP 700/750 2700/1030 3000/1060 3300/1130 2700/1220
SP 5700/1350 6800/1400 10600/1430 9000/1500 10600/1530
SP 10000/1730
31. SP 1000/650 1100/770 1600/840 2500/1000 3900/1110 4700/1170
SP 6700/1180 232. SP 500/920 600/1100
33. SP 800/980 1000/1030 1100/1160 4200/1330 5000/1640
34. SP 800/780 800/840 1500/940 1200/1010 2500/1140 6400/1190
35. Q 7/220 236. Q 12/200 237. Q 650/320
38. SP 2400/510 4200/630 4000/800 5900/1020 6500/1150
39. Q 6/130 240. Q 4/80 241. Q 145/75 242. Q 63/350
43. Q 6/30 2600/290 6950/490 9300/660 10000/680 12000/950
44. Q 47/190 3350/290 8780/560 245. Q 31/90 246. Q 107/160
47. Q 136/150 248. Q 109/160 249. Q 38/120 2860/310 8310/600

NORTH CAROLINA AND SOUTH CAROLINA (CONTINUED)

0. Q 37/190   251. Q 26/150   252. Q 110/150   253. Q 4/160   254. Q 4/420

5. Q 26/370   70/450   3100/620   256. Q 7/220   257. Q 9/250

8. Q 210/100   259. Q 1020/220

0. Q 1300/270   1900/480   6350/690   6650/990

1. Q 235/230   262. Q 486/170   263. Q 760/280

4. Q 19/70   1710/290   2082/680   6300/1010   5780/1140   8250/1270

5. Q 1550/210   8100/1530   266. SP 2200/950   1800/1060   1900/1120

7. Q 60/10   760/300   650/600   2400/770   3700/1000   4500/1210

8. SP 1300/760   1100/980   1200/1020   2200/1050   1500/1130

VIRGINIA

. Q 2/680   2. Q 2/450   3. Q 3/530   4. Q 10/690   5. Q 3/610

. Q 3/500   7. Q 5/700   8. Q 16/600   9. Q 399/660   10. Q 150/1010

1. Q 66/120   12. Q 64/200   13. Q 17/210   14. Q 12/180   15. Q 55/240

5. Q 12/200   17. Q 9/230   18. Q 1600/370   19. Q 690/170   20. Q 29/200

1. Q 20/125   22. Q 21/430   23. Q 14/200   24. Q 2/500   25. Q 160/900

5. Q 3/1200   27. Q 6/550   28. Q 187/600   29. Q 10/500   30. 9/450

1. Q 39/650   32. Q 1848/620   33. Q 1820/800   34. Q 355/700

5. Q 1800/700   36. Q 1500/400   37. Q 1110/390   38. Q 120/260

9. Q 210/250   40. Q 12/400   41. Q 99/480   42. Q 55/460   43. 27/350

4. Q 200/380   45. Q 240/430   46. Q 2150/1170   47. Q 408/500

3. Q 600/700   49. Q 3/900   50. Q 4/310   51. Q 16/580   52. Q 194/510

3. Q 180/380   54. Q 185/655   400/790   1270/1030   55. Q 227/650

6. Q 189/800   57. Q 964/850   1380/950   1680/1040   4200/1260

Q 9560/1620   26000/2370   26900/2500   58. Q 2580/650   59. Q 21/500

0. Q 132/800   61. Q 18/660   62. Q 15/615   63. Q 15/600   64. Q 96/500

5. Q 392/800   66. Q 3/500   67. Q 34/370   68. Q 52/700   69. 65/800

0. Q 57/750   71. Q 580/1100   72. Q 29/440   73. Q 32/530   2250/1000

4. Q 30/590   71/760   456/900

5. Q 24/420   360/670   SP 800/1160

SP 1800/1250   2100/1370   3300/1410   3000/1440   5000/1750

6. SP 22000/620   2400/1020   3000/1170   3400/1810   2600/1880

SP 6000/1950   8000/2230   13200/2290   9000/2510   15400/2620

SP 13200/2800

7. Q 240/280   2038/600   1929/740   1485/1030   1762/1270   2045/1430

SP 700/610   1000/860   1400/960   1900/1030   2400/1270   2200/1430

Figure 1.--Graphs showing relation of chloride concentration to depth in selected wells.

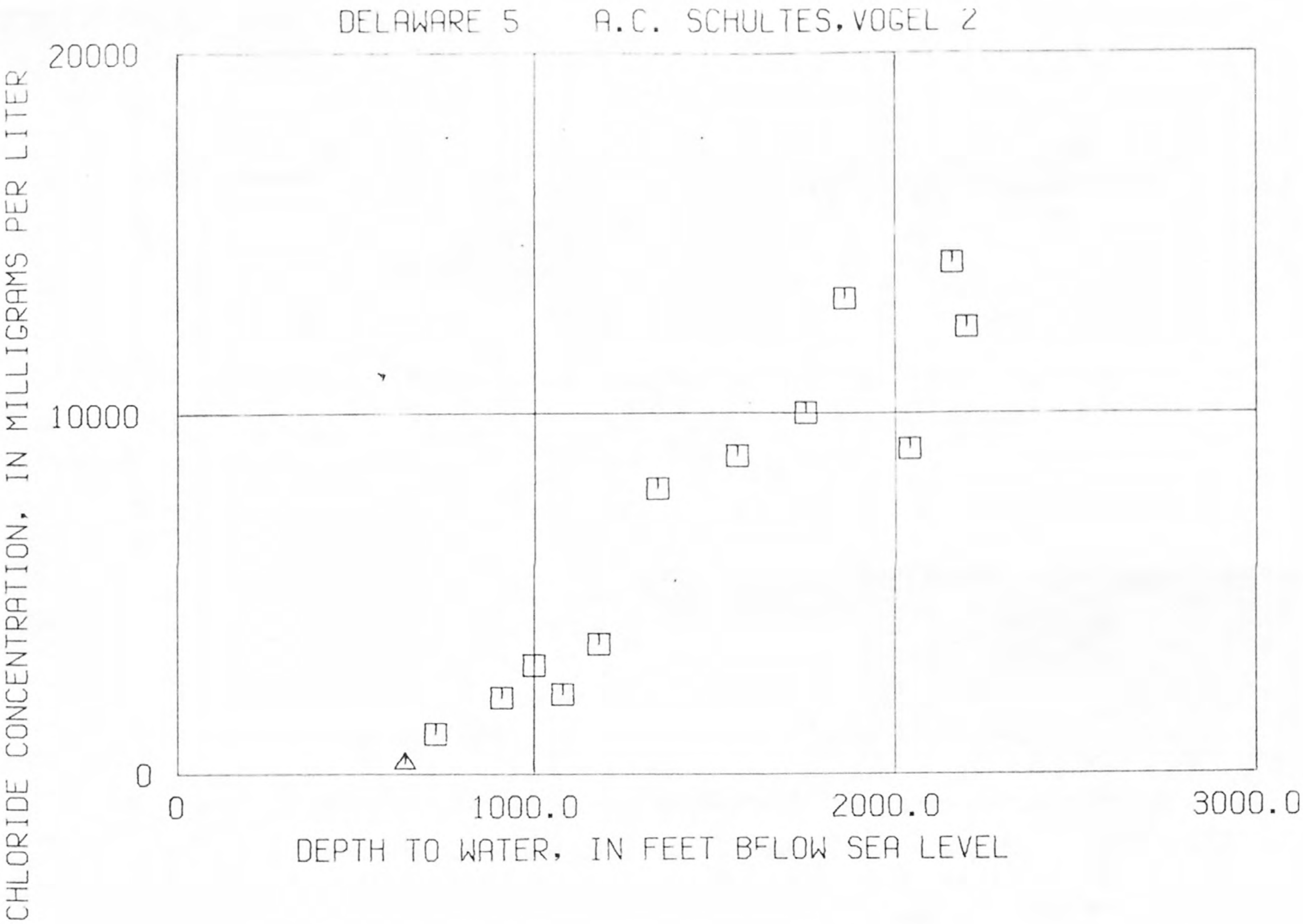
EXPLANATION

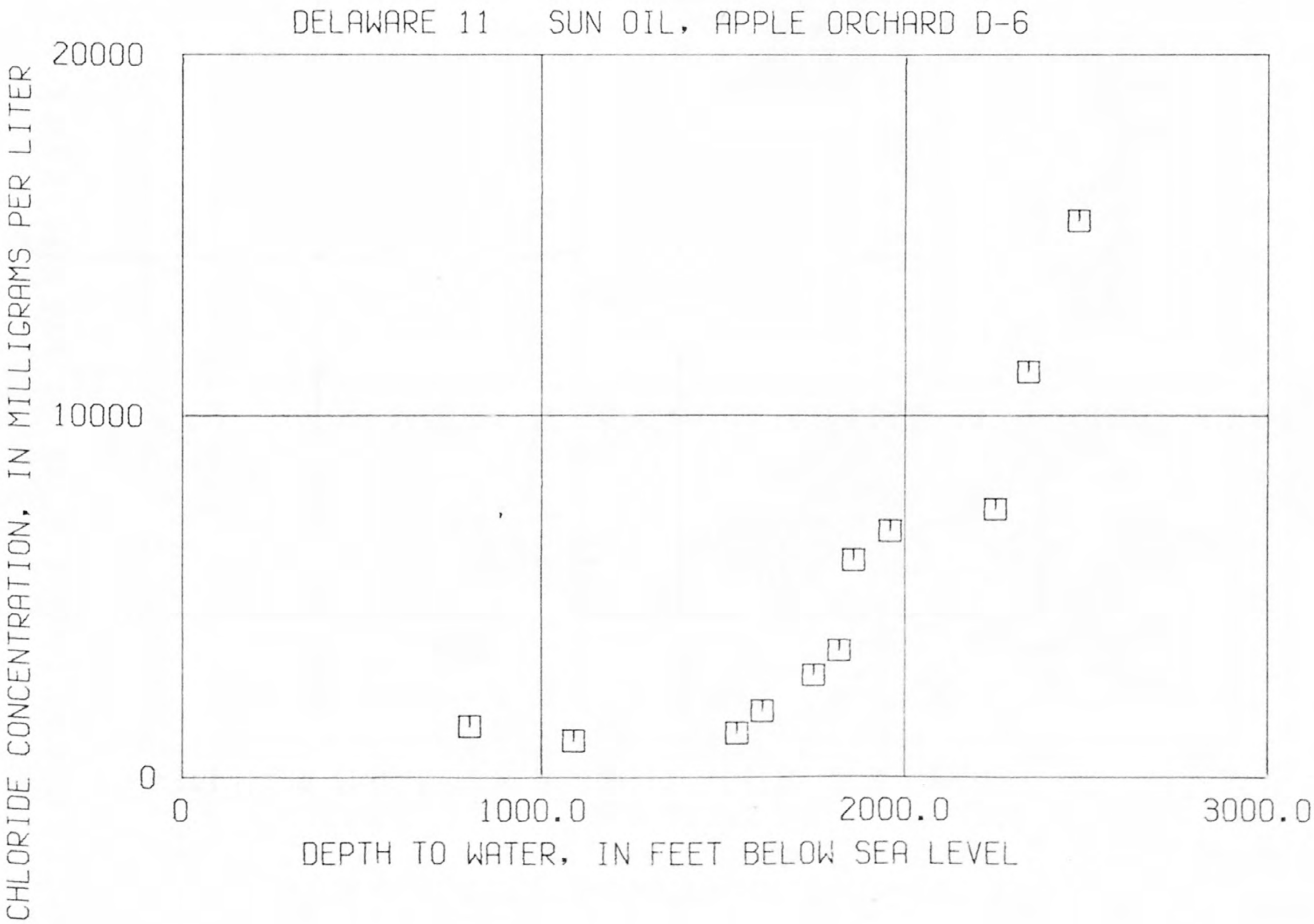
Each well is identified by a State identification number (for example, Delaware 5) followed by a local name (for example, A.C. Schultes, Vogel 2). The State identification number also appears in table 1 and figures 2-5.

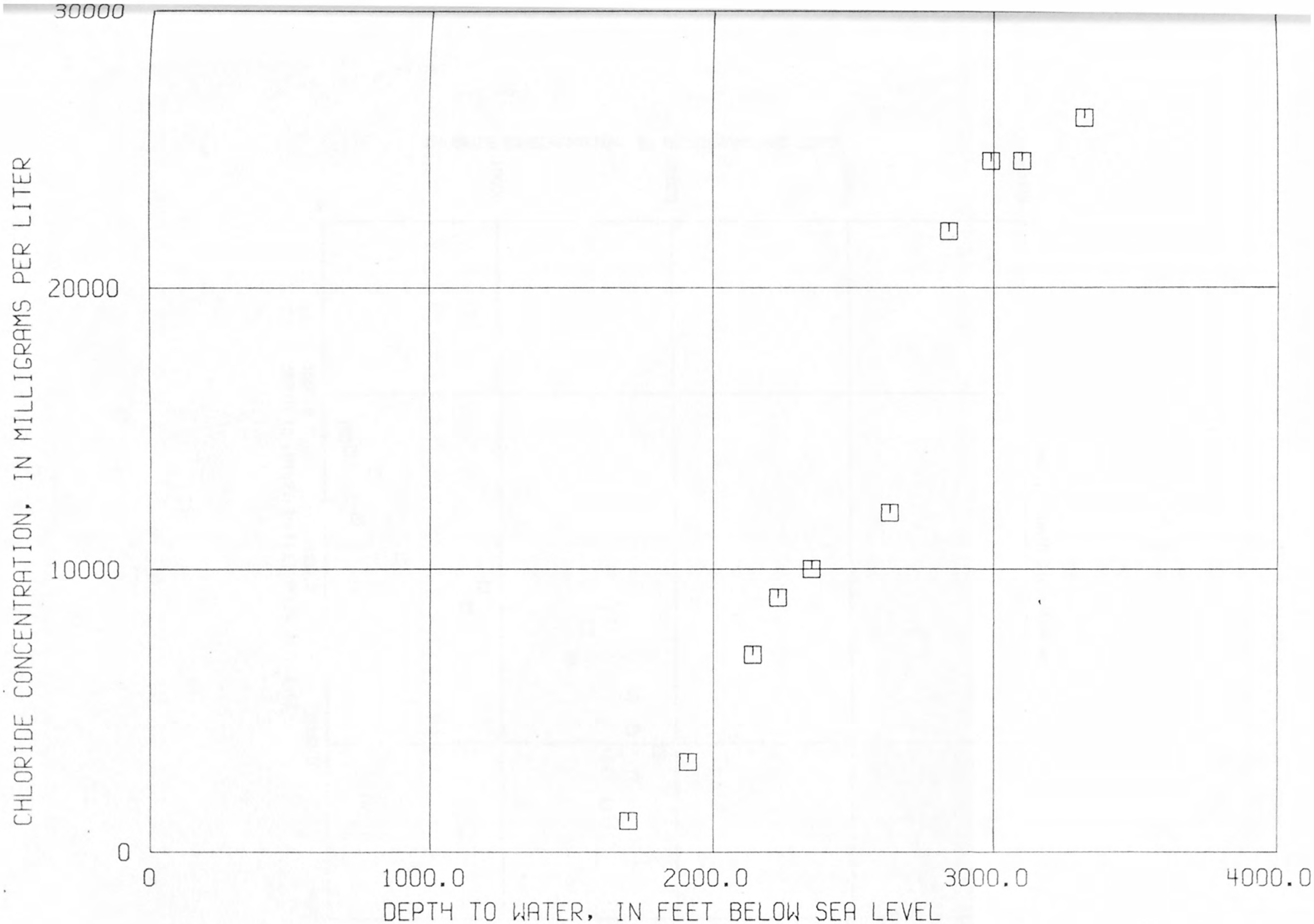
The source of the chloride concentration is identified as follows:

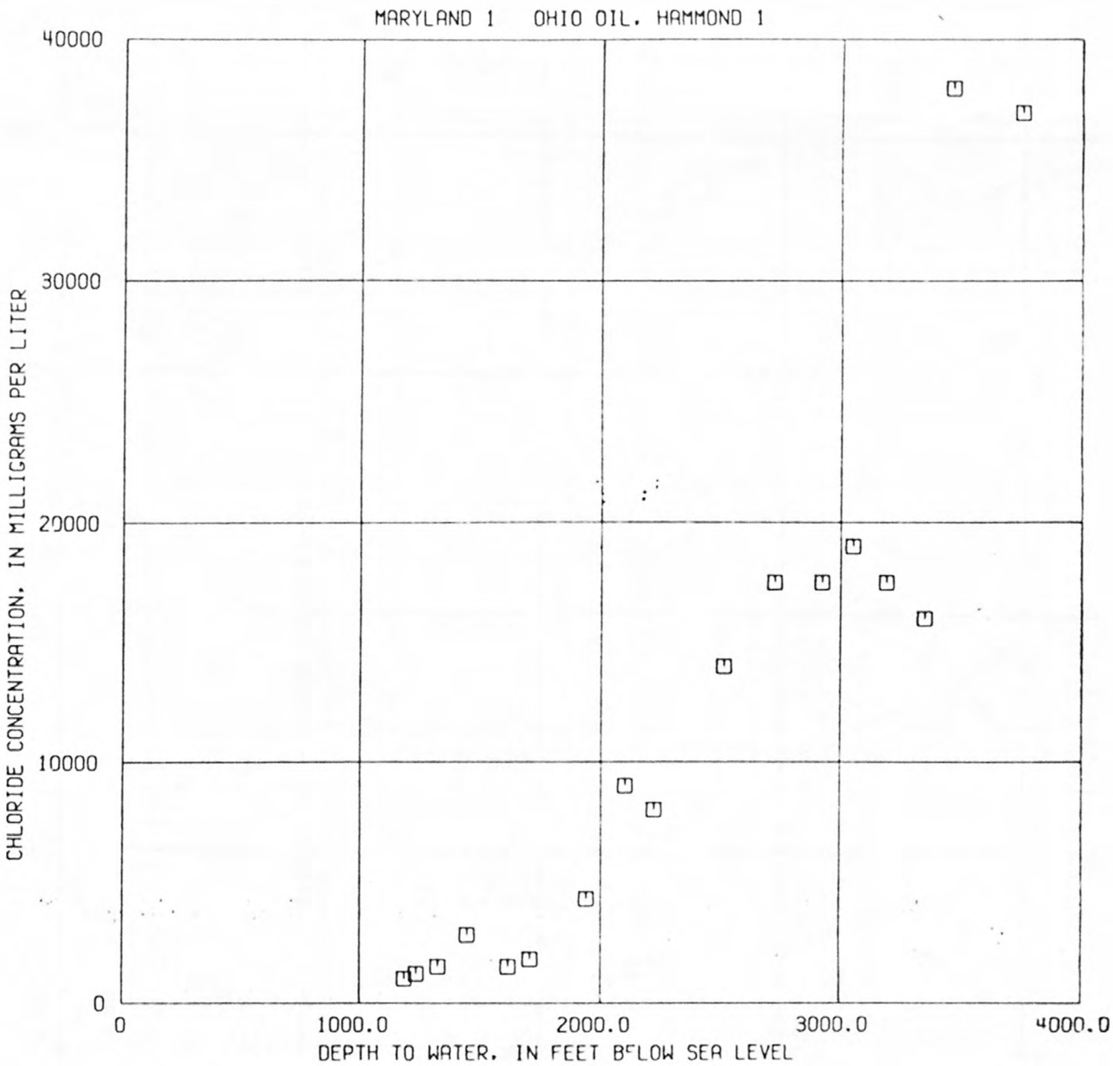
△ Chemical analysis

◻ SP log

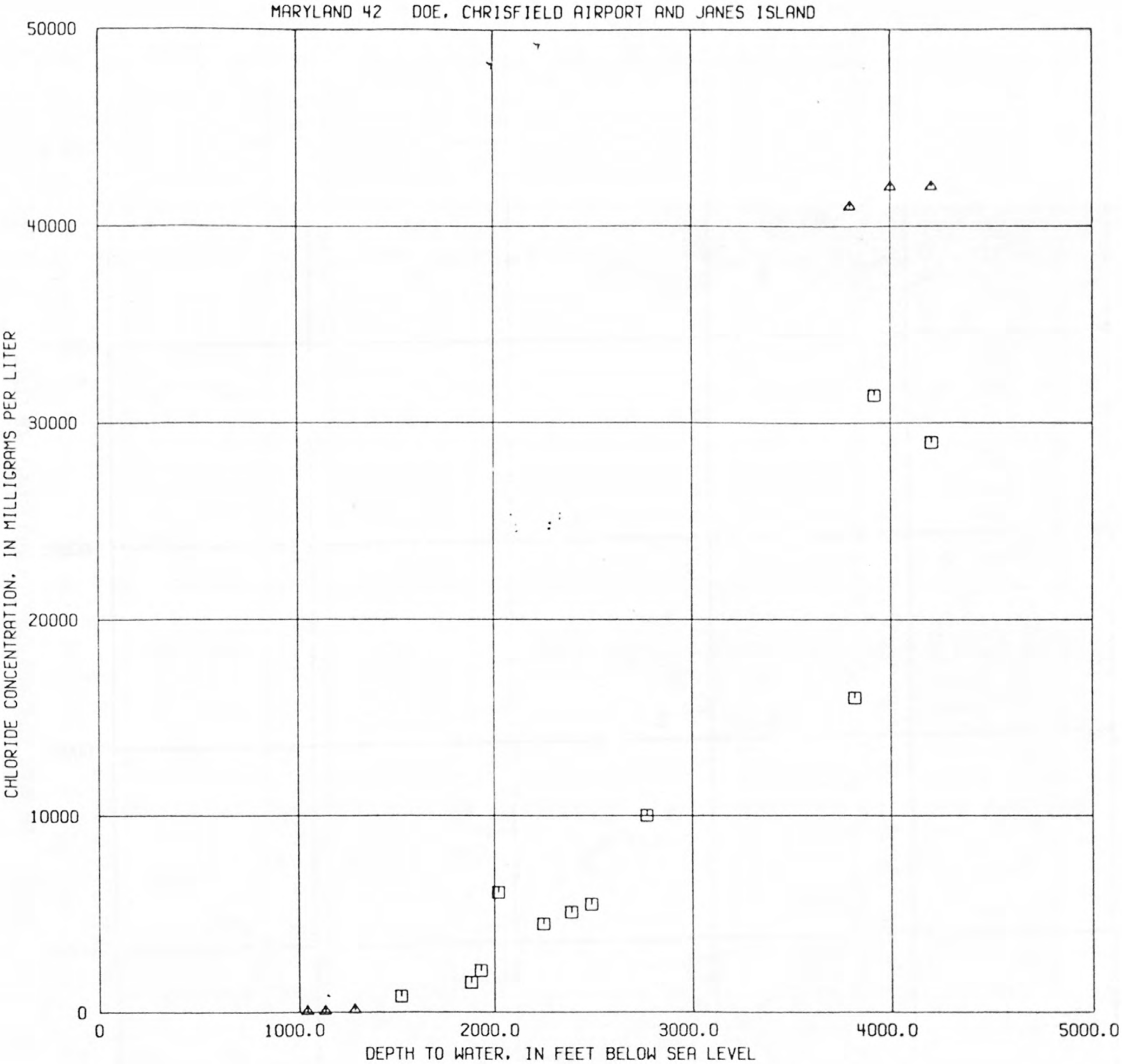

DELAWARE 5 A.C. SCHULTES, VOGEL 2
20000
10000
0
0
1000.0
2000.0
3000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER

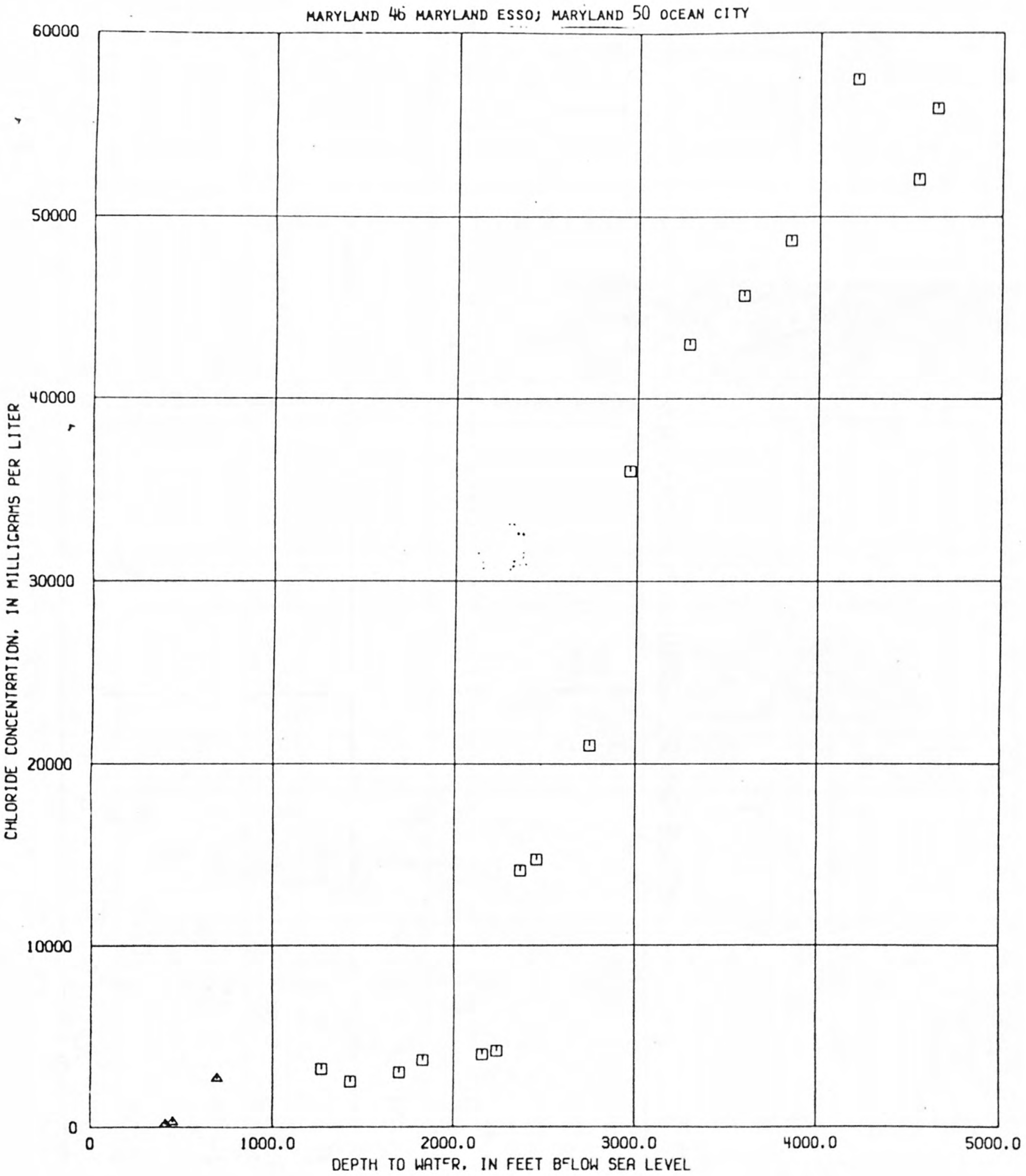

DELAWARE 11 SUN OIL, APPLE ORCHARD D-6
20000
10000
0
0
1000.0
2000.0
3000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER

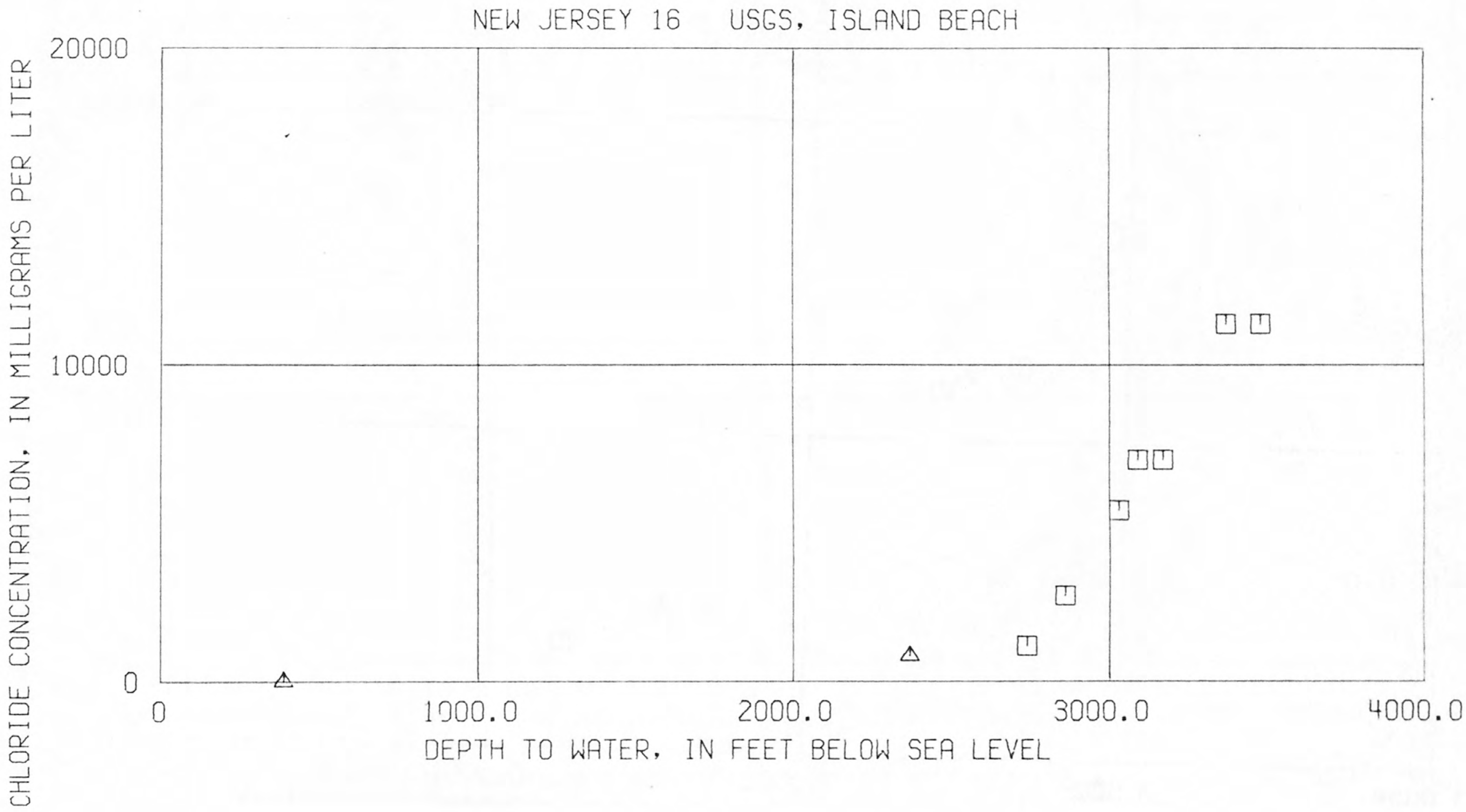

30000
20000
10000
0
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
0
1000.0
2000.0
3000.0
4000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL

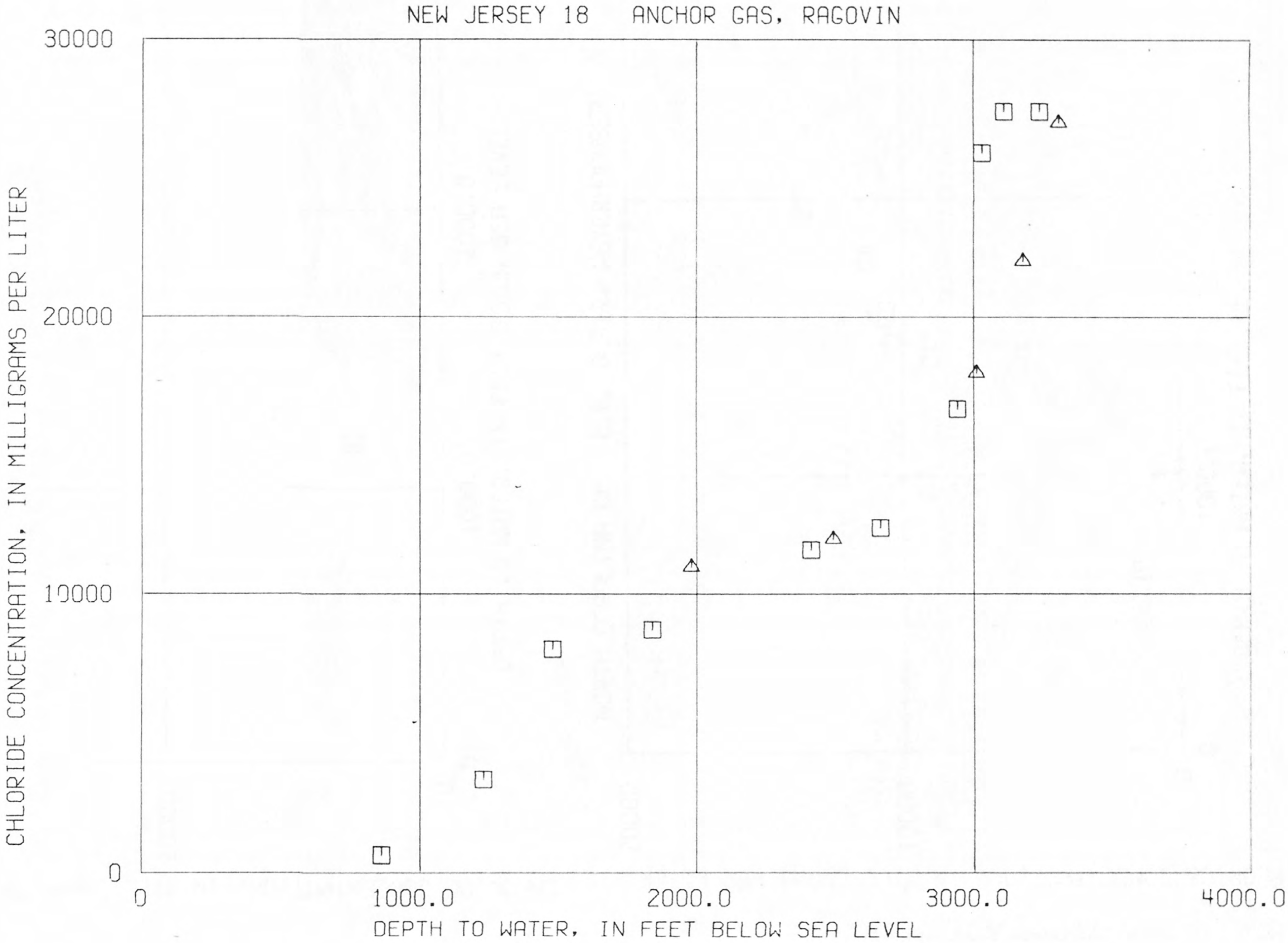


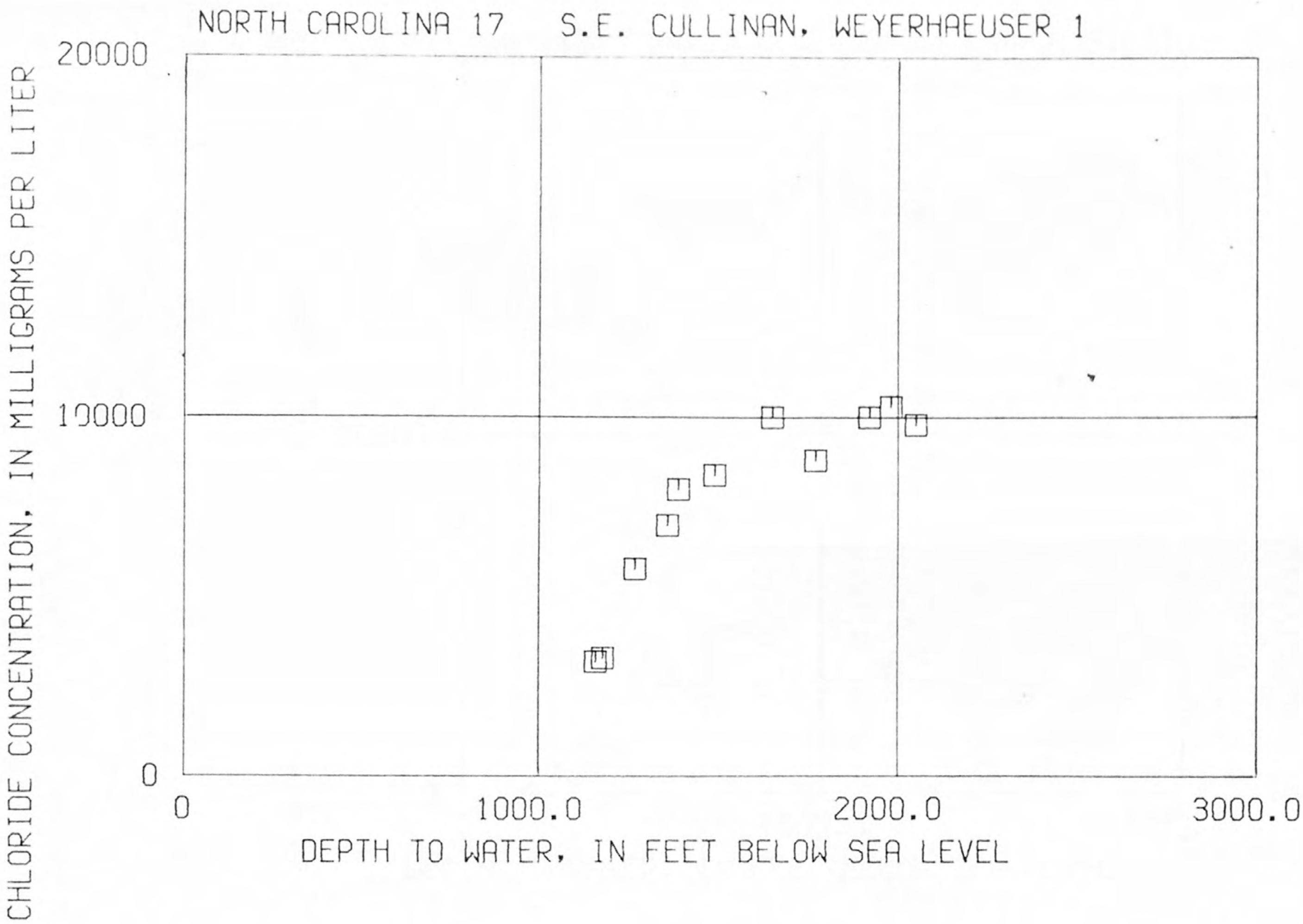
MARYLAND 1 OHIO OIL. HAMMOND 1
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
40000
30000
20000
10000
0
0
1000.0
2000.0
3000.0
4000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL

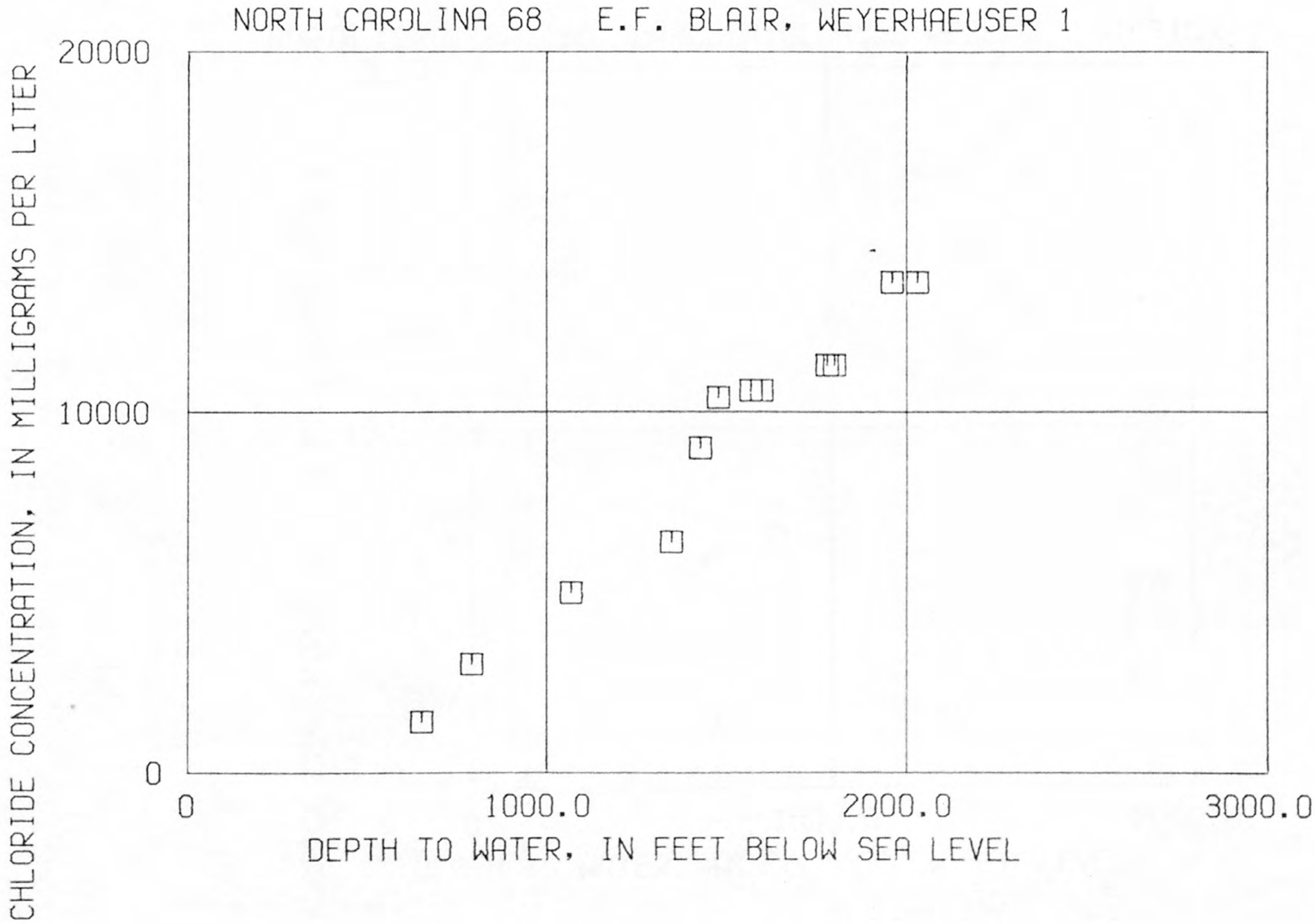

MARYLAND 42 DOE, CHRISFIELD AIRPORT AND JANES ISLAND
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
50000
40000
30000
20000
10000
0
0
1000.0
2000.0
3000.0
4000.0
5000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL


MARYLAND 46 MARYLAND ESSO; MARYLAND 50 OCEAN CITY
60000
50000
40000
30000
20000
10000
0
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
0
1000.0
2000.0
3000.0
4000.0
5000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL

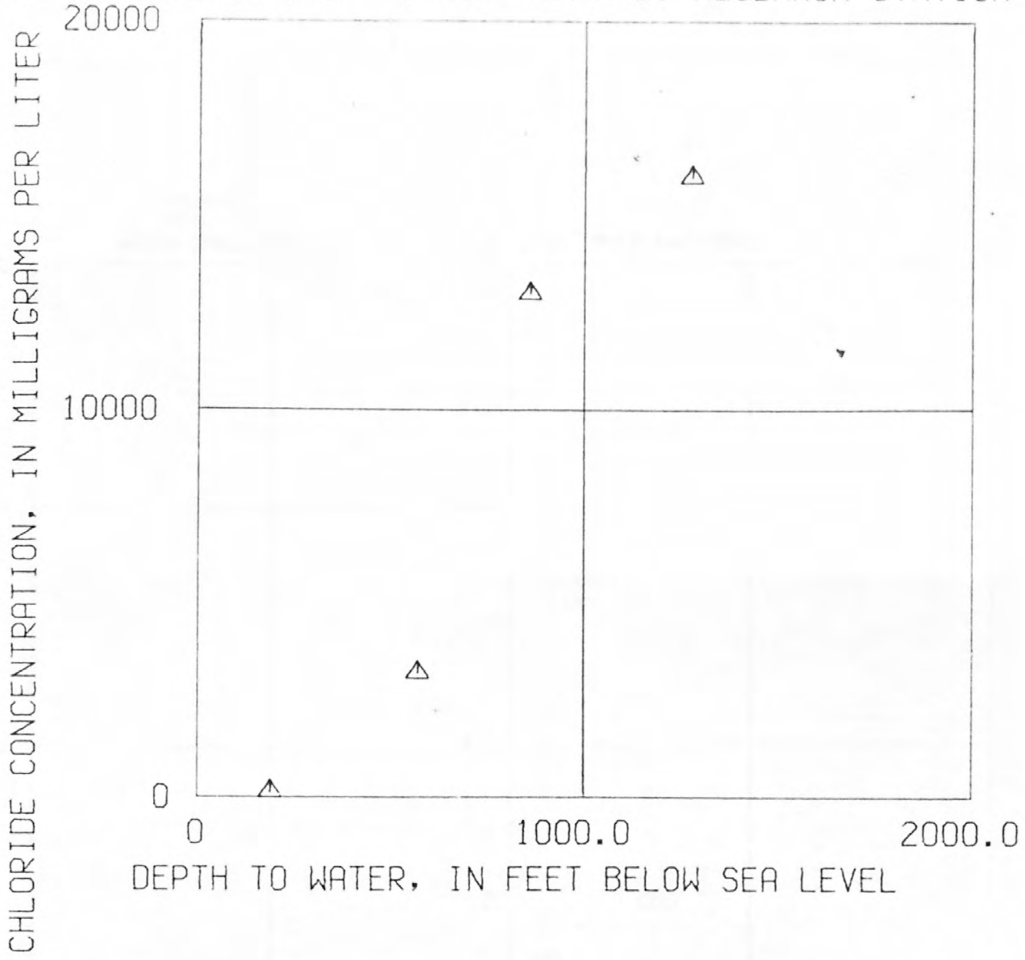

NEW JERSEY 16   USGS, ISLAND BEACH
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
20000
10000
0
0
1000.0
2000.0
3000.0
4000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL


NEW JERSEY 18   ANCHOR GAS, RAGOVIN
30000
20000
10000
0
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
0
1000.0
2000.0
3000.0
4000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL

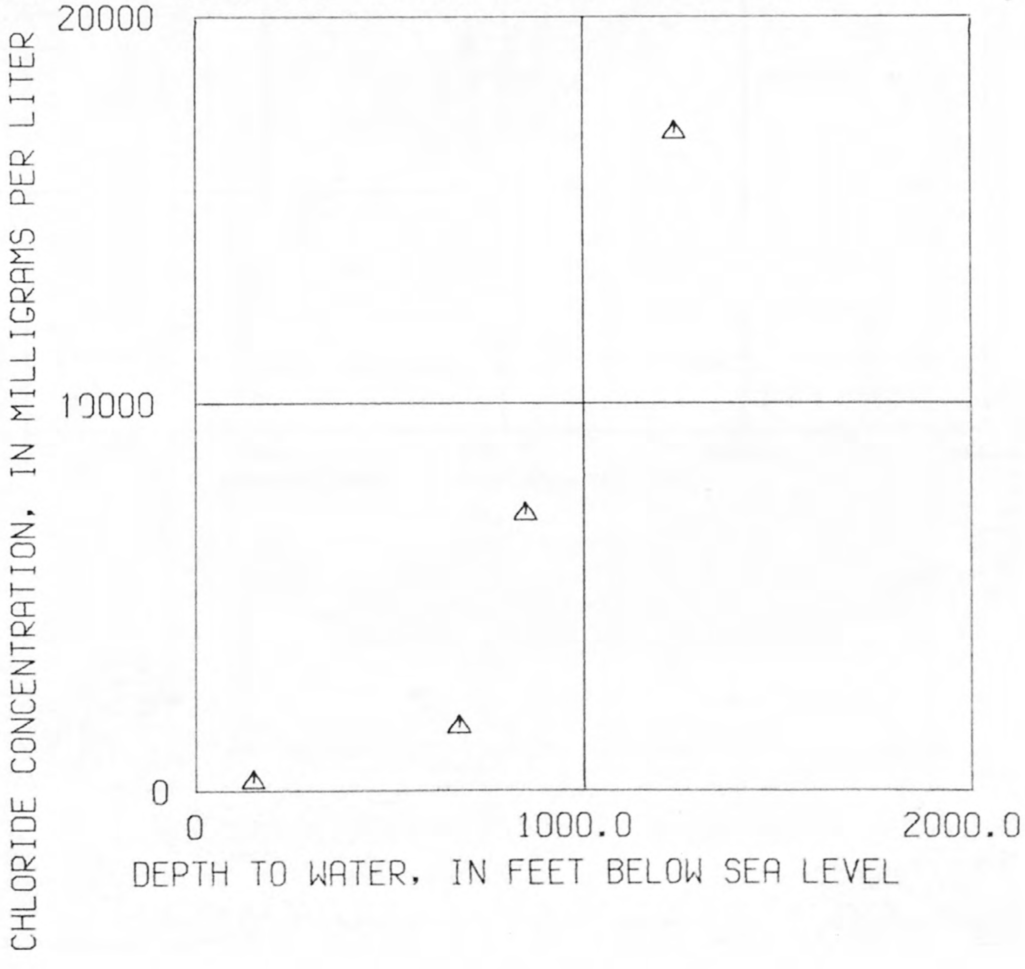

NORTH CAROLINA 17 S.E. CULLINAN, WEYERHAEUSER 1
20000
10000
0
1000.0
2000.0
3000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER

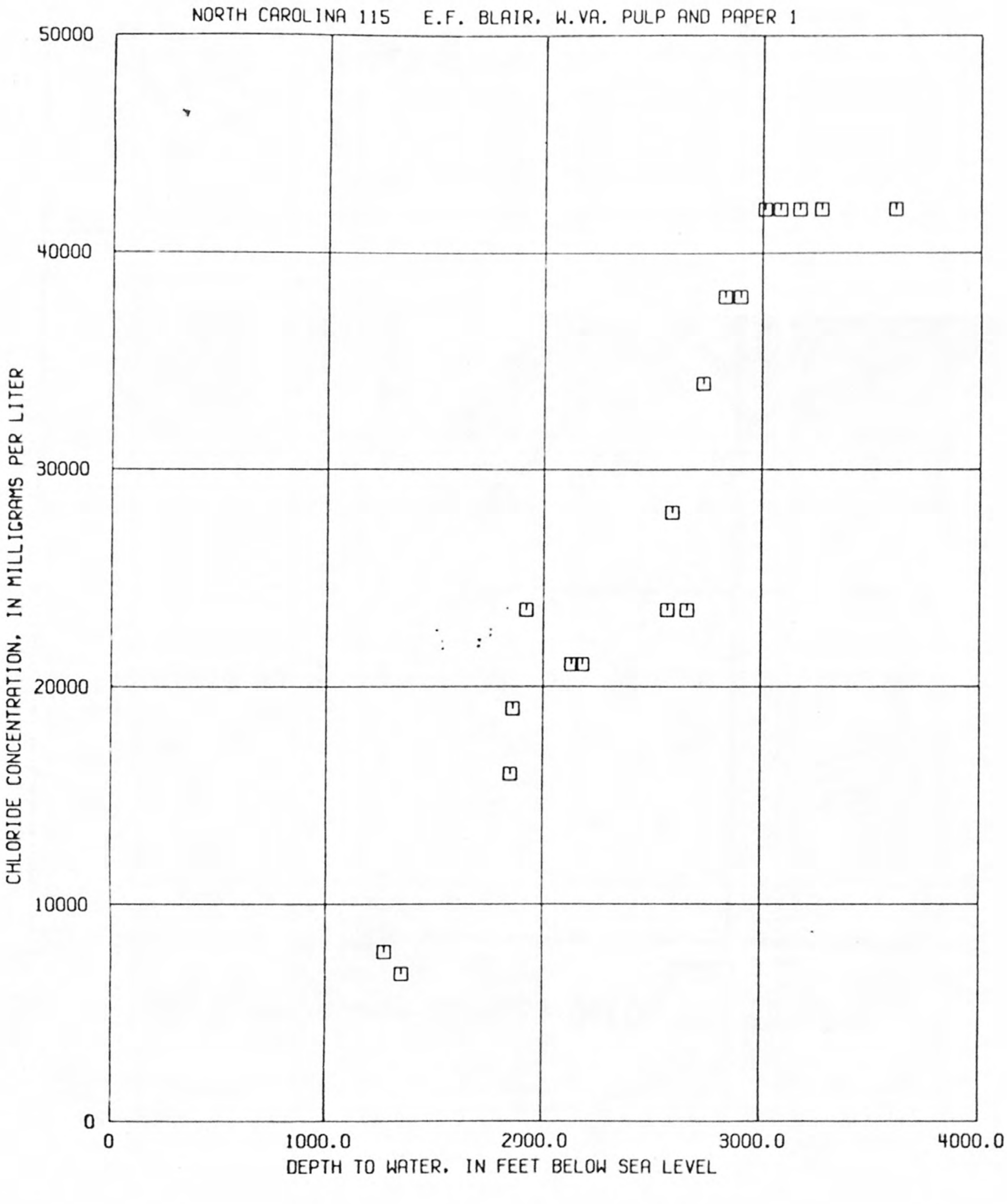

NORTH CAROLINA 68 E.F. BLAIR, WEYERHAEUSER 1
20000
10000
0
1000.0
2000.0
3000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER

NORTH CAROLINA 110 DNRCD NEWLANDS RESEARCH STATION

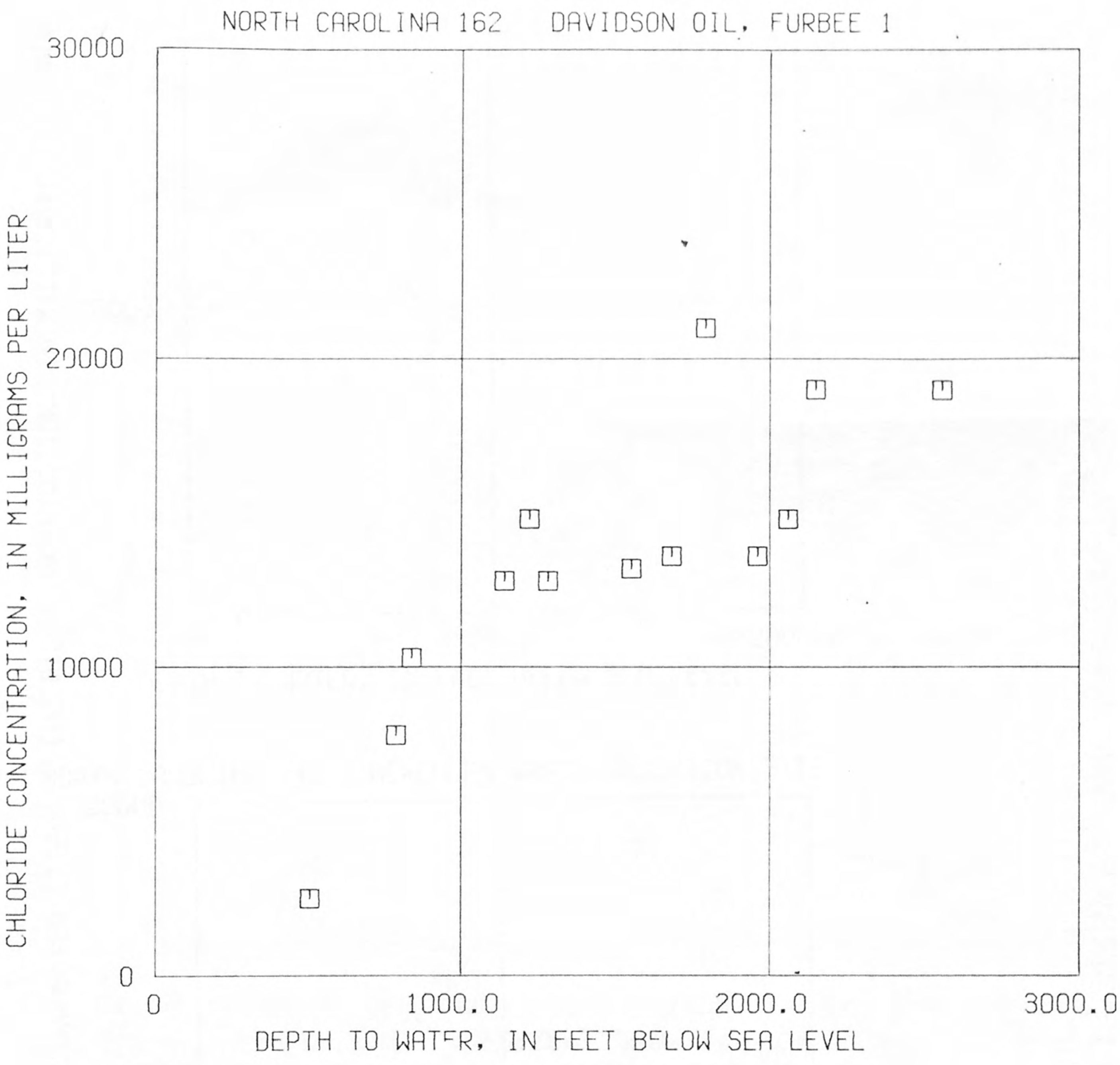


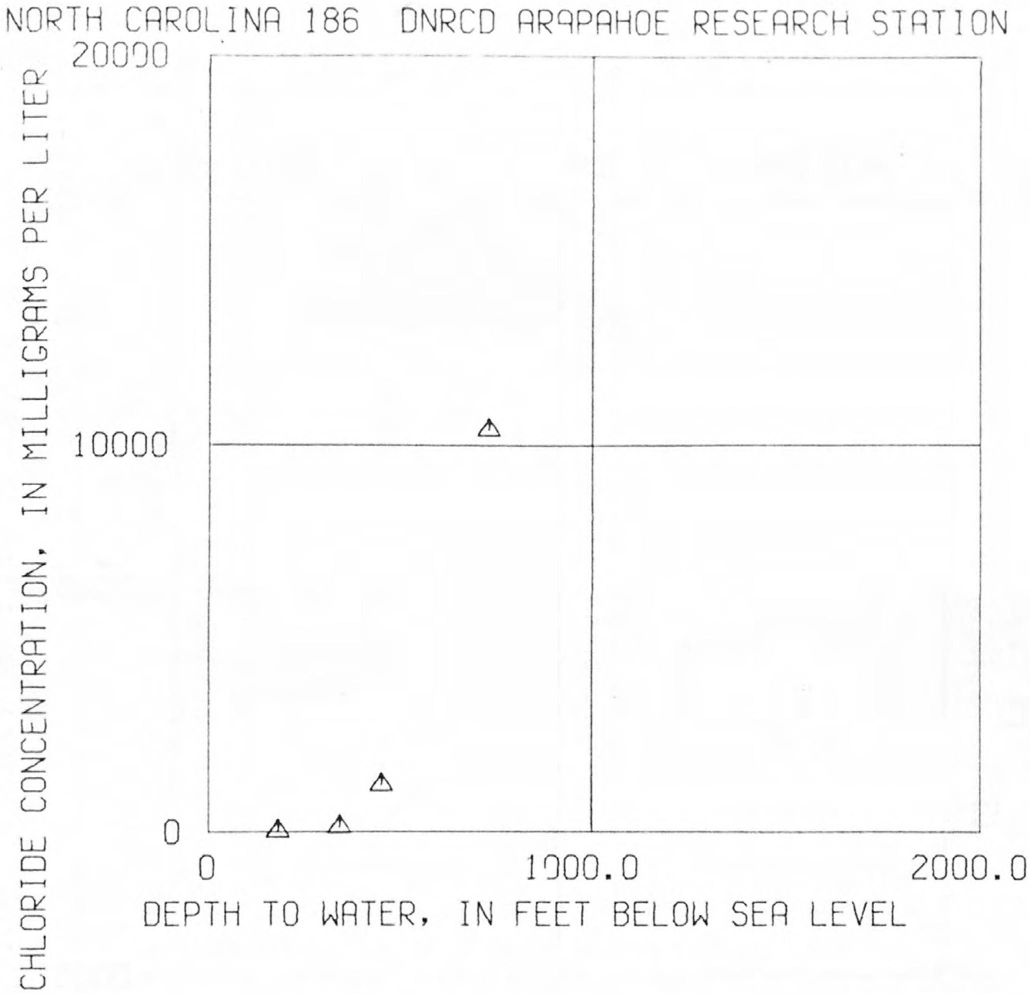
NORTH CAROLINA 160 DNRCD HYDELANDS RESEARCH STATION



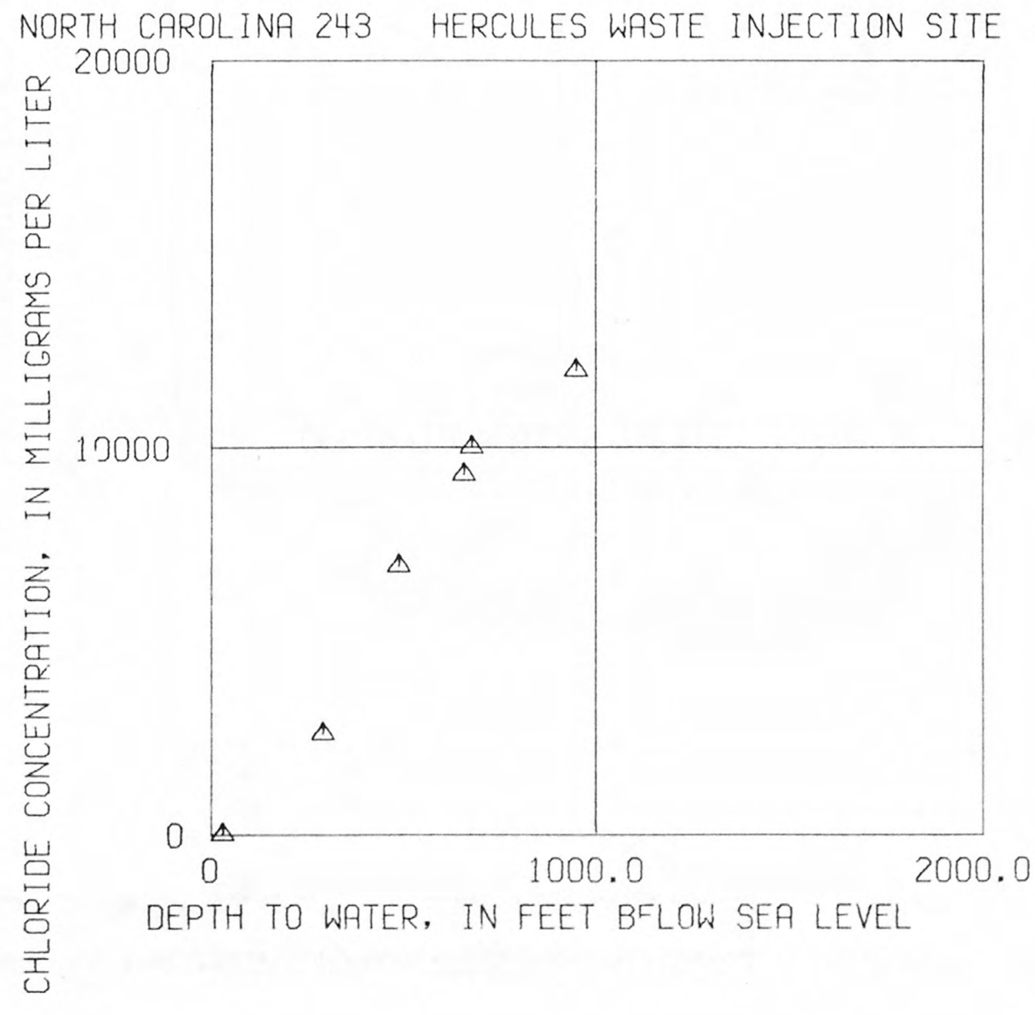


NORTH CAROLINA 115 E.F. BLAIR, W.VA. PULP AND PAPER 1
50000
40000
30000
20000
10000
0
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
0
1000.0
2000.0
3000.0
4000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL

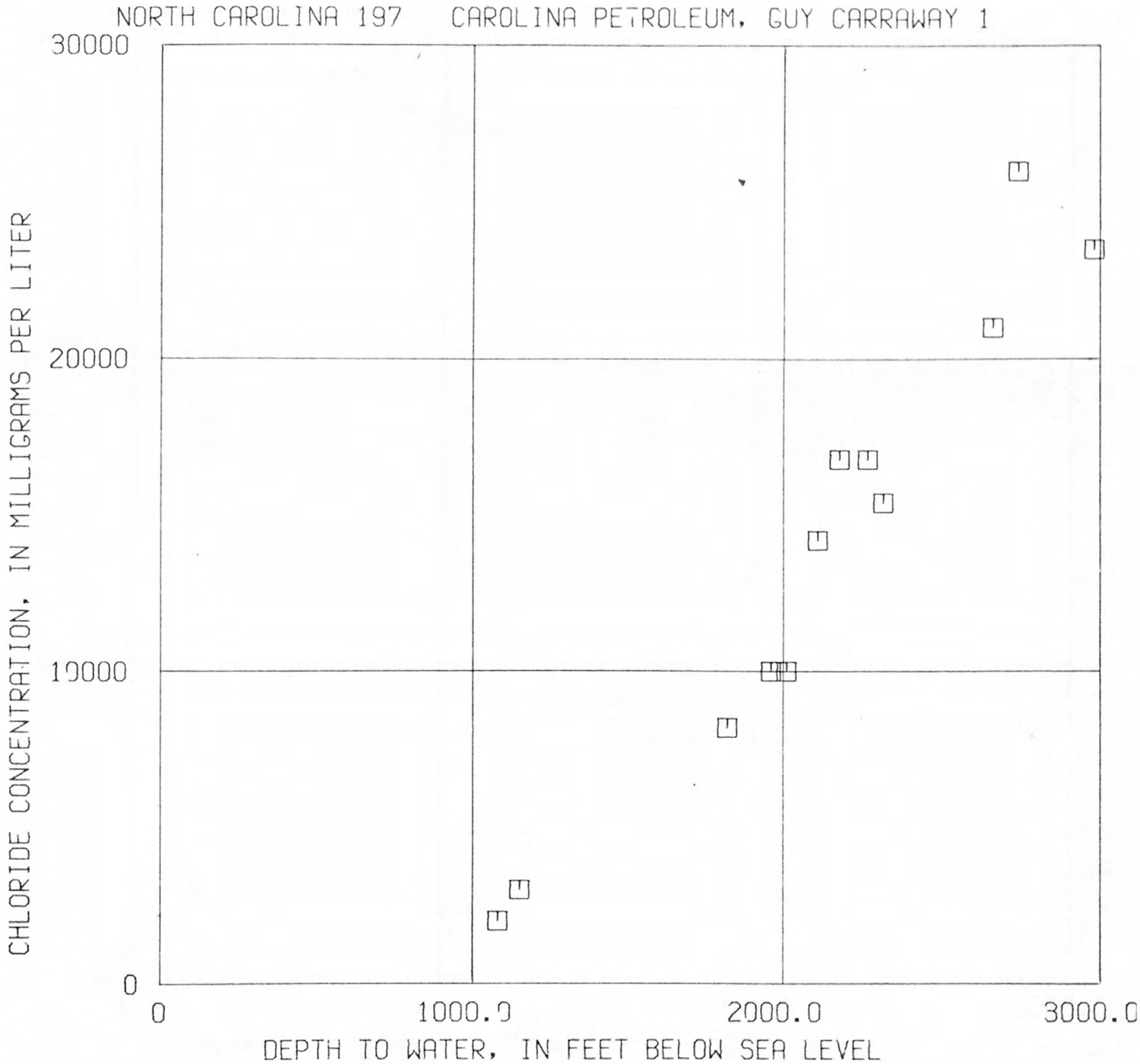

NORTH CAROLINA 162 DAVIDSON OIL, FURBEE 1
30000
20000
10000
0
0
1000.0
2000.0
3000.0
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
DEPTH TO WATER, IN FEET BELOW SEA LEVEL

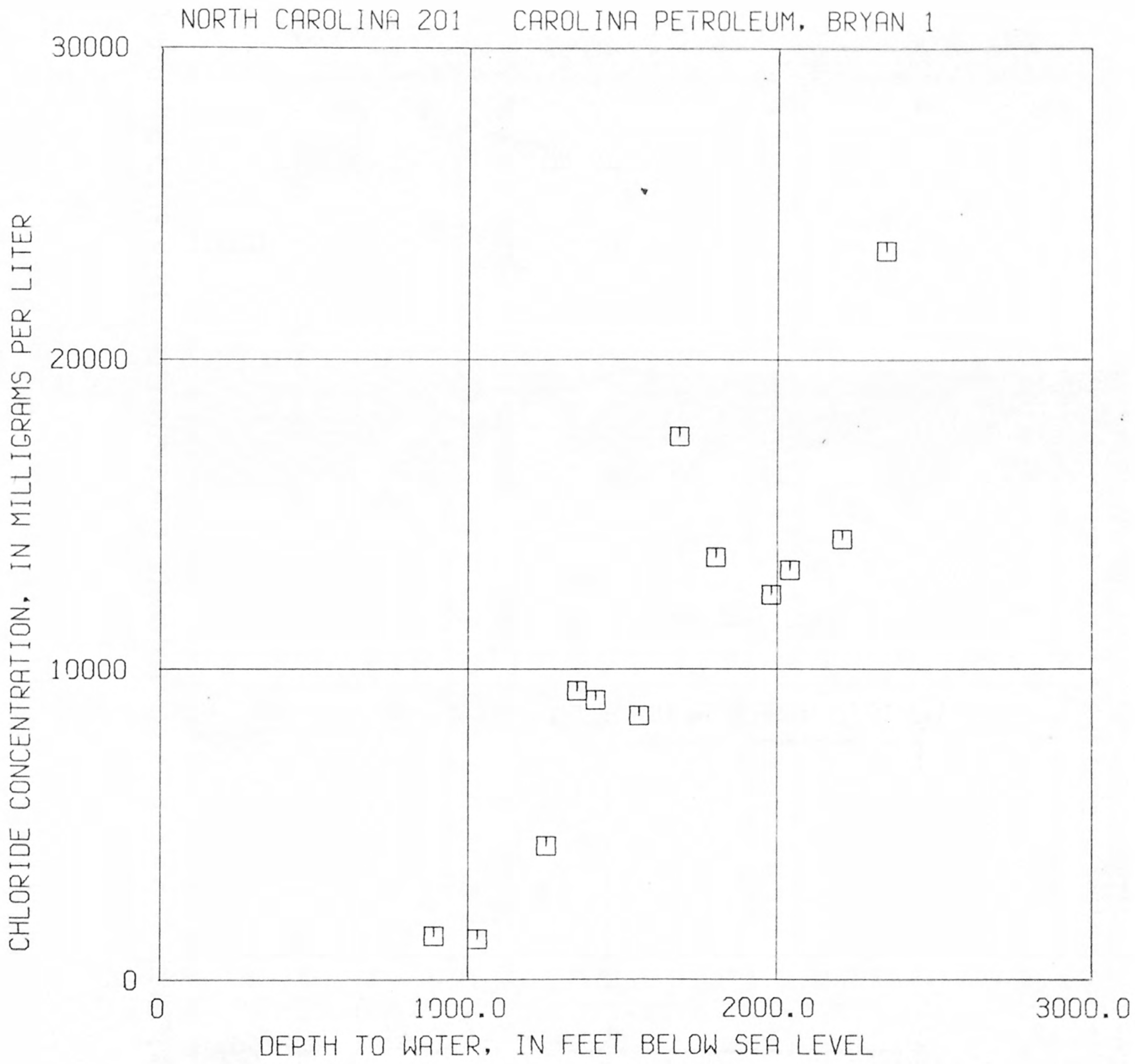


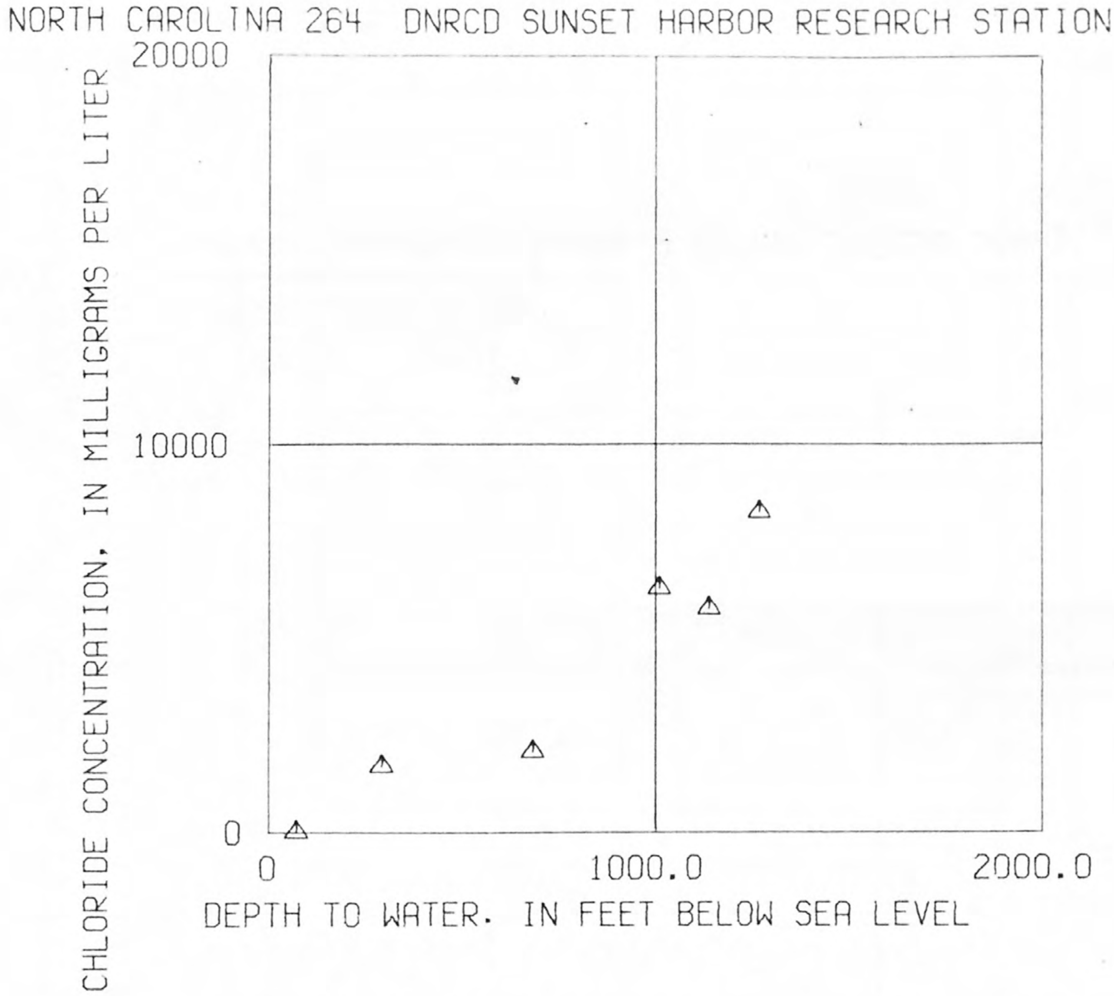
NORTH CAROLINA 186 DNRCD ARAPAHOE RESEARCH STATION
20000
10000
0
0
1000.0
2000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER

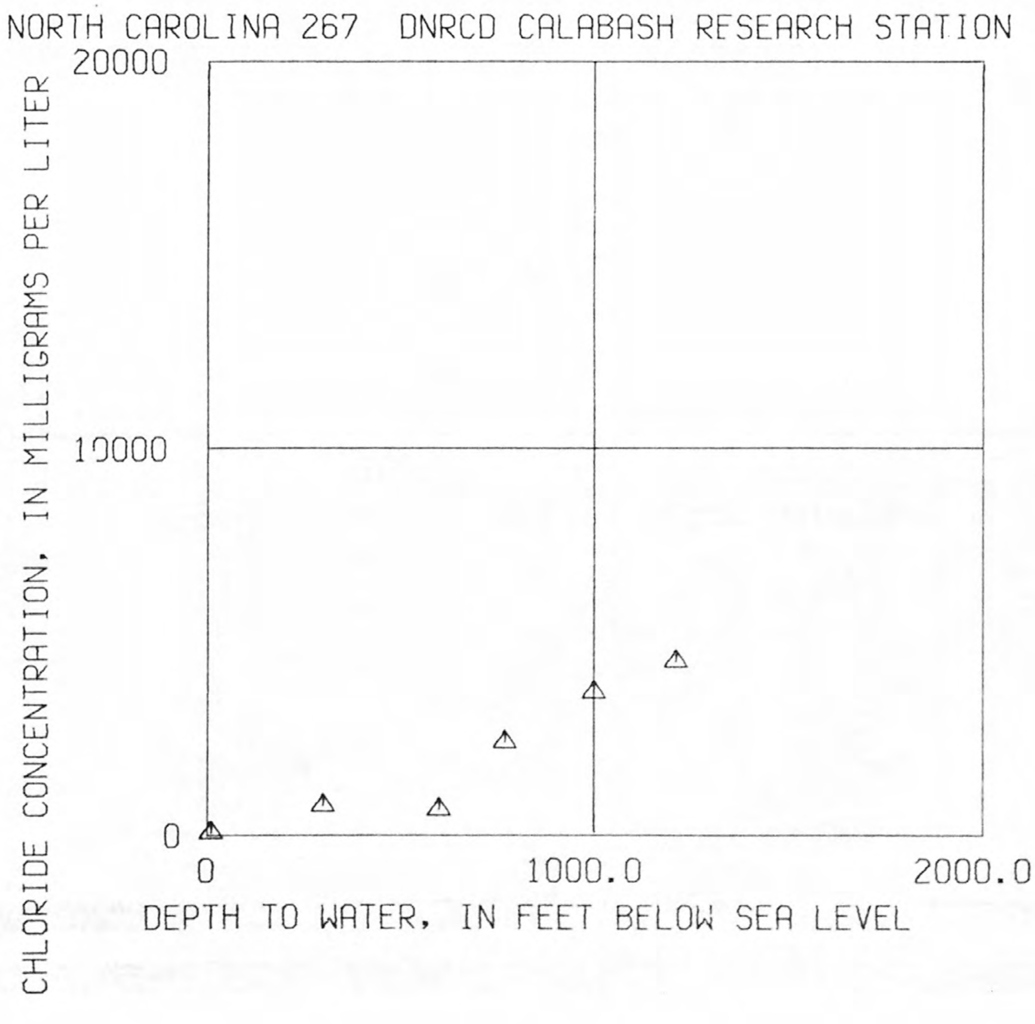


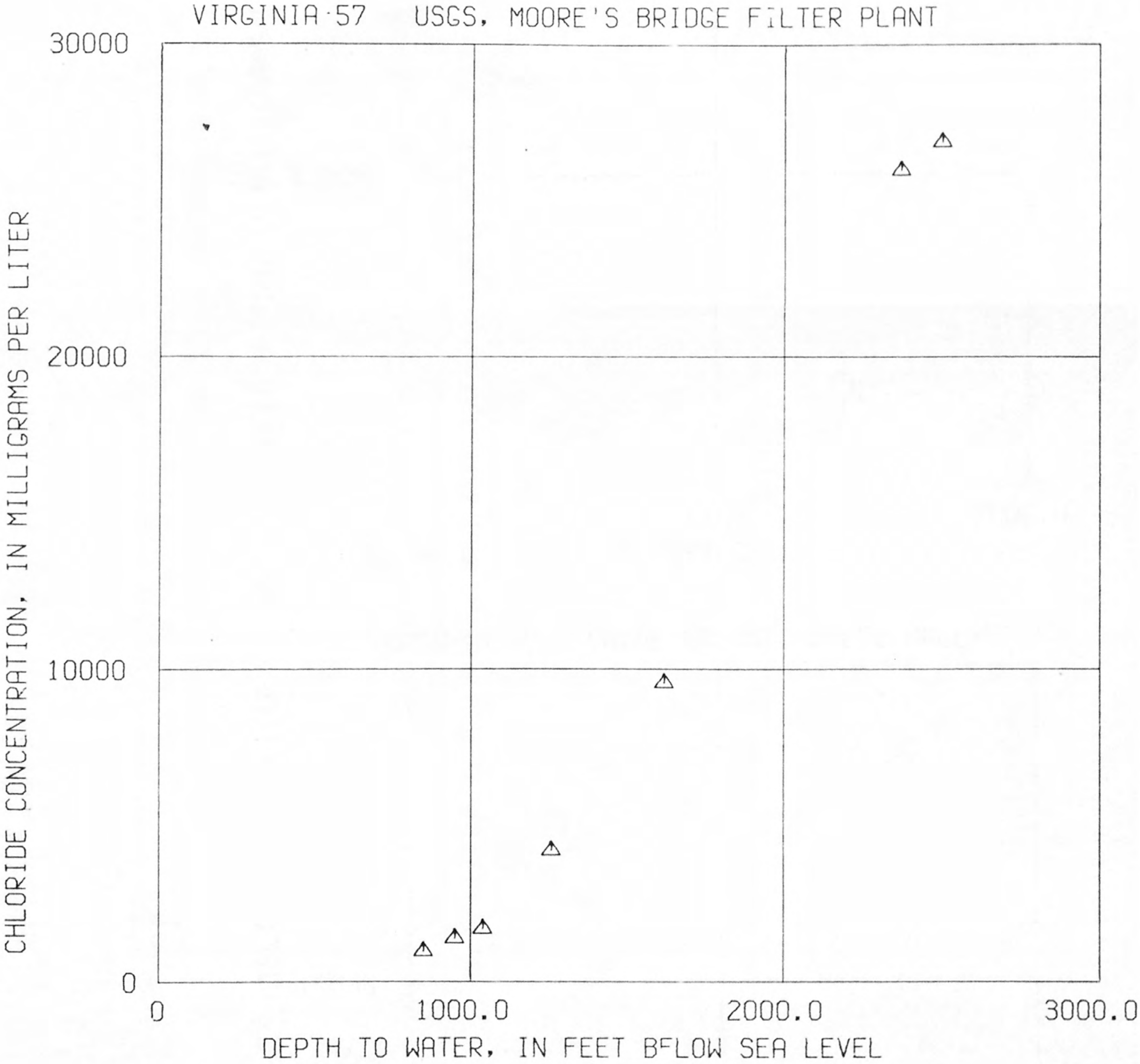
NORTH CAROLINA 243 HERCULES WASTE INJECTION SITE
20000
10000
0
0
1000.0
2000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER

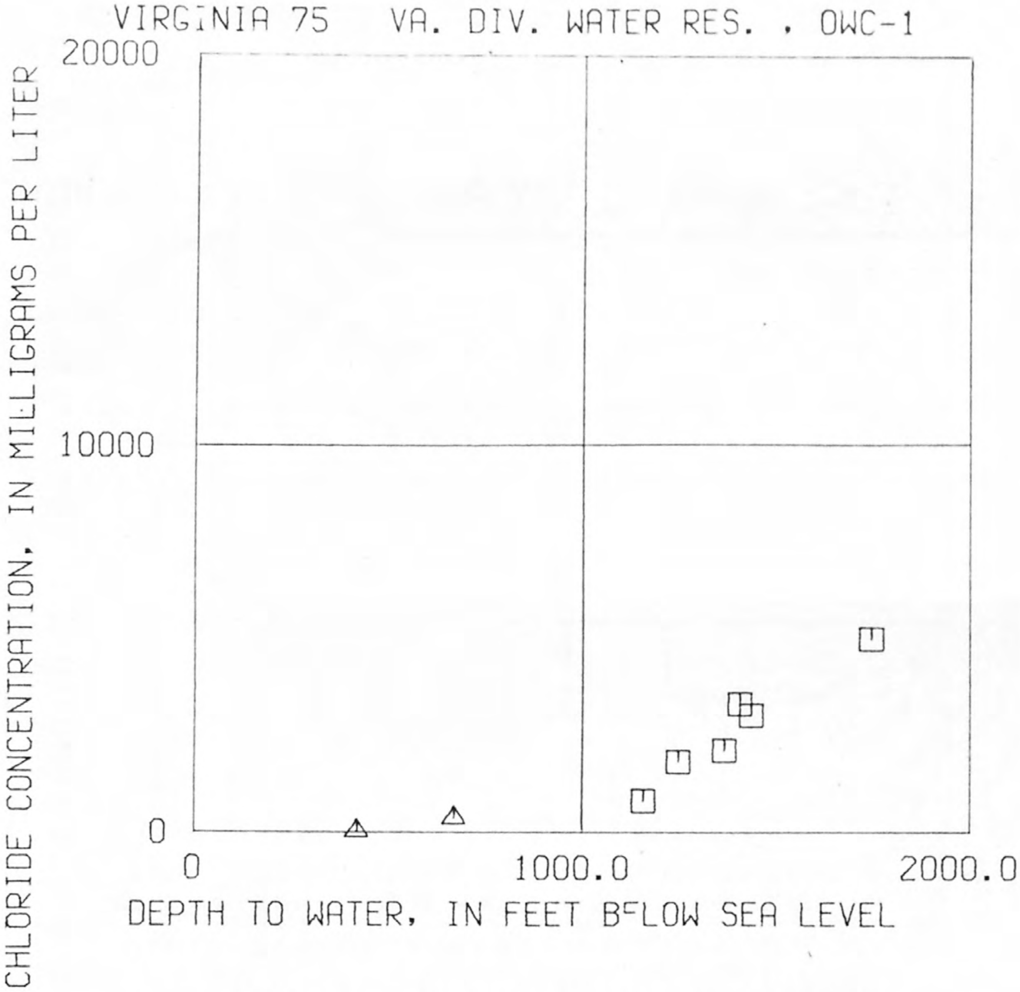

NORTH CAROLINA 197 CAROLINA PETROLEUM, GUY CARRAWAY 1
30000
20000
10000
0
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
0
1000.0
2000.0
3000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL

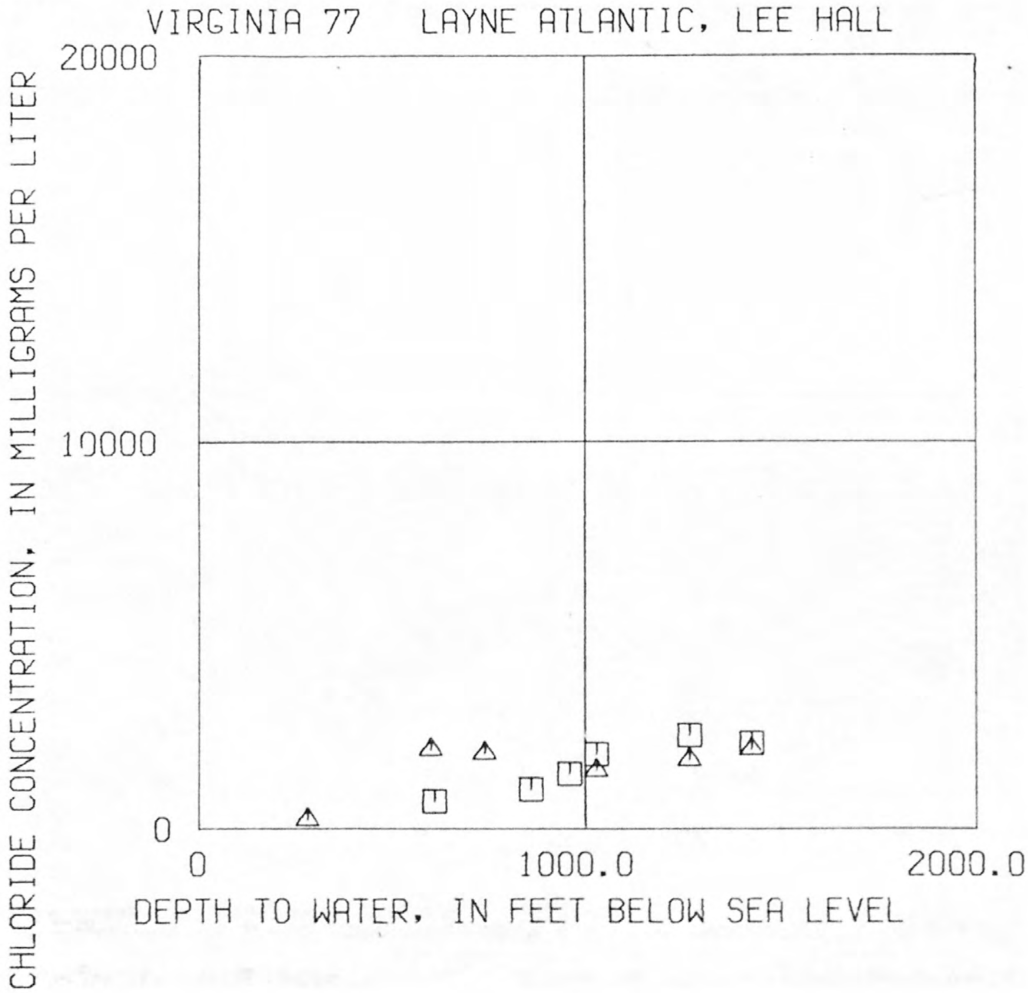

NORTH CAROLINA 201 CAROLINA PETROLEUM, BRYAN 1
30000
20000
10000
0
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
0
1000.0
2000.0
3000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL

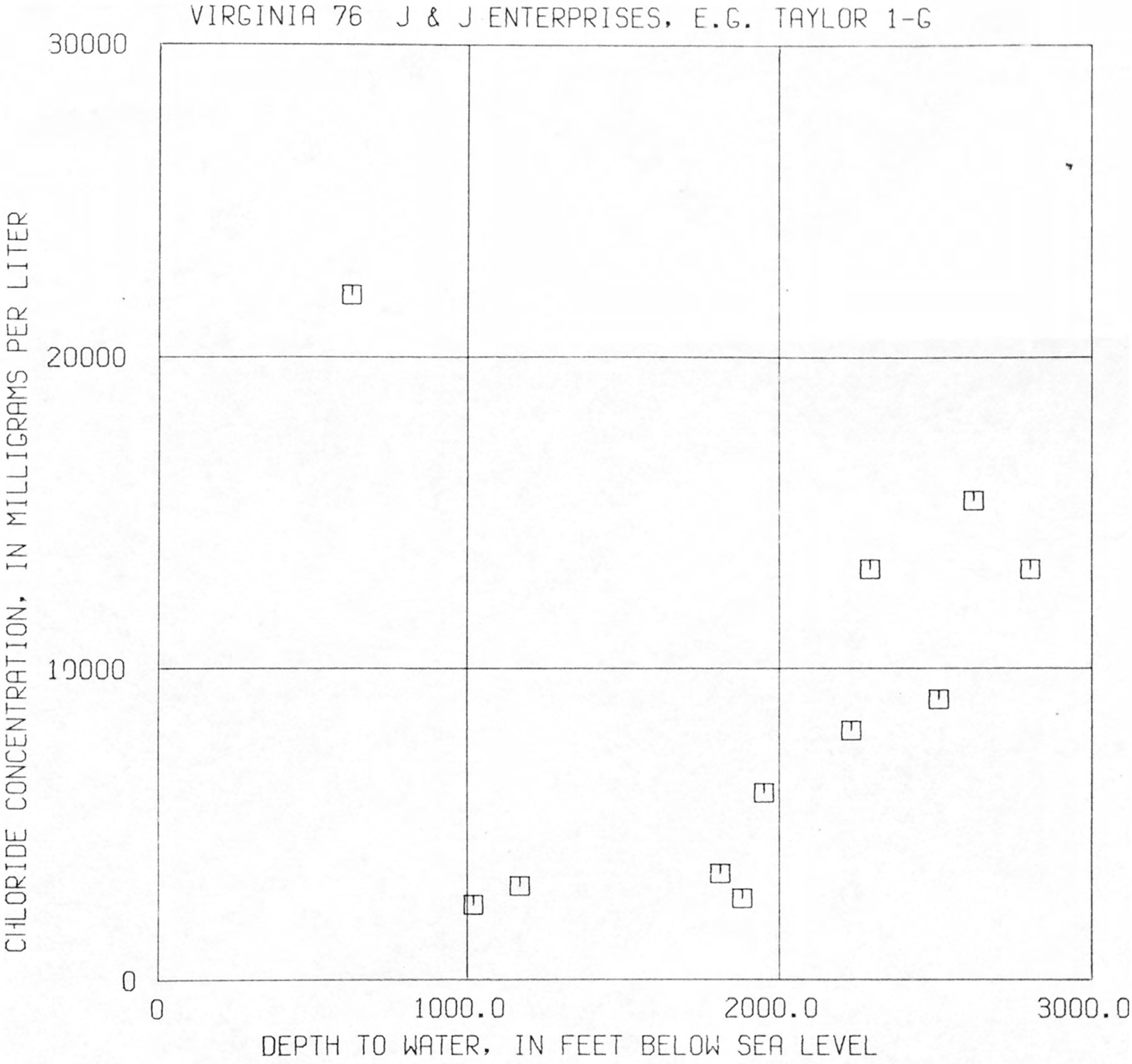

NORTH CAROLINA 264 DNRCD SUNSET HARBOR RESEARCH STATION
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
20000
10000
0
0
1000.0
2000.0
DEPTH TO WATER. IN FEET BELOW SEA LEVEL


NORTH CAROLINA 267 DNRCD CALABASH RESEARCH STATION
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
20000
10000
0
0
1000.0
2000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL


VIRGINIA-57 USGS, MOORE'S BRIDGE FILTER PLANT
30000
20000
10000
0
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
0
1000.0
2000.0
3000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL


VIRGINIA 75 VA. DIV. WATER RES. . OWC-1
20000
10000
0
0
1000.0
2000.0
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
DEPTH TO WATER, IN FEET BELOW SEA LEVEL


VIRGINIA 77 LAYNE ATLANTIC, LEE HALL
20000
10000
0
0
1000.0
2000.0
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
DEPTH TO WATER, IN FEET BELOW SEA LEVEL



VIRGINIA 76 J & J ENTERPRISES, E.G. TAYLOR 1-G
30000
20000
10000
0
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
0
1000.0
2000.0
3000.0
DEPTH TO WATER, IN FEET BELOW SEA LEVEL