FINAL REPORT
STUDY OF GROUND-WATER CONDITIONS AND
FUTURE WATER-SUPPLY ALTERNATIVES
SALEM/HOPE CREEK GENERATING STATION
ARTIFICIAL ISLAND, SALEM COUNTY, NEW JERSEY
PSE&G

JULY 15, 1988
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Dames & Moore

CRANFORD, NEW JERSEY

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July 15, 1988

Mr. Edward Keating
Public Service Electric & Gas Company
P.O. Box 236
Hancocks Bridge, New Jersey 07038

Re: Submittal of Final Report
Water-Supply Alternatives
Salem/Hope Creek Generating Stations

Dear Mr. Keating:

We are pleased to submit to you ten (10) copies of our report, "Final Report, Study of Long-Term Ground-Water Withdrawals and Water-Supply Alternatives, PSE&G's Salem and Hope Creek Generating Stations." Your comments on the draft version have been incorporated in the report.

Please feel free to call us if you have any questions regarding the report.

Very truly yours,

DAMES & MOORE

James G. McWhorter
Project Manager

Andrew C. Mills
Principal Investigator

JGM:jp
Enclosure

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STUDY OF GROUND-WATER CONDITIONS AND FUTURE WATER-SUPPLY ALTERNATIVES SALEM/HOPE CREEK GENERATING STATIONS ARTIFICIAL ISLAND, SALEM COUNTY, NEW JERSEY PSE&G

1.0 INTRODUCTION

Dames & Moore was retained by Public Service Electric and Gas Company (PSE&G) to investigate the status of ground-water supply at their Salem and Hope Creek generating stations on Artificial Island in Salem County, NJ. The scope of work included:

- an investigation of the condition of site production and observation wells;
- a study of current ground-water levels and ground-water quality in site wells;
- modeling of the effects of future withdrawals from site aquifers, particularly as such withdrawals relate to the position and possible movement of salt-water/fresh-water interfaces;
- performing a feasibility study of water-supply alternatives. This involved formulation and screening of water-supply alternatives, including water recycling and surface-water sources, to possibly replace a portion or all of the ground water currently being used for the plant service-water requirements;
- development of a site-wide ground-water monitoring program;
- development of a plan for the abandonment of selected site wells.

The work on the project commenced in July 1987 and was completed in April 1988. Field investigation activities, including well inspection, down-hole TV surveys and performance of pumping tests, took place from mid-July through the end of September. Literature search and data evaluation were performed during the fall and early winter. The ground-water modeling task as well as the feasibility study of water-supply alternatives were undertaken during February and March of 1988.

This report provides a detailed summary of the work we performed under the project including all relevant data. Appendices A and B provide the data and graphs associated with the pumping tests performed in 1987, while Appendices C and D provide the data and graphs relevant to earlier pumping tests of site wells.

Section 2.0 consists of a description of the nature of the field investigation performed on site including the specific procedures employed. In Section 3.0, we present a discussion of site ground-water conditions including aquifer geometry and properties, ground-water levels, ground-water quality and trends in ground-water pumpage.

In Section 4.0 we describe the present condition of site wells from the point of view of physical appearance and specific capacity; the potential for cross-contamination in damaged wells is also discussed. Section 5.0 is a report of the ground-water modeling task including the results of predictive simulations extending 20 years into the future.

Sections 6.0 and 7.0 describe the results of the feasibility study performed to identify and evaluate alternative water-supply sources for the service-water needs of the stations. And in Sections 8.0 and 9.0 we present details of a site-wide ground-water monitoring program and a well-abandonment program, respectively. Finally, a summary of our findings and our recommendations are presented in Section 10.0.

2.0 FIELD INVESTIGATION AND PROCEDURES

2.1 WELL INVENTORY AND INITIAL INSPECTION

The first task of the field program was to obtain an accurate inventory of all the wells still in existence at the site and to locate and inspect these wells. To do this we began by examining the files at both PSE&G and Dames & Moore. This was followed up by discussions with plant employees and a thorough search of the facility in areas where wells were known to have existed.

2.1.1. Production Wells

The seven existing production wells were inspected on July 21-22, 1988. At that time we recorded relevant construction details and, where possible, collected water level measurements. All seven of the wells had pumps in place and six (all but PW-1) were regularly used for potable water.

2.1.2. Observation Wells

Although PSE&G identified 12 observation wells (OW series) at the site, plant personnel initially could not locate five of the wells.

Maps were found in various reports identifying the general location of each of these five wells. From these maps or location sketches we were able to find one well (OW-G) immediately. A second well (OW-I) was located in an area of dense vegetation. It was uncovered after PSE&G personnel cleared the general area.

The remaining three wells were not conclusively identified in the field. Well OW-B could not be located. A second well (OW-E) was previously located near PW-4. A report was located stating that OW-E was sealed and abandoned in 1975 when PW-4 was also sealed (Dames & Moore, 1977).

There is doubt regarding the location and status of the remaining missing well, OW-F. It should be located near production well HC-2, but there is no sign of the well in that area. There is also no record of any abandonment. It is possible that the well still exists but has been covered.

2.1.3. Dewatering Wells

The small group of wells designated as dewatering wells (DW-series) still existing at the site are all that remain of a much larger group of wells installed to observe dewatering operations during the construction of the Hope Creek Generating Station. The vast majority of the dewatering wells were sealed and abandoned in the 1970's.

The remaining wells were identified by PSE&G personnel, who have inspected the grounds and indicated 12 locations where wells were still present. In our initial inspection, we discovered that at one of these locations (DW-322D), there was no well. Although a metal protective casing was in place, the "well" did not extend more than 1 foot below ground surface. At another location, Well DW-17 was reportedly located beneath sod southeast of the Hope Creek turbine building. In our inspection, we attempted to find the well by probing the sod, but were unsuccessful. Finally, at a third location an additional well was identified (DW-25A). This small-diameter well was possibly installed as a piezometer to monitor the nearby well DW-25.

Investigations revealed that Well DW-505S was not connected hydraulically to the aquifer. We now believe that this well is sealed from above the screen to the base of the well. This conclusion is supported by the fact that the PVC cap on the well was found to be glued in place.

2.2 WATER-LEVEL MEASUREMENTS

In our initial inspection of the wells we attempted to obtain water level measurements at each well. This proved to be a problem in many instances as various wells were inaccessible to standard water-level probes. Many of the wells equipped with pumps did not have large enough ports for inserting the water-level probe into the well. In two instances the available ports were too small and had to be enlarged (PW-2 and PW-3). In other wells, new access holes had to be drilled (OW-D, OW-6) or alternately, the pump had to be pulled in order to provide access (OW-I, PW-1).

In the case of PW-1, the access port in place appeared to go into the well, but actually led into the oil pan. Because of this, we recorded incorrect water-level measurements during the first pumping test of the well. Another minor source of error is the fact that the access port in HC-1 and HC-2 is at an angle to the well's vertical bore. This results in a recorded elevation consistently lower than the actual elevation.

An additional problem, unique to the Well OW-D, which is located in the switch yard, was electrical problems with the water-level indicator. Due to the electrical charge in the area and specifically on the steel casing, the probe head shorted out each time we tried to use it. Therefore, for this well we had to use less accurate methods involving reading water lines on a weighted tape.

A full round of ground-water level measurements were taken near the end of the field investigation, on September 22, 1988.

2.3 PUMPING TESTS AND WELL SAMPLING

To evaluate aquifer and well characteristics we conducted a series of short-term pumping tests and collected water samples at each

well. These two tasks were done simultaneously with samples being collected in the last half hour of each test. Water samples were packed in ice and delivered to the laboratory for analysis. The laboratory which performed the analysis was South Jersey Testing Laboratory, Millville, NJ, which is certified by the New Jersey Department of Environmental Protection (NJDEP). Parameters analyzed for by the laboratory included calcium, magnesium, soldium, chloride, alkalinity, specific conductance, total dissolved solids, pH and total coliform bacteria. In addition, onsite analyses were performed for pH, chloride content and temperature using analytical field kits. Generally these measurements were taken every two hours.

The procedure followed in each pumping test was very similar. Initial water level readings were taken at the pumping well and any observation wells being monitored. After pumping began, water levels were taken periodically. When sufficient time had passed, the pump was turned off and water-level measurements were taken during the recovery period. These measurements were generally taken until at least 90% recovery had occurred relative to the initial water level.

The following paragraphs describe in turn the pumping test performed in each well.

2.3.1. Production Wells

PW-1 7/24/87 and 9/22/87

The test on 7/24/87 at PW-1 was conducted prior to our knowledge that the well's access port led to the oil pan rather then the well. Therefore, no water level data were collected from the pumping well. However, water levels were taken from an observation well (OW-C) screened in the same aquifer. This test ran for 6.8 hours with water samples taken in the last half hour.

The second test on 9/22/87 at PW-1 occurred after the removal of the production pump. This test, which ran for 4 hours, was completed with a portable submersible pump set at a depth of 80 feet.

PW-2 8/12/87

The test at PW-2 was completed with the production pump and ran for 9.8 hours. Several short-term interruptions in pumping occurred because certain plant personnel turned the pump off. However, the overall effect of these stoppages on the pump test was minimal.

PW-3 8/13/87

The test at PW-3 was completed with the production pump and ran for 10.3 hours.

PW-5 8/4/87

The test at PW-5 was completed with the production pump and ran for 7.5 hours.

PW-6 8/14/87

The test at PW-6 was completed with the production pump and ran for 12.3 hours. The nearby observation well (OW-6) was also monitored over this time period.

HC-1 8/10/87

The test at HC-1 was completed with the production pump and ran for 10 hours. Initially flow was restricted (for about 10 minutes) by the failure of plant personnel to open a valve in the fire water tank. There were also two very brief (less than one-minute) interruptions in pumping due to the maintenance staff shutting off the pump.

HC-2 8/11/87

The test at HC-2 ran for 9.8 hours and was completed with the production pump.

2.3.2. Observation Wells

OW-A 7/27/87 and 9/14/87

The pumping test at OW-A was completed on August 27, 1987 using the submersible pump already present in the well. Samples taken during the two hour test were analyzed. Due to anomalous analytical results, a second set of samples was collected and sent to the laboratory on September 14, 1987, after purging the well of at least three well volumes.

OW-B

Well OW-B was not located, therefore, no pumping test was performed and no samples collected.

OW-C 7/27/87 and 9/14/87

The pumping test and sampling for OW-C were completed in exactly the same manner as OW-A. As with Well OW-A, resampling had to be performed on September 14, 1987.

OW-D 9/15/87

The pumping test at OW-D had to be terminated in 10 minutes due to drawdown below the level of the pump intake. The submersible pump used for the test was set at a depth of 60 feet. After measuring recovery, the well was purged of more than three times the well volume and samples were taken.

OW-G 8/5/87 and 9/14/87

The 2-hour pumping test at OW-G was performed on August 5, 1987, with a portable submersible pump set at a depth of 80 feet. Due to anomalous results from the ground-water analysis, an additional sample set was collected on September 14, 1987. Approximately three well volumes were purged from the well prior to sampling.

OW-H 7/28/87

Due to the small-diameter of Well OW-H, the 2-hour pumping test at OW-H was performed with a centrifugal pump.

OW-I 9/15/87

The 2-hour pumping test at OW-I was performed without problems, using a portable submersible pump set at a depth of 90 feet.

OW-S1 7/23/87

The pumping test at OW-S1 was completed in 1.9 hours using a portable submersible pump set at a depth of 75 feet.

OW-S2 7/28/87

The 2-hour pumping test on OW-S2 was completed with a portable submersible pump placed at a depth of 63 feet.

2.3.3 Dewatering Wells

DW-17

Since this well could not be located, no pumping tests or sampling were performed.

DW-25 and DW-25A 7/30/87

A 2-hour pumping test was completed at DW-25 using a sub pump set at a depth of 75 feet. The adjacent piezometer (DW-25A) tested or sampled due to its very close proximity to DW-25.

DW-42 8/6/87

Due to the shallow depth of the well, we decided to use a centrifugal pump for the pumping test. After removing some debris from the well we began the test. After ten minutes of pumping, there was no further drawdown and the test was stopped after 15 minutes. After measuring recovery we pumped the well several more times to remove at least three well volumes. Due to the turbidity of the sample taken from the pump, the sample was taken by means of a clean bailer.

DW-502S 7/29/87

The initial attempt to pump DW-502S with a submersible pump drew the water level in the well all the way down in less than 2 minutes. Therefore, it was decided to let the well recover and begin a new pumping test with a centrifugal pump of lower capacity. Using the centrifugal pump, the well went dry in fifteen minutes. After measuring recovery we pumped the well until approximately three well volumes were removed and collected our samples.

DW-502D 7/29/87

The 2 hour pumping test on DW-502D was completed with the submersible pump. Due to an obstruction in the well, the pump intake was placed at a depth of 37 feet rather than the usual 75 feet.

DW-505S 7/31/87

Well DW-505S was pumped with a centrifugal pump for approximately one minute before the well went dry. Over the next twelve minutes we attempted to measure recovery but found that no water was flowing into the well. During a subsequent visit to the well, eight days later, we found less than one inch of water in the well. From this we conclude that the well is effectively sealed or plugged.

DW-505D 7/31/87

The pumping test at DW-505D only ran for 5 minutes before the water level went below the pump intake. For the test, we used a submersible pump set at a depth of 73 feet. After measuring recovery, we purged the well again and collected our samples.

DW-509S 8/3/87

The pumping test at DW-509S was completed with a submersible pump set at a depth of 40 feet. Rapid drawdown to below the pump intake occurred and the pump was turned off after one minute. After measuring recovery, the well was purged again and water samples were collected.

DW-509D 8/3/87

The pumping test at DW-509D was completed with a submersible pump set at a depth of 80 feet. During the two-hour test, water levels in DW-509S were monitored and showed no change.

DW-514S and DW-514D 8/7/87

Since both of these wells are located in a well-traveled portion of the site and neither well is capped, a large quantity of debris was found in the wells. We successfully removed much of the debris in DW-514D by fishing, but were not successful with DW-514S. Therefore, we did not conduct a pumping test on DW-514S.

The pumping test of DW-514D ran for approximately one minute due to rapid drawdown to the pump intake. The submersible pump was set at 32 feet due to an obstruction encountered in the well. Following initial recovery, DW-514D was pumped to the pump intake level and allowed to recover four more times. The estimated water volume removed by the five discharges was about one well volume. The ground water samples were taken at the end of the final purge.

2.4 TELEVISION CAMERA SURVEY

To evaluate the structural integrity of the wells at the site, a downhole television camera survey was completed. Dames & Moore sub-contracted with W.C. Services, Inc. of Woodbury, NJ to perform the downhole TV survey of onsite wells.

The procedures employed for each well were very similar. Where possible, each well was flushed with clear water for 24 hours prior to filming. Such flushing tends to increase the clarity of the picture, but is not always essential. When water availability was a problem, as was the case for a number of wells at the site, filming could still take place, particularly if the wells were shallow PVC wells.

After flushing the wells, a special television camera was lowered by a calibrated steel cable into the borehole. The camera contains its own light source and the video was viewed on a monitor as it was being taped.

Of the 27 wells located in our field investigation, 15 were surveyed by the television camera. Due to the presence of pumps in the active production wells, only one production well was surveyed (PW-1). This well is currently out of service and plant personnel pulled the pump for us prior to the television camera work.

Seven of the ten observation wells (OW-sequence) and eight of the ten dewatering wells (DW-sequence) were filmed. Most of the observation/dewatering wells not filmed were excluded because the wells were of too small a diameter to allow access for the camera (OW-A, OW-B, OW-H and DW-25A). The other well that was not filmed (DW-514S) contained too much debris to permit lowering the camera into the well.

3.0 SITE GROUND-WATER CONDITIONS

Artificial island is underlain by two primary fresh-water aquifers or aquifer systems which form a part of the unconsolidated Atlantic Coastal Plain sediments. These are the Mt. Laurel-Wenonah aquifer and the underlying aquifers associated with the Magothy and Raritan Formations. The Mt. Laurel-Wenonah Sand is a marine Cretaceous unit made up of glauconitic sand with varying amounts of silt and clay. The Magothy and Raritan units are older Cretaceous deposits laid down by fresh water under continental conditions. They consist of extensive zones of variegated clay with sandy layers or zones occurring to a lesser extent. Each of the existing seven production wells at the Salem and Hope Creek generating stations tap one of the above aquifers. Figure 1 provides a plan of the Salem and Hope Creek stations indicating the location of site production wells and observation wells.

In New Jersey, the United States Geological Survey (U.S.G.S.) identifies the Raritan-Magothy aquifer system as the 'Potomac-Raritan-Magothy Aquifer System", and individual aquifers within that system are termed 'Upper', 'Middle' and 'Lower' (Zapecza, 1984). According to this classification, what was formerly considered the Magothy Sand is now identified as the Upper Aquifer of the Potomac-Raritan-Magothy Aquifer System. Also according to this system, what has been termed the Upper Raritan Aquifer at the site, is classified as the 'Middle Aquifer'. In Delaware, on the other hand, the Magothy Aquifer is apparently still considered to be a separate unit by the

U.S.G.S., and the underlying continental sand and clay zones are considered to belong to the Potomac Formation (Martin and Denver, 1982). Under the Delaware system of nomenclature, what has been termed the Upper Raritan Aquifer at the site, is classified as the 'Upper Potomac Aquifer'. Because of the lack of agreement in the nomenclature adopted by the U.S.G.S. for Delaware and New Jersey, we believe it simpler to retain the old terminology for Artificial Island. Hence, we will continue to identify the Magothy aquifer as a separate unit, and the underlying aquifers will be designated 'Upper Raritan', and 'Middle Raritan', as in the past.

3.1 AQUIFER CHARACTERISTICS

The aquifers at the site may be visualized by the hydrogeologic column shown on Figure 2, which provides the approximate range in thickness of each unit. As shown on the figure, the Mt. Laurel-Wenonah aquifer at the site is overlain, from the surface downward, by:

hydraulic fill,
a relatively thin layer of river sand and gravel,
the Kirkwood Formation (primarily clay),
the Vincentown Formation, and
the Hornerstown-Navesink aquitard.

The Vincentown Formation at the site ranges from a sand to a silty sand and has the potential to serve as a fresh-water aquifer were it not for the fact that it contains brackish water. The chloride content of the Vincentown beneath the site currently ranges from about 1800 to 4300 mg/l. There is evidence that leakage has been occurring from the Vincentown to the underlying Mt. Laurel-Wenonah aquifer through the leaky confining layer (aquitard) composed of the Hornerstown and Navesink Formations. This leakage appears to be the primary cause of the increasing chloride levels in the Mt. Laurel-Wenonah. The evidence which identifies leakage from the Vincentown to the Mt. Laurel-Wenonah is the

high chloride levels in Wells OW-D and OW-G (discussed later in this section), while in the intervening area, chloride levels in the Mt. Laurel-Wenonah are much lower.

The depth to the top of the Mt. Laurel-Wenonah aquifer at the site ranges from about 160 to 200 feet, based on well logs. The aquifer ranges in thickness from 100 to 125 feet.

The Mt. Laurel-Wenonah aquifer is directly underlain by the Matawan aquitard, which is composed of the Marshalltown, Englishtown, Woodbury and Merchantville Formations. With the exception of the Englishtown Formation, a generally sandy unit which is believed to be absent beneath a portion of the site, the Matawan aquitard consists of silty or clay layers which together are expected to act as an effective confining layer for the underlying Magothy aquifer.

The Magothy aquifer at the site consists of fine to coarse sand and one or more interbedded layers of black clay. The depth to the unit at the site ranges from about 410 to 465 feet, and its thickness ranges from 20 to 45 feet. The aquifer is believed capable of providing moderate yields to wells, but has not yet been tested at the site.

The Upper Raritan aquifer is separated from the Magothy aquifer by a layer comprised primarily of dense Raritan clay, which at the site is about 260 to 290 feet thick. At Well PW-1, this confining layer includes a 35-foot thick layer of sand. The depth to the top of the Upper Raritan aquifer has been found to range from 740 to 765 feet. The unit generally consists of tan fine to medium sand, with little to some coarse sand, and trace to little silt. Lenses of clay are common within the aquifer in places. The aquifer ranges in thickness from 70 to 100 feet beneath he site.

The Middle Raritan and Upper Raritan aquifers at the site are separated by a layer ranging in thickness from 230 to 255 feet. At Well PW-6, this intervening confining layer includes a 50-foot thick layer of

sand with some gravel, which was encountered in the depth interval 930 to 980 feet. The Middle Raritan aquifer, consisting generally of fine sand, is found at a depth of 1,085 to 1,135 feet beneath the site. It has been found to range in thickness from 45 to 55 feet.

3.2 GROUND-WATER LEVELS

Water levels were measured on two separate days in the production wells and observation wells on site during the field investigation in the summer of 1987. The results of these synoptic water-level observations, taken on July 21 and September 22, are given in Table 1. In addition, static water levels were recorded individually at the time each well was pump tested, when water samples were obtained for analysis. These are provided in Table 2.

Table 1 provides the depth to water level from the well reference point (RP)--either the top of casing or the well access port--and in addition provides an estimate of the corresponding water-level elevation in each case. As will be discussed in Section 4.4, surveying data for the production wells and observation wells on site are incomplete and often contradictory. Hence, the water-level elevations provided in Table 1 must be considered as only approximate. However, we believe the data on water levels assembled provide a sufficient accuracy for the purposes of this study.

As indicated in Tables 1 and 2, in the summer of 1987 the approximate static water-level elevations of the water-bearing sub-surface units relative to mean sea level datum (msl) were:

River Sand and Gravel	+3 to +7 ft.
Vincentown Formation	0 to +4 ft.
Mt. Laurel-Wenonah aquifer	-2 to -8 ft.
Upper Raritan aquifer	-57 to -62 ft.
Middle Raritan aquifer	-49 ft.

The water level shown in Table 1 at PW-3 is not believed to be a true static level because of the lack of complete recovery of the well following its pumping. The levels indicated in the table at Wells OW-A and OW-H do not reflect the water level in the Upper Raritan aquifer because of an apparently direct hydraulic connection in both wells with an overlying aquifer. This condition is probably due to corroded or damaged well casing, and will be discussed further in Section 4.0.

Based on the summary of water-level elevations shown above, it is clear that there is a downward hydraulic gradient at the site extending from the River Sand and Gravel to the Upper Raritan aquifer. The data further indicates that there is an upperward gradient from the Middle Raritan aquifer to the Upper Raritan aquifer, due to the relatively high pumping occurring in the latter unit. Thus, under the existing pumping conditions, there appears to be a downward component of ground-water flow from the surface, or near-surface, down to the Upper Raritan aquifer and an upward component of flow from the Middle Raritan to the Upper Raritan aquifer. Calibration of the ground-water model, to be discussed in Section 5.0, showed that the effective vertical permeability of the confining units separating the aquifers beneath the site is quite low and that the rate of vertical flow through these units is therefore also low.

Records of water levels observed in site wells since the time of their installation were examined in the course of the project. These data, in terms of depth to water level, have been plotted vs. time, and are shown for each monitored well in Figures 3 through 12. Figures 3 through 6 show the water level vs. time in Mt. Laurel-Wenonah wells and no trends are discernible. This indicates that steady-state conditions have been achieved, quite possibly through the contribution of leakage from the overlying Vincentown Formation. In the northern portion of the site, the aquiclude separating the Vincentown from the Mt. Laurel thins considerably and is interbedded with sand, thereby allowing increased cross-flow between the Vincentown and Mt. Laurel-Wenonah.

Water-level trends in the Upper Raritan aquifer are shown in Figures 7 through 10. As mentioned above, the recent water levels in Wells OW-A and OW-H do not presently reflect those for the Upper Raritan aquifer. In Figure 8, it is seen that in only one case, in 1984, did the water level at OW-A begin to approach the depths evidenced in PW-5. The rest of the time the levels were only 30 feet or less below the reference point. In Figure 9, it is shown that water levels at OW-H tended to decline in a reasonable response to the continued pumping on the plant site up until near the end of 1984, when the water levels rose dramatically to a level about 10 feet below the reference point, where they have remained ever since. This sudden rise is associated, we believe, with the sudden establishment of a hydraulic connection with the overlying Vincentown Formation through holes corroded through the upper part of the well casing. The trends in the water level in OW-I, shown in Figure 10, demonstrate what we believe to be a reasonable response of an observation well tapping the Upper Raritan aquifer to significant nearby pumping in the aquifer. There, the depth to water level declined from about 20 feet in early 1974 to the present level of about 70 feet.

Water-level trends in the two Middle Raritan Wells, PW-6 and OW-6, are shown in Figures 11 and 12. As shown in Figure 12, water levels in OW-6 since 1981 have fluctuated between 42 and 48 feet below the reference point. From the middle of 1983 until the middle or end of 1984, there appears to have been a uniform decline from 42 to 48 feet in OW-6. After that, the available data indicate a leveling off occurred.

3.3 WATER QUALITY

The results of laboratory analyses performed on well-water samples obtained during the investigation in the summer of 1987 are given in Table 2. The results of fields tests for chloride, pH and temperature performed at the same time are provided in Table 3. The samples taken for laboratory analysis were taken close to the end of the pumping test in each case, while the field samples were taken at intervals in the course of each test, as shown in Table 3.

Table 2 shows that the chloride content of water from the Vincentown ranges from 1,760 to 4,280 mg/l across the site. The results of field tests (Table 3) indicate a range of 2,184 to 3,610 mg/l chloride for the unit. As shown in Table 2, the River Sand and Gravel unit contains a lower level of chloride, ranging from 174 to 1,380 mg/l.

As shown in Table 2, with the exception of Well OW-C, the chloride values in Mt. Laurel-Wenonah wells range from 120 to 870 mg/l, with the highest values at Well OW-G. As will be discussed in Sections 4.0 and 9.0, Well OW-C is not considered to be a reliable well; thus, the chloride level of 1,310 mg/l shown for that well is not considered to be representative of the Mt. Laurel-Wenonah aquifer at that location.

Table 2 shows a very wide range in the apparent concentration of chloride in the Upper Raritan aquifer, 8.7 to 2,060 mg/l. However, as discussed above, two of the Upper Raritan observation wells, OW-A and OW-H, are not considered to provide reliable or representative information on the aquifer. Also, based on the results shown for PW-5 in Table 3, there is some doubt about the laboratory value of 150 mg/l chloride given for the well in Table 2. As shown in Table 3, toward the end of the pumping test of PW-5, the field value was consistently in the range of 38 to 46 mg/l. We believe that this value is more typical of the well at that time. Taking all the above into consideration, we believe the chloride levels in the aquifer at the site presently range from about 9 to 46 mg/l. Placing the upper limit for PW-5 at about 46 mg/l is also consistent with the historic chloride trend in that well, which will be discussed shortly.

As shown in Table 2, a chloride concentration of 189 mg/l was determined by laboratory analysis for Well PW-6. Field tests, however, indicated a range of 235 to 334 mg/l during the course of the pumping test, as shown in Table 3.

We examined trends in chloride levels in site wells over past years and prepared plots of chloride levels versus time (Figures 13 through 24. The trends in Mt. Laurel-Wenonah wells are provided in Figure 13 through 16. There has clearly been an upward trend in chloride occurring in all these wells since 1970. The chloride level in Wells PW-1, PW-2 and PW-3 climbed from below 50 mg/l in the early 1970s to peaks ranging from 200 to 500 mg/l, the highest levels being experienced in Well PW-2. Even higher values are shown for Well OW-C, on the order of 1,000 mg/l or higher, with two peak values of 4,000 and 5,500 mg/l occurring in mid-1983. Although remedial work was subsequently done on this well (in the spring of 1984) involving installation of a new well screen and casing, we believe as mentioned previously, that Well OW-C still does not provide representative information concerning the Mt. Laurel-Wenonah aquifer.

Figures 17 through 22 provide trends in chloride concentrations for wells tapping the Upper Raritan aquifer. The chloride level in Well PW-5 in general rose gradually from about 25 mg/l in 1975 to between 40 and 50 mg/l in 1987. However, in mid-1981 as shown in Figure 17, chloride levels rose briefly to about 220 mg/l and then returned to below 50. In Well OW-A (Figure 18), chlorides rose from less than 50 mg/l in 1968 to about 530 mg/l in early 1983, after which the levels declined to values fluctuating between 160 to 380 mg/l. Chloride levels in the Upper Raritan wells located on the northern side of the PSE&G property--Wells HC-1, HC-2 and OW-I--have fluctuated only between 1 and 27 mg/l since their construction. In the last three years Well HC-1, HC-2 and OW-I have exhibited maximum chloride values of only 18, 15, and 10 mg/l, respectively.

The rise of chloride values in Well OW-H, shown in Figure 21, coincides in time and degree with the sudden rise of the water level in that well, shown in Figure 9. Both rises began in mid to late 1984 and are believed to have resulted from the sudden establishment of a hydraulic connection with the overlying Vincentown Formation through

holes corroded through the upper part of the well casing, as discussed in Section 3.2. Such high chloride values (2,060 mg/l) are not representative of the Upper Raritan aquifer at the site

No clear trends are discernible in the plots of chloride concentration vs. time for the two Middle Raritan wells (Figures 23 and 24). Chloride concentration in PW-6 started at about 210 mg/l in 1981, reached a peak of about 240 mg/l near the end of 1984, and since that time have fluctuated between 130 and 230 mg/l with an average of about 180 mg/l. Figure 24 shows that chloride levels in Well OW-6 have averaged close to about 250 mg/l; however, a peak value of about 510 mg/l was measured in the well near the end of 1984.

3.4 RESULTS OF PUMPING TESTS

As described in Section 2.0, as part of the field investigations performed in the summer of 1987, a pumping test was conducted on each functioning site well, with the exception of Well OW-6. The pumping tests provided information on the specific capacity of each well and on aquifer properties (transmissivity and storativity), as well as on water quality as discussed in the foregoing section.

The data from the pumping tests were entered into Dames & Moore's computer program PUMDAT for data reduction and performance of calculations to aid in interpretation of the data. The resulting reduced data sheets are included in Appendix A. The output from the computer program was then plotted with a graphics program to obtain drawdown vs. log (time) plots for the pumping-period data, and residual drawdown vs. log (t/t') for recovery data. Here, 't' refers to the time since pumping started and t' to the time since pumping stopped. In a few wells which would permit only very low withdrawal rates, the recovery data were analyzed by using slug-test theory. In these cases, the log of H, the residual drawdown, was plotted against the time of recovery. The figures showing all these plots are provided in Appendix B.

In addition to analyzing the pumping-test data obtained from the present investigation, we also analyzed data from earlier pumping tests which was available for a few of the site wells -- PW-5, PW-6, HC-1, HC-2 and OW-I. These tests were conducted between 1974 and 1984. The output data from Program PUMDAT are provided in Appendix C, and the plots of drawdown vs. log (t) and of residual drawdown vs. log (t/t') are provided in Appendix D.

A summary of the results of analyzing the data from the pumping tests performed in 1987 is given in Table 4. The comparable table for the earlier pumping tests is Table 5. Table 6 provides a concise summary of the transmissivities and specific capacities for each water-bearing unit.

Table 4 provides estimates of aquifer transmissivity and permeability at each well, and of storativity for those pumping wells at which reliable observation-well data were available. In addition, the computed specific capacity in gallons per minute per foot of drawdown (gpm/ft) for each well is given for the duration of pumping involved. For the normal analyses, we estimated aquifer parameters (transmissivity and permeability) using the Jacob semi-log method, involving the plot of drawdown vs log (t). However, in cases where the 'u' value in Theis's equation was too large, we plotted the data on log-log paper and used the type-curve analysis based on Theis-Hantush type curves for non-leaky and leaky confined aquifers. The values shown for transmissivity in Table 4 under the columns headed by 'Jacob' and 'Theis-Hantush' represent the average of values computed from pumping-period data and from recovery data, unless it is specifically indicated that only pumping-period data or only recovery data were used.

The wells which permitted only very low discharge were analyzed using slug-test theory either by the Cooper, Bredehoeft and Papadopulos (1967) method ('Cooper, et al'), or by the method developed in 1976 by Bouwer and Rice ('Bouwer-Rice').

Table 5 provides the results of the analysis of earlier pumping-test data. The data given therein is similar to that described for Table 4, except that no slug-test analysis was performed.

Review of the results shown in Tables 4 and 5 provides ranges in the transmissivity of the major water-bearing units beneath the site. The transmissivity of the Vincentown Formation is seen to generally range from 5,000 to 11,000 gallons per day per foot (gpd/ft). The lower values shown in Table 4 at DW-505D and DW-514D are not believed to be representative of the unit. The comparable range for the Mt. Laurel-Wenonah aquifer is seen to be generally from about 4,900 to 8,700 gpd/ft. The low value of 552 gpd/ft found at Well OW-D is not believed to be typical of the aquifer at the site, and the extremely low value of 47 gpd/ft for Well OW-C indicates that the hydraulic connection between that well and the aquifer is tenuous at best.

The data given in Tables 4 and 5 show that the transmissivity of the Upper Raritan ranges from 9,600 to 27,000 gpd/ft. The low value of 870 gpd/ft determined for Well OW-H is another indication that that well cannot supply accurate information about the aquifer it supposedly taps. The tables also show that the transmissivity for the Middle Raritan aquifer ranges from 670 to 4,000 gpd/ft.

3.5 GROUND-WATER WITHDRAWALS

Data on pumpage at the Salem and Hope Creek Generating Stations over the past years were reviewed and evaluated. We prepared graphs (Figures 25 through 33) to aid in assessing the trends in ground-water withdrawals from each aquifer and from each well.

Figures 25 and 26 are bar charts representing mean monthly withdrawals or pumpage from the Mt. Laurel-Wenonah and the Upper Raritan aquifers, respectively. Figure 27 shows the quarterly pumpage from the Middle Raritan aquifer since 1984. Figure 25 indicates that pumpage from

the Mt. Laurel-Wenonah aquifer has been declining from 1978 through 1986. On the other hand, Figure 26 shows that pumpage from the Upper Raritan aquifer has been maintained fairly constant, or slightly increasing from 1982 to the present.

4.0 CONDITION OF PRODUCTION WELLS AND OBSERVATION WELLS

Each production well and observation well on site was carefully inspected and tested, as described in Section 2.0. The purpose of this was twofold: to determine the physical condition of each well in some detail; and to assess the useability of each well, either as a production well or observation well, to meet site water-supply and monitoring objectives. One particular concern was the possibility that if one or more wells were damaged or corroded, they might serve as conduits for the intrusion of brackish water from one aquifer into another.

The methods used to evaluate the condition of each well included:

- Visual assessment of the condition of the above-ground portion of the well casing,
- Plumbing the well to determine total depth and the presence of any sediment in the bottom of the well,
- Down-hole TV survey of each well,
- Performance of a pumping test in each well to evaluate its specific capacity, and,
- Analysis of the water quality in each well.

4.1 ASSESSMENT OF PHYSICAL STATUS OF SITE WELLS

The basic data on the site wells are provided in Table 7. Included in the table are details on the aquifer tapped, well depth, screened interval, pump capacity, access for water-level measurements, and the well reference point.

Table 8 provides a summary of our assessment of the condition of the site wells. The table includes information obtained from our visual assessment and plumbing of each well, as well as results of the TV survey of each well.

4.2 SPECIFIC CAPACITY OF SITE PRODUCTION WELLS

A comparison of past and present values of specific capacity and chloride levels in each production well is given in Table 9. The specific capacity, which is the well discharge rate in gpm divided by the number of feet of drawdown, is a useful measure of a well's condition at the well screen. Specific capacities tend to drop when a well screen becomes clogged as a result of corrosion, chemical or biological encrustation, or the accumulation of sediment inside the screen. Generally, specific capacities are reported for a pumping duration of 24 hours, but in the case of the present investigation this was not possible as pumping durations for the production wells were in the range of 4 to 12 hours.

Table 9 presents the specific capacities obtained from this investigation along with the corresponding values from earlier tests, with the duration of pumping noted in each case. Specific capacities are related in an approximate manner with aquifer transmissivity. Table 9 indicates the following ranges of specific capacities in gpm/ft by aquifer unit:

Mt. Laurel-Wenonah	3.2 - 5.0
Upper Raritan	10.6 - 17.2
Middle Raritan	1.9 - 2.1.

The specific capacity of PW-1 may have effectively declined somewhat since it was first tested in 1968. The value of 3.7 gpm/ft in 1987, although higher than that given for 1968 (3.2), represents a pumping period only one-sixth as long as that for 1968. It is possible that during the recent period of non-pumping of PW-1, screen encrustation has occurred to some extent.

As Wells PW-2 and PW-3, the data in Table 9 seem to indicate a decline in specific capacity since they were tested in 1970. But this is probably not the case because the duration of the tests in 1970 for which data are available was only about 30 minutes, compared to about 10 hours in 1987. We believe that the current specific capacity of both wells is approximately the same as that when the wells were first tested.

Table 9 shows that the specific capacities of the Upper Raritan wells have not changed significantly since the time of their initial testing. At Well PW-5 the specific capacity appears to have declined slightly from 11.6 gpm/ft in 1974 to 11.2 in 1987, and at Well HC-1 the specific capacity remains approximately what it was in 1976, about 17 gpm/ft. The specific capacity at Well HC-1 actually appears to have risen slightly since the first test in 1976--from 14.4 to 15.9 gpm/ft. This may reflect some continuing well development that took place following the initial test.

The specific capacity of Well PW-6 has remained essentially the same since it was tested in 1981. During the first test it registered 1.9 gpm/ft, while the value obtained during the 1987 test was 2.1 gpm/ft.

In summary, we can say that based on specific capacities, the production wells at the site appear to be in reasonably good condition. They have not yet reached the stage where we would recommend re-development with the use of acidifying or oxidizing chemicals or dispersing agents. The specific capacities of Wells PW-1 and PW-5 have declined by less than 10% since their initial testing, while that for the

other production wells has remained essentially the same. The UOP Johnson Well Screen Division recommends that well treatment be undertaken as soon as the specific capacity has dropped by 25 to 35 percent of its original value.

Because of the importance of the capacity of the site production wells, we recommend that PSE&G maintain a log of measurements of the specific capacity of each well, to be recorded once every three months. The length of time the well has been pumping at the time the measurement is taken should also be noted as part of the record. In general, the pumping period after which the measurement is taken should be at least 12 hours.

4.3 POTENTIAL FOR CROSS-CONTAMINATION IN DAMAGED WELLS

As mentioned briefly in Sections 3.2 and 3.3, recent water level, water-quality and pumping-test data indicate that three observation wells (OW-A, OW-C and OW-H) may serve as conduits for cross-contamination. This is because these wells exhibit characteristics that are not representative of the aquifer in which they are screened, and therefore we suspect that there may be a hydraulic connection between the well and an upper, more-brackish, aquifer probably through holes in the well casing. There is a concern that contamination of the Upper Raritan aquifer or the Mt. Laurel-Wenonah aquifer with brackish water from an upper unit(s) may be occurring in this fashion.

Table 10 provides a comparison of aquifer characteristics at these three potentially damaged wells with the corresponding values for other wells tapping the same aquifer. With respect to Well OW-A, the table indicates that while the measured transmissivity is within the range for the Upper Raritan aquifer, the static-water level and the chloride content are much higher than those for the other wells tapping the aquifer. These differences are even more pronounced with Well OW-H, whose water-level elevation and chloride content are dramatically higher than those for the other (reliable) site wells screened in the Upper Raritan aquifer.

As shown in Table 10, there is room for doubt as to whether or not a hydraulic connection has been established between Well OW-C and an upper aquifer, such as the Vincentown, through a hole(s) in the well casing. The water level measured in OW-C is within the range of Mt. Laurel-Wenonah levels at the site. However, we consider that the chloride concentration (1,310 mg/l) is too high to be representative of the aquifer at OW-C's location. Moreover, the computed value for transmissivity at Well OW-C of 47 gpd/ft is two orders of magnitude lower than the low end of the transmissivity range for the aquifer at the site. It is possible that OW-C does not have any hydraulic connection with an upper aquifer, but the data indicate that in any case its present condition is such that it cannot function as an effective observation/monitoring well. This matter will be pursued further in Section 9.0, Wells Recommended for Abandonment. Nothing was observed in the television survey of well OW-C that indicated any well corrosion or degradation.

4.4 DATA ON WELL ELEVATIONS AND COORDINATES

In carrying out the project, all the available data pertaining to the surveyed coordinates and elevations of the reference points at each production and observation well were collected and reviewed. Table 11 provides a summary of the surveying data we were able to locate on the site wells. As can be seen in the table, coordinates are not available for some of the wells. The locations of the wells shown on Figure 1 must, therefore, be considered to be only approximate.

There is even less information available with respect to well elevations. As shown on Table 11, the elevation data is spotty and at times inconsistent. For example, the ground and slab elevations shown for Wells PW-2 and PW-3 are inconsistent when one considers that an elevation of 100 ft with the PSE&G datum is equivalent to an elevation of 11 ft with the USGS mean-sea-level datum. Because of such uncertainties and missing elevation data, water-level elevations at the site cannot be

computed precisely, as was mentioned in Section 3.2 in connection with the discussion of the water-level data in Table 1. However, we believe that the water level data (when known or when estimated) are sufficiently accurate for the purposes of this study.

We would recommend that PSE&G arrange for the surveying of all the production wells and observation wells on site. This will be important in evaluating and comparing piezometric water levels in the several aquifers. In the absence of accurate level and coordinate data, only approximate piezometric contour maps can be prepared, which we feel does not compromise the value of the results of this study. However, for more detailed and specific studies done in the future, these data will be required.

5.0 SIMULATION OF FUTURE GROUND-WATER WITHDRAWALS

5.1 PURPOSE

Simulation of future ground-water withdrawal scenarios at PSE&G's Salem and Hope Creek generating stations on Artificial Island was accomplished by means of ground-water modeling. This task was undertaken to assess the effects of selected scenarios on the piezometric water levels and chloride contents of the major aquifers underlying the site. This information was needed to assess the quantity of ground water that can safely be withdrawn from each aquifer in the future without significantly increasing chloride levels or decreasing piezometric heads. The modeling was also performed to assess the likely proximity and potential movement of the salt-water/fresh-water interface in each aquifer.

5.2 SELECTION OF MODEL

The Princeton Transport Code (PTC) was selected for the modeling task. This code was developed by Dr. George Pinder, Mr. A. Niemi and Mr.

D. K. Babu and has recently been modified by Mr. David Ahlfeld, all at the Department of Civil Engineering of Princeton University. The code is a fully three-dimensional code providing for simulation of both fluid flow and mass transport. The code uses quadrilateral finite elements in the horizontal plane, and a finite-difference approach for incorporating more than one layer and for advancing time steps. The code has been verified by comparing its results with the results of analytical solutions and with the results of the 3-D MODFLOW program of the USGS. More details regarding the assumptions of the code and the manner of its use may be found in Chemical Transport by Three Dimensional Groundwater Flows, by D. K. Babu, G. F. Pinder, A. Neimi and D. P. Ahlfeld, 85-WR-3, Revised January 1988, Department of Civil Engineering, Princeton University.

Dames & Moore modified the code slightly so that it would run on a Macintosh computer. The code was developed at Princeton to run on an IBM PC. After the modification, two test cases were run with the code up on the Macintosh to confirm that the code was operating correctly: the numerical results obtained were identical to those provided in the user's manual.

The Princeton Transport code does not include the feature for coupling the flow and mass transport equations. Such a feature is important for correcting the flow equation results for the effects of the density and viscosity of the fluid (as affected by salt-water content) on flow. The lack of this feature in the code could have been a serious drawback had we attempted to model the entire front of the salt-water/fresh-water interface in even one aquifer. However, the available data and the results of model calibration showed that this was not necessary. With the highest chloride levels handled being 1,000 mg/l and that only in the Middle Raritan aquifer along the southern boundary, the effect of salt content on the modeled flow was negligible. Our calculations showed that for this worst-case layer, the relative error, by not using a model with coupling, introduced in computing travel times

from the southern end of the modeled domain to well PW-6, was approximately 0.2 percent, much smaller than the uncertainties in the input data.

5.3 GRID FORMULATION AND DATA PREPARATION

Consideration was initially given to the appropriate size of the domain to be modeled. There would be certain advantages if the modeled area were large, with dimensions on the order of 30 to 50 miles. If this were done, all the major pumping wells in the region, in Delaware and New Jersey, drawing from the Magothy-Raritan aquifers and from the Mt. Laurel-Wenonah aquifer could be incorporated, and natural aquifer boundaries might also be used as the model boundaries. However, it was decided that the modeled area should be restricted to the vicinity of the Artificial Island in order better to simulate and assess the influence of local hydrogeologic properties and conditions on future pumping. Another reason for this decision was that we determined that the closest major wells withdrawing from the two aquifer units of concern are located 8.5 miles from the Salem/Hope Creek stations. We defined a major well as one pumping greater than 0.1 million gallons per day (mgd). These nearest wells are the Texaco production wells at Delaware City which tap the Raritan aquifers. Since significant pumping of the aquifers of concern only takes place at locations greater than eight miles away, we concluded that modeling of the aquifers over a modest-sized domain centered around the site would be unlikely to be affected significantly by trends in pumping of any of these distant wells. Thus, we concluded, a limited domain would be most suitable for meeting the objectives of the project.

As shown on Figure 34, the domain we formulated, in plan, consisted of a rectangle, with its long axis approximately parallel to the direction of dip (northwest-southeast) of the coastal-plain hydrologic units modeled. The grid consisted of 475 nodes and 432 elements for each of seven layers. The modeled domain was 42,500 feet long (southeast to northwest) and 33,000 feet wide (southwest to northeast), or about 8 miles long by 6.25 miles wide. As indicated on

Figure 2, individual element size was 500 x 500 feet in the plant area proper with larger and larger dimensions the greater the distance from the plant area. The largest elements were at the four corners of the domain and were 4,500 x 5,000 feet in size. Figure 35 shows details of the finite-element mesh, including element numbers, in the immediate vicinity of the plant site. The seven layers making up the model comprise the following, from lowest to highest in the geologic column:

Layer 1	Middle Raritan Sand
Layer 2	Middle Raritan Clay
Layer 3	Upper Raritan Sand
Layer 4	Upper Raritan Clay
Layer 5	Magothy Sand
Layer 6	Matawan Aquitard, consisting of the Merchantville, Woodbury, Englishtown and Marshalltown Formations
Layer 7	Mt. Laurel-Wenonah Sand.

A number of references and information sources were collected and consulted with respect to aquifer geometry, aquifer properties and water-quality and piezometric-head conditions. In addition, Delaware and New Jersey state reports and records were consulted to obtain current pumping rates of wells located within 15 miles of the site and tapping the Magothy-Raritan aquifers or the Mt. Laurel-Wenonah Sand. Figure 36 is a regional map showing the location of all the major water-supply wells (ground-water withdrawal 100,000 gpd) by aquifers which are located within 15 miles of the site. The Bibliography given in this report provides a listing of the publications and files searched and consulted in preparing the data for the construction of the model. Some of the most important data incorporated into the model was, of course, the data obtained from well logs and pumping tests of on-site production and observation wells, along with piezometric and water-quality data for the site wells over time.

5.4 MODEL CALIBRATION

Following the organization and preparation of the data files for the model, the calibration of the model was undertaken. This consisted of the simulation of a period of 14.5 years which represented the period from March 1973 to September 1987. It was decided that this period could best be simulated by breaking it up into three separate stress (pumping) periods. Table 12 provides details of the three periods and the approximate constant rates of pumping of each site production well over each period. In estimating the equivalent rates of pumping for each well, we made use of PSE&G well records, including a few periods for which only records for total diversions were available. We estimated the individual rates for these periods by applying average proportional rates for the given well obtained from the remainder of the records.

As shown in Table 12, the first period (March 1973 to January 1976) involved a mean total withdrawal rate of 0.218 mgd (million gallons per day). All of this pumpage, from PW-1, PW-2 and PW-3, was from the Mt. Laurel-Wenonah aquifer. During the second period (January 1976 to June 1984), the mean pumpage was 0.879 mgd, which was taken from both the Mt. Laurel-Wenonah and the Upper Raritan aquifer. In the last period (June 1984 to September 1987), the mean ground-water withdrawal was 1.06 mgd which involved withdrawals from the Mt. Laurel-Wenonah aquifer, the Upper Raritan aquifer and the Middle Raritan aquifer.

Figures 37 through 39 provide the assumed initial piezometric contours at the time of the start-up of pumping from the Middle Raritan, the Upper Raritan and the Mt. Laurel-Wenonah aquifers, respectively. In a similar way, Figures 40 through 42 show the contours of the assumed initial chloride concentrations in the Middle Raritan, the Upper Raritan and the Mt. Laurel-Wenonah aquifers, respectively. In both cases, the contours reflect the data available at the time of the start-up of pumping the respective aquifers.

Figures 43 through 46 show the piezometric contours for the summer of 1987 for the Middle Raritan, the Upper Raritan, the Mt. Laurel-Wenonah and the Vincentown aquifers, respectively. In the case of the first three aquifers, the contours reflect the piezometric surface obtained when calibrating the model, while for the Vincentown aquifer the contours are directly based on the field data. Similarly, Figures 47 through 50 provide the contours of chloride concentrations in the Middle Raritan, the Upper Raritan, Mt. Laurel-Wenonah and the Vincentown aquifers, respectively. In the case of the first three aquifers, the contours reflect the chloride concentrations obtained when calibrating the model, while for the Vincentown aquifer the contours are directly based on the field data.

A total of 18 calibration runs were carried out before a satisfactory comparison for mid-1987 was attained between observed and computed water-level elevations and between observed and computed chloride levels. After each calibration run, parameter values and, in some cases, initial conditions were adjusted to improve the correspondence of computed values for 1987 with the observed values. Table 13 shows for the final calibration run the observed and computed values of head (piezometric level) and chloride concentration at each selected well. During calibration, attention was paid particularly to the non-pumping wells, i.e., observation wells. As noted in the table, the water levels measured in the production wells in the summer of 1987 are believed to represent neither true pumping levels not true static water levels, as we doubt that in the relatively short time available to test each well that full recovery of the piezometric level was achieved in the production wells. Thus, in the calibration process we concentrated on matching the heads in the observation wells.

Table 13 shows that there is s close correspondence in both head and chlorides at Well OW-I between observed and computed values. Also, the computed chloride concentrations for production wells in the Middle Raritan and the Upper Raritan are close to the observed values. Computed head values for the Mt. Laurel-Wenonah observation wells OW-D and OW-G are within the range measured in mid-1987.

Up to and including the last calibration run, an exact calibration of the model with respect to chloride concentrations in the Mt. Laurel-Wenonah aquifer was not achieved. The difficulty encountered here centered around the mode of salt-water intrusion into the aquifer. Based on all the evidence available to us, the most reasonable explanation for the intrusion of brackish or saline water into that aquifer is that leakage is occurring locally, and perhaps for some distance to the north, from the overlying Vincentown aquifer through the intervening Hornerstown-Navesink aquitard. Investigations performed by Dames & Moore during the summer of 1987 indicated that chloride levels in the Vincentown aquifer at the site ranged from about 1,800 to 4,300 mg/l. Thus, any significant leakage downward into the Mt. Laurel-Wenonah aquifer could result in notable increases in its chloride content.

During the calibration process, we assumed that over the northern portion of the domain the Hornerstown-Navesink aquitard was approximately ten times more permeable than that over the southern portion. In addition, in order to reproduce a high level of chlorides at Well OW-G it was necessary to assume a limited area of relatively high permeability for the aquitard in the vicinity of that well. As shown in Table 2, for the last calibration run, computed and observed chloride levels in the Mt. Laurel-Wenonah wells corresponded within a few tens of mg/l with the exception of that for Well OW-G, where the computed concentration of 441 mg/l was about 260 mg/l short of the observed value of 700 mg/l. A closer correspondence could have been achieved with additional fine tuning of aquitard permeability in the vicinity of Well OW-G, but it was felt that due to the assumed local nature of the brackish quality of OW-G water, the overall utility of the model as a predictive tool would not be substantially improved by continuing the calibration process further.

The parameter values that were most important in achieving model calibration, were layer permeability (horizontal and vertical), the leakance of the Hornerstown-Navesink aquitard overlying the Mt. Laurel-Wenonah aquifer, and the lateral leakances of the aquifer units.

For the Upper Raritan aquifer (Layer 3), the assumed chloride concentration of ground water leaking laterally through the side boundaries was important in the calibration process, and even more so was the assumed initial chloride concentrations in the aquifer. Good correspondence between observed and computed chloride values at Well PW-5 in the Upper Raritan aquifer was attained only after setting the initial chloride concentration in the aquifer so that a maximum concentration of 300 mg/l existed at the southeast (eastern) corner of the domain, which declined in a southwestward direction to reach 40 mg/l at the southwest (southern) corner. Northward, the chloride values were assumed to decline to a constant 10 mg/l across the northern third of the domain. Figure 41 shows the contours of the assumed initial (1976) chloride concentration in the Upper Raritan aquifer for the portion of the domain in the immediate vicinity of the generating stations.

The final aquifer parameters, boundary conditions and initial conditions for the model achieved through the process of calibration are provided in Table 14. In many cases, a range of values are given indicating that the parameter value varied across the layer. In most cases, the spatial distribution of the parameters was not random but varied relatively uniformly across the site. For such ranges shown in Table 14, the highest value is usually followed by a compass direction in parentheses. This means that the highest value was on that side of the domain, and that the lower values tended to be on the opposite side.

As shown in Table 14, the lateral boundary conditions for the confining units or aquitards included in the model (Layers 2, 4 and 6) consisted of 'no-flow' boundaries on all sides. However, for the aquifer units, the 'third-type' boundary condition was selected for the four sides. This involves the provision of lateral leakage across the boundary by identification of a constant head (HLEAK) at a selected distance (L) away from the domain boundary and a leakance (horizontal permeability divided by the distance L). Flow into or out of the domain then occurs by computing the flow at each boundary node by

$$Q = (HLEAK - H_i)(Leakance)(Area),$$

where H_i is the computed head at the ith boundary node for the given time step. It was felt that, under the circumstances, this type of boundary condition provided a greater degree of realism for the aquifer layers than either a constant-head or a constant-flux type of boundary condition.

5.5 PREDICTIVE SIMULATIONS

Following the calibration of the model, four predictive simulations were performed to evaluate how well the aquifer system would perform to satisfy the water-supply needs of the two generating stations over the next 20 years. The allocation of pumping among the several production wells for each of the four predictive runs is detailed in Table 15.

Run No. 1 represents a continuation of the present pumping of each of the wells currently utilized at each of their present rates of withdrawal. Run No. 2 involves the same amount of total pumpage as Run No. 1, but involves increasing the pumping at Well PW-5 while decreasing the withdrawal an equal amount from Mt. Laurel-Wenonah wells. Under Run No. 2, Well PW-2 is not pumped at all, while pumpage from Well PW-3 is decreased from 0.108 to 0.072 mgd. Pumpage from Well PW-5, on the other hand, is increased from 0.209 to 0.288 mgd.

Run No. 3 involves the complete elimination of pumping from the Mt. Laurel-Wenonah wells and the elimination of pumping from the lone Middle Raritan well, Well PW-6. This loss of pumpage was completely compensated for by increasing the pumpage from Wells PW-5 and HC-1 tapping the Upper Raritan aquifer and by pumping from a hypothetical well, called 'PW-7', which would tap the Magothy aquifer. The reason for eliminating pumping from the Middle Raritan aquifer and the Mt. Laurel-Wenonah aquifer was the fact that Runs 1 and 2 showed relatively high chloride concentrations occurring from Wells PW-2, PW-3 and PW-6 by the Year 2007.

Run No. 4 was similar to Run No. 3 except that pumpage from the Upper Raritan aquifer was increased by 0.2 mgd (0.1 mgd added to HC-1 and 0.1 mgd to HC-2). Thus, this case simulated a situation where all the current water needs of the two stations (1.06 mgd) would be completely provided by the three wells tapping the Upper Raritan aquifer. An additional 0.2 mgd would also be provided under this case from the hypothetical Magothy well, 'PW-7'

A summary of the results of the 20-year simulations (1987 to 2007) is provided in Table 16, which consists of four parts--(A) Middle Raritan Aquifer, (B) Upper Raritan Aquifer, (C) Magothy Aquifer, and (D) Mt. Laurel-Wenonah Aquifer. A discussion of the results by aquifer follows.

5.5.1 Middle Raritan Aquifer

Little change in either the piezometric heads or the chloride contents of the Middle Raritan aquifer is predicted to take place as a result of pumping of PW-6 at present levels, as assumed under Runs 1 and 2. Chloride levels are predicted to rise to only about 304 mg/l after 20 years of pumping under these two cases, compared to the starting level of 295 mg/l in 1987. Hence, the salt-water/fresh-water interface in the Middle Raritan can be assumed to have moved northward slightly over the 20-year period.

5.5.2 Upper Raritan Aquifer

Table 16 shows that only modest increases in chloride concentrations are predicted as a result of continuing the present level of withdrawal from the Upper Raritan aquifer. The results for Run No. 1 show that chlorides in Well PW-5 are expected to rise from the present level of about 44 mg/l to only 63 mg/l in the year 2007, while the levels in Wells HC-1 and HC-2 would increase only marginally--from 10.4 to 11.8 mg/l in HC-1 and from 11.0 to 14.5 in HC-2. The chloride level at the

southern end of the domain is predicted to increase by only 2 to 4 mg/l over the 20-year period, while no change is predicted for the northern end. One would estimate that the position of the salt-water/fresh-water interface in the aquifer may have moved northward ever so slightly over the 20-year period.

Essentially no change in piezometric levels is predicted in the Upper Raritan aquifer under the assumptions involved in Run No. 1 (Table 16). This indicates that at the present levels of withdrawal from this aquifer, nearly steady-state conditions have already been achieved.

Run No. 2 is an important case as it could be adopted for the near-term (the coming 12 to 18 months) as a feasible, though not long-term, pattern of ground-water withdrawal. Table 16 shows that by pumping from PW-5 an additional 0.079 mgd, chloride levels at this well would increase from 44 to 59 mg/l, and 1 to 2 mg/l increases would be seen at Wells HC-1 and HC-2. At the northern and southern ends of the domain, chloride levels would be essentially the same as those predicted under Run No. 1. However, under Run No. 2, piezometric levels would clearly decline relative to the starting values. The greatest drop would be seen at PW-5 (from Elevation -76.4 ft to -88.8 ft), and a 4.7 ft decline would be registered at Well OW-I. Head declines at the southern end of the domain over the 20-year period would range from 2 to 4 feet, while at the northern end declines would amount to 0 to 2 feet.

Under Run No. 3, an additional 0.072 mgd would be pumped from the aquifer, relative to that under Run No. 2, the additional amount coming from Well HC-1. This results in slightly increased chloride levels relative to run No. 2. For example, chlorides in Wells HC-1 and PW-5 would increase from 11.0 to 14.1 mg/l and from 44 to 61 mg/l, respectively, over the 20-year period. Increases of 3 to 4 mg/l are also predicted for the southern end of the domain, similar to that for Run No. 2, while no increase in chlorides is predicted for the northern end.

Table 16 shows that under Run No. 3, piezometric levels in the aquifer would fall at a rate greater than that predicted for Run No. 2Over the 20-year period, the heads at Wells HC-1 and PW-5 would fall by 15.4 and 16.7 feet, respectively. And at the northern and southern ends of the domain, the 20-year decline would range from 2 to 4 ft and from 3 to 6 feet, respectively.

By increasing withdrawal from the Upper Raritan aquifer from the present level of 0.709 mgd to 1.06 mgd, as assumed under Run No. 4, Table 5 shows that by the Year 2007 chloride levels would increase slightly, relative to those for Run No. 3. The predicted levels are 68 mg/l in PW-5, 13 mg/l in HC-1 and 16 mg/l in HC-2. Chloride concentrations are predicted to increase by 3 to 5 mg/l at the southern end of the domain, with no change predicted at the northern end. Thus, even with the additional pumping from the aquifer involved with Run 4, little northward movement of the salt-water/fresh-water interface in the aquifer would be expected over the 20-year period.

Piezometric levels in the aquifer will naturally decline as a result of the increased pumpage under Run No. 4. At the pumping wells the predicted decline, comparing Run 4 to Run 1, ranges from 30 feet at PW-5 to 38 feet at HC-1. At the northern and southern boundaries of the domain, pizeometric levels are seen to decline by 6 to 9 feet, and by 8 to 11 feet, respectively, comparing the results of Run No. 4 with those for Run No. 1.

Figure 51 provides the piezometric contours in the Upper Raritan aquifer in the Year 2007 in the immediate vicinity of the site, as predicted from Run No. 4. Figure 52 shows contours of chloride concentration in the aquifer predicted by the same simulation. For the portion of the domain shown, it is seen that chloride levels in the year 2007 range from greater than 100 mg/l at the southwest corner to less than 20 mg/l in the northern area. Graphs showing the predicted change in piezometric head and chloride levels over time from 1987 to 2007 at Wells PW-5 and HC-2 are shown on Figures 53 and 54, respectively.

5.5.3 Magothy Aquifer

Table 16 shows that pumping from the Magothy aquifer (hypothetical well 'PW-7') at a rate of 0.2 mgd (Runs 3 and 4) results in essentially no change in the chloride level over the 20-year period. The chloride concentration actually is predicted to decline slightly over the period, from the starting level of 94 mg/l to about 90 mg/l. The reason for the decline is probably due to the assumed increased transmissivity of the aquifer toward the north, because of increased aquifer thickness in that direction. Because lower initial chloride levels were assumed for the aquifer north of the site, and because a greater proportion of the pumped water came from the northern, lower-chloride, zone (due to higher transmissivity in that direction), a slight decline in the chloride level resulted after 20 years of pumping. Table 16 indicates that the decline in the piezometric level at the hypothetical well amounted to about 69 feet, while at the northern and southern boundaries of the domain declines over the 20-year period ranged from only 1.5 to 3 feet.

5.5.4 Mt. Laurel-Wenonah Aquifer

Table 16 shows that the water-quality effects of continued pumping of the Mt. Laurel-Wenonah aquifer at present levels (Run No. 1) are seen to be significant. While no change in piezometric levels is predicted over the 20-year period, the model demonstrated that increased degradation of water quality in the aquifer beneath the plant site due to saline-water intrusion can be expected. For example, over the 20-year period the chloride content is predicted to increase from 391 to 659 mg/l in Well PW-2 and from 209 to 318 mg/l in Well PW-3. Some improvement is seen as a result of stopping the pumping of Well PW-2 and reducing the pumping of Well PW-3 from 0.108 to 0.072 mgd (Run No. 2). However, even under this scenario, chloride levels in Well PW-3 are predicted to increase from 209 to 285 mg/l over the period.

Figure 55 provides the piezometric contours in the Mt. Laurel-Wenonah aquifer in the Year 2007 in the immediate vicinity of the site, as predicted from Run No. 1. Figure 56 shows contours of chloride concentration in the aquifer predicted by the same simulation. For the portion of the domain shown, it is seen that chloride levels in the year 2007 range from greater than 700 mg/l in the vicinity of Wells PW-2 and OW-G to less than 200 mg/l. Graphs showing the predicted change in piezometric head and chloride levels over time from 1987 to 2007 at Wells PW-2 and PW-3 are shown on Figures 57 and 58, respectively.

Table 16 shows that Runs 1 and 2, no significant changes in heads or chloride levels are expected over the 20-year period at the northern or southern ends of the domain. At the southern end, a decline in chlorides of 3 mg/l is predicted, with no change in chlorides at the northern end. With respect to the piezometric levels, a decline of 0 to 0.2 ft is predicted for the northern end, and a rise in the level of about 0.5 ft at the southern end.

5.6 SALT-WATER/FRESH-WATER INTERFACES

The location of the 250 mg/l chloride contour in the Middle Raritan aquifer is known to be located at, or in close proximity to, the site. This may be considered to represent the leading edge of the salt-water/fresh-water interface in that aquifer. However, as no data are available indicating what levels of chloride exist in the aquifer downdip of Well PW-6, the concentration gradient at the interface is not known. For the modeling of the Middle Raritan aquifer, we assumed that ground water entering the model domain on the southern (southeastern) boundary would have a chloride content of 1,000 mg/l.

No water-quality data are available to indicate the specific location of the salt-water/fresh-water interfaces in the Upper Raritan and Magothy aquifers. However, the presence of chlorides in these two aquifers at levels greater than 20 mg/l (90 to 100 mg/l in the Magothy aquifer and up to 43 mg/l at Well PW-5 in the Upper Raritan aquifer)

indicates that some degradation of water quality has occurred. The cause of this is believed to be the updip movement of saline water associated with the salt-water/fresh-water fronts in the two aquifers.

Based on the available data, the updip movement of these fronts or interfaces in the Upper Raritan and Magothy aquifers appears to be progressing very slowly. The model could be calibrated with respect to the Upper Raritan aquifer's chloride levels only by assuming that the maximum initial chloride content in the domain was 300 mg/l, at its southeastern (eastern) corner, and that the maximum chloride concentration of waters passing into the domain across its boundaries was 350 mg/l (at the southeastern corner). Based on this, it would appear that at whatever distance the salt-water/fresh-water interface occurs in the Upper Raritan aquifer, the front associated with the interface is a very diffuse one. Also, as discussed in Section 5.5, the results of the predictive simulations indicate that the fronts in the Upper Raritan and Magothy aquifers would move updip only to a small extent over the next 20 years.

The salt-water/fresh-water interface in the Mt. Laurel-Wenonah aquifer is believed to be located some distance downdip of the site. As discussed in Section 5.4, it appears that the source of the high chloride levels in that aquifer is the overlying Vincentown Formation, from which leakage through the intervening Hornerstown-Navesink aquitard seems to be occurring. Such leakage is indicated by data in boring logs, which show that on the northern side of the site the aquitard thins and is comprised generally of sandier material than in the south.

The relatively high chloride content found in Well OW-G (700 mg/l), which is located on the south side of the side and which taps the Mt. Laurel-Wenonah aquifer, could indicate the presence of the salt-water/fresh-water interface in the aquifer on the southernmost side of the site. However, the chloride concentration gradient between OW-G and nearby PW-3 (chloride level of about 140 mg/l) appears to be too

steep for it to represent the salt-water/fresh-water interface. We conclude that the Hornerstown-Navesink aquitard is relatively permeable in the vicinity of Well OW-G which, in that local area, results in enhanced leakage and salt-water intrusion from above.

6.0 EVALUATION OF WATER-SUPPLY ALTERNATIVES

The results of the ground-water modeling study described in Section 5.0 indicated that ground water from the Mt. Laurel-Wenonah aquifer would have steadily increasing concentrations of salinity. In addition, it is clear that chloride levels in the Middle Raritan well will remain as high as, or higher than, the present level, which ranges between 180 to 330 mg/l.

In this evaluation, we have assumed that ground-water withdrawals from the three existing Upper Raritan wells will continue at their current level, but that an alternate water source will probably have to be found to replace the water currently being withdrawn from the Mt. Laurel-Wenonah aquifer and the Middle Raritan aquifer. Currently, about 0.15 million gallons per day (mgd) is being withdrawn from the Mt. Laurel-Wenonah aquifer and about 0.20 mgd from the Middle Raritan aquifer. Thus, an alternate supply must be found to provide 0.35 mgd of water of acceptable quality for the fresh-water requirements of the two generating stations.

6.1 IDENTIFICATION OF WATER-SUPPLY ALTERNATIVES

Eight water-supply alternatives were identified in the study. They are summarized as follows:

1. Construction and testing of two new production wells. -- One of these wells would be screened in the Magothy Formation (after initial testing of the aquifer), and the other well would be screened in the Upper Raritan Sand and would be located on the northern side of the site.

2. Construction of Recharge Basins. -- This included a single large shallow retention basin or a series of smaller basins or recharge channels.

3. Installation of a Series of Injection Wells. -- This included preliminary analysis of the installation of an appropriate number of injection wells to recharge the Upper Raritan aquifer to compensate for the additional withdrawal required to meet the water requirements of the two generating stations.

4. Construction of a Fresh-Water Pipeline. -- Potential sources of surface water supply such as the Cohansey River and Stow Creek were reviewed and their feasibility addressed.

5. Construction of a Surface-Water Reservoir. -- This included the location and preliminary sizing of a surface-water reservoir which could store the required quantity of water.

6. Utilization of municipal-grade water from the City of Salem.

7. Desalination of Delaware Bay Water. -- Desalination through reverse osmosis was studied and the feasibility of this technology for the needs of the plant site was evaluated.

8. Tertiary treatment of effluent from the on-site sewage treatment plants.

6.2 EFFECTS OF ALTERNATIVES ON SALT WATER/FRESH-WATER INTERFACES

All the eight water-supply alternatives identified in Section 6.1 would be designed to replace, or substitute for, the present ground-water withdrawals from the Mt. Laurel-Wenonah Aquifer. Thus, all eight alternatives should have a positive effect on salt-water intrusion into that aquifer. However, as shown by the results of the last two predictive simulations, Runs 3 and 4, in which no pumping of the Mt.

Laurel-Wenonah was assumed for the next 20 years (Section 5.5 and Table 16), no improvement (decrease) in chloride levels is predicted at the end of the period. Instead, the chloride levels remain essentially the same as those in 1987, with a slight rise of 6 to 14 mg/l predicted for Wells PW-1, PW-2 and OW-D. This indicates that leakage from the Vincentown would continue to some extent over a portion of the area. This would be due to the small downward vertical gradient maintained between the two aquifers, even after pumping in the Mt. Laurel-Wenonah aquifer is discontinued. The primary benefit of discontinuing pumping of the aquifer is that major continued deterioration of the ground-water quality would be prevented.

It is possible that stopping pumping of the Mt. Laurel-Wenonah aquifer at the site would also halt any updip movement of the salt-water/fresh-water interface in the aquifer. As mentioned in Section 5.6, we believe that the salt-water/fresh-water interface in the Mt. Laurel-Wenonah aquifer is located some distance downdip of the site, and that the present pumping levels at the site have essentially no effect on that interface.

Alternative 1 would have essentially no effect on the present position of the salt-water/fresh-water interface in the Middle Raritan aquifer, as the present level of pumping from that aquifer is assumed. The alternative is further predicted to have a small, but nearly negligible, effect on the location of the salt-water/fresh-water interfaces in the Magothy and Upper Raritan aquifers over the next 20 years. Assuming that the water demand remains the same as in 1987 (an average of about 1.06 mgd), the results from simulation Run No. 3 best indicates the effects of Alternative 1 on heads and chloride levels in these two aquifers, as shown in Table 16. Chloride levels at the end of the period are seen to be essentially the same as those predicted if the <u>present</u> pumping pattern continues into the future. Thus, little or no movement of the salt-water/fresh-water interfaces for the Magothy and Upper Raritan aquifers is predicted for the 20-year period under Alternative 1. This is in spite of the decrease in heads shown for the

two aquifers under Run No. 3, relative to those for Run No. 1. Alternatives 2 through 8 would have no positive or negative effect on the positions of the salt-water/fresh-water interfaces in the Middle Raritan, the Upper Raritan, or the Magothy aquifers, relative to their present locations. In all these seven cases, it is assumed that pumping of the Middle Raritan and Upper Raritan aquifers would continue at the present level. The effects of such pumping over the next 20 years were simulated in Run 1, as discussed in Sections 5.5.1 and 5.5.2.

6.3 SCREENING OF ALTERNATIVES

In this section, we will discuss each alternative in sufficient detail to demonstrate whether or not it is a feasible alternative and hence worthy of further consideration. Those alternatives deemed feasible were considered in more detail including the performance of a preliminary cost analysis, which is reported in Section 7.0.

6.3.1 Alternative 1 -- Construction of Two New Production Wells

One potential alternative that might be considered would involve the simple expedient of increasing the pumping of the three existing Upper Raritan wells (PW-5, HC-1 and HC-2) by the required 0.35 mgd. As discussed in Section 5.0, this was simulated in predicted Run No. 4 and no significant adverse effects were predicted to occur. Nevertheless, Dames & Moore believes that it would be injudicious for the two generating stations to depend for all of their service water needs on only three production wells. An additional two wells would clearly be advisable from consideration of redundancy and standby capacity. This led to the formulation of Alternative 1.

This alternative would involve the construction of a new well tapping the Magothy aquifer ('PW-7') and an additional well in the Upper Raritan aquifer ('PW-8'). Because the Magothy aquifer is untested at the site, an initial testing program would be undertaken, which would involve

the construction of a test well and two observation wells tapping the aquifer, followed by a 72-hour pumping test. At the present, all that is known about the Magothy at the site is lithologic and stratigraphic information on the formation from boring logs, and the results of one chloride analysis of Magothy water (114 mg/l) taken in the course of drilling Well PW-5.

It is proposed that the new Upper Raritan well be constructed on the north side of the site, perhaps 100 to 300 feet north of Well OW-I. The performance of such a new Upper Raritan well can be estimated closely from the results of model simulation Run 3, even through the well was not specifically included in the simulation. Our experience with the model and these runs, makes us confident that the results of a simulation that included 'PW-8' would be very similar to Run 3. In such a simulation, some of the pumpage occurring under Run 3 from the existing three Upper Raritan wells would be assigned to the new well. One expected effect of the new well would be localized drawdown in the aquifer which would probably be evidenced in well OW-I.

This alternative would then require that PSE&G formally apply to the NJDEP for a reassignment of the ground-water diversion presently given for the Mt. Laurel-Wenonah wells and the Middle Raritan well to a new Magothy ('PW-7') well and a new Upper Raritan well ('PW-8'). It is assumed that 0.15 mgd would be withdrawn from the Magothy aquifer and that 0.20 mgd would be withdrawn from the new Upper Raritan well. Assuming that the results of the test program are satisfactory and that the NJDEP agrees to a reassignment of the diversion allocation, the Magothy production well would be constructed in the Salem generating station area. We conclude that this alternative is a feasible one, so a preliminary cost analysis was performed.

6.3.2 Alternative 2 — Construction of Recharge Basins

Fresh water utilized by the two generating stations is supplied by wells that withdraw water from the Mt. Laurel-Wenonah aquifer, the

Upper Raritan aquifer and the Middle Raritan aquifer. A recharge basin constructed in the recharge areas for one of these aquifers could potentially offset the withdrawal by the plants. The recharge area for the Mt. Laurel-Wenonah aquifer is closest to the site and therefore was considered in this analysis. The recharge area considered is located north of the City of Salem extending northeast toward Auburn near Oldman Creek, about 14 miles north of the Salem/Hope Creek stations. Any water that would infiltrate into the aquifer at that site would either tend to discharge into local streams or rivers, or flow directly downdip toward the southeast in the direction of Cumberland County rather than south toward the plants. For this reason, it was felt that construction of a recharge basin to offset ground-water withdrawal is not a feasible alternative. As discussed in Section 5.4, the source of the brackish water reaching the Mt. Laurel-Wenonah aquifer is probably leakage from the overlying Vincentown aquifer. Ground-water recharge would have to occur relatively close to the Mt. Laurel-Wenonah production wells in order for salinities to be significantly reduced. The depth to the aquifer at the site is on the order of 160 to 200 feet. Because of these problems associated with recharge basins, this alternative was not considered further in this study.

6.3.3 Alternative 3 — Installation of a Series of Injection Wells

Water to be injected into the Upper Raritan aquifer would not only have to be low in total dissolved solids but would have to be relatively clean in order to comply with anti-degradation requirements of the New Jersey Department of Environmental Protection (NJDEP). This rules out most possible sources of water near the plant. The most available source of water for ground-water injection would be treated wastewater from the existing six package wastewater treatment plants, which are scheduled for replacement by a single oxidation ditch system. The effluent standards for the existing and proposed wastewater treatment plants are 30 mg/l biochemical oxygen demand (BOD) and 30 mg/l suspended solids. These standards are too high to permit the use of plant wastewater effluent for ground-water injection. The other source of

water for injection would be a remote fresh surface-water supply. Treatment of the fresh water supply would probably be necessary so that the injection wells would not become clogged by suspended solids present in the water supply. If a fresh water supply is to be pumped to the Artificial Island with subsequent treatment, then it will clearly be more economical to simply use the water directly rather than to pump the water into an aquifer and then pump the water back up to the surface. For these reasons, this alternative was not considered further in this study.

6.3.4 Alternative 4 — Construction of a Fresh-Water Pipeline

An investigation of stream-flow capacity was conducted of the rivers and streams in the vicinity of the generating stations. The rivers and streams investigated and the distances from the site are given below:

River or Stream	Drainage Area (sq. mi.)	Distance (miles)
Alloway River at Alloway	21.9	14.5
Salem River at Woodstown	14.6	20.3
Salem River at Sharptown	27.3	18.8
Cohansey River at Seeley	28.0	21.0
Stow Creek at Jerico	8.0	12.4.

We conducted a preliminary analysis of low-flow conditions utilizing low-flow data from the USGS Open-File Report 81-1110 of January 1982 (Low-Flow Characteristics and Flow Duration of New Jersey Streams). The results indicated that adequate flow would be available in Stow Creek, the Cohansey River, and the Salem River at Sharptown. Because Stow Creek was closest to the site, the analysis focused on this creek. In the event that some future unforeseen circumstance should render the use of water from this creek not viable, flows for the Salem River at Sharptown and for the Cohansey River at Seeley were also analyzed. The

two projects -- (4A) Stow Creek and (4B) Cohansey River -- were considered feasible alternatives.

6.3.5 Alternative 5 — Construction of a Surface-Water Reservoir

Analysis of this alternative was not initiated because the analysis of the Stow Creek and Cohansey River flows indicated that adequate flows were available from these sources, as will be described in the following section.

6.3.6 Alternative 6 — Utilization of Municipal-Grade Water from the City of Salem

The City of Salem currently utilizes surface water from Laurel Lake on a tributary of Alloway Creek that is located below Alloway Lake. We contacted the City of Salem Water Department to determine if there was excess capacity at their municipal water treatment plant. The current capacity is 3.0 mgd, and the average current demand is approximately 1.9 mgd. Preliminary discussions with city personnel indicated that it would be possible to purchase water from the City of Salem. Under this alternative, it would be necessary to construct a pumping station as well as a pipeline from the City of Salem to the generating stations. This alternative was considered to be a feasible alternative.

6.3.7 Alternative 7 — Desalination of Delaware Bay Water

There is virtually an unlimited supply of water that could be withdrawn from the Delaware Bay. Therefore, this alternative was considered feasible, and we conducted a cost analysis of a reverse-osmosis treatment plant utilizing Delaware Bay water. Cost data from EMCO, Inc. of Canton, Massachusetts for the reverse osmosis plant were used to prepare this cost estimate.

6.3.8 Alternative 8 — Tertiary Treatment of Sewage Treatment Effluent

This alternative would involve the tertiary treatment of effluent from the site sewage treatment units. Available data indicate that the current average flow to the sewage treatment units at both stations ranges from 40,000 to 50,000 gallons per day or 0.04 to 0.05 mgd. We consider this flow too low a portion of the total required flow of 0.35 mgd for this alternative to merit consideration. Hence, this alternative was not considered further in this study.

6.4 Water Conservation Considerations

In addition to the primary objectives of this study, there is a need to assess existing water usage at the power stations to evaluate areas where water conservation practices may eliminate or significantly reduce possible wastage. The implementation of feasible conservation practices will have the effect of prolonging the life of the sources of water supply. Conservation practices also have the potential to reduce operating costs by reducing water requirements and hence the cost associated with meeting these requirements.

Water usage at the power stations may be grouped into two categories. One category is usage for the power generation processes. The other is incidental usage which includes drinking and sanitary water uses, and on-site irrigation water use.

6.4.1 Process Water Usage

An evaluation of plant processes was conducted to identify specific areas where improvements in water use efficiency are feasible. On the basis of available water balance data for the Salem Station for the January to September 1987 period, it appears significant reductions in process water requirements at the stations are potentially feasible. Significant steps have already been taken to reduce water consumption.

For example, a condensate recovery system was installed in 1984 which reduced water consumption by 30 percent. Also, a blowdown recovery system was installed at the Salem Generating Station in 1982 when the Salem Unit 2 generating station was brought on-line, which recovers 500 to 600 gpm. This recovery system allows water consumption to remain at the same rate while overall power generation significantly increased.

The water balance data indicated that plant cycle leakage averaged an estimated 55 to 60 gallons per minute (gpm) over a nine month period, accounting for 18 percent of total well production for the Salem Station. Cycle leakage is primarily leakage from pumps that is required to keep the packing in each pump wet so that the packing does not fail. The leakage per pump is small, however, the number of pumps in the plant is large. Therefore, the pump leakage is significant in relation to overall water consumption. This leakage, however, is necessary and cannot be reduced. Storage tank capacity was also exceeded occasionally and resulted in overflow to the yard drain. When they occurred, the overflows averaged between 1 and 5 percent of the total well production. High level cut-outs were installed in 1987 to prevent this when the well pumps are on automatic. In addition to these losses, unaccounted for water usage at the Salem Station was as high as 24 percent during the nine-month period for which water balance data were available. Unaccounted for water usage includes water uses that cannot be quantified, such as:

- truck washing
- system vents (high points in pipe systems)
- washdown of chemical handling areas (primarily acids and bases)
- fire protection system testing
- three yard drains
- sump pumps

The yard drains are subject to tidal action and metering would cost more than $50,000 per drain. There are 12 sump pumps which discharge to four inch lines. Possibly these pumps could be metered which could provide further information on water usage.

6.4.2 Incidental Water Usage

Under incidental water usage are drinking and sanitary water use and on-site irrigation water use.

Of these, sanitary usage was identified by PSE&G in 1986 (Refer: Letter report by NUS Operating Services Corporation, dated April 30, 1986) as a source of water wastage. Specifically, it was noted that the flush valve mechanisms on the toilets and urinals occasionally malfunctioned, causing the valves to remain open for extended periods. In addition, on occasion, the toilets were inadvertently supplied with hot water which damaged wax ring seals and other parts of the flush mechanisms. This source of leakage was eliminated in 1987 when all flush mechanisms were replaced.

Potable water consumption usage is often as high as 10 percent of total monthly consumption. The months that have high potable water consumption often coincide with planned outages for plant maintenance. Water uses include sanitary uses for maintenance crews (up to 600 men, 7 days per week) as well as water consumption to support portable air compressors and concrete drilling. It is possible that additional metering of these potable water uses could identify areas where conservation would be feasible.

On-site irrigation water usage may also provide some opportunity for water conservation. However, the irrigated area is only 40,000 square feet. Thus, while measures are available to improve irrigation efficiency, the overall water savings would most likely be insignificant

on account of the relatively low irrigation water demand. Similarly, unless specific data from the stations indicate otherwise, it is believed opportunities for significant savings with respect to drinking and other minor incidental uses are limited.

7.0 RESULTS OF ANALYSIS OF FEASIBLE ALTERNATIVES

As discussed in Section 6.0, the feasible water-supply alternatives include:

Alternative 1 -- Construction of Two New Wells,
Alternatives 4A and 4B -- Construction of Fresh-Water Pipelines,
Alternative 6 -- Municipal Water from the City of Salem, and
Alternative 7 -- Desalination of Delaware Bay Water.

The results of feasibility-level evaluation and cost analysis for these alternatives are provided in this section. A summary of the costs estimated for these alternatives is given in Table 17. The section concludes with a comparative assessment of the low-cost feasible alternatives.

7.1 ANALYSIS OF INDIVIDUAL FEASIBLE ALTERNATIVES

7.1.1 Alternative 1 — Construction of Two New Production Wells

Preliminary cost analyses were performed for the construction of the two wells proposed under this alternative, their testing, and the construction of pipelines to carry the water to existing storage facilities onsite.

The proposed Magothy well ('PW-7') would be drilled in the Salem plant area, and its expected depth would be 500 feet. Initial testing of this aquifer would involve the construction of an 8-inch steel test well

and two 4-inch observation wells constructed with Schedule 80 PVC casing and screen. A 72-hour pumping test would then be performed and analyzed, together with the results of chemical analysis of water samples taken in the course of the test. The total cost of this initial testing program is estimated to be $160,000. The production well tapping the Magothy would be triple-cased, with the inner casing being 12 inches in diameter and including a 12-inch stainless steel well screen. The well-construction cost is estimated to be $180,000. The cost of the pump installed, and the required electrical connections and pump shed is estimated to be $50,000. We estimate that the cost to provide piping to the storage tank will not exceed $50,000. The cost for engineering, including design, preparation of specifications and supervision is estimated to be $100,000. Thus, the total capital costs is expected to be approximately $540,000. Annual operation and maintenance (O & M) costs, including electricity for pumping, repairs and maintenance are estimated to be $25,000. At an annual interest rate of 8 percent and an assumed lifetime of 20 years, the present-worth cost for O&M is $245,500.

The proposed new Upper Raritan well ('PW-8') would be drilled at a location a few hundred feet north of well OW-I. The expected depth is 900 feet. The well would be triple-cased, with its inner casing being 12 inches in diameter and including a 12-inch stainless steel well screen. The well-construction cost is estimated to be $230,000. The cost of the pump installed, and the required electrical connections and pump shed is estimated to be $50,000. We further estimate that the cost to provide piping to the nearest plant storage tank will not exceed $150,000. The cost for engineering, including design, preparation of specifications and supervision is estimated to be $140,000. Thus, the total capital costs is expected to be approximately $570,000. Annual operation and maintenance (O & M) costs, including electricity for pumping, repairs and maintenance are estimated to be $30,000. At an annual interest rate of 8 percent and an assumed lifetime of 20 years, the present-worth cost for O&M is $294,500.

As shown in Table 17, the total capital cost for this alternative is $1,100,000. Adding to this the present-worth cost for O&M of $540,000, we obtain the total present-worth cost for the alternative of $1,640,000.

7.1.2 Alternatives 4A and 4B — Construction of Fresh-Water Pipelines

United States Geological Survey (USGS) gaging stations are maintained on the Cohansey River at Seeley and on the Salem River at Woodstown. Flow duration data were obtained for these two gaging stations from the USGS. An analysis was conducted of these two data sets to determine the minimum discharges during drought conditions. There are approximately 10 years of discharge data for these stations.

It appears that the Cohansey River at Seeley has adequate flows, in that a withdrawal of 0.35 mgd would represent less than 50% of the total stream flow for the duration of the record. Stream flow measurements by Dames & Moore on March 22, 1988 at the Cohansey River at Seeley and at Stow Creek at Jerico indicate the Stow Creek flow in cubic feet per second per square mile (cfs/sq. mi.) was greater than the corresponding unit-area flow for the Cohansey River at Seeley. Therefore, it is reasonable to assume that the Stow Creek flow could be calculated from the USGS data for the Cohansey River at Seeley. In this analysis, we assumed that Stow Creek flows could be estimated by multiplying the USGS recorded flows on the Cohansey River by the ratio of the Stow Creek drainage area to the Cohansey River drainage area. The resulting estimated Stow Creek flows always exceeded 4.0 cfs. Therefore, it appears that there is adequate capacity in Stow Creek for the diversion of 0.35 mgd (0.54 cfs).

A similar method was utilized to estimate stream flow for the Salem River at Sharptown. Flows from the USGS gaging station on the Salem River at Woodstown were multiplied by the ratio of the drainage areas to obtain the flows at Sharptown. The analysis indicated that

adequate flows are available from the Salem River at Sharptown. Adequate flows are not available from the Salem River at Woodstown without storage in a reservoir.

A number of New Jersey streams have current allocation requirements. In order to ensure that the subject streams were not currently allocated, an investigation was conducted of current water users for the subject streams. The analysis indicated that allocations are not excessive for the Cohansey River at Seeley and Stow Creek at Jerico. There are more users of surface water from the Salem River at Woodstown, however the flows allocated to each user were not available.

Cost estimates were developed for pumping of surface water from the Cohansey River at Hands Pond (39°29'40" latitude, 75°15'21" longitude) and Stow Creek at Jerico (39°28'15" latitude, 75°21'15" longitude). The general scope of the project for each proposed fresh-water source included construction of a pumping station to deliver water to a water storage tank at the high elevation point between the source and the destination, followed by water treatment at the Salem/Hope Creek generating stations. High-density polyethylene pipe for water transmission was considered in the cost estimate. The water treatment plant was considered to consist of a clarifier with addition of lime, alum, and a polymer to assist in coagulation. Following clarification, the water would be filtered with pressure filtration. This is essentially the process utilized by the City of Salem in treating fresh water from a reservoir for municipal water supply.

As shown in Table 17, the Stow Creek project, Alternative 4A, is estimated to cost $3,406,000 for construction of the water treatment plant, installation of 60,500 feet of 6-inch pipe and 5,000 feet of 8-inch pipe, and construction of a 10 H.P. pumping station. Annual operation and maintenance costs (O&M) were estimated to cost $124,000. The total present-worth cost was estimated to be $4,623,000, assuming a 20-year life and an interest rate of 8 percent.

The Cohansey River Project, Alternative 4B, involves construction of a water treatment plant, a 25 H.P. pumping station, and installation of 27,800 feet of 8-inch pipe, and 80,000 feet of 6-inch pipe. The construction cost was estimated to be $4,787,000, the O&M cost was $134,000/year, and the total present-worth cost was estimated to be $6,103,000.

It should be noted that the land around Stow Creek is all in private ownership, which may be a complicating factor if the landowner(s) is not interested in providing an easement to PSE&G.

7.1.3 Alternative 6 — Utilization of Municipal-Grade Water from the City of Salem

This alternative involves installation of 86,900 feet of 6-inch high-density polyethylene pipe, construction of two 20 H.P. pumping stations, and purchase of City of Salem water. It was assumed that water would be available from the City of Salem at a cost of $1.30 per 1,000 gallons. The construction cost was estimated to be $2,089,000 and the O&M cost was estimated to be $194,000. The total present-worth cost was estimated to be $3,994,000.

7.1.4 Alternative 7 — Desalination of Delaware Bay Water

This alternative would utilize package reverse-osmosis units which are now commercially available. The reverse-osmosis process would use Delaware Bay water. Chemicals would be added to the treatment process to enhance the treatment efficiency. These chemicals include calcium hypochlorite, sulfuric acid, soda ash, and sodium metabisulfite. In addition, cleaning chemicals are required.

The main O&M costs are electricity to operate the unit, an operator to maintain the system, and disposal of residue. The construction cost was estimated to be $1,700,000, the O&M cost was estimated to be $561,000/year, and the total present-worth cost was estimated to be $7,208,000.

7.2 COMPARATIVE ASSESSMENT OF THE LOW-COST FEASIBLE ALTERNATIVES

As shown in Table 17, the total present-worth cost for Alternative 1 of $1,640,000 is significantly lower than that for any of the other alternatives. The two alternatives with the next highest total costs are Alternative 6 with a cost of $3,994,000 and Alternative 4A with a cost of $4,623,000.

In deciding among these three relatively low-cost alternatives, certain characteristics of the alternatives in addition to cost will be considered. To assist PSE&G in selecting the most suitable alternative, we have listed in Table 18 the advantages and drawbacks of each of these three alternatives.

From the financial point of view, Alternative 1 is clearly to be preferred. However, if the Magothy aquifer does not prove to have adequate capacity, or it there are any difficulties involved in obtaining the required diversion allocations from the NJDEP, then preference may be given to Alternative 6.

In selecting the most appropriate water-supply alternative, factors other than those listed in Table 18 may have to be taken into consideration. Such factors that may be relevant in the decision-making process relate to schedule, timing of capital investments, tax considerations, utility regulatory rulings and public acceptance. We believe that any one of the three low-cost alternatives would provide an adequate supply of good-quality water to meet PSE&G's service water needs for the next two decades.

8.0 PROPOSED GROUND-WATER MONITORING PROGRAM

The establishment of a carefully designed monitoring program will be essential to assess the hydrogeologic conditions of the aquifers being utilized at the two stations. Properly located and constructed

monitoring wells will provide the necessary water-level and water-quality information to be able to assess, and in some cases predict, the local effects of pumping from the aquifers.

8.1 MONITORING OBJECTIVES

The objectives of the monitoring program are to:

1. Provide on a regular and frequent basis the information on current trends in pumpage, piezometric levels and ground-water quality in aquifers being utilized at the two stations. The location and design of the monitoring wells should be selected so that any potential adverse changes in piezometric levels and water quality at the production wells might be anticipated by timely analysis of the trends in the observation wells making up the monitoring network.

2. Provide water-level and water-quality data on aquifers which may be in hydraulic connection with the aquifers being pumped and which might negatively affect the exploited aquifers. An example of this is the Vincentown Formation from which brackish water is presently leaking through the Hornerstown-Navesink Aquitard to the Mt. Laurel-Wenonah aquifer.

8.2 SELECTION OF MONITORING WELLS

The wells that should comprise the ground-water monitoring network would include:

- o Existing production wells,
- o All production wells to be constructed in the future,
- o Selected existing observation wells, and,
- o New observation wells which we recommend be constructed to meet the objectives of this monitoring program.

The existing production wells to be monitored comprise of course PW-1, PW-2, PW-3, PW-5, PW-6, HC-1 and HC-2. Possible new production wells which may be constructed in the future include, as discussed in Section 6.0, a Magothy well PW-7, and a new Upper Raritan well, which we will refer to as PW-8. Possible locations for these two wells are shown on Figure 45, Map of Plant and Vicinity Showing Location of Proposed New Observation Wells and Production Wells. PW-7 could be located about 200 to 300 feet north of existing well PW-2, and PW-8 could be located about 200 feet north of existing observation well OW-I.

Of the existing observation wells, we have selected eight which we believe should be maintained and included in the monitoring network -- OW-D, OW-G, OW-I, OW-6, OW-S1, DW-25, DW-509S and DW-509D. Table 19A lists these wells along with the aquifer each of them taps. And, as shown in Table 19B, three other existing observation wells may also be included in the monitoring-well network if PSE&G so desires. These are OW-S2, DW-502D and DW-502S, which tap the Vincentown Formation and the River Sand & Gravel unit. All the wells listed in Tables 19A and 19B have been demonstrated to be in satisfactory condition, and they all reflect aquifer characteristics which are consistent with our current knowledge of the aquifers at the site. The remaining existing observation wells should be abandoned in an appropriate manner. A listing of the wells recommended for abandonment along with the reason for abandonment is given in Table 20. The abandonment of these wells will be discussed in Section 9.0

New observation wells should be constructed to replace the wells which we recommend for abandonment and which tap the Upper Raritan aquifer or the Mt. Laurel-Wenonah aquifer. After the abandonment of Wells OW-A and OW-H, the only Upper Raritan observation well remaining will be Well OW-I. We recommend that two new observation wells be drilled to monitor this aquifer. The first, OW-J, would be located about 400 feet northwest of existing production well PW-6, as shown on Figure 45, and the second, OW-K, would be located about 2,000 feet southeast of

Well PW-5. We believe that Well OW-K may be particularly important in helping to detect the possible movement of brackish water in the aquifer from the southeast.

An additional Mt. Laurel-Wenonah observation well, OW-L, is also recommended but only if PSE&G decides to continue to pump that aquifer for some years in the future at or above the current level of pumping. If that is the decision, then we recommend that Well OW-L be drilled. As shown on Figure 45, Well OW-L would be located about 400 feet northwest of production well PW-6 and about 50 feet west of the location for Well OW-J, the proposed Upper Raritan observation well. If, as discussed in Section 6.0, a water-supply alternative is selected to replace the water currently being withdrawn from the Mt. Laurel-Wenonah aquifer, then presumably pumpage in that aquifer would be terminated within one or two years, and observation well OW-L would, in our opinion, not be needed.

If the Magothy well PW-7 is constructed, NJDEP would probably require a minimum of two observation wells for use in proving the aquifer during the long-term pumping test. We would recommend that one of these, OW-M, be retained for use as in the monitoring network. The proposed Well OW-M would be located 100 to 200 feet south of the Magothy production well PW-7.

8.3 SPECIFICATION OF MONITORING PARAMETERS AND FREQUENCY

Water levels and chemical parameters are to be monitored in all the wells comprising the monitoring network. In addition, accurate pumping rates would be monitored in each production well.

Water levels should be measured manually at least as often as monthly in each of the wells. These measurements should all be taken on a single day. If a production well is pumping at the time of the measurement, the pumping water level should be measured and a note made of the pumping rate and the time when the pumping started. In addition,

we recommend that an automatic water-level recorder, such as a Leupold-Stevens Type F or Type A recorder, be installed at each selected well representing one of the three major aquifers - Mt. Laurel-Wenonah, Upper Raritan and Middle Raritan aquifers. Thus, we recommend that a recorder be set up at Well OW-J (for the Upper Raritan aquifer) and at Well OW-6 (for the Middle Raritan aquifer). If pumping of the Mt. Laurel-Wenonah wells is expected to continue for a few years, then Well OW-L would be drilled, according to our recommendation, and we would recommend that it be fitted with an automatic water-level recorder. Similarly, if Magothy well PW-7 is constructed, we would recommend that a recorder be placed in its observation well, OW-M.

Water samples should be obtained quarterly from each well comprising the monitoring network. We recommend that the samples be analyzed for each of the following parameters by a laboratory certified by the state of New Jersey:

- Chlorides
- Specific Conductance
- Total Dissolved Solids
- pH.

We recommend that once a year duplicate samples be obtained from each well, and that the samples be analyzed in two different NJDEP-certified laboratories.

Our recommendation is that each production well be fitted with recording flow meters. These meters should be initially calibrated when first installed and then recalibrated according to factory-prescribed specifications at least once every six months. Properly maintained, such recording flow meters will provide complete and accurate records of pumpage for each well.

Table 21 provides cost estimates for construction of the recommended monitoring wells.

8.4 DATA EVALUATION

Every six months, a monitoring data report should be prepared which would involve the evaluation and reduction of the data obtained from the intervening monitoring activities. Piezometric contour maps should be prepared for each aquifer for at least two selected months over the six-month period. Hydrographs showing the fluctuation of water-level elevations over the six-month period should be presented, one for each representative well for each aquifer monitored.

The trends in chlorides, specific conductance, TDS and pH should also be presented and discussed, based on quarterly measurements of these parameters in each well. In addition, fluctuations in the pumpage from each production well should be presented, in graphs derived from the recommended recording flow meters.

The monitoring data report should analyze and discuss any downward trends in ground-water quality and in the drawdown at each well. In addition, increasing trends in ground-water withdrawal should be noted.

9.0 WELLS PROPOSED FOR ABANDONMENT

9.1 SELECTION OF WELLS TO ABANDON

Table 20 provides a list of the ten observation wells which we recommend be formally abandoned--OW-A, OW-C, OW-H, DW-17, DW-25A, DW-42, DW-505S, DW-505D, DW-514S and DW-514D. The reasons for the proposed abandonment are given in the table.

With respect to Wells OW-A, OW-C and OW-H, as discussed in Section 4.3, the data provided in Table 10 show that the static water-level data, chloride concentrations or computed transmissivities, or all three, are inconsistent with the nature and state of the aquifers

observed in other wells. The data on Wells OW-A and OW-H clearly imply that chloride contamination of the Upper Raritan aquifer is probably occurring through holes or cracks in the upper part of the well casings through which hydraulic connection has been established with an upper, more brackish, aquifer. In the case of OW-H, we infer from the data that that well is in hydraulic connection with the Vincentown Formation. There is less clear evidence that cross-contamination is occurring in Well OW-C, but the data lend some credence to the possibility. In any case, we feel that the condition of Well OW-C is poor and that there is adequate justification for its abandonment.

The remaining wells recommended for abandonment (DW-17, DW-25A, DW-42, DW-505S, DW-505D, DW-514S and DW-514D) tap the Vincentown Formation or the River Sand & Gravel unit. These wells should be abandoned because the hydraulic connection with the unit they supposedly tap appears to be poor. Usually this was indicated by a very low yield during the pumping test, or in some cases by evidence the well was completely plugged up. Thus, these wells cannot in any sense function as effective observation wells.

9.2 PLAN AND PROCEDURES FOR WELL ABANDONMENT

9.2.1. General and Preliminary Procedures

The wells to be abandoned would be sealed in conformance with the NJDEP regulations for well abandonment, as given in the NJDEP's "Standard Specifications for Sealing Abandoned Wells," (Subchapter 9. Sealing of Abandoned Wells). Because the wells to be sealed are at a location where salt-water intrusion exists or is imminent in the aquifers involved, a drawing and a description of the method proposed for sealing each well must be submitted for approval to the Bureau of Water Supply Planning and Management in the NJDEP, in advance of beginning the work. Following the sealing, a detailed description of the well and the method used for sealing must be submitted to the Bureau of Water Supply Planning

and Management. The sealing operations must be performed under the immediate supervision of a person possessing a valid New Jersey well drillers' license.

Before beginning the sealing of the wells, some preliminary work must be done. Any obstruction in the wells should be removed, either by cleaning, or if needed, by redrilling. Then a good attempt should be made to pull the casing in each case. If it appears that the casing can be pulled, then a tremie pipe should be introduced into the well all the way to the bottom. A bentonite slurry should then be introduced through the tremie while the casing is being pulled. If it is not possible to pull the entire casing, then an attempt should be made to cut the casing somewhere in the depth range between the top of the well screen and where the next highest aquifer occurs. Then this upper portion of the casing should be pulled, and clay slurry tremied in as the pulling progresses.

9.2.2 <u>Details Of The Clay Slurry And Its Use For Sealing</u>

A bentonite slurry is recommended as the sealing material in preference to cement slurry, for the following reasons (Smith and Mason, 1985):

- o Cement slurries separate easily during emplacement, allowing gradation of the mixture and the formation of weak spots;
- o As the cement sets it shrinks, unless bentonite is added as an anti-shrinkage agent, and then cracks can form;
- o Experiments with models indicate a tendency of cement grout. even with bentonite as an additive, to adhere to one surface but not to the other in a borehole. On the other hand, bentonite slurries swell, adhere to all surfaces, and tend to remain wet and flexible.

Bentonite slurries require the presence of an inorganic polymer mixing agent, which actually delays the wetting of the bentonite granules to permit the emplacement of the slurry in the hole before it turns into an unpumpable gel mass. State specifications require that any clay slurry used for sealing must consist of sterilized clay (bentonite, in this case).

The bentonite slurry should be prepared in the proportion of 150 to 200 lbs of commercial ground bentonite and one quart of the inorganic polymer mixing agent to 100 gallons of water. The mixing of the slurry should be carried out in a large tank and then the mixture will be pumped through a 1-inch tremie pipe into the hole, using a positive displacement pump.

The mixing process begins by placing the water in the large tank and then checking and adjusting the pH so it is in the range of 7 to 8. The inorganic polymer is then added to the water by using a high-shear pump or mixer at a ratio of 1 quart polymer per 100 gallons of water. Then the bentonite is added slowly to the polymer water to prevent lumping and it is mixed using a paddle or hoe. The proper ratio is 1-1/2 to 2 lbs granulated bentonite per gallon of polymer water.

Once the slurry is mixed, there is only about 20 minutes before it starts to set up. The one-inch tremie pipe should be run to the bottom of the hole and left there. Then pumping should commence from the tank into the tremie pipe. As soon as a batch is pumped, the pump, hose and tremie pipe should be flushed with clear water or polymer water (Smith and Mason, 1985).

9.2.3 Preparation Of Concrete Seal And Slab At The Top

Following the completion of the well sealing, the well-drilling contractor is required by state specifications to return to the well no sooner than 24 hours following sealing. At this time, he is to fill the

remaining space at the top of the well with concrete and then build a concrete slab six inches high above the top of the casing. The slab should have dimensions at least two feet greater than the diameter of the outer casing.

Table 22 provides an approximate cost estimate to abandon and seal those wells recommended for abandonment

10.0 SUMMARY AND RECOMMENDATIONS

10.1 SUMMARY

- Based on current aquifer piezometric levels, there is a downward hydraulic gradient from the River Sand & Gravel down to the Upper Raritan aquifer, and an upward gradient from the Middle Raritan aquifer to the Upper Raritan. This is due to the significant amount of onsite pumping occurring from the Upper Raritan.

- Essentially steady-state conditions seem to have been attained in the Mt. Laurel-Wenonah aquifer, probably because of leakage from the overlying Vincentown Formation. Nearly steady conditions seem to have also been attained in the Upper Raritan aquifer, judging from the water levels measured in Well OW-I over the past five years.

- Chloride levels in the Mt. Laurel-Wenonah aquifer at the site currently range from 120 to 870 mg/l. In the underlying Upper Raritan aquifer, chlorides appear to range from about 50 mg/l at the southern end of the site to 10 mg/l at the northern end. For the Middle Raritan aquifer, recent data indicate that chloride levels vary from about 190 to 335 mg/l.

- Records of past water-quality data at the site indicate that chloride levels in the Mt. Laurel-Wenonah aquifer, at least beneath the Salem Station portion of the site, have risen since the time of construction of Wells PW-1, PW-2 and PW-3--from about 50 mg/l in the beginning to peaks on the order of 200 to 500 mg/l in the production wells and up to 870 mg/l at Well OW-G. This rise in chlorides is believed to be caused by leakage into the Mt.Laurel-Wenonah aquifer from the overlying Vincentown Formation, which presently contains about 1800 to 4300 mg/l chloride. In the Upper Raritan aquifer, average chloride levels in PW-5 have risen since the time of its construction from about 25 mg/l to the current level of nearly 50 mg/l. No discernible upward trends in chloride are evidenced in the Upper Raritan wells on the north side of the site--in Wells HC-1, HC-2 and OW-I, where chlorides have never exceeded 27 mg/l and are generally below 15 mg/l.

- Mean transmissivity values for the water-bearing units beneath the site were computed to be: 5,000-11,000 gpd/ft for the Vincentown, 4,900-8,700 gpd/ft for the Mt. Laurel-Wenonah, 9,600-27,000 gpd/ft for the Upper Raritan, and 670-4,000 gpd/ft for the Middle Raritan aquifer.

- Ground-water withdrawals from the Mt. Laurel-Wenonah aquifer at the site have been declining from 1978 to 1986. Pumpage from the Upper Raritan aquifer has remained fairly constant, with a slight increase from 1982 to the present.

- Physical inspection and the down-hole TV survey indicated that from a visual point of view most wells appear to be in good condition. Also, past and recent drawdown data indicate that specific capacities of the production wells have remained essentially the same since the time of well construction. A minor decline in specific capacity has apparently occurred at

PW-1 and PW-5, but the data indicate that the current specific capacity is still greater than 90 percent of what it was when each well was initially tested. Because of the relatively small decline in specific capacity, no well redevelopment or well treatment is recommended for PW-1 and PW-5 at this time. However, specific capacities should be monitored regularly so that an annual assessment can be made regarding the advisability of treating production wells of concern.

- Recent water-level, water-quality and pumping-test data indicate that three observation wells (OW-A, OW-C and OW-H) may serve as conduits for cross-contamination. There is a concern that contamination of the Upper Raritan aquifer or the Mt. Laurel-Wenonah aquifer with brackish water from an upper unit(s) may be occurring in this fashion. Water-level data and chloride levels found in Observation Wells OW-A and OW-H indicate that both of these wells probably tap an upper, more brackish, aquifer, in addition to the Upper Raritan aquifer which they were intended to monitor. With respect to Well OW-C, although the measured water levels are consistent with those for other Mt. Laurel-Wenonah wells, the well's chloride levels and the computed transmissivity are out of the range demonstrated for the aquifer at the site.

- Numerical modeling of ground-water flow and chloride transport among seven layers (from the Mt. Laurel-Wenonah aquifer at the top, down to the Middle Raritan aquifer) was performed using the Princeton Transport Code. Predictive simulations showed that by continuing the present level of pumping in all aquifers for 20 years in the future, piezometric levels in the aquifers would not change perceptibly. However, over the 20-year period, small increases in chloride levels would occur in the Upper Raritan aquifer, and the increasing trend in chloride levels in the Mt. Laurel-Wenonah aquifer would continue at a significant level. By increasing pumpage in the Upper Raritan aquifer from the

present level of about 0.7 mgd to about 1.1 mgd which would continue for the next 20 years, the predicted chloride content at Well PW-5 rose from the current level of 46 mg/l to 68 mg/l by the end of the simulated period.

- The leading edge of the salt-water/fresh-water interface in the Middle Raritan aquifer, represented by the 250 mg/l chloride contour appears to be located beneath the site. The comparable interfaces in the Upper Raritan aquifer and the Mt. Laurel-Wenonah aquifer are believed to be situated downdip (southeast) of the site, but data are not available to indicate just how far downdip they are. The relatively high chloride levels in the Mt. Laurel-Wenonah aquifer at the site are believed to derive from leakage from the overlying Vincentown Formation which contains brackish water.

- Eight water-supply alternatives were identified and evaluated with the aim of providing water to replace that currently being withdrawn from the Mt. Laurel-Wenonah aquifer. The assumption was that because of the rising levels of chloride in the Mt. Laurel-Wenonah, this water will soon be unsuitable for use for service-water requirements, and will have to be replaced.

- Of the eight water-supply alternatives, four were concluded to be feasible: construction of two new wells; construction of fresh-water pipelines; municipal water from the City of Salem; and, desalination of Delaware Bay water. Feasibility-level cost estimates were prepared for each feasible alternative.

- The results of the feasibility analysis indicated that the water-supply alternative with the lowest total present-worth cost ($1.6 million) was the alternative involving construction of a Magothy production well and construction of a new Upper Raritan well. The two alternatives with the next higher costs were a pipeline carrying municipal water from the City of Salem

($4.0 million) and a pipeline carrying water from Stow Creek ($4.6 million). The advantages and drawbacks to each of the three lower-cost alternatives are provided in Table 18.

10.2 RECOMMENDATIONS

- o PSE&G should arrange for the surveying of all the production wells and observation wells on site. This will be important in evaluating and comparing piezometric water levels in the several aquifers. Only approximate piezometric contour maps can be prepared in the absence of reliable level and coordinate data for each well. These data would be essential for detailed or specific analyses done in the future.

- o A ground-water monitoring network should be established consisting of all existing production wells and eight of the existing observation wells--OW-D, OW-G, OW-I, OW-6, OW-S1, DW-25, DW-509S and DW-509D. Wells OW-S2, DW-502S and DW-502D may be added to the monitoring network at PSE&G's option. Two new Upper Raritan observation wells, OW-J and OW-K, are recommended to be constructed and incorporated into the monitoring network. An additional Mt. Laurel-Wenonah observation well, OW-L, is also recommended if pumping of the Mt. Laurel-Wenonah aquifer is expected to continue for a year or more in the future. An observation well, OW-M, tapping the Magothy aquifer will also be required if a Magothy production well is constructed.

- o Water levels should be monitored monthly in each well that is a part of the monitoring network, and automatic water-level recorders should be established on one selected observation well in each aquifer being utilized at the site. Wells in the monitoring system should be sampled quarterly and tested for chlorides, specific conductance, total dissolved solids and pH. Recording flow meters should be installed at each active production well.

- Eight observation wells are recommended for abandonment--OW-A, OW-C, OW-H, DW-42, DW-505S, DW-505D, DW-514S and DW-514D. The reasons for the proposed abandonment of each well are a given in Table 20. The wells should be sealed and abandoned by a licensed well-drilling contractor in accordance with procedures specified by the NJDEP, using a bentonite slurry.

- PSE&G should maintain a log of measurements of the specific capacity of each production well (average pumping rate in gpm divided by the drawdown in feet), to be recorded at least once every quarter. The length of time the well has been pumping at the time the measurement is taken should be noted as part of the record. In general, the pumping period after which the measurement is taken should be at least 12 hours. An annual assessment should be made regarding the advisability of treating production wells evidencing a continuing decline in specific capacity.

- In the light of the water-diversion requirements and restrictions imposed by the NJDEP and the Delaware Basin Commission, PSE&G should evaluate the results of the feasibility study presented in Sections 6.0 and 7.0 in conjunction with the possible need to replace Mt. Laurel-Wenonah water in the near future. Consideration should be given to selecting one of the three lower-cost feasible water-supply alternatives identified in Section 7.0.

11.0 QUALIFICATIONS AND CERTIFICATIONS OF PERSONNEL, EQUIPMENT AND COMPUTER CODES

11.1 QUALIFICATIONS OF PARTICIPATING PERSONNEL

The Project Director Mr. James T. Dette, has experience at Artificial Island extending back 20 years and began with the initial site and environmental studies performed by Dames & Moore for the Salem

Nuclear Generating Station in October, 1967. Mr. Dette is a Partner and has directed numerous multidisciplinary projects for the utility industry. He has been responsible for most of the work the firm has done for PSE&G at Artificial Island and for other proposed nuclear stations including Newbold Island and the Atlantic Generating Station. He is a registered Professional Engineer in the State of New Jersey.

Mr. James G. McWhorter, Project Manager for the study, has over 20 years experience participating in or directing geologic and geohydrolic investigations. He was most recently Principal Investigator for Geology and Seismology for the FSAR for Hope Creek Generating Station. Mr. McWhorter is a registered Geologist in Maine, Virginia, North Carolina, South Carolina and Georgia.

Principal Investigator for Hydrogeology and Modeling, Dr. Andrew C. Mills, has more than 25 years experience in hydrologic and geohydrologic analyses, both here and overseas. He has developed several in-house computer codes to evaluate ground water movement and quality. Dr. Mills has served as Principal Investigator, Geohydrology, on several nuclear and coal-fired power plant site characterization studies and was director of an 18 month long study of water development on the Sinai Peninsula (Egypt). Dr. Mills is a registered Professional Engineer in New Jersey and Maryland and a Certified Soil Scientist in the State of Maine.

Field Personnel utilized during the initial phase of this project included Mr. Michael Weinstein and Mr. Philip Barnes. Mr. Weinstein is a graduate geologist with 3 years experience in hydrologic and hazardous waste investigations. Mr. Barnes, also a graduate geologist, has 2 years experience in geologic and hydrogeologic investigations. Both gentlemen are experienced in monitoring well installation, pumping tests and collecting and analyzing hydrogeologic data.

11.2 EQUIPMENT UTILIZED DURING INVESTIGATION

Several pieces of equipment were utilized during the field portion of this investigation. They included:

1. Submersible pumps (for deep wells)

2. Centrifugal pumps (for shallow wells)

3. Hand held battery-powered water mark recorders, and

4. Hand held stop watches .

None of this equipment has been calibrated to any standard. However, since the submersible and centrifugal pumps have a rated discharge depending upon the total head they are pumping against, all that is required to measure their discharge is a container of known volume checked against the time it takes to fill the container. This method was utilized in each case where short term pumping tests were conducted on monitoring wells or production wells.

The battery-powered water level recorders are accurate to one-tenth of an inch and were backed up by steel tape and chalk where necessary.

11.3 COMPUTER CODES UTILIZED IN GROUND WATER MODELING

The Princeton Transport Code (PTC) is the result of contributions by many individuals at Princeton University. A two-dimensional code for ground water flow and contaminant transport was originally developed by G.F. Pinder and W.G. Gray. The extension of the code to three-space dimensions was carried out by D. Krishna Babu who also substituted Gaussian quadrature with analytical integration of basis functions. Auli Niemi revised the code and adapted it to the IBM-PC. New boundary condition capability and internal checking of the computed solution for mass balance were incorporated by David Ahlfeld.

PTC employs a unique splitting algorithm for solving the fully three-dimensional equations which reduces the computational burden significantly. The algorithm involves discretizing the domain into approximately parallel horizontal layers. Within each layer a finite element discretization (Pinder and Gray, 1977) is used allowing for accurate representation of irregular domains. The layers are connected vertically by a finite difference discretization. This hybrid coupling of the finite element and finite difference methods provides the opportunity to apply the splitting procedure. During a given time iteration, all the computations are divided into two steps. In the first step all the horizontal finite element discretizations are solved independently of each other. In the second step, the vertical equations which link the layers are solved.

The splitting scheme used by PTC to solve the governing equation involves approximating the terms of the equations which contain x and y derivatives by the finite element method. Finite elements in the horizontal plane are widely used (see, for example, Pinder and Gray, 1977). The finite element method, also known as Galerkin's method, assumes there exists an infinite sum of functions that will exactly represent the solution to the partial differential equation describing ground water flow.

The finite difference method is used to discretize the derivatives with respect to z and time. The central feature of this computer code is the use of a central differencing scheme for the space derivates in the z-direction in the governing equation. The vertical discretization is accomplished by requiring that the horizontal finite element meshes be replicated in layers with nodes stacked one above the other.

The code incorporates an implicit backward difference approximation for the time derivative to provide the most accurate solution to ground water flow problems at minimum cost. In the backward difference representation, a first order correct scheme is used to approximate the time derivative and the spatial derivatives are written at the new time level.

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TABLE 1

MEASURED GROUND-WATER LEVELS
SITE WELLS AT SALEM/HOPE CREEK STATIONS

WELL	AQUIFER	APPROXIMATE ELEVATION** OF R.P.	DEPTH TO WATER LEVEL ON: 7-21-87	DEPTH TO WATER LEVEL ON: 9-22-87	APPROXIMATE WATER-LEVEL ELEVATION** ON: 7-21-87	APPROXIMATE WATER-LEVEL ELEVATION** ON: 9-22-87
PW-1	MT. LAUREL-WENONAH	16.0	—	18.3	—	-2.3
PW-2	MT. LAUREL-WENONAH	13.6	—	19.0	—	-5.4
PW-3	MT. LAUREL-WENONAH	14.4	—	27.6	—	-13.2
PW-5	UPPER RARITAN	13.8	71.4	76.0	-57.6	-62.2
PW-6	MIDDLE RARITAN	13.0	105.5	(PUMPING)	-92.5	—
HC-1	UPPER RARITAN	10.0	70.8	71.9	-60.8	-61.9
HC-2	UPPER RARITAN	13.0	—	—	—	—
OW-A	UPPER RARITAN	16.2	—	26.8	—	-10.6
OW-C	MT. LAUREL-WENONAH	15.8	—	19.3	—	-3.5
OW-D	MT. LAUREL-WENONAH	12.0	—	19.4	—	-7.4
OW-G	MT. LAUREL-WENONAH	17.0	21.3	23.4	-4.3	-6.4
OW-H	UPPER RARITAN	10.2	7.7	9.2	2.5	1.0
OW-I	UPPER RARITAN	11.0	—	68.3	—	-57.3
OW-6	MIDDLE RARITAN	14.0	—	>100	—	—
OW-S1	VINCENTOWN	14.0	10.9	10.3	3.1	3.7
OW-S2	VINCENTOWN	13.2	—	10.6	—	2.6
DW-25	VINCENTOWN	14.2	12.5	11.4	1.7	2.8
DW-42	RIVER SAND & GRAVEL	14.0	7.4	11.4	6.6	2.6
DW-502S	RIVER SAND & GRAVEL	13.0	7.2	9.9	5.8	3.1
DW-502D	VINCENTOWN	13.3	12.5	10.3	0.8	3.0
DW-505D	VINCENTOWN	13.0	12.9	12.6	0.1	0.4
DW-509S	RIVER SAND & GRAVEL	15.6	8.1	8.9	7.5	6.7
DW-509D	VINCENTOWN	15.0	12.7	12.4	2.3	2.6
DW-514D	VINCENTOWN	13.6	—	11.0	—	2.6

NOTE: R.P. = REFERENCE POINT. DEPTHS TO WATER WERE TAKEN FROM THE REFERENCE POINT, USUALLY TOP OF CASING.
**ELEVATIONS ARE VERY APPROXIMATE. REFERENCE POINTS AT EACH WELL NEED TO BE RESURVEYED.

TABLE 2

SUMMARY OF RESULTS OF WELL-WATER ANALYSIS
SITE WELLS AT SALEM/HOPE CREEK STATIONS

WELL	AQUIFER	SAMPLING DATE	DEPTH TO S.W.L. (ft below R.P.)	CALCIUM	MAGNESIUM	SODIUM	CHLORIDE	CARBONATES (as $CaCO_3$)	BICARBONATES (as $CaCO_3$)	TDS	SPECIFIC CONDUCTANCE (umhos/cm)	pH	TOTAL COLIFORMS (per 100 ml)
				CONCENTRATION OF PARAMETERS (IN MG/L, UNLESS OTHERWISE SPECIFIED)									
PW-1	Mt. Laurel-Wenonah	7-24-87	18	47	27	33	120	0	204	504	850	7.3	0
PW-2	Mt. Laurel-Wenonah	8-12-87	13.5	185	77	65	355	0	370	1060	1200	8	0
PW-3	Mt. Laurel-Wenonah	8-13-87	14.8	83	34	44	138	0	666	460	760	7.8	0
OW-C	Mt. Laurel-Wenonah	9-14-87	18.7	386	77	450	1310	0	194	2980	3700	7.9	0
OW-D	Mt. Laurel-Wenonah	9-15-87	13.2	25	20	93	189	0	84	552	945	7.5	0
OW-G	Mt. Laurel-Wenonah	8-5-87	21.1	176	104	180	870	0	167	1990	2200	7.3	0
		9-14-87	--	241	100	176	700	0	135	1790	2100	7.2	0
PW-5	Upper Raritan	8-4-87	67.9	218	3.3	85	150	0	222	520	700	8	0
HC-1	Upper Raritan	8-10-87	78.2	17	4	80	15	0	222	372	340	7.5	0
HC-2	Upper Raritan	8-11-87	80.5	4.5	0.5	48	15	0	185	280	300	7.4	0
OW-A	Upper Raritan	9-14-87	18.8	25	13	182	203	0	219	676	1340	8.1	0
OW-H	Upper Raritan	7-28-87	7.8	590	66	726	2060	0	237	4670	5000	6.8	0
OW-I	Upper Raritan	9-15-87	68.5	1.1	0.4	75	8.7	18	169	256	220	8.7	0
PW-6	Middle Raritan	8-14-87	61.6	9.5	1.7	210	189	0	259	468	780	7.7	0
OW-S1	Vincentown	7-23-87	11.6	150	162	1080	1860	0	285	4280	5100	7.2	0
OW-S2	Vincentown	7-28-87	11.8	394	266	1720	2930	0	218	6840	6500	7.3	0
DW-25	Vincentown	7-30-87	12.1	114	188	1080	1760	0	969	3220	4250	7	0
DW-502D	Vincentown	7-29-87	12.6	250	186	2300	3280	0	492	6370	6400	7	0
DW-505D	Vincentown	7-31-87	13.4	218	316	2570	4280	0	574	7000	9460	6.7	0
DW-509D	Vincentown	8-3-87	12.8	436	182	952	2700	0	444	5670	5000	7.5	0
DW-514D	Vincentown	8-7-87	11.5	540	171	1180	2050	0	740	3840	4300	6.9	0
DW-42	River Sand & Gravel	8-6-87	7.3	180	57	125	174	0	296	908	1020	6.9	0
DW-502S	River Sand & Gravel	7-29-87	10	75	200	959	953	0	581	2830	3450	6.6	0
DW-509S	River Sand & Gravel	8-3-87	9.3	109	250	89	1380	0	1350	3710	3600	7.5	0

NOTE: WATER SAMPLES WERE ANALYZED BY SOUTH JERSEY TESTING LABORATORY, MILLVILLE, NEW JERSEY.

TABLE 3 (SHEET 1 OF 2)

RESULTS OF FIELD TESTS OF WELL WATER
SITE WELLS AY SALEM/HOPE CREEK STATIONS

WELL	AQUIFER	DATE OF TEST	MINUTES SINCE PUMP STARTED	CHLORIDE (mg/l)	pH	TEMPERATURE (Degrees C)
PW-1	Mt. Laurel-Wenonah	7-24-87	150	182	—	—
			232	273	6.7	16
			350	182	6.8	15
			467	121	6.5	16
		9-22-87	35	137	7.8	16
			110	174	8.2	17
			220	182	8	18
PW-2	Mt. Laurel-Wenonah	8-12-87	120	455	6.8	14
			240	455	7	14.5
			360	425	6.8	15
			480	455	7.1	15
			570	—	6.8	14
PW-3	Mt. Laurel-Wenonah	8-13-87	120	212	7.2	15
			240	167	7.3	15
			360	212	7.2	15
			480	273	7.3	15
			570	243	7.4	15
PW-5	Upper Raritan	8-4-87	35	121	6.7	18
			110	46	6.8	18
			210	46	6.9	18
			360	38	6.9	18
			450	46	7	18
PW-6	Middle Raritan	8-14-87	120	303	7.1	20
			240	273	7.1	22
			360	273	6.8	22
			480	235	7.2	21
			570	334	6.9	21
HC-1	Upper Raritan	8-10-87	120	15	7.4	19
			240	20	7.3	19
			360	15	7.2	19
			480	15	6.9	18
HC-2	Upper Raritan	8-11-87	120	23	7.2	18
			240	23	6.9	19
			360	23	6.7	18
			570	15	7	19
OW-A	Upper Raritan	7-27-87	35	243	7.8	—
			110	243	7.5	—
OW-C	Mt. Laurel-Wenonah	7-27-87	35	910	7.2	—
			110	1001	7	—

TABLE 3 **(SHEET 2 OF 2)**

RESULTS OF FIELD TESTS OF WELL WATER
SITE WELLS AY SALEM/HOPE CREEK STATIONS

WELL	AQUIFER	DATE OF TEST	MINUTES SINCE PUMP STARTED	CHLORIDE (mg/l)	pH	TEMPERATURE (Degrees C)
OW-D	Mt. Laurel-Wenonah	9-15-87	40	455	6.9	22
OW-G	Mt. Laurel-Wenonah	8-5-87	35	941	6.6	15
			110	819	6.6	15
OW-H	Upper Raritan	7-28-87	35	2215	6.4	—
			110	2306	6.4	—
OW-I	Upper Raritan	9-15-87	30	46	8.5	12
			100	15	8	13
OW-S1	Vincentown	7-23-87	15	2336	—	—
			60	2184	—	—
			100	—	6.8	16
OW-S2	Vincentown	7-28-87	35	2943	6.5	—
			110	2700	6.4	—
DW-25	Vincentown	7-30-87	35	—	6.6	—
			110	—	6.5	—
DW-42	River Sand & Gravel	8-6-87	135	—	6.9	30
DW-502S	River Sand & Gravel	7-29-87	70	—	6.4	—
DW-502D	Vincentown	7-29-87	35	3429	6.7	15
			110	3610	6.4	15
DW-505S	River Sand & Gravel	7-31-87	pumped dry	—	—	—
DW-505D	Vincentown	7-31-87	38	—	6.6	—
DW-509S	River Sand & Gravel	8-3-87	1	—	6.4	—
DW-509D	Vincentown	8-3-87	35	3004	6.6	14
			110	2700	6.6	14
DW-514D	Vincentown	8-7-87	21	—	6.2	15

TABLE 4

SUMMARY OF RESULTS OF PUMPING TESTS
SITE WELLS AT SALEM/HOPE CREEK STATIONS

						AVG TEST Q	TRANSMISSIVITY (GPD/FT) BY:			PERMEABILITY(GPD/ SQ FT) BY:			SPEC. CAPACITY
PUMPED WELL	DEPTH (FT)	OBSERVED WELL	AQUIFER	DATE OF TEST	TEST DURATION	(gpm)	JACOB*	THEIS-HANTUSH	COOPER, ET AL	COOPER, ET AL	BOUWER-RICE	STORATIVITY	(gpm/ft)
PW-1	298	PW-1	Mt. Laurel-Wenonah	9-22-87	4.0 hr	35.7	4860	—	—	—	—	—	3.7
		OW-C	Mt. Laurel-Wenonah	7-24-87	6.8 hr	416	8,590**	6820	—	—	—	0.00019	—
PW-2	286	PW-2	Mt. Laurel-Wenonah	8-12-87	9.8 hr	342	7050	—	—	—	—	—	3.8
PW-3	292	PW-3	Mt. Laurel-Wenonah	8-13-87	10.3 hr	207	6660	—	—	—	—	—	3.8
PW-5	840	PW-5	Upper Raritan	8-4-87	7.5 hr	442	20640	—	—	—	—	—	11.2
PW-6	1138	PW-6	Middle Raritan	8-14-87	12.3 hr	487	3840	1780	—	—	—	—	2.1
		OW-6	Middle Raritan	8-14-87	12.3 hr	487	1680	670	—	—	—	0.003	—
HC-1	816	HC-1	Upper Raritan	8-10-87	10.0 hr	750	22240	—	—	—	—	—	15.9
HC-2	816	HC-2	Upper Raritan	8-11-87	9.8 hr	683	24210	—	—	—	—	—	17.2
OW-A	840	OW-A	Upper Raritan	7-27-87	2.0 hr	10.2	9,610 (R)	—	—	—	—	—	1.9
OW-C	285	OW-C	Mt. Laurel-Wenonah	7-27-87	2.0 hr	4	47 (R)	—	—	—	—	—	0.1
OW-D	270	OW-D	Mt. Laurel-Wenonah	9-15-87	10 min	9	51***	—	552	5	34	—	0.2
OW-G	311	OW-G	Mt. Laurel-Wenonah	8-5-87	2.0 hr	21.8	8670	—	—	—	—	—	2.5
OW-H	946	OW-H	Upper Raritan	7-28-87	2.0 hr	3.63	870 (P)	—	—	—	—	—	0.3
OW-I	790	OW-I	Upper Raritan	9-15-87	2.0 hr	20	19,920 (R)	—	—	—	—	—	26.7
OW-S1	94	OW-S1	Vincentown	7-23-87	1.95 hr	21.2	8380	—	—	—	—	—	2.4
OW-S2	90	OW-S2	Vincentown	7-28-87	2.0 hr	26	10480	—	—	—	—	—	3
DW-25	86	DW-25	Vincentown	7-30-87	2.0 hr	26.7	5990	—	—	—	—	—	1.9
DW-42	39	DW-42	River Sand & Gravel	8-6-87	10 min	7.1	440 (R)	—	9	0.9	3.5	—	0.6
DW-502S	43	DW-502S	River Sand & Gravel	7-29-87	15 min	2	31 (R)	—	131	13.1	3.9	—	0.1
DW-502D	80	DW-502D	Vincentown	7-29-87	2.0 hr	24	5230	—	—	—	—	—	1.6
DW-505S	43	DW-505S	River Sand & Gravel	7-31-87	0.5 min	—	—	—	—	—	—	—	no recovery
DW-505D	80	DW-505D	Vincentown	7-31-87	5 min	19.4	1460 (R)	—	1150	19.3	19.4	—	0.3
DW-509S	43	DW-509S	River Sand & Gravel	8-3-87	1.0 min	22	13.2	—	24.1	2.4	1.5	—	0.7
DW-509D	80	DW-509D	Vincentown	8-3-87	2.0 hr	21.6	11430 (R)	—	—	—	—	—	1
DW-514D	80	DW-514D	Vincentown	8-7-87	1.0 min	26.7	90.8 (R)	—	428	7.1	7.7	—	1.3

* (P) - ONLY PUMPING-PERIOD VALUES USED; (R) - ONLY RECOVERY VALUES USED

** VALUE INVALID AS VALUE OF 'u' WAS TOO LARGE

*** VALUE INVALID AS CASING-STORAGE EFFECTS PREDOMINATED DURING TEST

TABLE 5

SUMMARY OF RESULTS OF EARLIER PUMPING TESTS
SITE WELLS AT SALEM/HOPE CREEK STATIONS

PUMPED WELL	DEPTH (FT)	OBSERVED WELL	AQUIFER	DATE OF TEST	TEST DURATION	AVG TEST Q (gpm)	SPEC. CAPACITY (gpm/ft)	TRANSMISSIVITY (GPD/FT) BY: JACOB*	TRANSMISSIVITY (GPD/FT) BY: THEIS-HANTUSH	STORATIVITY	CONFINING BED PERM. (gpd/sq ft)	DIST FROM O.W. TO BARRIER WELL
PW-5	840	PW-5	Upper Raritan	8-26-74	30 hr	800	10.6	17455	—	—	—	—
		OW-A	Upper Raritan	8-26-74	30 hr	800	—	11733 (high u)	—	1.6 E-4	—	—
		OW-I	Upper Raritan	8-26-74	30 hr	800	—	14979 (high u)	—	6.5 E -5	—	—
PW-6	1138	PW-6	Middle Raritan	3-23-81	24 hr	412	1.87	2653	—	—	—	—
		OW-6	Middle Raritan	3-23-81	24 hr	412	—	3021	—	1.2 E-4	—	—
PW-6	1138	PW-6	Middle Raritan	11-9-84	5 hr	403	2.11	4015 (P)	—	—	—	—
		PW-6	Middle Raritan	11-9-84	5 hr	403	—	1716 (R)	—	—	—	—
HC-1	816	HC-1	Upper Raritan	10-26-76	60 hr	805	11.1	20240 (P)	—	—	—	—
		HC-1	Upper Raritan	10-26-76	60 hr	805	—	26565 (R)	—	—	—	—
		HC-2	Upper Raritan	10-26-76	60 hr	805	—	—	11532 (P)	1.55 E-4	0.116	5715 ft
HC-2	817	HC-2	Upper Raritan	4-14-76	66 hr	751	12.5	9657 (P)	—	—	—	—
OW-I	790	OW-I	Upper Raritan	8-20-74	4.0 hr	200	11.1	17600	—	—	—	—

NOTE: O.W. = OBSERVATION WELL
(P) - ONLY PUMPING-PERIOD VALUES USED; (R) - ONLY RECOVERY VALUES USED

TABLE 6

SUMMARY OF TRANSMISSIVITY VALUES AND SPECIFIC CAPACITIES SALEM/HOPE CREEK GENERATING STATIONS

UNIT	TRANSMISSIVITY (GPD/FT)	SPECIFIC CAPACITY (GPM/FT)
VINCENTOWN	5,000 - 11,000	0.3 - 1.9
MT. LAUREL-WENONAH	4,900 - 8700	0.2 - 3.8
UPPER RARITAN	9,600 - 27,000	10.6 - 26.7
MIDDLE RARITAN	670 - 4,000	1.9 - 2.1

TABLE 7

DATA ON SITE WELLS
SALEM AND HOPE CREEK STATIONS

WELL NO.	AQUIFER TAPPED	TOTAL DEPTH (ft)	SCREENED INTERVAL(ft)	DIAMETER (INCHES)	MATERIAL	PUMP CAPACITY	DEPTH TO WATER ON 9-22-87	ACCESS	REFERENCE POINT (RP)	STICKUP OF RP	COMMENTS
PW-1	Mt. Laurel-Wenonah	298	245 - 295 (louvered)	10	Steel	200 gpm	18.26	port in housing	t.o. casing	0.5 ft (approx)	
PW-2	Mt. Laurel-Wenonah	286	—	24 X 16 X 8	Steel	300 gpm	19.01	port in housing	port in housing	—	
PW-3	Mt. Laurel-Wenonah	292	—	24 X 16 X 8	Steel	330 gpm	27.6	port in housing	port in housing	0.62 ft(from floor)	
PW-5	Upper Raritan	840	765 - 840 (UOP S.S.)	26 X 18 X 12	Steel	800 gpm	76.02	port in housing	port in housing	2.29 ft (from floor)	
PW-6	Middle Raritan	1138	1115 - 1135 (S.S.)	36 X 26 X 18	Steel	600 gpm	(pumping)	port in housing	port in housing	1.73 ft (from floor)	
HC-1	Upper Raritan	816	—	24 X 16 X 8	Steel	650 gpm	71.91	slanted access tube	access tube	—	
HC-2	Upper Raritan	817	740 - 811	24 X 16 X 8	Steel	650 gpm	(pumping)	slanted access tube	access tube	—	
OW-A	Upper Raritan	840	823 - 828 (louvered)	6	Steel	10 gpm	26.78	hole in prot. casing side	t.o. casing	1.83 ft	3-in casing grouted in to 187'
OW-B	Mt. Laurel-Wenonah	—	—	—	—	no pump	—	—	—	—	Orange pipe located N. of PW-1?
OW-C	Mt. Laurel-Wenonah	285	260 - 285	4 X 6	PVC/Steel	5 gpm	19.26	hole in prot. casing side	t.o. casing	1.8	Prob. ≈ 30' sediment in bottom
OW-D	Mt. Laurel-Wenonah	270	264 - 270 (S.S.)	4	Steel	9 gpm	19.4 (approx)	hole in prot. casing side	hole in casing	—	Prob. ≈ 5' sediment in bottom
OW-F	Mt. Laurel-Wenonah	260	255-260	4	Stainless	—	—	casing was open	t.o. casing	—	Well not located in present study
OW-G	Mt. Laurel-Wenonah	291	271 - 291 (S.S.)	6	Steel	no pump	23.43	casing is open	t.o. casing	0.40 ft(above pad)	≈ 20' sediment in bottom
OW-H	Upper Raritan	946	943 - 946 (S.S.)	1-5/8	Steel	no pump	9.24	casing is open	t.o. casing	2.05 ft	a lot of silt in bottom
OW-I	Upper Raritan	790	760 - 790 (UOP S.S.)	6	Steel	no pump	68.26	casing is open	t.o. casing	—	
OW-6	Middle Raritan	1132	1112 - 1132	8	Steel	10-15 gpm	(PW-6 pumping)	hole in casing side	t.o. casing	2.21 ft	
OW-S1	Vincentown	94	76-93 (PVC)	4	PVC	no pump	10.3	casing is open	t.o. casing	2.70 ft	
OW-S2	Vincentown	90	60 - 90 (PVC)	4	PVC	no pump	10.55	casing is open	t.o. casing	2.25 ft	has Fischer Recorder
DW-17	Vincentown	82	--	—	—	no pump	—	—	—	—	located somewhere under sod
DW-25	Vincentown	118	15.9 - 118 (PVC)	8	PVC	no pump	11.38	casing is open	t.o. casing	1.33 ft	
DW-25a	—	—	—	1-3/4	PVC	no pump	—	casing is open	t.o. casing	—	
DW-42	River Sand & Gravel	59	0 - 59 (PVC)	8	PVC	no pump	11.35	casing is open	t.o. prot. casing	2.25 ft	Prob. > 15' sediment in bottom
DW-502S	River Sand & Gravel	44	34 - 44	4	PVC	no pump	9.88	casing is open	t.o. prot. casing	2.12 ft	
DW-502D	Vincentown	80	—	4	PVC	no pump	10.29	casing is open	t.o. prot. casing	2.58 ft	
DW-505S	River Sand & Gravel	23.1	—	4	PVC	no pump	9.99	casing is open	t.o. prot. casing	—	No recovery after pumping water out
DW-505D	Vincentown	91	78 - 88	4	PVC	no pump	12.58	casing is open	t.o. prot. casing	4.12 ft	
DW-509S	River Sand & Gravel	43		4	PVC	no pump	8.87	casing is open	t.o. casing	2.33 ft	
DW-509D	Vincentown	82	72 - 82 (louvered)	4	PVC	no pump	12.4	casing is open	t.o. casing	1.08 ft	must cut casing level
DW-514S	River Sand & Gravel	(Top of debr	—	4	PVC	no pump	on top of debris	casing blocked by debris	t.o casing	—	Soft plastic debris @ 3-5 ft below
DW-514D	Vincentown	80	—	4	PVC	no pump	10.96	casing is open	t.o. prot. casing	1.8 ft	

NOTE: t.o. = 'top of'

TABLE 8

(SHEET 1 OF 2)

RESULTS OF INSPECTION OF SITE WELLS
SALEM AND HOPE CREEK STATIONS

WELL	AQUIFER TAPPED	OBSERVATIONS FROM TV SURVEY: CONDITION OF CASING	CONDITION OF SCREEN	OTHER
PW-1	MT. LAUREL-WENONAH	0-245'; APPEARS INTACT EXCEPT FOR POSSIBLE LEAK AT 85' AT JOINT WHERE SILT BUILDUP EXISTS	245-290'; APPEARS INTACT; PROBABLY SILTED UP FROM 290 TO 295'	NO ACCESS EXISTS FOR ACCURATE WATER-LEVEL MEASUREMENTS WITH THE PUMP IN PLACE
PW-2	MT. LAUREL-WENONAH	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	PACKING AT TOP OF PUMP LEAKS
PW-3	MT. LAUREL-WENONAH	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	
PW-5	UPPER RARITAN	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	
PW-6	MIDDLE RARITAN	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	
HC-1	UPPER RARITAN	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	
HC-2	UPPER RARITAN	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	NO DATA—ENTRY OF TV CAMERA PREVENTED BY IN-PLACE PUMP	
OW-A	UPPER RARITAN	NO DATA—WELL DIAMETER (3-IN) TOO SMALL FOR CAMERA ACCESS	NO DATA—WELL DIAMETER (3-IN) TOO SMALL FOR CAMERA ACCESS	
OW-B	MT. LAUREL-WENONAH	WELL NOT LOCATED	WELL NOT LOCATED	WELL NOT LOCATED
OW-C	MT. LAUREL-WENONAH	0-245; APPEARS INTACT	NOT IDENTIFIED	DARK GREENISH-BROWN MEDIUM SAND IN SCREEN FROM 245-285'; SAND REMOVED FROM 245-255' DURING SUBSEQUENT PUMPING
OW-D	MT. LAUREL-WENONAH	0-265'; APPEARS INTACT, BUT MAY BE BENT OR OFFSET AT THE JOINTS	NOT IDENTIFIED	THE HIGH-VOLTAGE ELECTRIC LINES SHORT OUT THE WATER-LEVEL INDICATORS
OW-G	MT. LAUREL-WENONAH	0-273'; APPEARS INTACT	273-291'; APPEARS INTACT, BUT PROBABLY SILTED UP FROM 291-311'	
OW-H	UPPER RARITAN	NO DATA—WELL DIAMETER (1.62-IN) TOO SMALL FOR CAMERA ACCESS	NO DATA—WELL DIAMETER (1.62-IN) TOO SMALL FOR CAMERA ACCESS	

TABLE 8 (SHEET 2 OF 2)

RESULTS OF INSPECTION OF SITE WELLS
SALEM AND HOPE CREEK STATIONS

OBSERVATIONS FROM TV SURVEY:

WELL	AQUIFER TAPPED	CONDITION OF CASING	CONDITION OF SCREEN	OTHER
OW-1	UPPER RARITAN	0-760'; APPEARS INTACT	760-790'; APPEARS INTACT	
OW-6	MIDDLE RARITAN	0-1114'; APPEARS INTACT	1114-1132'; APPEARS INTACT	
OW-S1	VINCENTOWN	0-76'; APPEARS INTACT	76-93'; APPEARS INTACT	
OW-S2	VINCENTOWN	0-60'; APPEARS INTACT	60-75'; APPEARS INTACT, BUT CAMERA CAUGHT ON AN OBSTRUCTION	
DW-17	VINCENTOWN	WELL NOT LOCATED--UNDER SOD	WELL NOT LOCATED--UNDER SOD	WELL NOT LOCATED--UNDER SOD
DW-25	VINCENTOWN	0-80'; APPEARS INTACT	NOT IDENTIFIED	
DW-25a	?	NO DATA--WELL DIAMETER (1.75-IN) TOO SMALL FOR CAMERA ACCESS	NO DATA--WELL DIAMETER (1.75-IN) TOO SMALL FOR CAMERA ACCESS	
DW-42	RIVER SAND & GRAVEL	0-25'; APPEARS INTACT	NOT IDENTIFIED	PLUMBED DEPTH IS 31' BELOW TOP OF STEEL PROTECTIVE CASING
DW-502S	RIVER SAND & GRAVEL	0-34'; APPEARS INTACT	34-44'; APPEARS INTACT	
DW-502D	VINCENTOWN	0-35'; APPEARS INTACT; CAMERA CAUGHT ON JOINT AT 35'	NOT IDENTIFIED	
DW-505S	RIVER SAND & GRAVEL	NOT TESTED	NOT TESTED	GIVES NO FLOW; PROBABLY NOT A WELL
DW-505D	VINCENTOWN	0-78'; APPEARS INTACT	78-88'; APPEARS INTACT	TOTAL DEPTH IS 91', INCLUDING 3 FT BELOW SCREEN
DW-509S	RIVER SAND & GRAVEL	0-29'; APPEARS INTACT, POOR VISIBILITY	29-41'; APPEARS INTACT, POOR VISIBILITY	PLUMBED DEPTH IS 43' BELOW TOP OF CASING
DW-509D	VINCENTOWN	0-71; APPEARS INTACT	71-81'; APPEARS INTACT	PLUMBED DEPTH IS 83' BELOW TOP OF CASING
DW-514S	RIVER SAND & GRAVEL	NOT TESTED	NOT TESTED	WELL CLOGGED WITH DEBRIS
DW-514D	VINCENTOWN	0-30'; APPEARS INTACT	NOT IDENTIFIED	OBSTRUCTION AT 30'; PLUMBED DEPTH IS 85' BELOW TOP OF CASING

NOTE: DEPTHS GIVEN UNDER THE TV SURVEY RESULTS ARE FROM THE GROUND SURFACE AND ARE ONLY APPROXIMATE.

TABLE 9

COMPARISON OF PRESENT AND PAST SPECIFIC CAPACITIES AND CHLORIDE LEVELS SITE PRODUCTION WELLS AT SALEM/HOPE CREEK STATIONS

PRODUCTION WELL	DEPTH (FT)	AQUIFER TAPPED	DATE	SPECIFIC CAPACITY (gpm/ft)	CHLORIDE (mg/l)
PW-1	298	Mt. Laurel-Wenonah	10-4-68	3.2 (24 hr)	32
			7-24-87	N.A. (7 hr)	120
			9-22-87	3.7 (4 hr)	182
PW-2	286	Mt. Laurel-Wenonah	8-4-70	≈ 5.0 (0.5 hr)	50
			8-12-87	3.8 (9.8 hr)	355
PW-3	292	Mt. Laurel-Wenonah	7-30-70	≈ 5.0 (0.5 hr)	40
			8-13-87	3.8 (10.3 hr)	138
PW-5	840	Upper Raritan	8-26-74	10.6 (24 hr)	—
			8-26-74	11.6 (9 hr)	18
			8-4-87	11.2 (7.5 hr)	46
PW-6	1138	Middle Raritan	3-23-81	1.9 (12 hr)	227
			11-9-84	2.1 (5 hr)	250
			8-14-87	2.1 (12.3 hr)	189
HC-1	816	Upper Raritan	10-26-76	14.4 (10 hr)	—
			10-27-76	12.8 (24 hr)	—
			10-28-76	11.5 (48 hr)	—
			10-29-76	11.1 (60 hr)	—
			8-10-87	15.9 (10 hr)	15
HC-2	817	Upper Raritan	4-14-76	16.7 (12 hr)	—
			4-14-76	13.65 (24)	—
			4-14-76	12.5 (48 hr)	—
			5-3-76	14.6 (9 hr)	—
			8-11-87	17.2 (9.8 hr)	15

TABLE 10

COMPARISON OF AQUIFER CHARACTERISTICS AT POTENTIALLY DAMAGED WELLS

ITEM	WELL OW-A	WELL OW-H	WELL OW-C
AQUIFER TAPPED	UPPER RARITAN	UPPER RARITAN	MT. LAUREL-WENONAH
WATER-LEVEL ELEVATION (FT):			
(A) AT WELL	-11	1	-3
(B) AT OTHER WELLS IN AQUIFER	-57 to -62	-57 to -62	-2 to -7
CHLORIDE CONTENT (MG/L):			
(A) AT WELL	203	2,060	1,310
(B) AT OTHER WELLS IN AQUIFER	9 - 46	9 - 46	120 - 870
AQUIFER TRANSMISSIVITY (GPD/FT):			
(A) AT WELL	9,610	870	47
(B) AT OTHER WELLS IN AQUIFER	9,600 to 27,000	9,600 to 27,000	4,900 to 8700

NOTE: WATER-LEVEL ELEVATIONS AND CHLORIDE CONTENTS REFER TO 1987 VALUES.

TABLE 11

SURVEYING DATA AVAILABLE FOR SALEM/HOPE CREEK WELLS

WELL NO.	AQUIFER TAPPED	TOTAL DEPTH (ft)	SCREENED INTERVAL (FT)	LATITUDE	LONGITUDE	N-S LOCAL CORRDINATES	E-W LOCAL CORRDINATES	ELEV. OF RP (PSE&G DATUM)	ELEV. OF GD (PSE&G DATUM)	ELEV. OF GD (MSL DATUM)	ELEV. OF SLAB (PSE&G DATUM)
PW-1	Mt. Laurel-Wenonah	298	245 - 295 (louvered)		75° 32' 00"	N 01 + 80	E 11 + 50			17	
PW-2	Mt. Laurel-Wenonah	286	—	39° 27' 44" (or 54")	75° 32' 05"	N 03 + 20	E 01 + 00			20	102.58
PW-3	Mt. Laurel-Wenonah	292	—	39° 27' 40" (or 45")	75° 32' 02"	S 07 + 10	E 06 + 85			20	102.75
PW-5	Upper Raritan	840	765 - 840 (UOP S.S.)	39° 27' 43"	75° 31' 48"			102.83			
PW-6	Middle Raritan	1138	1115 - 1135 (S.S.)	39° 27' 54"	75° 31' 57"	N 02 + 10	W 01 + 60				
HC-1	Upper Raritan	816	—	39° 28' 11"	75° 32' 28"						
HC-2	Upper Raritan	817	740 - 811	39° 28' 11"	75° 32' 10"						
OW-A	Upper Raritan	840	823 - 828 (louvered)			N 06 + 20	E 11 + 30		103.37	14.37	
OW-B	Mt. Laurel-Wenonah	—	—			N 03 + 18.9	E 12 + 02.7				
OW-C	Mt. Laurel-Wenonah	285	260 - 285			N 05 + 10	E 06 + 00.9		103	11	
OW-D	Mt. Laurel-Wenonah	270	264 - 270 (S.S.)			N 11 + 00	E 05 + 35		98.75		
OW-G	Mt. Laurel-Wenonah	291	271 - 291 (S.S.)								
OW-H	Upper Raritan	946	943 - 946 (S.S.)						97.19	8.19	
OW-I	Upper Raritan	790	760 - 790 (UOP S.S.)						97.87		
OW-6	Middle Raritan	1132	1112 - 1132			N 02 + 10	W 01 + 30				
OW-S1	Vincentown	94	76-93 (PVC)			S 06 + 32	W 01 + 20	102.97			
OW-S2	Vincentown	90	60 - 90 (PVC)			N 00 + 07	W 02 + 29		≈ 100.0		
DW-17	Vincentown	82	—								
DW-25	Vincentown	118	15.9 - 118 (PVC)			N 06 + 11	W 08 + 14.35	103.2	102		
DW-25a	River Sand & Gravel	—	—								
DW-42	River Sand & Gravel	59	0 - 59 (PVC)			N 08 + 78.84	W 03 + 80.76		36		
DW-502S	River Sand & Gravel	44	34 - 44			N 13 + 33.2	W 12 + 31 (or 24.9)	102			
DW-502D	Vincentown	80	—			N 13 + 32.4	W 12 + 39 (or 31.9)	102.26			
DW-505D	Vincentown	91	78 - 88			N 26 + 62 (or 57)	W 11+95 (or 12+05)				
DW-509S	River Sand & Gravel	43	—			N 19 + 89	W 05 + 29	104.64			
DW-509D	Vincentown	82	72 - 82 (louvered)			N 19 + 89	W 05 + 40				
DW-514D	Vincentown	80	—			N 16 + 98.75	W 05 + 74.2	102.58			

NOTE: BLANKS OR DASHES INDICATE THAT REQUIRED DATA WERE NOT AVAILABLE.

TABLE 12

PUMPAGE SIMULATED DURING MODEL CALIBRATION (MGD)

WELL	AQUIFER TAPPED	PERIOD 1 (MAR 1973 - JAN 1976)	PERIOD 2 (JAN 1976 - JUNE 1984)	PERIOD 3 (JUNE 1984 - SEPT 1987)
PW-1	MT. LAUREL-WENONAH	0.104	0.138	0
PW-2	MT. LAUREL-WENONAH	0.054	0.093	0.043
PW-3	MT. LAUREL-WENONAH	0.060	0.127	0.108
PW-5	UPPER RARITAN	0	0.398	0.209
HC-1	UPPER RARITAN	0	0.025	0.214
HC-2	UPPER RARITAN	0	0.098	0.286
PW-6	MIDDLE RARITAN	0	0	0.200
	TOTALS	0.218	0.879	1.060

TABLE 13

COMPARISON OF OBSERVED AND COMPUTED HEADS AND CHLORIDE CONCENTRATIONS IN MID-1987
FINAL CALIBRATION RUN

WELL	AQUIFER	MODEL LAYER	ASSUMED INITIAL HEAD (FT, MSL DATUM)	OBSERVED HEAD (FT, MSL DATUM)	COMPUTED HEAD (FT, MSL DATUM)	ASSUMED INITIAL CHLORIDE CONC. (MG/L)	OBSERVED CHLORIDE CONCENTRATION (MG/L)	COMPUTED CHLORIDE CONCENTRATION (MG/L)
PW-6	MIDDLE RARITAN	1	-11.0	-48*	-69.1	290.0	189 - 334	294.9
PW-5	UPPER RARITAN	3	-5.0	-54 to -62*	-76.4	25.0	40 - 46	43.5
HC-1	UPPER RARITAN	3	-6.0	-62 to -68*	-77.1	10.0	4 - 15	10.4
HC-2	UPPER RARITAN	3	-6.0	-68*	-84.6	10.0	4 - 15	11.0
OW-I	UPPER RARITAN	3	-6.0	-57 to -58	-55 to -61**	10.0	9.0	10.3
PW-1	MT. LAUREL-WENONAH	7	2.0	-2.0*	-5.1	35.0	120.0	146.5
PW-2	MT. LAUREL-WENONAH	7	2.0	0 to -5.0*	-7.1	35.0	355.0	390.7
PW-3	MT. LAUREL-WENONAH	7	2.0	0 to -13*	-14.1	40.0	138.0	209.1
OW-D	MT. LAUREL-WENONAH	7	2.0	-1.0 to -7.0	-1.4	35.0	189.0	240.3
OW-G	MT. LAUREL-WENONAH	7	2.0	-4.0 to -6.0	-4.7	45.0	700.0	441.3

* WATER LEVELS TAKEN IN PUMPING WELLS ARE CONSIDERED TO LIE BETWEEN ACTUAL PUMPING LEVELS AND STATIC LEVELS.
** WELL OW-I WAS LOCATED IN THE MIDDLE OF A MODEL ELEMENT, EQUIDISTANT FROM FOUR NODES.

TABLE 14

CALIBRATED MODEL PARAMETERS

PARAMETER	LAYER 1 (MIDDLE RARITAN SAND)	LAYER 2 (MIDDLE RARITAN CLAY)	LAYER 3 (UPPER RARITAN SAND)	LAYER 4 (UPPER RARITAN CLAY)	LAYER 5 (MAGOTHY AQUIFER)	LAYER 6 (MATAWAN AQUITARD)	LAYER 7 (MT. LAUREL-WENONAH SAND)
LAYER THICKNESS (ft)	45 - 80 (south)	110 - 480 (south)	70 - 150 (south)	60 - 290 (south)	33 - 70 (north)	125 - 167 (south)	90 - 128
HOR. PERM. (ft/day)	7 - 15 (north)	6.0E-04	9 - 18 (north)	1.4E-05	10	1.2E-04	5
VERT. PERM. (ft/day)	0.2 - 0.4	3.0E-05	0.25 - 0.5	7.0E-07	0.25	6.0E-06	0.15
STORATIVITY	2.0E-04	1.0E-03	9.0E-05	1.0E-03	9.0E-05	1.0E-03	1.0E-04
POROSITY	0.30	0.35	0.25	0.35	0.30	0.35	0.30
LONG. DISPERSIVITY(ft)	30	30	30	30	30	30	30
TRANS. DISPERSIVITY(ft)	6	6	6	6	6	6	6
LEAKAGE FROM VINCENTOWN :							
HEAD (ft, msl datum)	—	—	—	—	—	—	+2 to +5 (north)
LEAKANCE (1/day)	—	—	—	—	—	—	2.0E-5 to 2.0E-4 (north)
CHLORIDE CONC.(mg/l)	—	—	—	—	—	—	2500
BOUNDARY CONDITIONS:							
SOUTH							
TYPE	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE
HLEAK (ft,msl datum)	-3	—	0	—	0	—	-3
LEAKANCE (1/day)	2.5E-05	—	1.0E-05	—	3.0E-05	—	3.0E-05
CHLORIDE (mg/l)	1000	—	60 - 350 (SE corner)	—	300	—	200
NORTH							
TYPE	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE
HLEAK (ft,msl datum)	-40	—	-20	—	0	—	5
LEAKANCE (1/day)	1.0E-04	—	2.4E-05	—	5.0E-05	—	3.0E-05
CHLORIDE (mg/l)	30	—	10	—	20	—	100
WEST							
TYPE	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE
HLEAK (ft,msl datum)	-10	—	-4	—	-2	—	2
LEAKANCE (1/day)	6.0E-05	—	1.3E-05	—	3.0E-05	—	3.0E-05
CHLORIDE (mg/l)	70 - 560 (south)	—	10 - 40 (south)	—	20 - 220 (south)	—	35 - 90 (south)
EAST							
TYPE	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE	NO FLOW	LATERAL LEAKAGE
HLEAK (ft,msl datum)	-10	—	-6	—	-2	—	2
LEAKANCE (1/day)	6.0E-05	—	1.3E-05	—	3.0E-05	—	3.0E-05
CHLORIDE (mg/l)	70 - 560 (south)	—	10 - 280 (south)	—	20 - 220 (south)	—	35 - 90 (south)
INITIAL CONDITIONS:							
HEADS (ft, msl datum)	-5 to -18 (north)	-4 to -14 (north)	-3 to -10 (north)	-2 to -7 (north)	-1 to -4 (north)	0 to -1 (north)	1 to 3 (north)
CHLORIDE CONC. (mg/l)	50 - 600 (south)	30 - 465 (south)	10 - 300 (SE corner)	15 - 290 (south)	20 - 250 (south)	28 - 175 (south)	35 - 100 (south)

TABLE 15

PUMPAGE DURING EACH PREDICTIVE SIMULATION
(IN MGD)

WELL	AQUIFER TAPPED	RUN 1	RUN 2	RUN 3	RUN 4
PW-1	MT. LAUREL-WENONAH	0	0	0	0
PW-2	MT. LAUREL-WENONAH	0.043	0	0	0
PW-3	MT. LAUREL-WENONAH	0.108	0.072	0	0
PW-5	UPPER RARITAN	0.209	0.288	0.288	0.288
HC-1	UPPER RARITAN	0.214	0.214	0.286	0.386
HC-2	UPPER RARITAN	0.286	0.286	0.286	0.386
PW-6	MIDDLE RARITAN	0.200	0.200	0	0
'PW-7'	MAGOTHY	0	0	0.200	0.200
	TOTALS	1.06	1.06	1.06	1.26

NOTE: WELL 'PW-7' IS A HYPOTHETICAL WELL SCREENED IN THE MAGOTHY AQUIFER.

TABLE 16 (SHEET 1 OF 4)

RESULTS OF PREDICTIVE SIMULATIONS
(A) MIDDLE RARITAN AQUIFER

LOCATION	ITEM	UNITS	INITIAL VALUE IN 1987	VALUE IN YEAR 2007 ACCORDING TO: RUN 1	RUN2	RUN3	RUN4
PW-6	PUMPAGE	MGD	--	0.200	0.200	0	0
	HEAD	FT, MSL DATUM	-69.1	-69.3	-69.4	-17.8	-18.0
	CHLORIDE	MG/L	294.9	303.7	303.7	302.1	302.1
SOUTHERN END OF DOMAIN	HEAD	FT, MSL DATUM	-8	-8	-8 to -9	-6 to -7	-6 to -7
	CHLORIDE	MG/L	608	624	623 - 625	619	619
NORTHERN END OF DOMAIN	HEAD	FT, MSL DATUM	-37	-35 to -37	-35 to -37	-34 to -36	-34 to -36
	CHLORIDE	MG/L	49	47	45 - 48	45 - 48	45 - 48

TABLE 16 (SHEET 2 OF 4)

RESULTS OF PREDICTIVE SIMULATIONS
(B) UPPER RARITAN AQUIFER

LOCATION	ITEM	UNITS	INITIAL VALUE IN 1987	VALUE IN YEAR 2007 ACCORDING TO: RUN 1	RUN2	RUN3	RUN4
PW-5	PUMPAGE	MGD	—	0.209	0.288	0.288	0.288
	HEAD	FT, MSL DATUM	-76.4	-76.6	-88.8	-93.1	-106.8
	CHLORIDE	MG/L	43.5	62.5	58.6	60.6	68.0
HC-1	PUMPAGE	MGD	—	0.214	0.214	0.286	0.386
	HEAD	FT, MSL DATUM	-77.1	-77.1	-82.1	-92.5	-114.9
	CHLORIDE	MG/L	10.4	11.8	11.3	12.1	12.9
HC-2	PUMPAGE	MGD	—	0.286	0.286	0.286	0.386
	HEAD	FT, MSL DATUM	-84.7	-84.7	-90.5	-95.7	-118.3
	CHLORIDE	MG/L	11.0	14.5	13.5	14.1	15.7
OW-I	HEAD	FT, MSL DATUM	-60.2	-60.3	-64.9	-70.6	-85.9
	CHLORIDE	MG/L	10.3	10.6	10.6	10.6	10.6
SOUTHERN END OF DOMAIN	HEAD	FT, MSL DATUM	-23	-22 to -25	-25 to -27	-26 to -29	-31 to -34
	CHLORIDE	MG/L	40 - 300	42 - 304	43 - 304	43 - 304	43 - 305
NORTHERN END OF DOMAIN	HEAD	FT, MSL DATUM	-31	-29 to -32	-31 to -33	-33 to -35	-37 to -40
	CHLORIDE	MG/L	10	10	10	10	10

TABLE 16 (SHEET 3 OF 4)

RESULTS OF PREDICTIVE SIMULATIONS
(C) MAGOTHY AQUIFER

LOCATION	ITEM	UNITS	INITIAL VALUE IN 1987	VALUE IN YEAR 2007 ACCORDING TO: RUN 1	RUN2	RUN3	RUN4
'PW-7'	PUMPAGE	MGD	—	0	0	0.200	0.200
	HEAD	FT, MSL DATUM	-1.0	-1.0	-1.0	-69.6	-69.6
	CHLORIDE	MG/L	93.7	93.7	93.7	90.2	90.2
SOUTHERN END OF DOMAIN	HEAD	FT, MSL DATUM	-0.5	-0.5	-0.5	-2 to -3	-2 to -3
	CHLORIDE	MG/L	250	250.0	250.0	251.5	251.5
NORTHERN END OF DOMAIN	HEAD	FT, MSL DATUM	-0.3	-0.3 to -0.5	-0.3 to -0.5	-1.5 to -2.5	-1.5 to -2.5
	CHLORIDE	MG/L	20	20	20	20	20

NOTE: WELL 'PW-7' IS A HYPOTHETICAL MAGOTHY WELL.

TABLE 16 (SHEET 4 OF 4)

RESULTS OF PREDICTIVE SIMULATIONS
(D) MT. LAUREL-WENONAH AQUIFER

LOCATION	ITEM	UNITS	INITIAL VALUE IN 1987	VALUE IN YEAR 2007 ACCORDING TO: RUN 1	RUN2	RUN3	RUN4
PW-1	HEAD	FT, MSL DATUM	-5.1	-5.1	-1.0	3.5	3.5
	CHLORIDE	MG/L	146.5	176.7	171.2	152.0	152.0
PW-2	PUMPAGE	MGD	—	0.043	0	0	0
	HEAD	FT, MSL DATUM	-7.1	-7.1	0.5	3.6	3.6
	CHLORIDE	MG/L	390.7	658.9	533.9	404.9	404.9
PW-3	PUMPAGE	MGD	—	0.108	0.072	0	0
	HEAD	FT, MSL DATUM	-14.1	-14.1	-7.0	3.4	3.4
	CHLORIDE	MG/L	209.1	318.4	285.0	202.3	202.3
OW-D	HEAD	FT, MSL DATUM	-1.4	-1.4	1.4	3.7	3.7
	CHLORIDE	MG/L	240.3	406.0	337.5	253.3	253.3
SOUTHERN END OF DOMAIN	HEAD	FT, MSL DATUM	-1	-0.6	-0.5	-0.5	-0.5
	CHLORIDE	MG/L	98	95	95	95	95
NORTHERN END OF DOMAIN	HEAD	FT, MSL DATUM	5	4.8 to 5.0	4.8 to 5.0	4.8 to 5.0	4.8 to 5.0
	CHLORIDE	MG/L	35	35	35	35	35

TABLE 17

SUMMARY OF COSTS OF FEASIBLE WATER-SUPPLY ALTERNATIVES

ALTERNATIVE	DESCRIPTION	INITIAL CAPITAL COST	ANNUAL O & M COST	O & M PRESENT WORTH COST*	TOTAL PRESENT WORTH COST
1	CONSTRUCTION OF MAGOTHY WELL AND ONE NEW UPPER RARITAN WELL	1,100,000	55,000	540,000	1,640,000
4A	STOW CREEK WATER	3,406,000	124,000	1,217,000	4,623,000
4B	COHANSEY RIVER WATER	4,787,000	134,000	1,316,000	6,103,000
6	CITY OF SALEM WATER	2,089,000	194,000	1,905,000	3,994,000
7	DESALINATION OF WATER FROM DELAWARE BAY	1,700,000	561,000	5,508,000	7,208,000

* PRESENT-WORTH PARAMETERS USED WERE AN ANNUAL INTEREST RATE OF 8 PERCENT AND AN EXPECTED LIFE OF 20 YEARS.

TABLE 18

ADVANTAGES AND DRAWBACKS OF LOW-COST FEASIBLE ALTERNATIVES

ALTERNATIVE	DESCRIPTION	ADVANTAGES	DRAWBACKS
1	CONSTRUCTION OF TWO NEW PRODUCTION WELLS	* LOWEST COST * FACILITY UNDER PSE&G'S CONTROL	* CAPACITY OF MAGOTHY FM. UNTESTED * REQUIRES NJDEP DIVERSION ALLOCATIONS
4A	FRESH-WATER PIPELINE FROM STOW CREEK	* RURAL PIPELINE ROUTE * SYSTEM WOULD BE 92% GRAVITY * WATER TREATMENT PROCESS UNDER PSE&G'S CONTROL	* WATER TREATMENT PROCESS REQUIRES MAINTENANCE AND ATTENTION BY PSE&G * LANDOWNER MAY NOT PROVIDE EASEMENT * REQUIRES NJDEP DIVERSION ALLOCATION * RELATIVELY HIGH COST
6	PURCHASE OF CITY OF SALEM WATER	* CITY WILLING TO SELL 0.9 MGD * TREATMENT PLANT MAINTENANCE NOT PSE&G'S CONCERN * NO WATER ALLOCATION PERMIT REQD	* CITY MAY ALLOCATE AVAILABLE WATER ELSEWHERE BEFORE PSE&G DECIDES * CITY MAY RAISE COST OF WATER IF A LONG-TERM CONTRACT NOT EXECUTED * RELATIVELY HIGH COST

TABLE 19A

OBSERVATION WELLS RECOMMMENDED TO MAINTAIN AS PART OF MONITORING-WELL NETWORK

Well No	Aquifer Tapped
OW-D	Mt. Laurel-Wenonah
OW-G	Mt. Laurel-Wenonah
OW-I	Upper Raritan
OW-6	Middle Raritan
OW-S1	Vincentown
DW-25	Vincentown
DW-509S	River Sand & Gravel
DW-509D	Vincentown

TABLE 19B

OBSERVATION WELLS THAT MAY BE MAINTAINED AS PART OF MONITORING-WELL NETWORK

OW-S2	Vincentown
DW-502S	River Sand & Gravel
DW-502D	Vincentown

TABLE 20 (Sheet 1 of 2)

OBSERVATION WELLS RECOMMENDED FOR ABANDONMENT

Well No	Aquifer Tapped	Reason for Abandonment
OW-A	Upper Raritan	Transmissivity is too low for Upper Raritan; Chloride content is closer to the Mt. Laurel-Wenonah than to the Upper Raritan; The static water level is much closer to that for the Mt. Laurel-Wenonah aquifer than to the Upper Raritan aquifer. May act as a conduit for cross-contamination of the Upper Raritan aquifer.
OW-C	Mt. Laurel-Wenonah	Transmissivity is far too low for the Mt. Laurel-Wenonah, and the chloride content seems too high. Well is pumping sand, as evidenced by the glauconitic sand that was pumped out at the time of the September sampling. May act as a conduit for cross-contamination of the Mt. Laurel-Wenonah aquifer.
OW-H	Upper Raritan	Transmissivity is far too low for the Upper Raritan; and, more importantly, the static water level is too high for the Upper Raritan; Chloride content is closer to that for the Vincentown than for the Upper Raritan. May act as a conduit for cross-contamination of the Upper Raritan aquifer.
DW-17	Vincentown	Unlocated; Belived to be underneath the sod southeast of the Hope Cceek Turbine building
DW-25A	River Sand & Gravel	Small-diameter observation well
DW-42	River Sand & Gravel	Well pumps dry in only 10 minutes; Will serve little purpose as an observation well.

TABLE 28 (Sheet 2 of 2)

DW-505S	River Sand & Gravel	Water level did not recover after pumping
DW-505D	Vincentown	Pumps dry in 5 minutes; Transmissivity is too low for the Vincentown.
DW-514S	River Sand & Gravel	Well is completely plugged up
DW-514D	Vincentown	Well pumps dry in one minute at 27 gpm; transmissvity is very low for the Vincentown.

TABLE 21

APPROXIMATE COSTS
MONITORING WELL CONSTRUCTION

WELL	AQUIFER TAPPED	APPROX. DEPTH (FT)	MOB/DEMOB COST	4-INCH PVC CASING	4-INCH PVC 0.020" SCREEN	DRILLING COST	SUPERVISION COST	APPROX. TOTAL COST
OW-J	UPPER RARITAN	800	$1500	$9560	$800	$22800	$5000	$39660
OW-K	UPPER RARITAN	800	$1500	$9560	$800	$22800	$5000	$39660
OW-L	MT. LAUREL-WENONAH	275	$1500	$2940	$800	$7050	$2750	$15040
OW-M	MAGOTHY	475	$1500	$5440	$800	$13050	$3400	$24190

TABLE 22

APPROXIMATE COSTS FOR ABANDONING AND SEALING WELLS

WELL NO.	DRILLING/LABOR COSTS	MATERIAL COSTS	CONCRETE PAD	TOTAL COST
OW-A	$11500	$1600	$250	$13350
OW-C	$2500	$200	$250	$2950
OW-H	$1750	$150	$250	$2150
DW-17		(NOT LOCATED)		
DW-25A	$950	$50	$250	$1250
DW-42	$3000	$260	$250	$3510
DW-505S	$1000	$100	$250	$1350
DW-505D	$1000	$100	$250	$1350
DW-514S	$1000	$100	$250	$1350
DW-514D	$1000	$100	$250	$1350
TOTALS	$23700	$2660	$2250	$28610

Land Surface	Thickness (ft):
HYDRAULIC FILL	30 - 40
RIVERBED SAND & GRAVEL	5 - 10
KIRKWOOD FORMATION	30 - 40
VINCENTOWN FORMATION	65 -70
HORNERSTOWN-NAVESINK AQUITARD	30 - 40
MT. LAUREL-WENONAH AQUIFER	100 - 125
MATAWAN AQUITARD	140 - 150
MAGOTHY AQUIFER	20 - 45
UPPER RARITAN CLAY	250 - 320
UPPER RARITAN AQUIFER	70 - 100
MIDDLE RARITAN CLAY	260 - 270
MIDDLE RARITAN AQUIFER	45 - 55

HYDROGEOLOGIC COLUMN
ARTIFICIAL ISLAND
SALEM COUNTY, NJ

Dames & Moore FIGURE 2

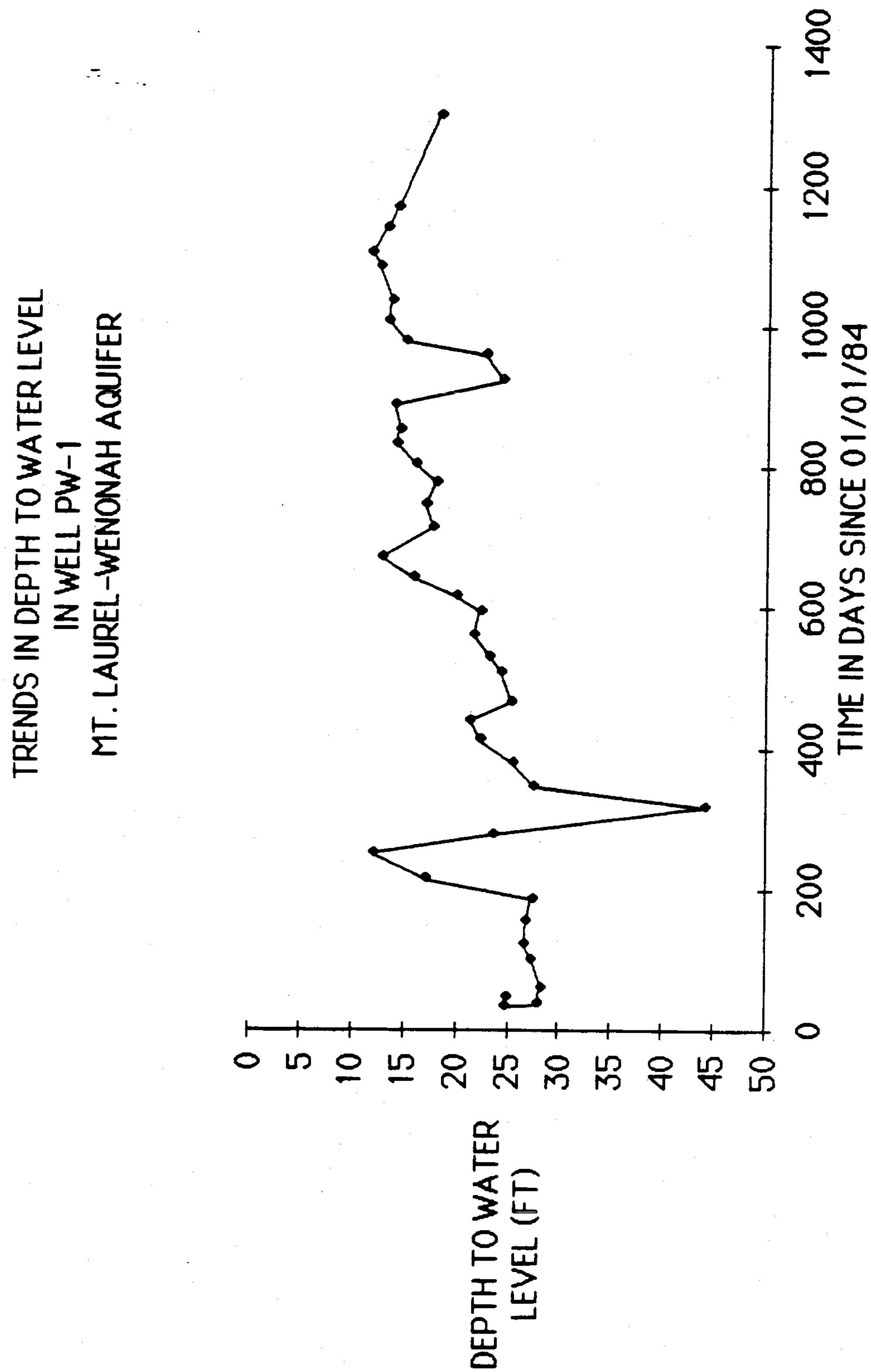

TRENDS IN DEPTH TO WATER LEVEL
IN WELL PW-1
MT. LAUREL-WENONAH AQUIFER
DEPTH TO WATER LEVEL (FT)
0
5
10
15
20
25
30
35
40
45
50
0
200
400
600
800
1000
1200
1400
TIME IN DAYS SINCE 01/01/84

FIGURE 3

TRENDS IN DEPTH TO WATER LEVEL
IN WELL PW-2
MT. LAUREL-WENONAH AQUIFER

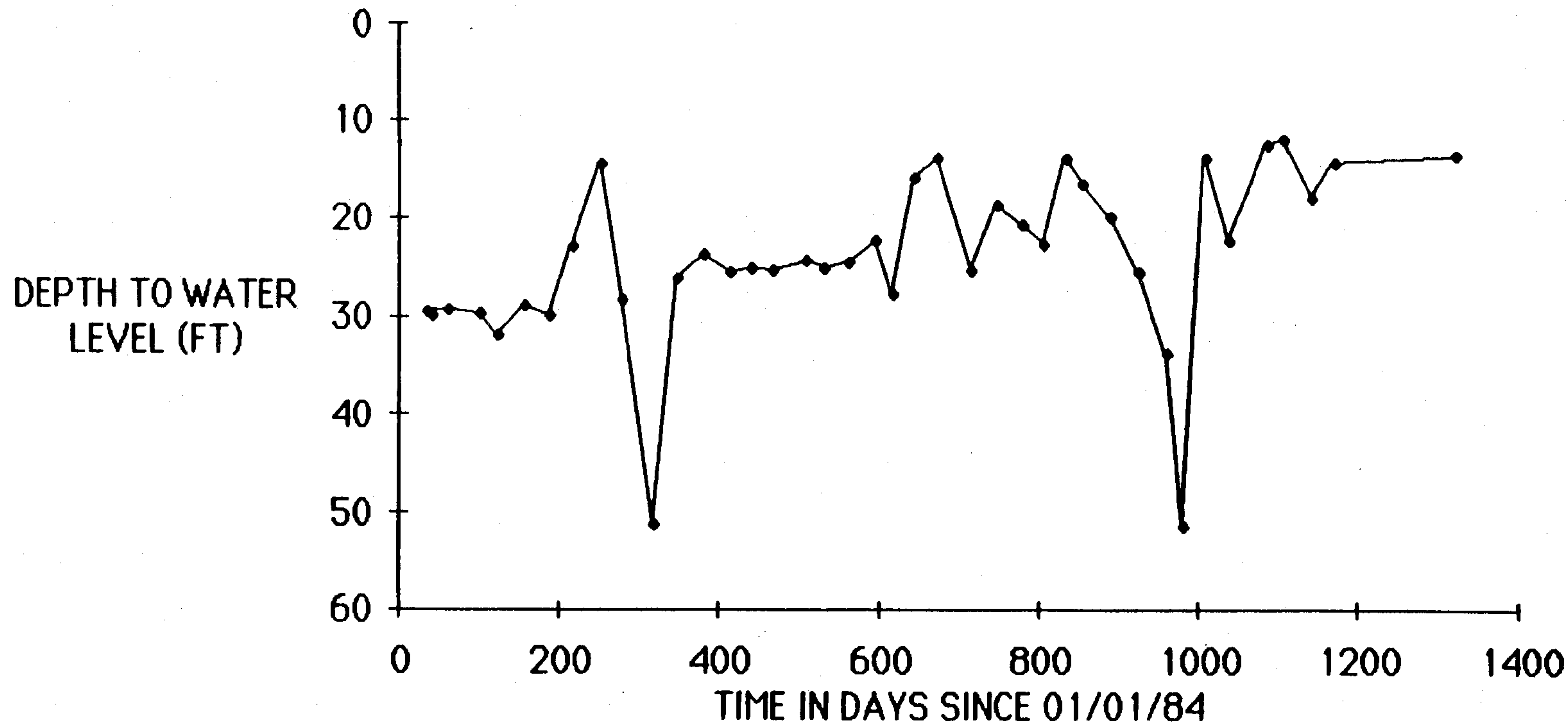


FIGURE 4

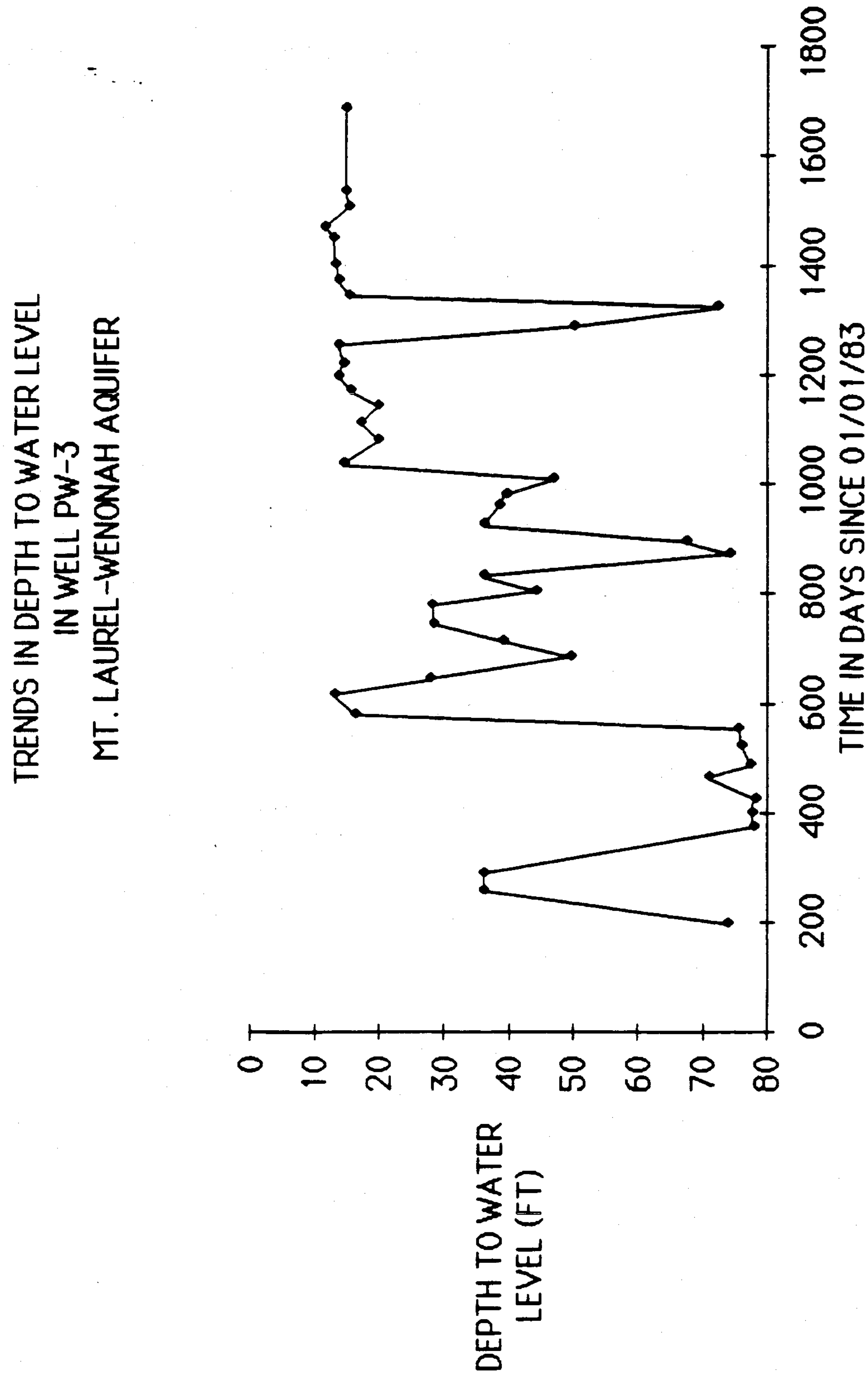

TRENDS IN DEPTH TO WATER LEVEL
IN WELL PW-3
MT. LAUREL-WENONAH AQUIFER
DEPTH TO WATER
LEVEL (FT)
0
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200
1400
1600
1800
TIME IN DAYS SINCE 01/01/83

FIGURE 5

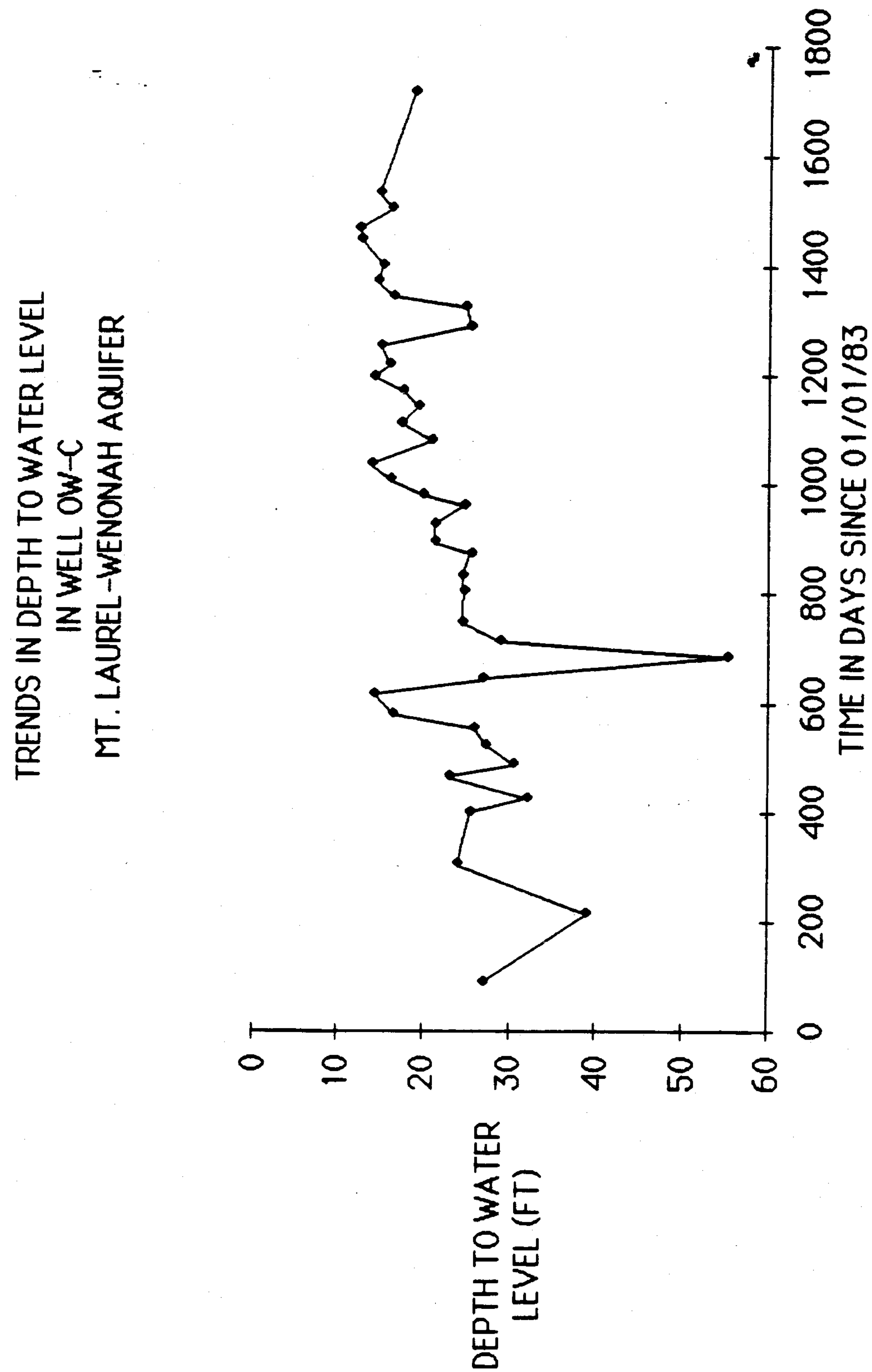

TRENDS IN DEPTH TO WATER LEVEL
IN WELL OW-C
MT. LAUREL-WENONAH AQUIFER
DEPTH TO WATER
LEVEL (FT)
0
10
20
30
40
50
60
TIME IN DAYS SINCE 01/01/83
0
200
400
600
800
1000
1200
1400
1600
1800

FIGURE 6

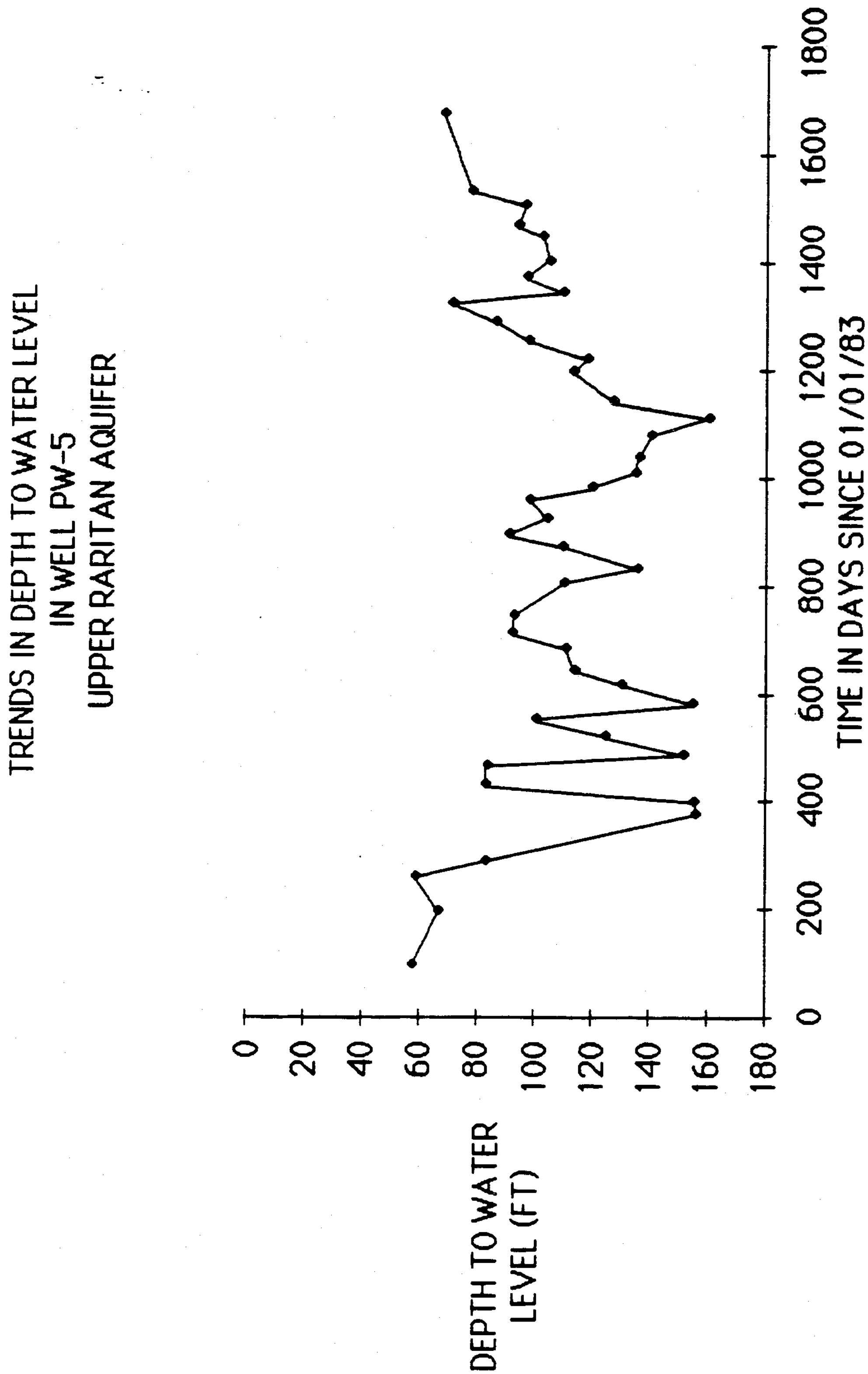
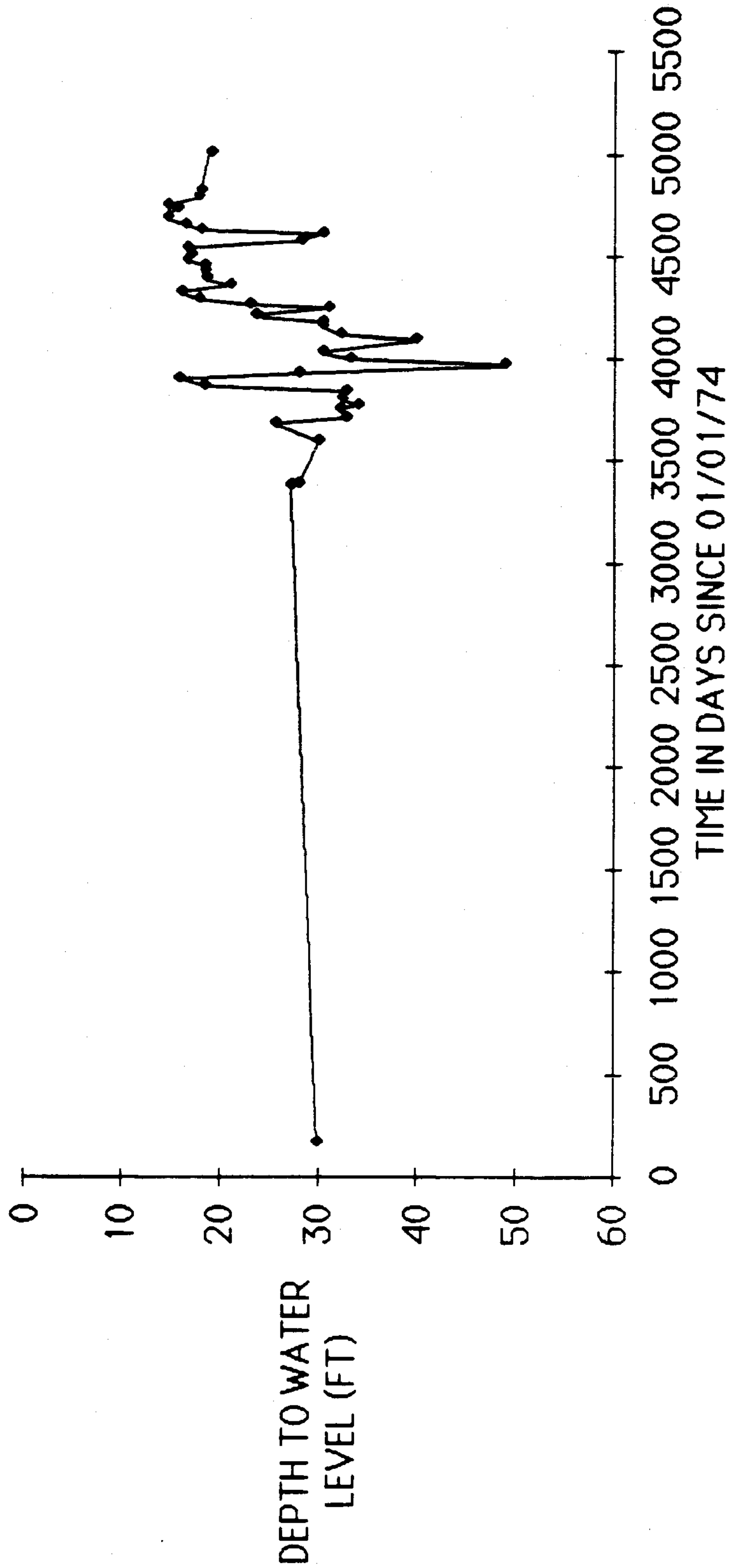

TRENDS IN DEPTH TO WATER LEVEL
IN WELL PW-5
UPPER RARITAN AQUIFER
DEPTH TO WATER
LEVEL (FT)
0
20
40
60
80
100
120
140
160
180
TIME IN DAYS SINCE 01/01/83
0
200
400
600
800
1000
1200
1400
1600
1800

FIGURE 7

TRENDS IN DEPTH TO WATER LEVEL
IN WELL OW-A
UPPER RARITAN AQUIFER



FIGURE

TRENDS IN DEPTH TO WATER LEVEL
IN WELL OW-H
UPPER RARITAN AQUIFER

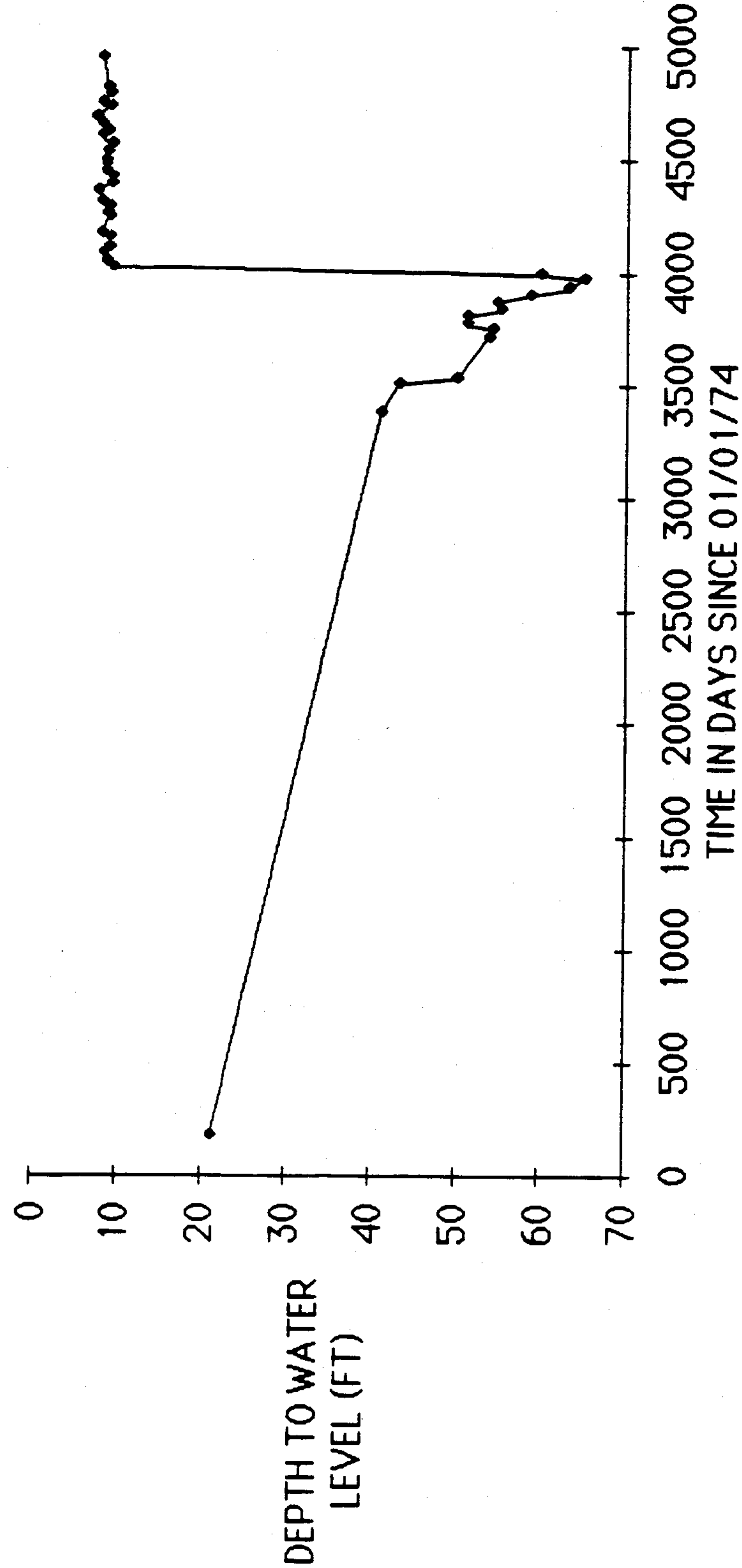


FIGURE 9

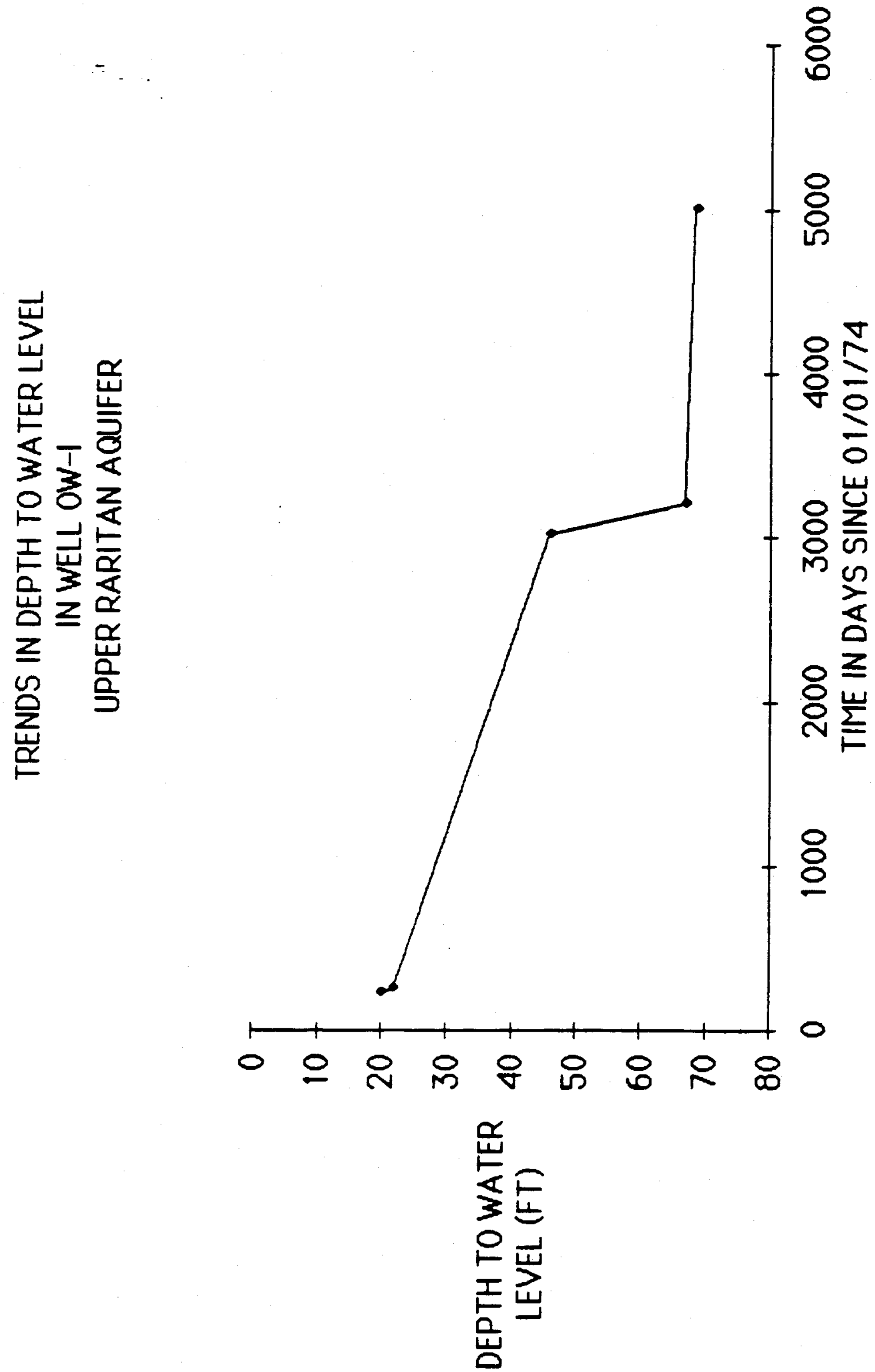

TRENDS IN DEPTH TO WATER LEVEL
IN WELL OW-1
UPPER RARITAN AQUIFER
DEPTH TO WATER
LEVEL (FT)
0
10
20
30
40
50
60
70
80
TIME IN DAYS SINCE 01/01/74
0
1000
2000
3000
4000
5000
6000

FIGURE 1

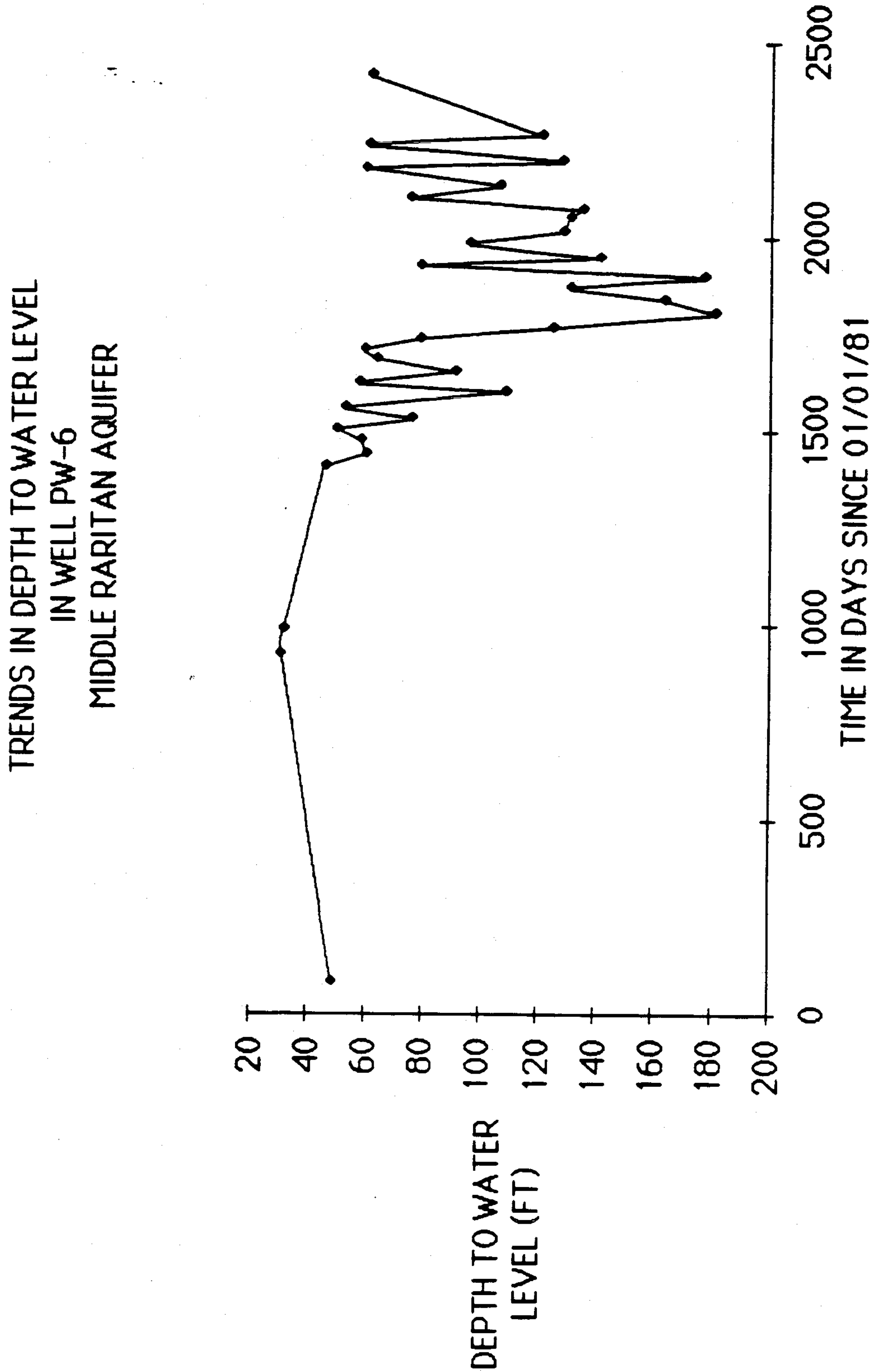

TRENDS IN DEPTH TO WATER LEVEL
IN WELL PW-6
MIDDLE RARITAN AQUIFER
DEPTH TO WATER
LEVEL (FT)
20
40
60
80
100
120
140
160
180
200
0
500
1000
1500
2000
2500
TIME IN DAYS SINCE 01/01/81

FIGURE 11

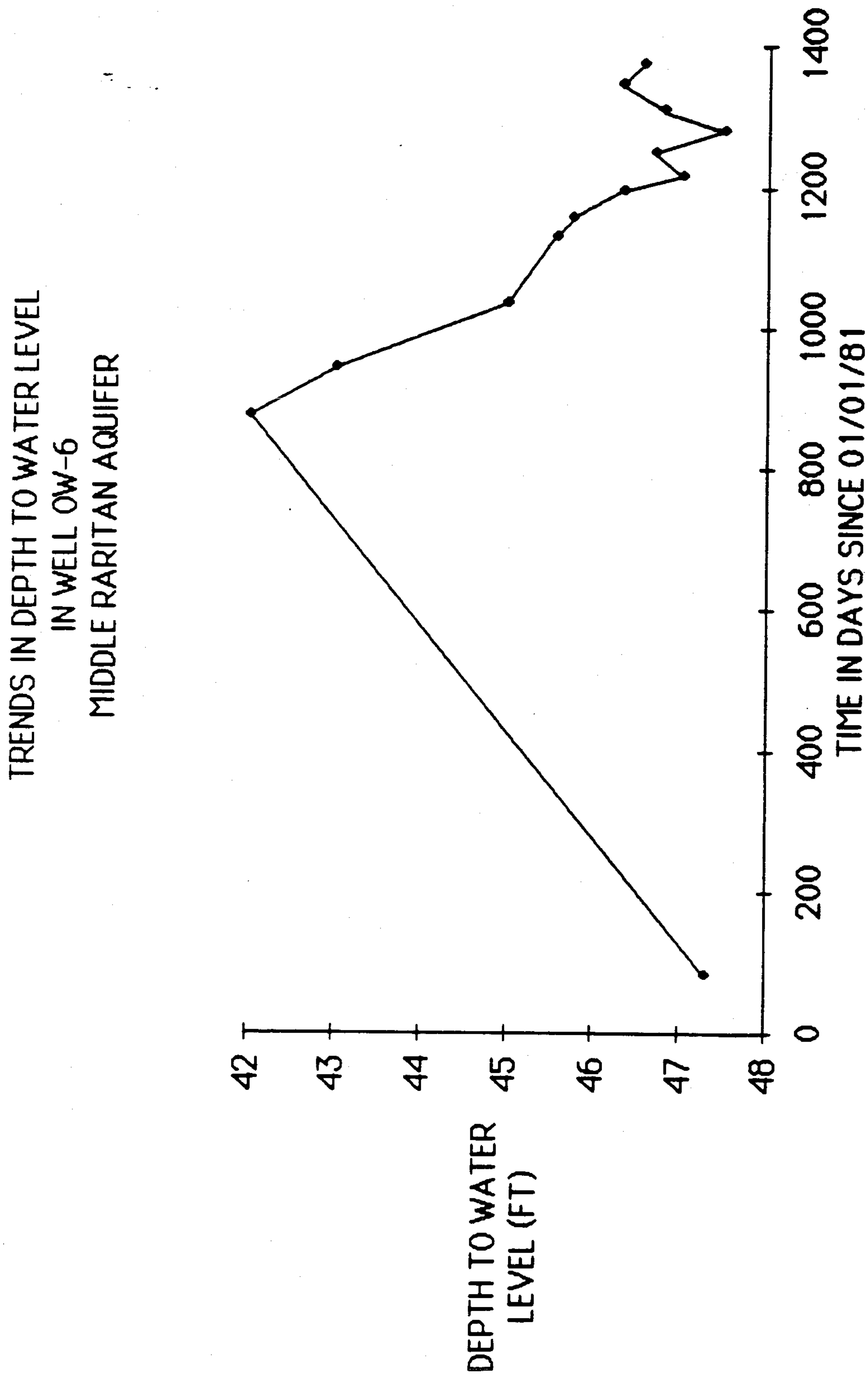

TRENDS IN DEPTH TO WATER LEVEL
IN WELL OW-6
MIDDLE RARITAN AQUIFER
DEPTH TO WATER
LEVEL (FT)
42
43
44
45
46
47
48
0
200
400
600
800
1000
1200
1400
TIME IN DAYS SINCE 01/01/81

FIGURE 12

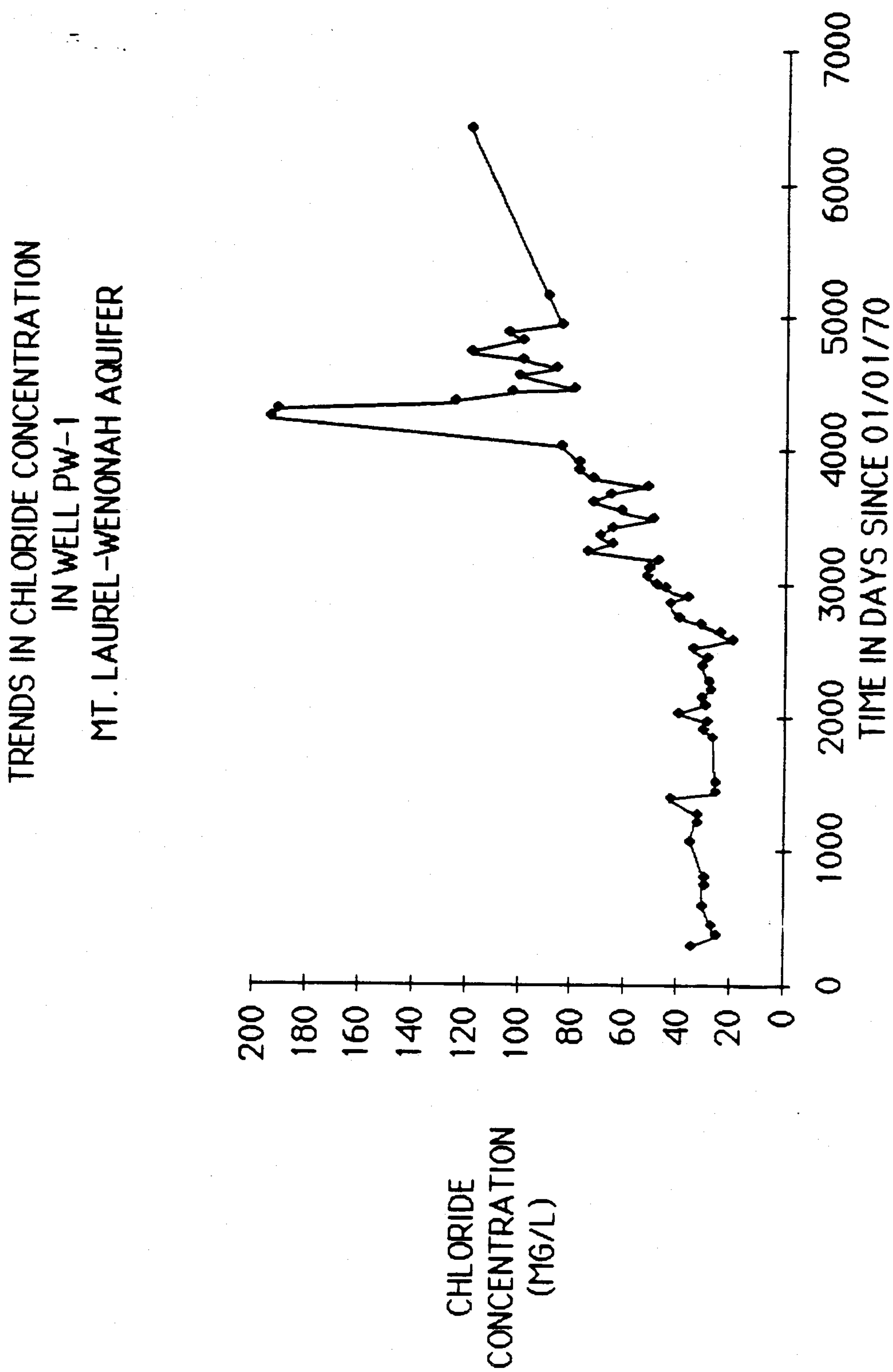

TRENDS IN CHLORIDE CONCENTRATION
IN WELL PW-1
MT. LAUREL-WENONAH AQUIFER
CHLORIDE CONCENTRATION (MG/L)
0
20
40
60
80
100
120
140
160
180
200
TIME IN DAYS SINCE 01/01/70
0
1000
2000
3000
4000
5000
6000
7000

FIGURE 13

TRENDS IN CHLORIDE CONCENTRATION
IN WELL PW-2
MT. LAUREL-WENONAH AQUIFER

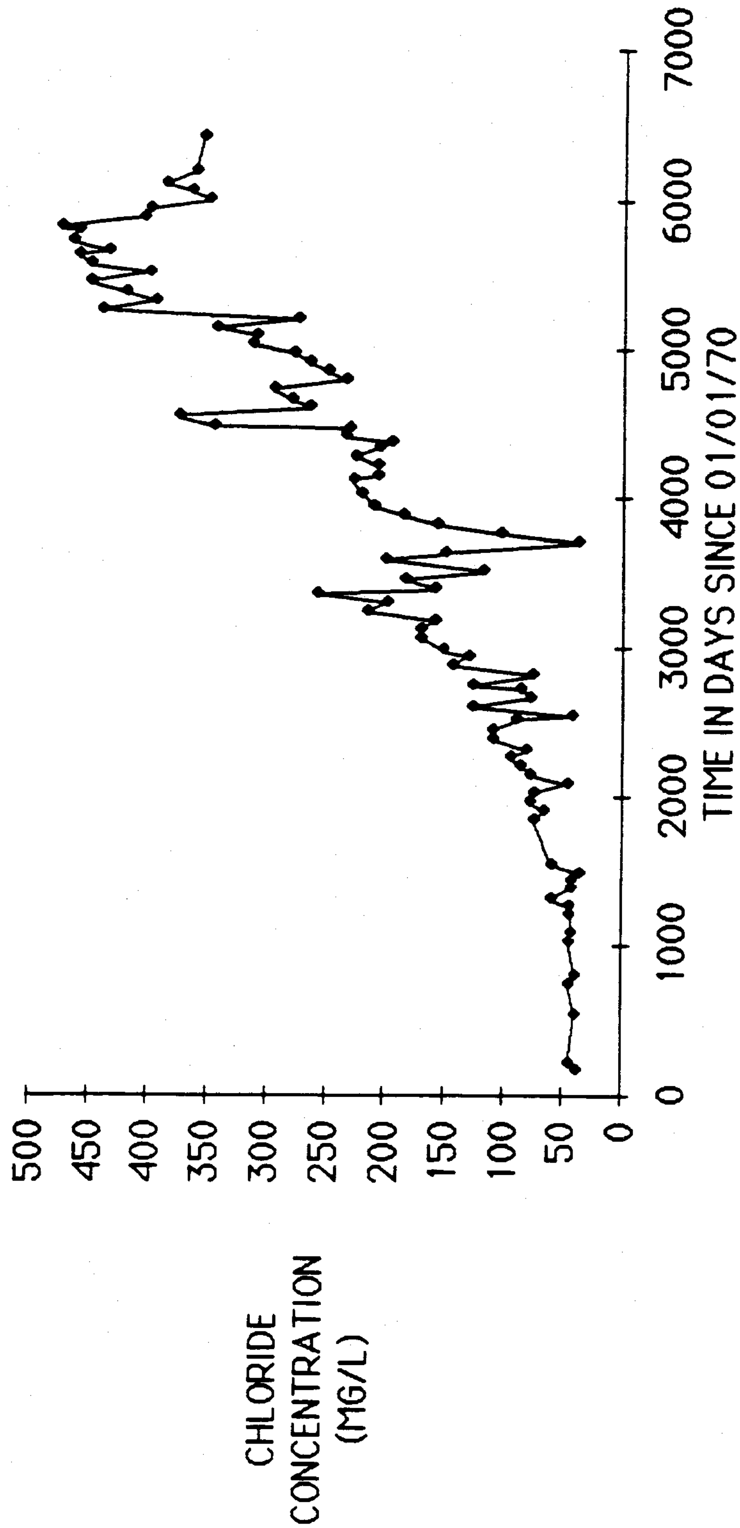


FIGURE 14

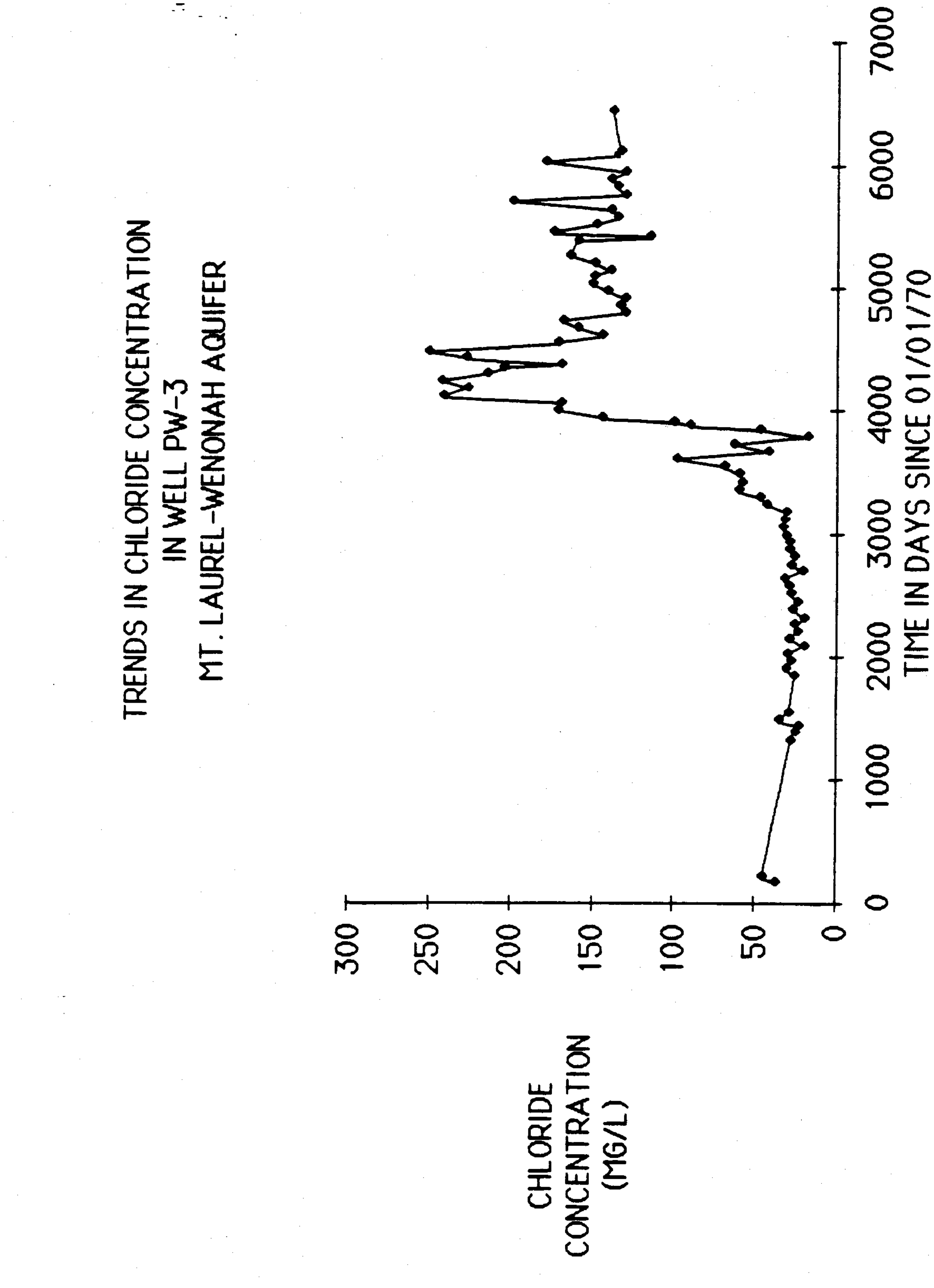
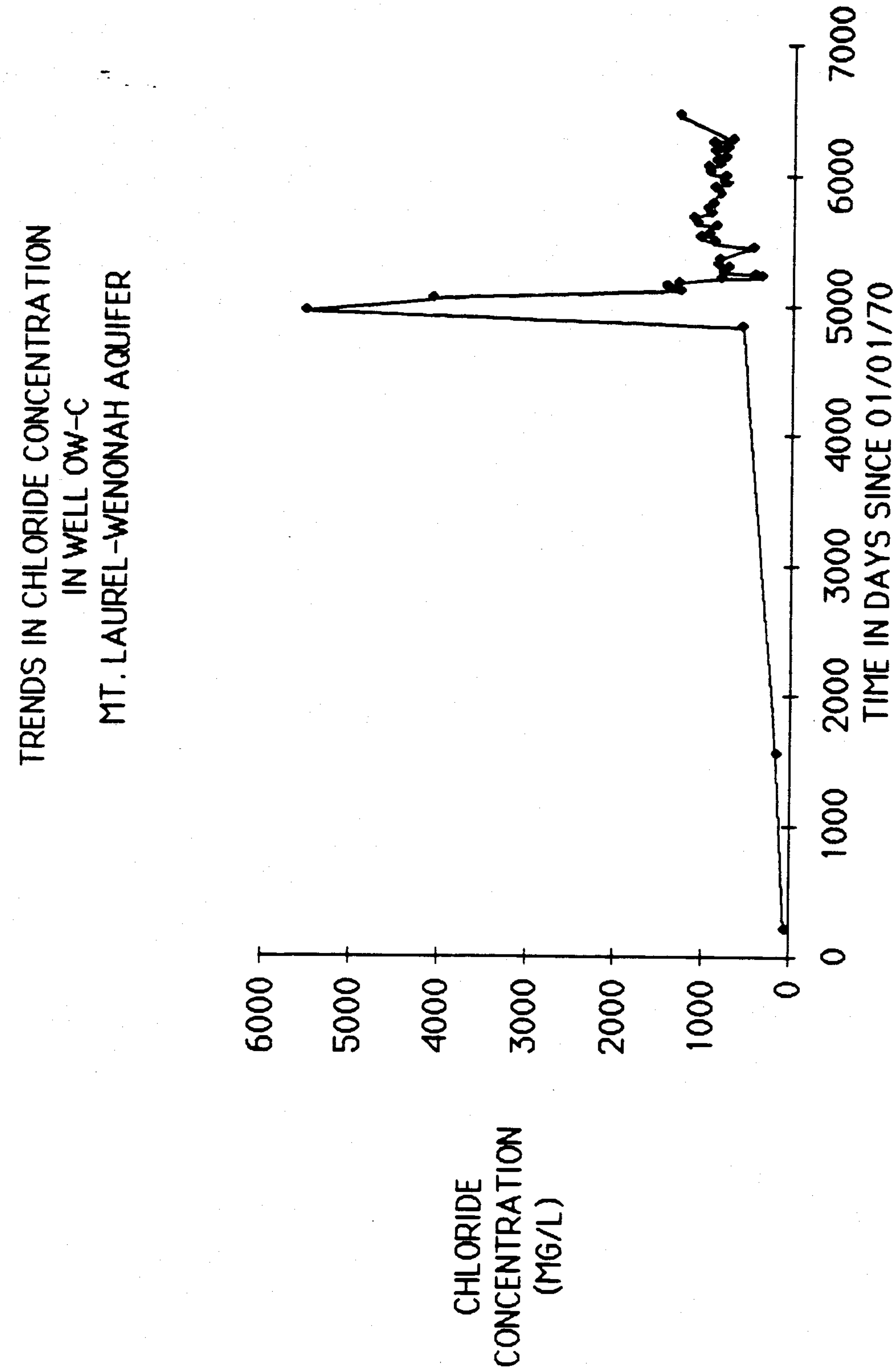

TRENDS IN CHLORIDE CONCENTRATION
IN WELL PW-3
MT. LAUREL-WENONAH AQUIFER
CHLORIDE
CONCENTRATION
(MG/L)
300
250
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
7000
TIME IN DAYS SINCE 01/01/70

FIGURE 15



TRENDS IN CHLORIDE CONCENTRATION
IN WELL OW-C
MT. LAUREL-WENONAH AQUIFER
CHLORIDE
CONCENTRATION
(MG/L)
6000
5000
4000
3000
2000
1000
0
0
1000
2000
3000
4000
5000
6000
7000
TIME IN DAYS SINCE 01/01/70

FIGURE 16

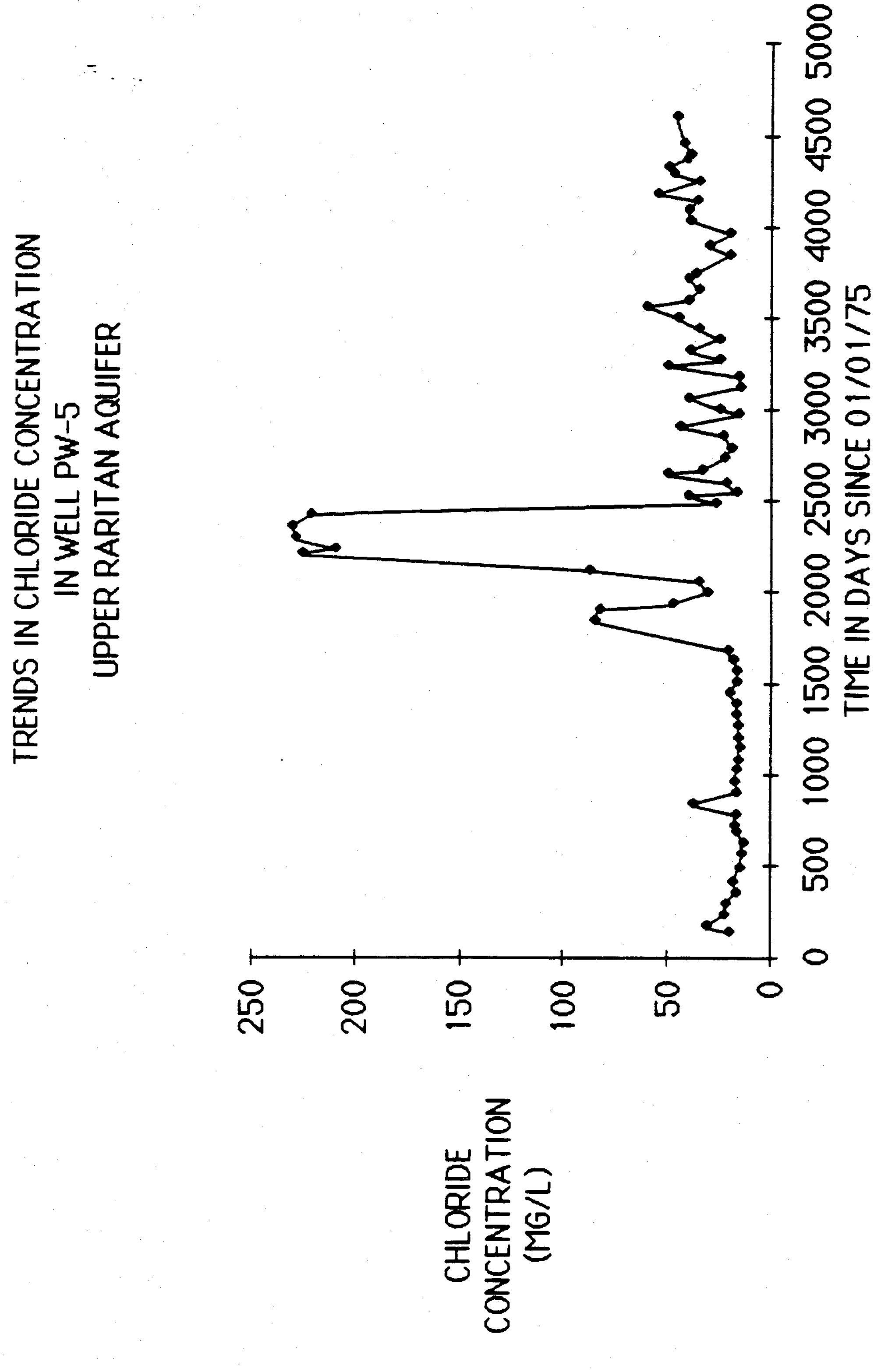

TRENDS IN CHLORIDE CONCENTRATION
IN WELL PW-5
UPPER RARITAN AQUIFER
CHLORIDE
CONCENTRATION
(MG/L)
250
200
150
100
50
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
TIME IN DAYS SINCE 01/01/75

FIGURE 17

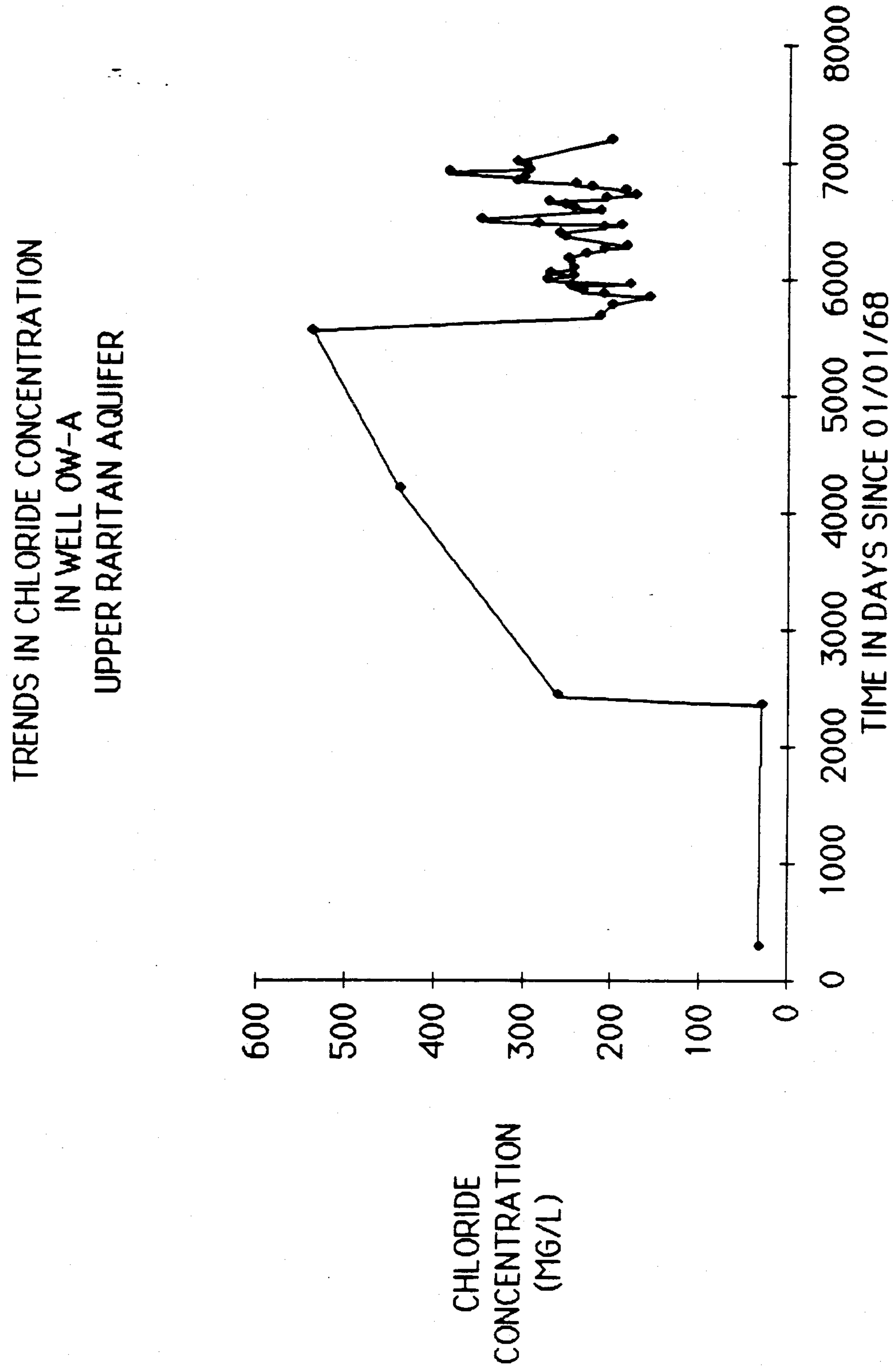

TRENDS IN CHLORIDE CONCENTRATION
IN WELL OW-A
UPPER RARITAN AQUIFER
CHLORIDE
CONCENTRATION
(MG/L)
0
100
200
300
400
500
600
0
1000
2000
3000
4000
5000
6000
7000
8000
TIME IN DAYS SINCE 01/01/68

FIGURE 18

TRENDS IN CHLORIDE CONCENTRATION
IN WELL HC-1
UPPER RARITAN AQUIFER

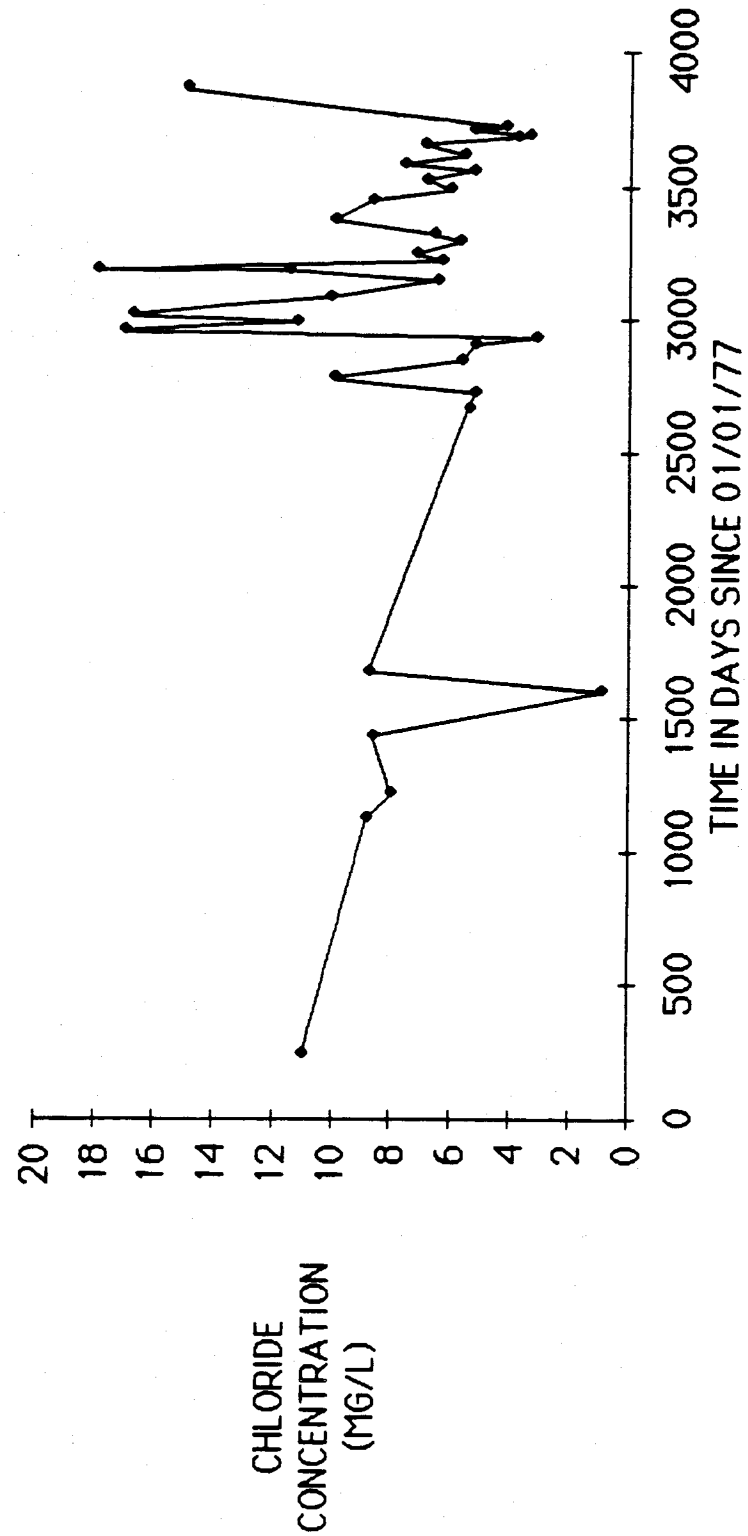


FIGURE 19

TRENDS IN CHLORIDE CONCENTRATION
IN WELL HC-2
UPPER RARITAN AQUIFER

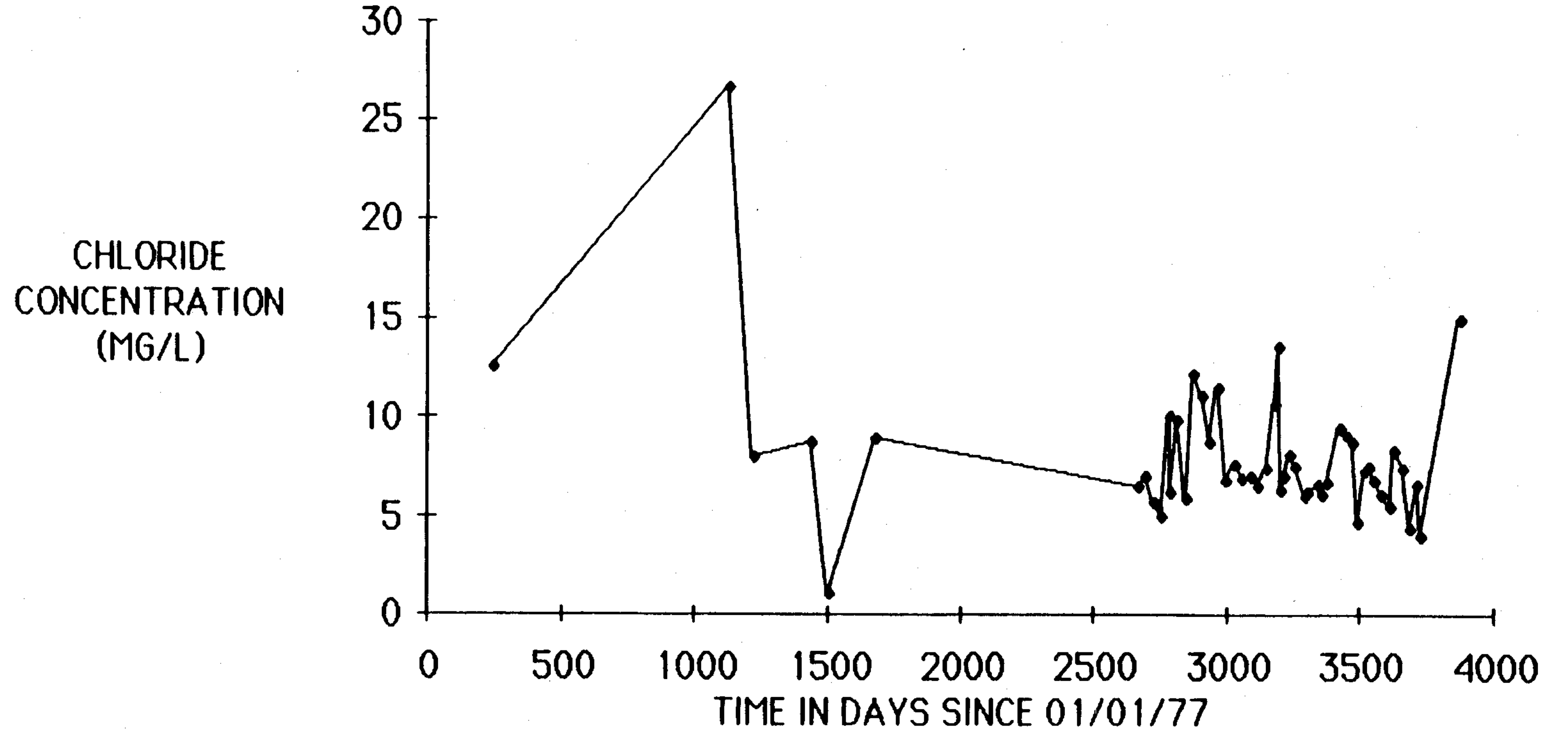


FIGURE 20

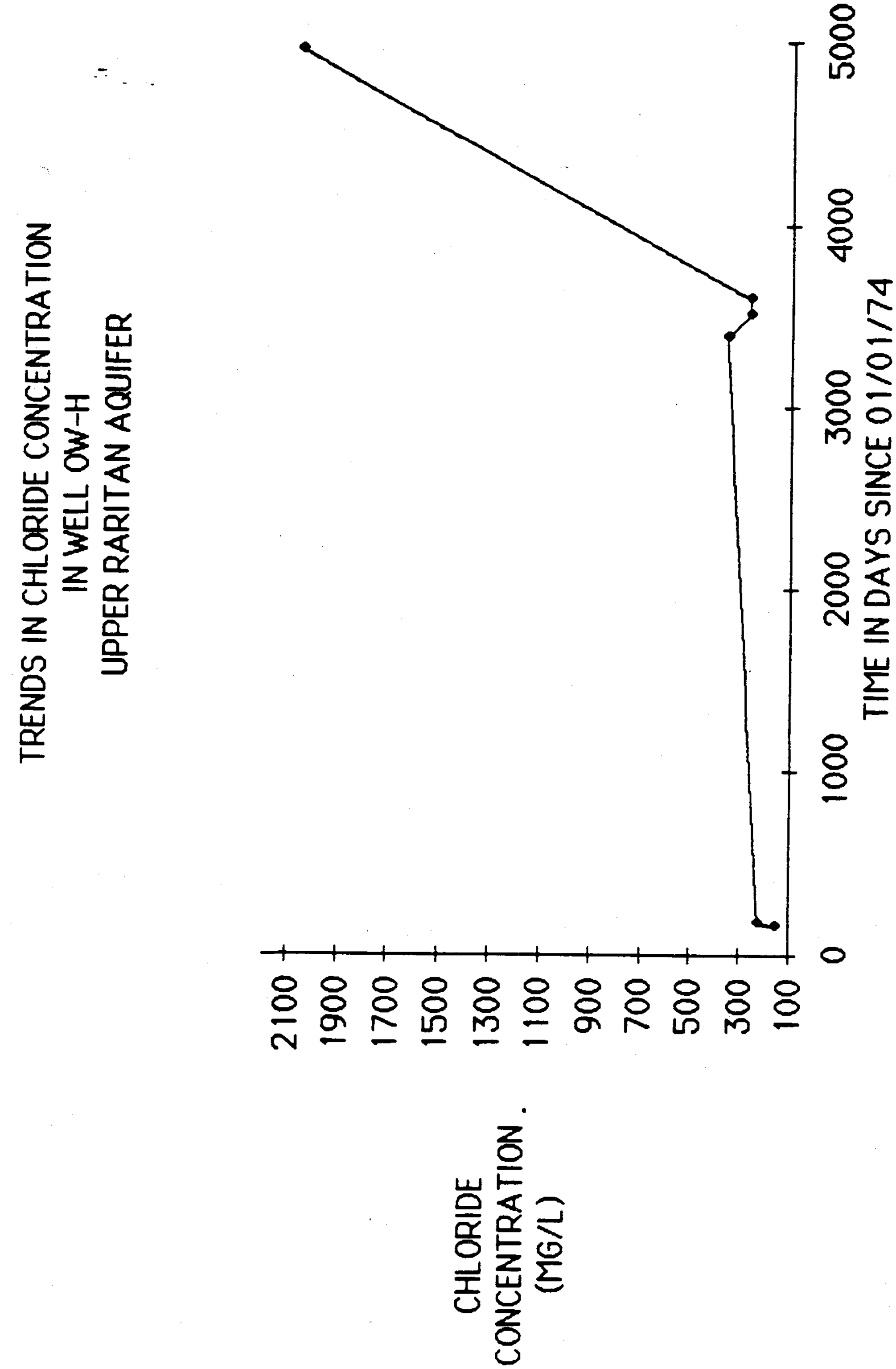
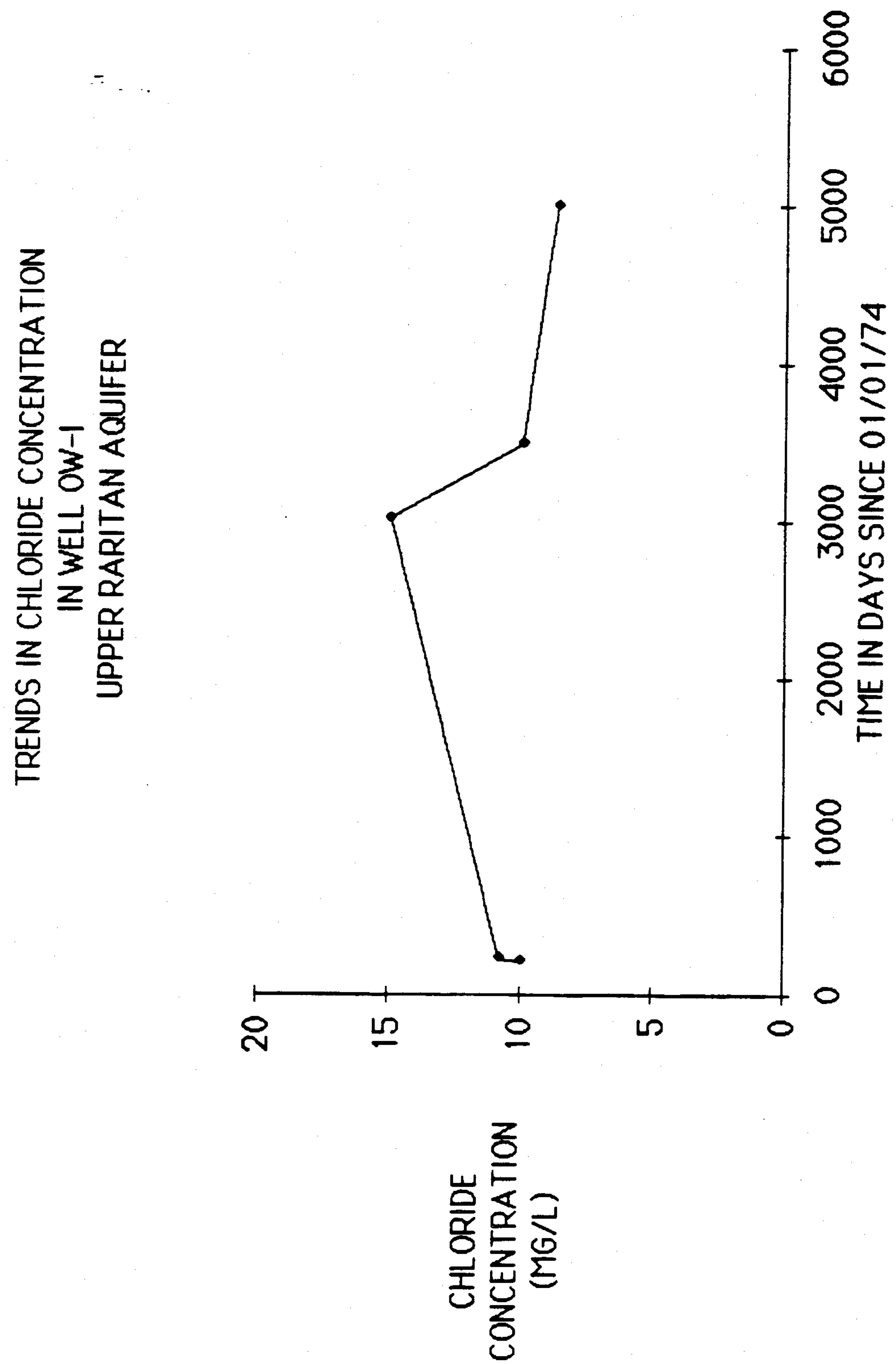

TRENDS IN CHLORIDE CONCENTRATION
IN WELL OW-H
UPPER RARITAN AQUIFER
CHLORIDE
CONCENTRATION
(MG/L)
2100
1900
1700
1500
1300
1100
900
700
500
300
100
0
1000
2000
3000
4000
5000
TIME IN DAYS SINCE 01/01/74

FIGURE 2



TRENDS IN CHLORIDE CONCENTRATION
IN WELL OW-1
UPPER RARITAN AQUIFER
CHLORIDE
CONCENTRATION
(MG/L)
0
5
10
15
20
0
1000
2000
3000
4000
5000
6000
TIME IN DAYS SINCE 01/01/74

FIGURE 22

TRENDS IN CHLORIDE CONCENTRATION
IN WELL PW-6
MIDDLE RARITAN AQUIFER

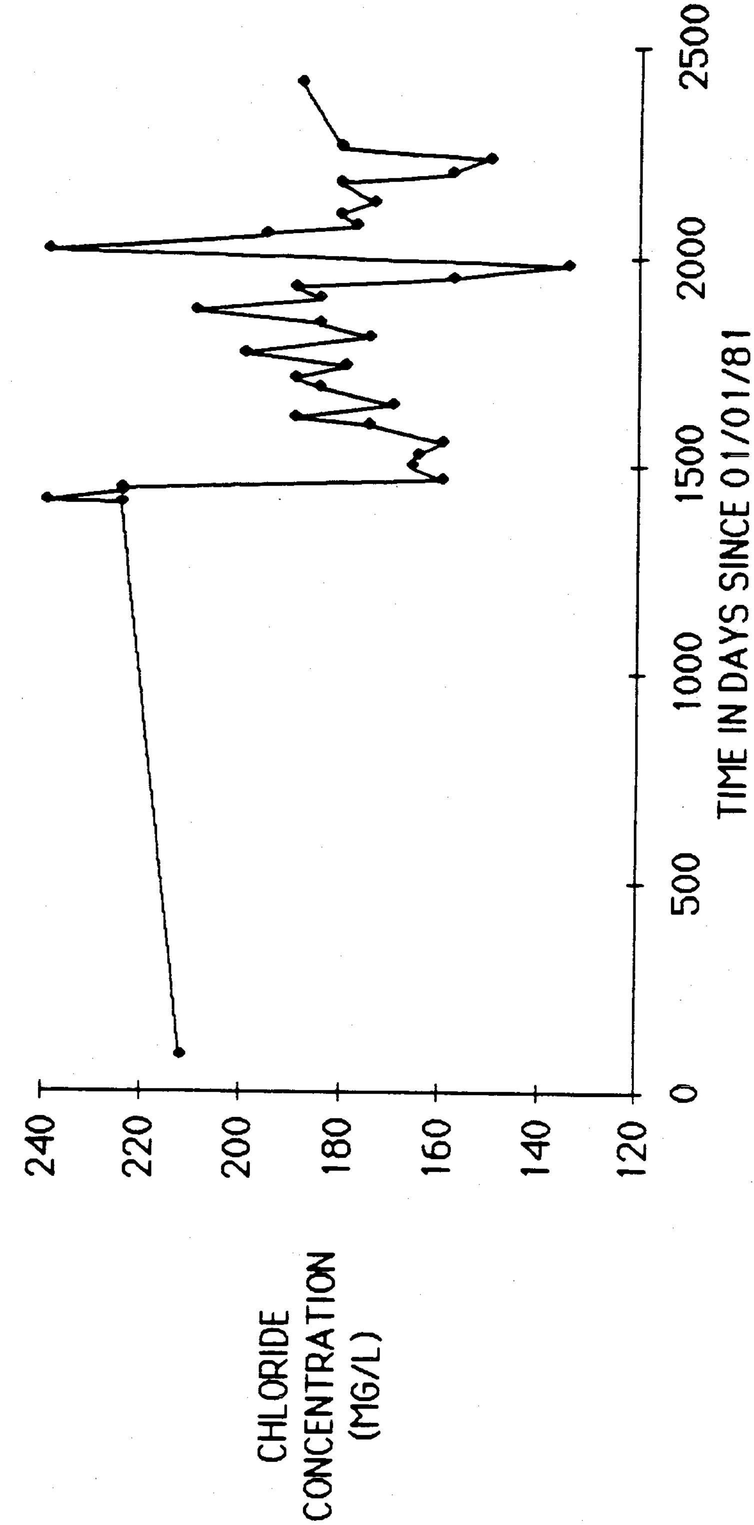


FIGURE 23

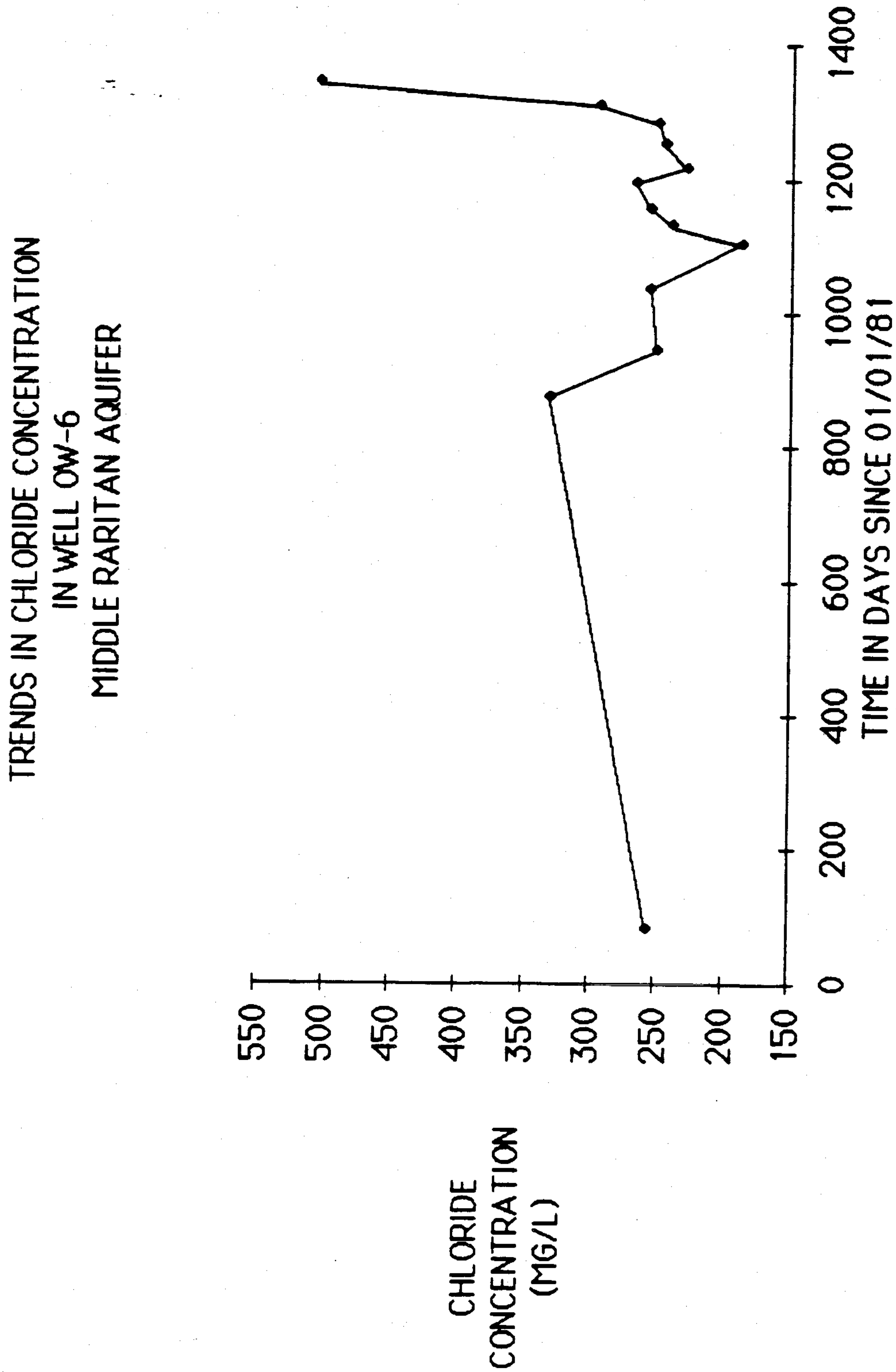

TRENDS IN CHLORIDE CONCENTRATION
IN WELL OW-6
MIDDLE RARITAN AQUIFER
CHLORIDE
CONCENTRATION
(MG/L)
550
500
450
400
350
300
250
200
150
0
200
400
600
800
1000
1200
1400
TIME IN DAYS SINCE 01/01/81

FIGURE 2

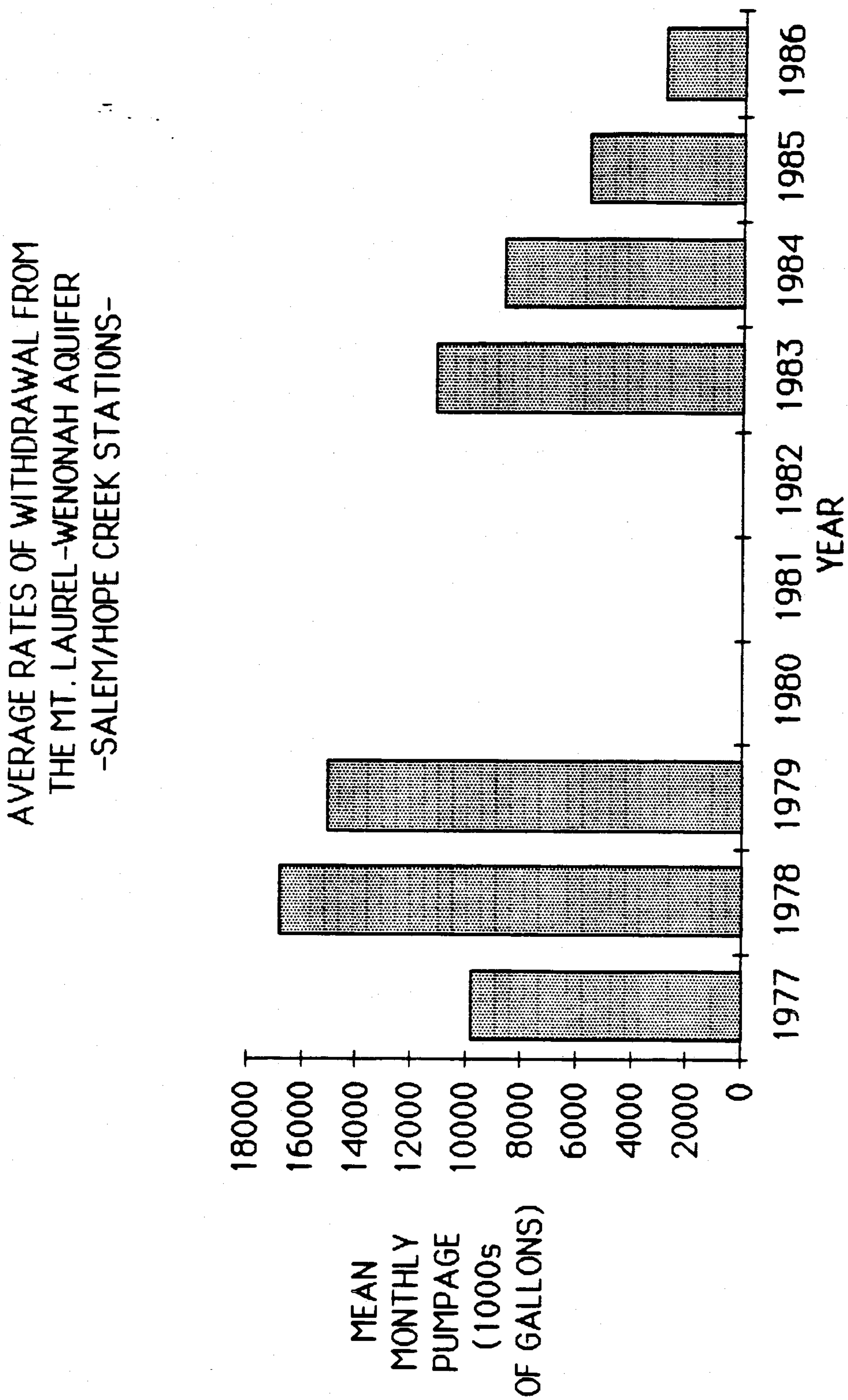

AVERAGE RATES OF WITHDRAWAL FROM
THE MT. LAUREL-WENONAH AQUIFER
-SALEM/HOPE CREEK STATIONS-
MEAN
MONTHLY
PUMPAGE
(1000s
OF GALLONS)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
YEAR

FIGURE 25

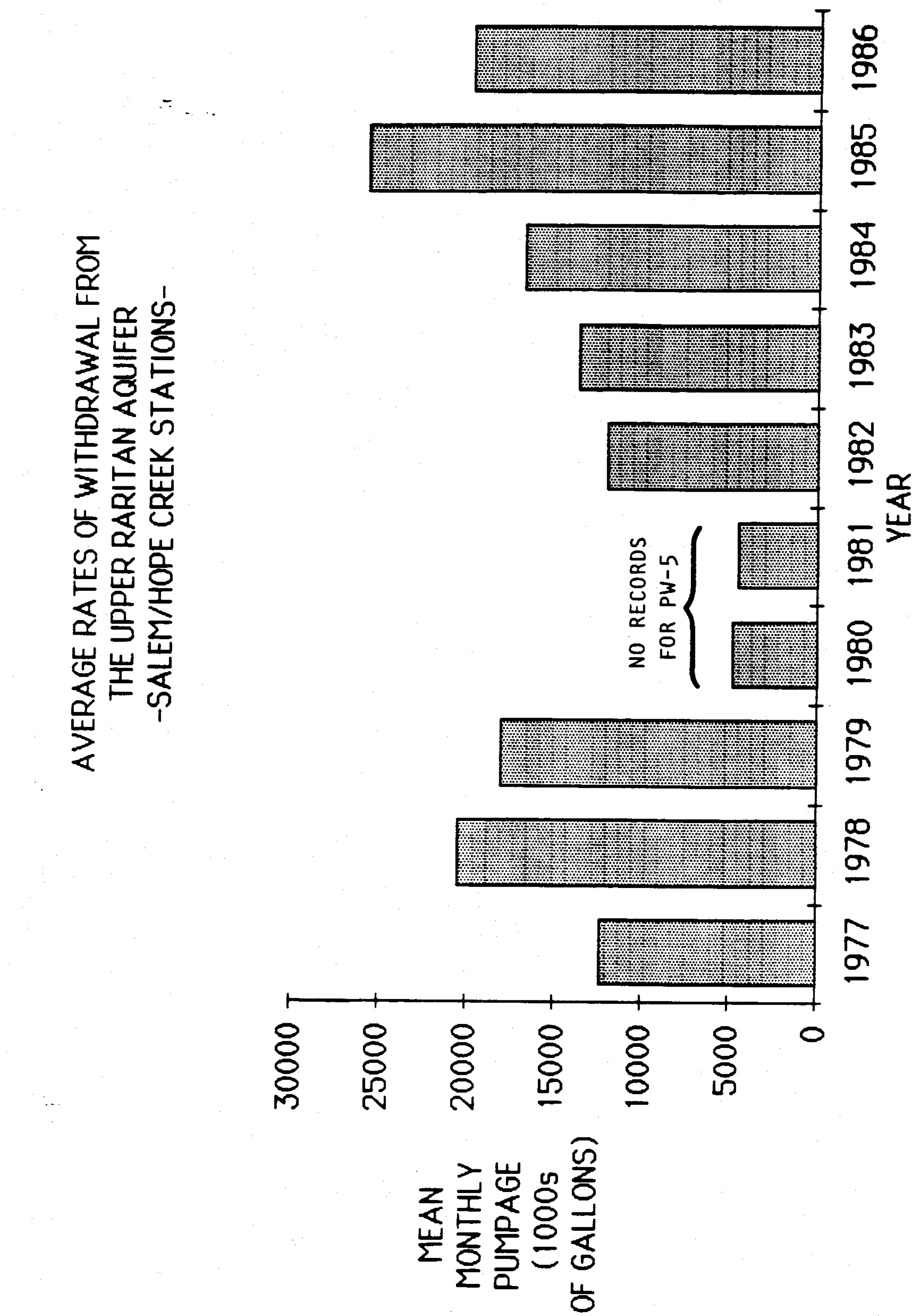

AVERAGE RATES OF WITHDRAWAL FROM
THE UPPER RARITAN AQUIFER
-SALEM/HOPE CREEK STATIONS-
MEAN MONTHLY PUMPAGE (1000s OF GALLONS)
30000
25000
20000
15000
10000
5000
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
YEAR
NO RECORDS FOR PW-5

FIGURE 26

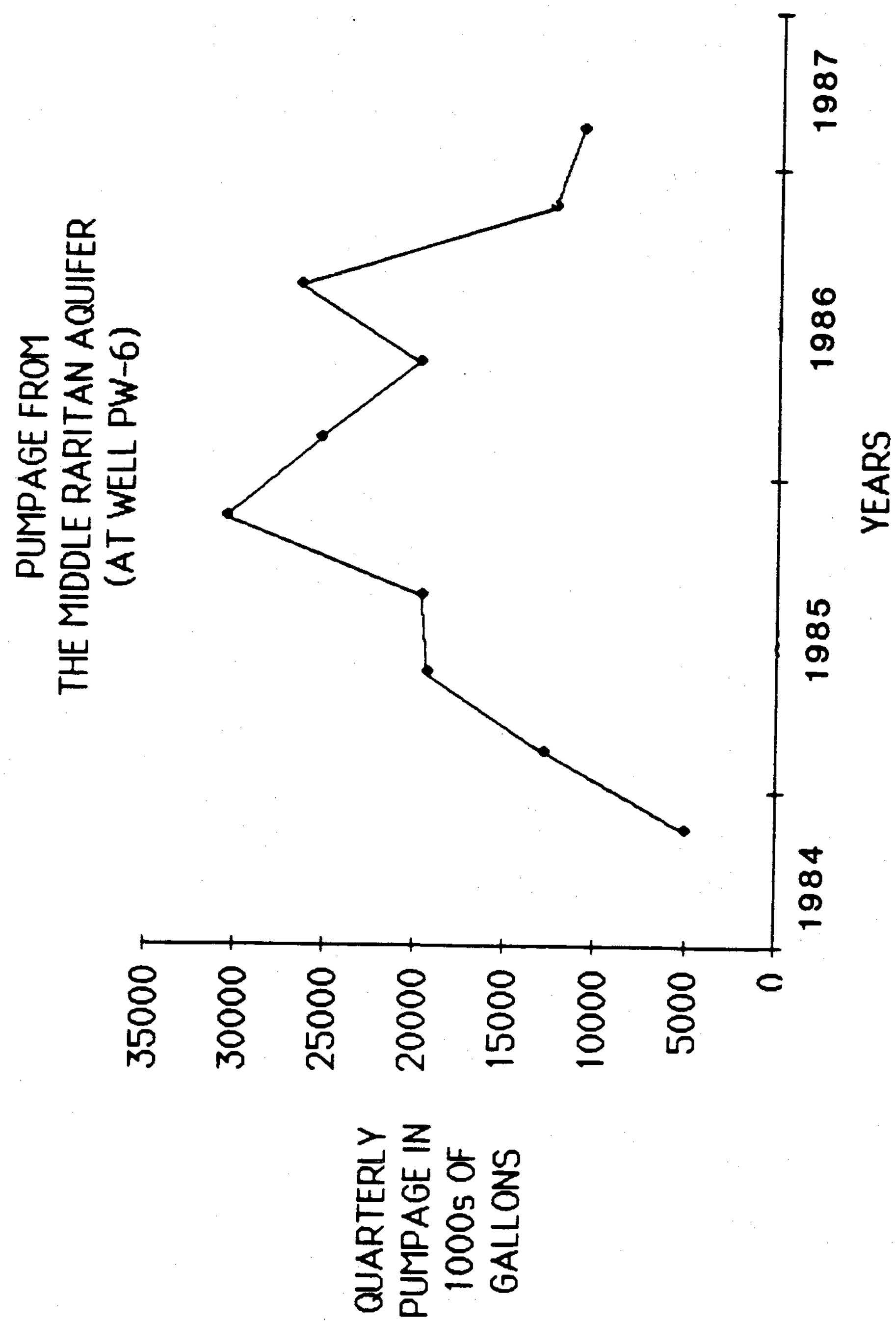
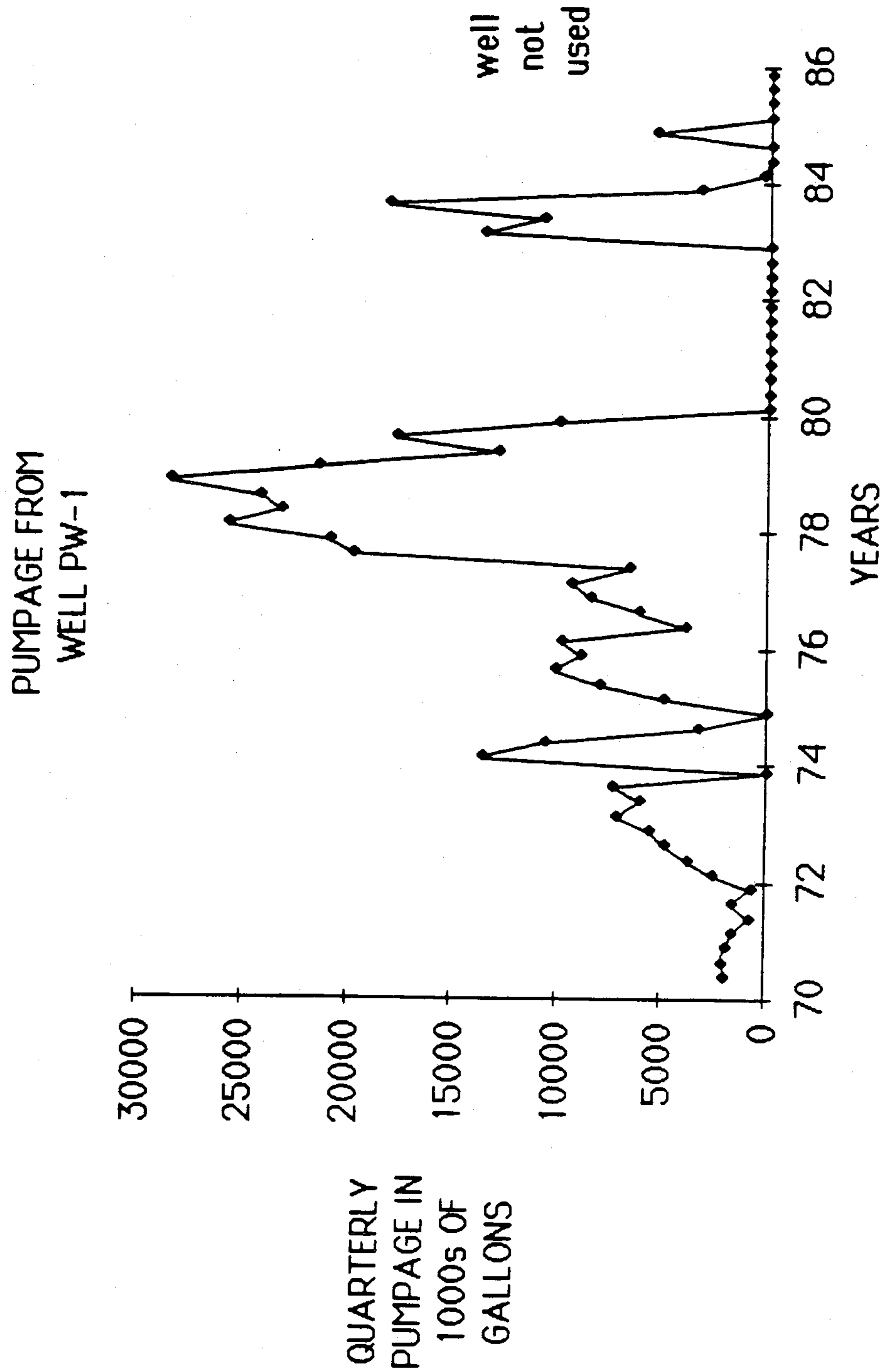

PUMPAGE FROM
THE MIDDLE RARITAN AQUIFER
(AT WELL PW-6)
QUARTERLY
PUMPAGE IN
1000s OF
GALLONS
35000
30000
25000
20000
15000
10000
5000
0
1984
1985
1986
1987
YEARS

FIGURE 27



PUMPAGE FROM
WELL PW-1
QUARTERLY
PUMPAGE IN
1000s OF
GALLONS
30000
25000
20000
15000
10000
5000
0
70
72
74
76
78
80
82
84
86
YEARS
well
not
used

FIGURE 28

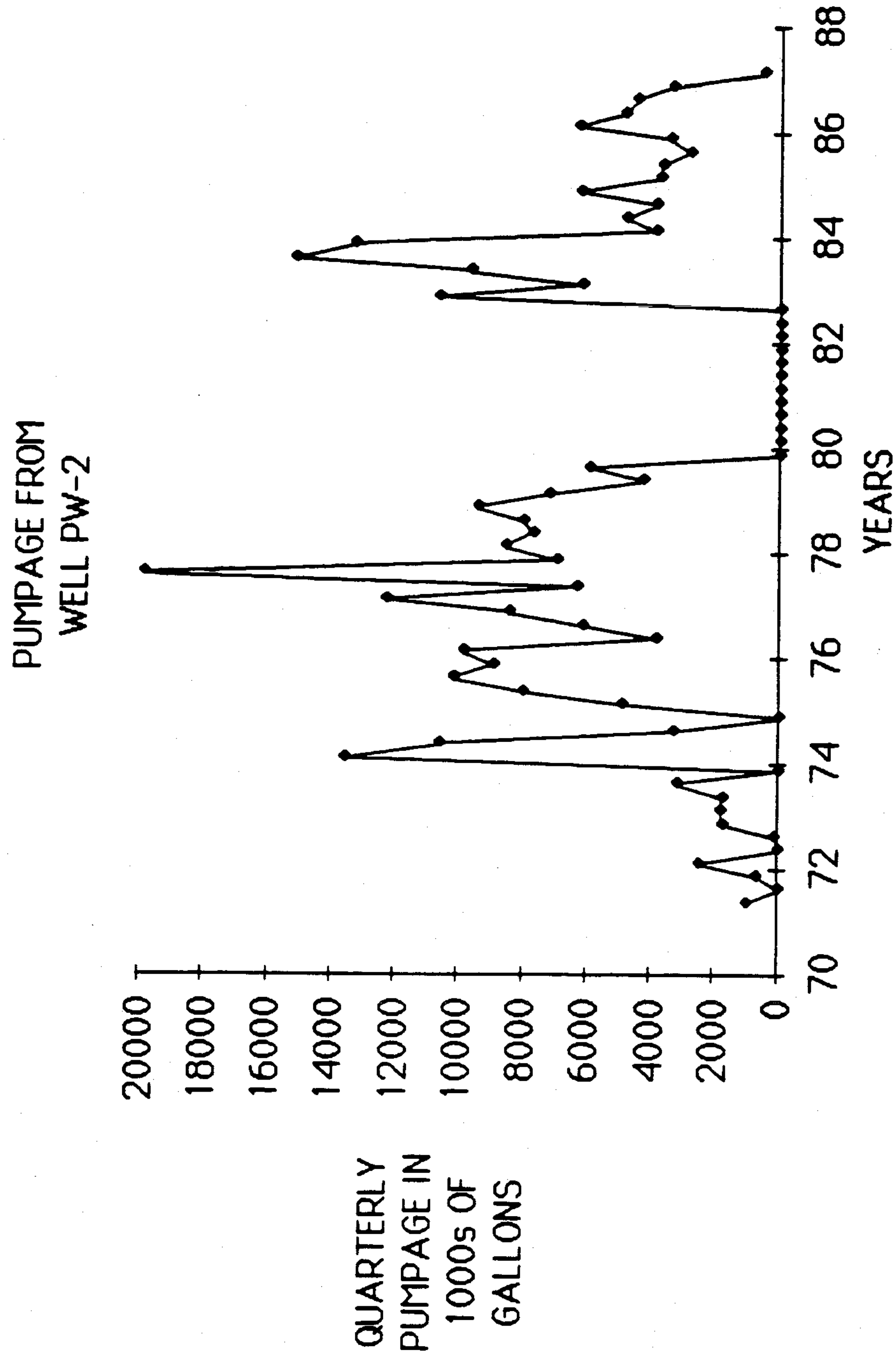

PUMPAGE FROM
WELL PW-2
QUARTERLY
PUMPAGE IN
1000s OF
GALLONS
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
70
72
74
76
78
80
82
84
86
88
YEARS

FIGURE 29

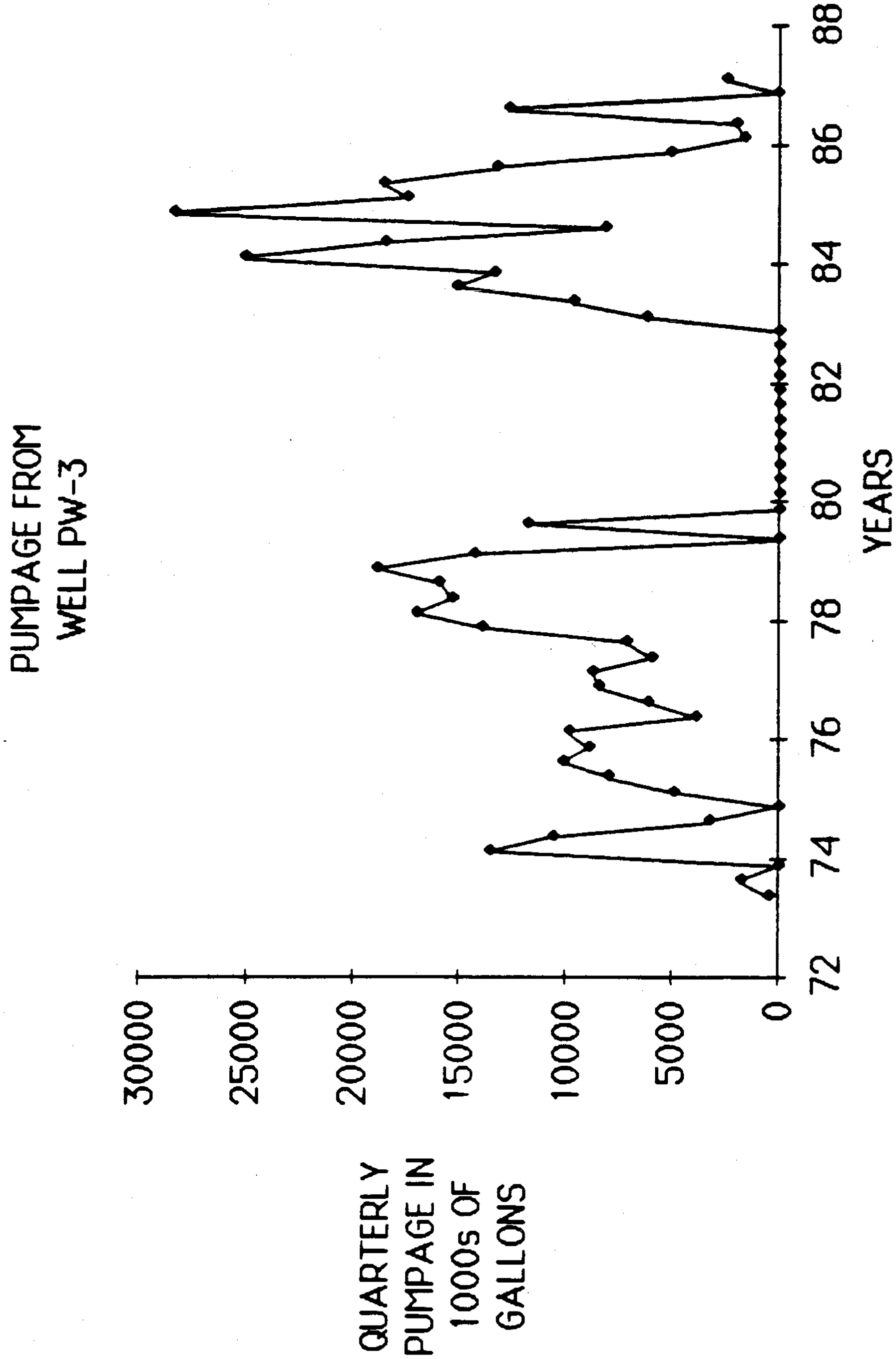

PUMPAGE FROM
WELL PW-3
QUARTERLY
PUMPAGE IN
1000s OF
GALLONS
30000
25000
20000
15000
10000
5000
0
72
74
76
78
80
82
84
86
88
YEARS

FIGURE 30

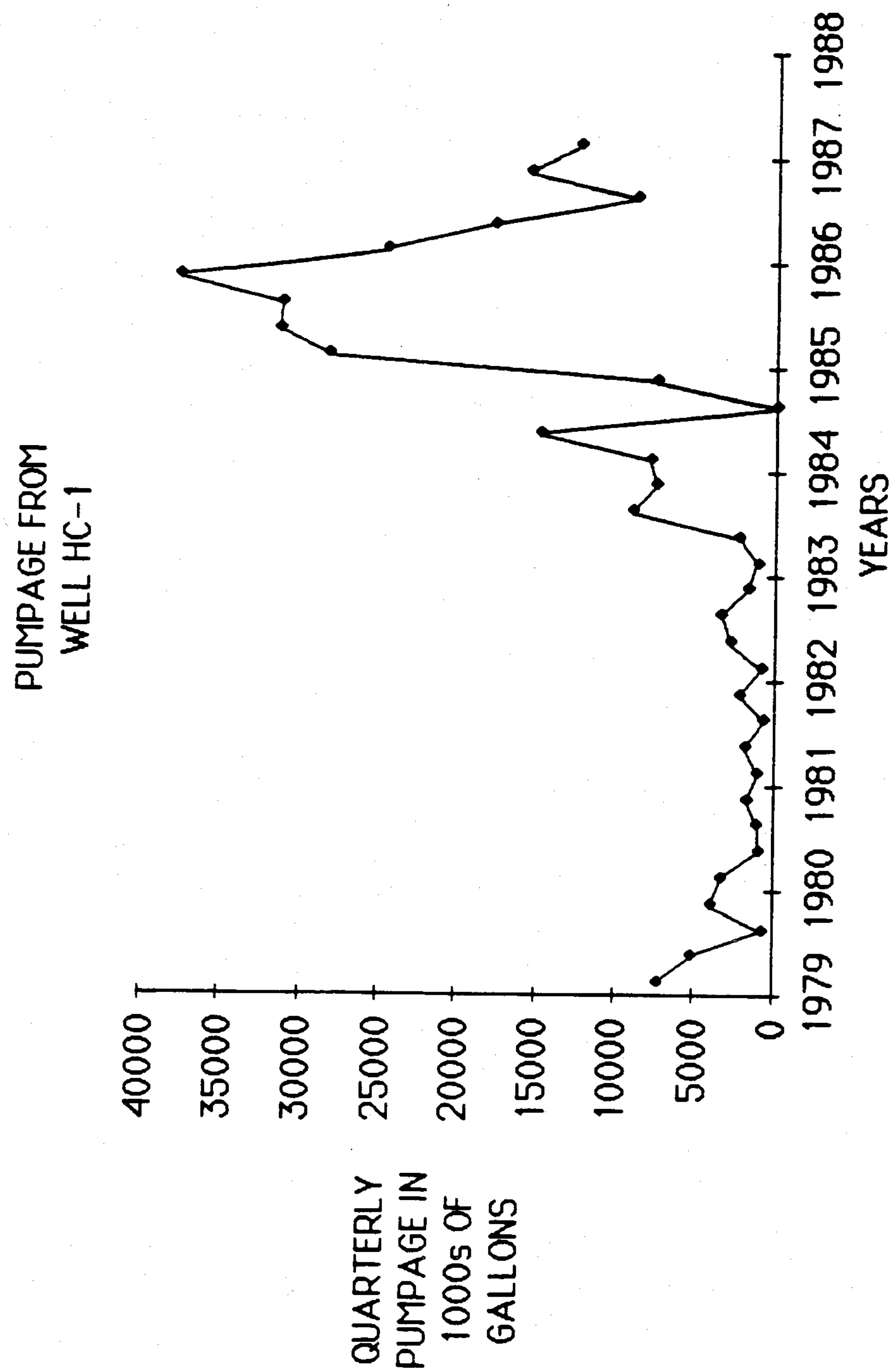

PUMPAGE FROM
WELL HC-1
QUARTERLY
PUMPAGE IN
1000s OF
GALLONS
40000
35000
30000
25000
20000
15000
10000
5000
0
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
YEARS

FIGURE 32

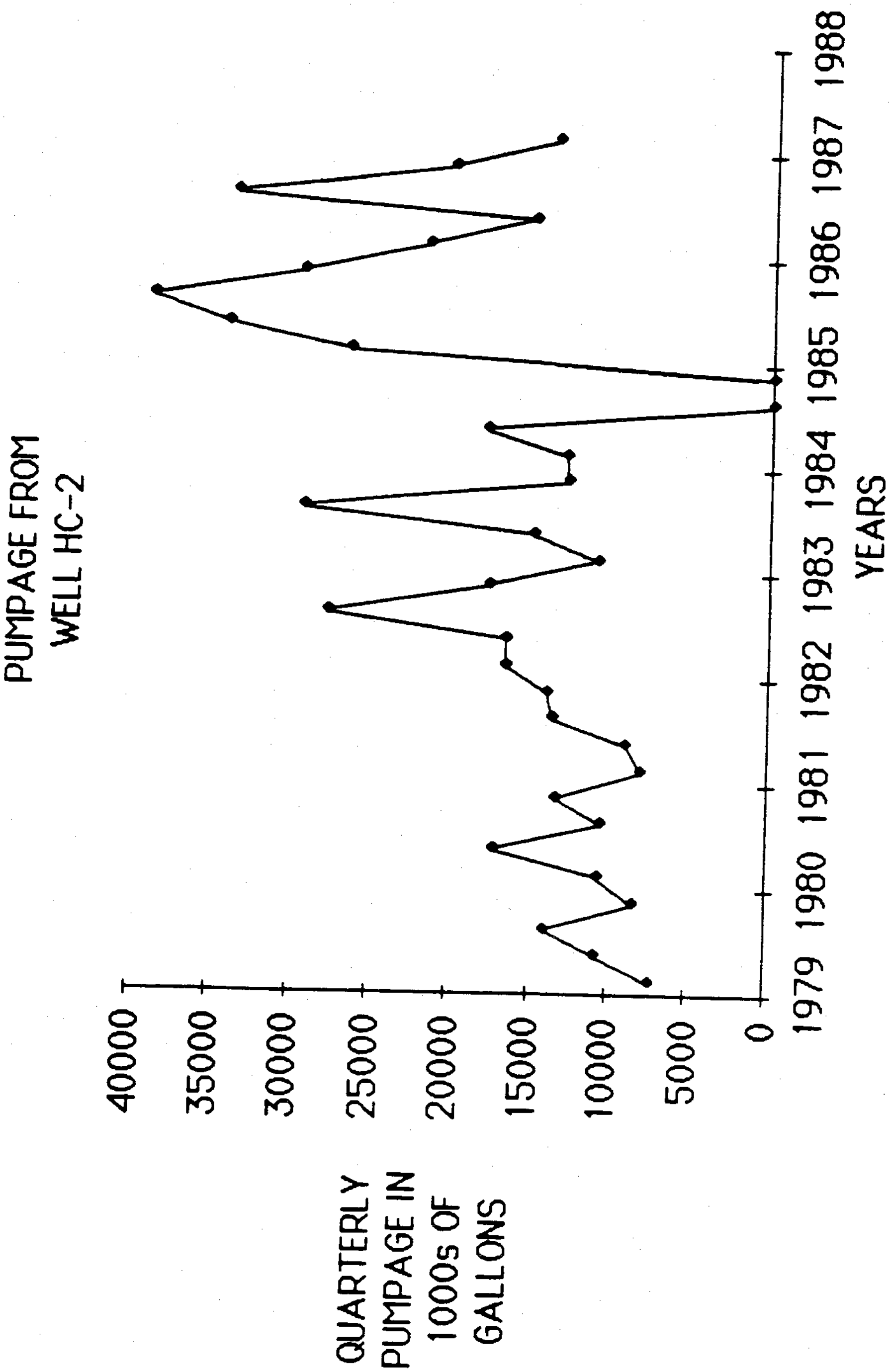
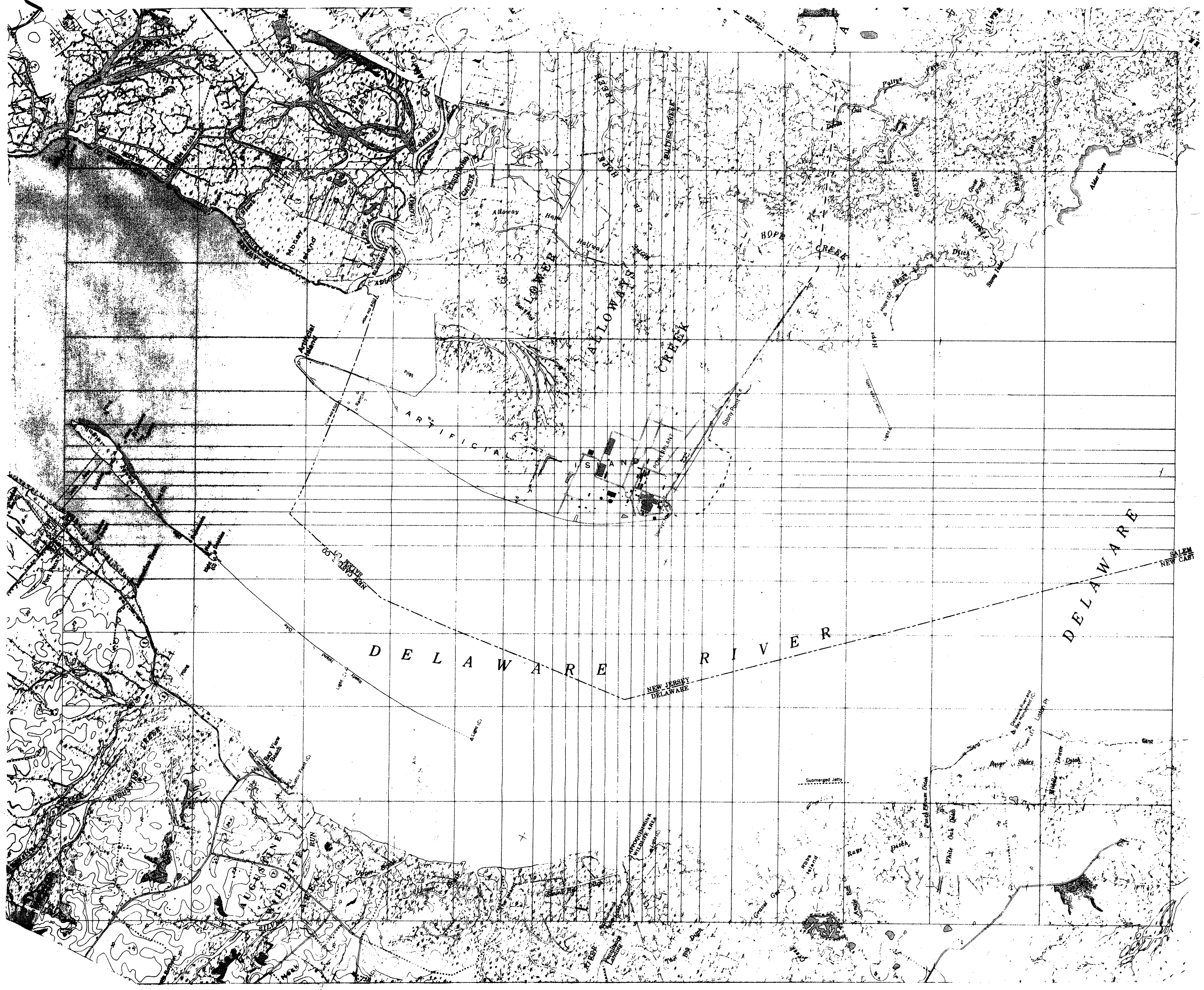

PUMPAGE FROM
WELL HC-2
QUARTERLY
PUMPAGE IN
1000s OF
GALLONS
40000
35000
30000
25000
20000
15000
10000
5000
0
1979 1980 1981 1982 1983 1984 1985 1986 1987 1988
YEARS

FIGURE 33

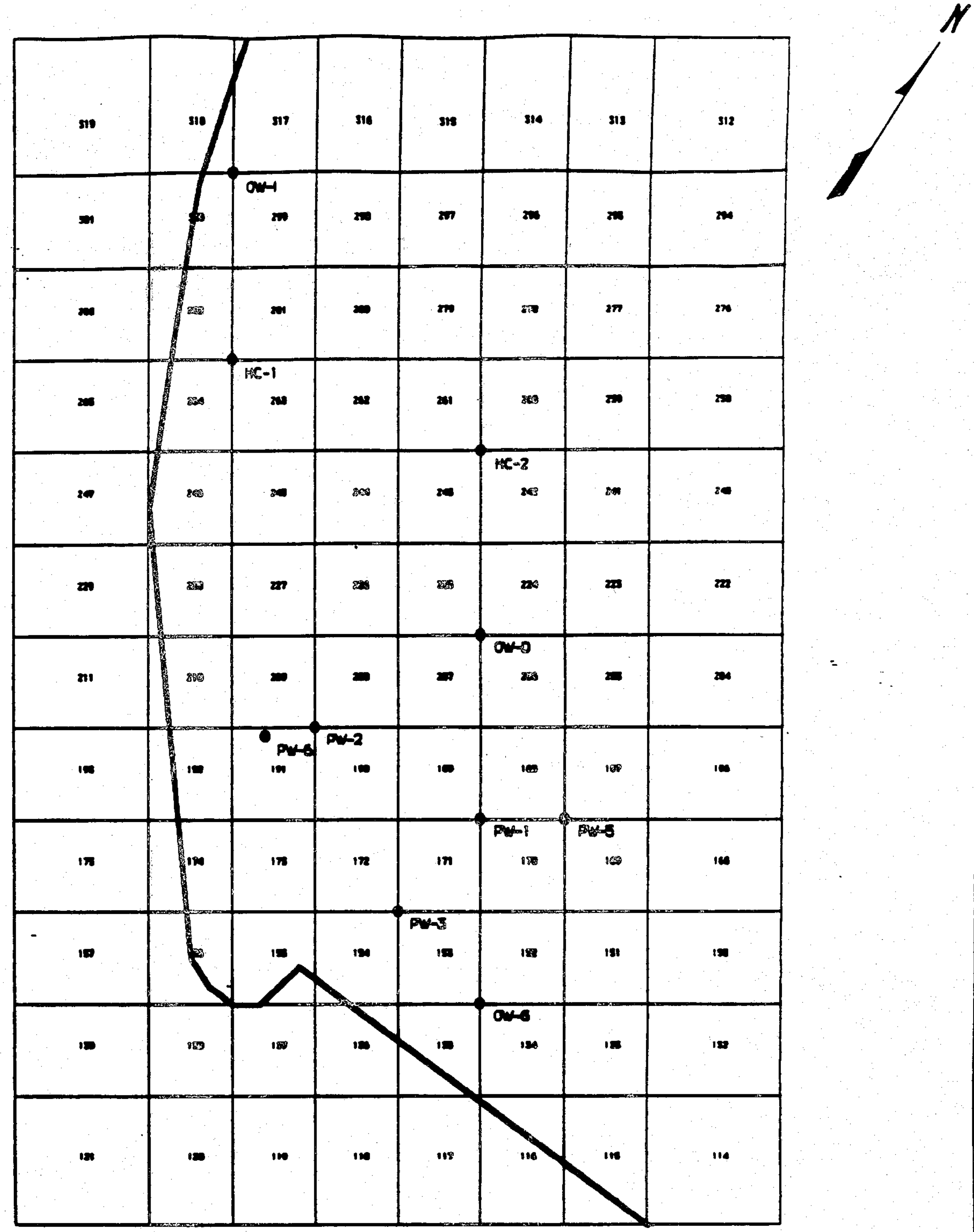


SALEM/HOPE CREEK
GENERATING STATIONS
PSE&G

MAP SHOWING MODELED DOMAIN AND
DETAILS OF
FINITE-ELEMENT MESH

DAMES & MOORE

FIGURE 34



DETAILS OF MODEL FINITE-ELEMENT MESH IN VICINITY OF PLANT SITE

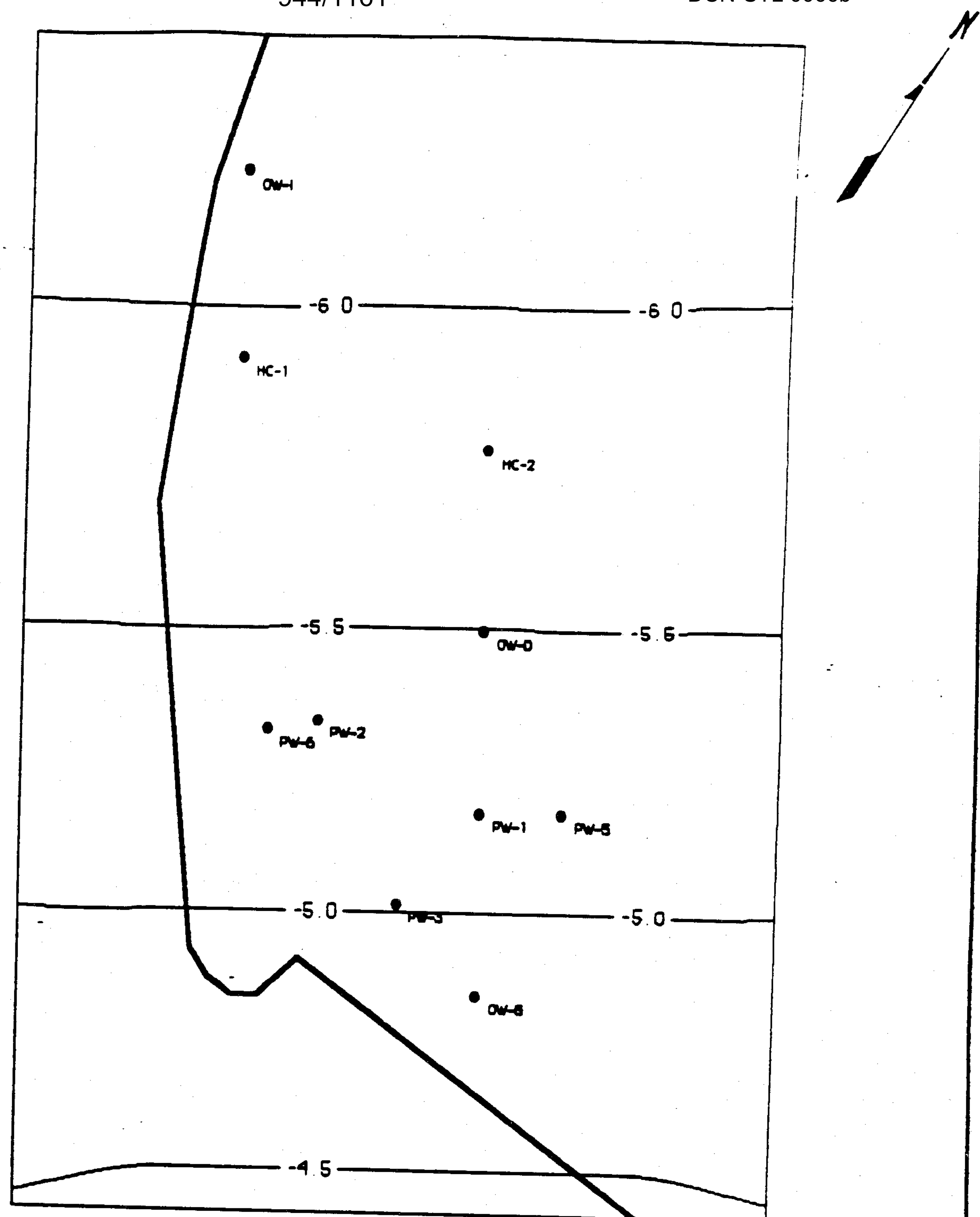
SALEM/HOPE CREEK GENERATING STATIONS

PSE&G

0 500 1,000 FEET

Dames & Moore

FIGURE 35



CONTOURS OF ASSUMED INITIAL PIEZOMETRIC SURFACE OF THE UPPER RARITAN AQUIFER IN JANUARY 1976

SALEM/HOPE CREEK GENERATING STATIONS

PSE&G

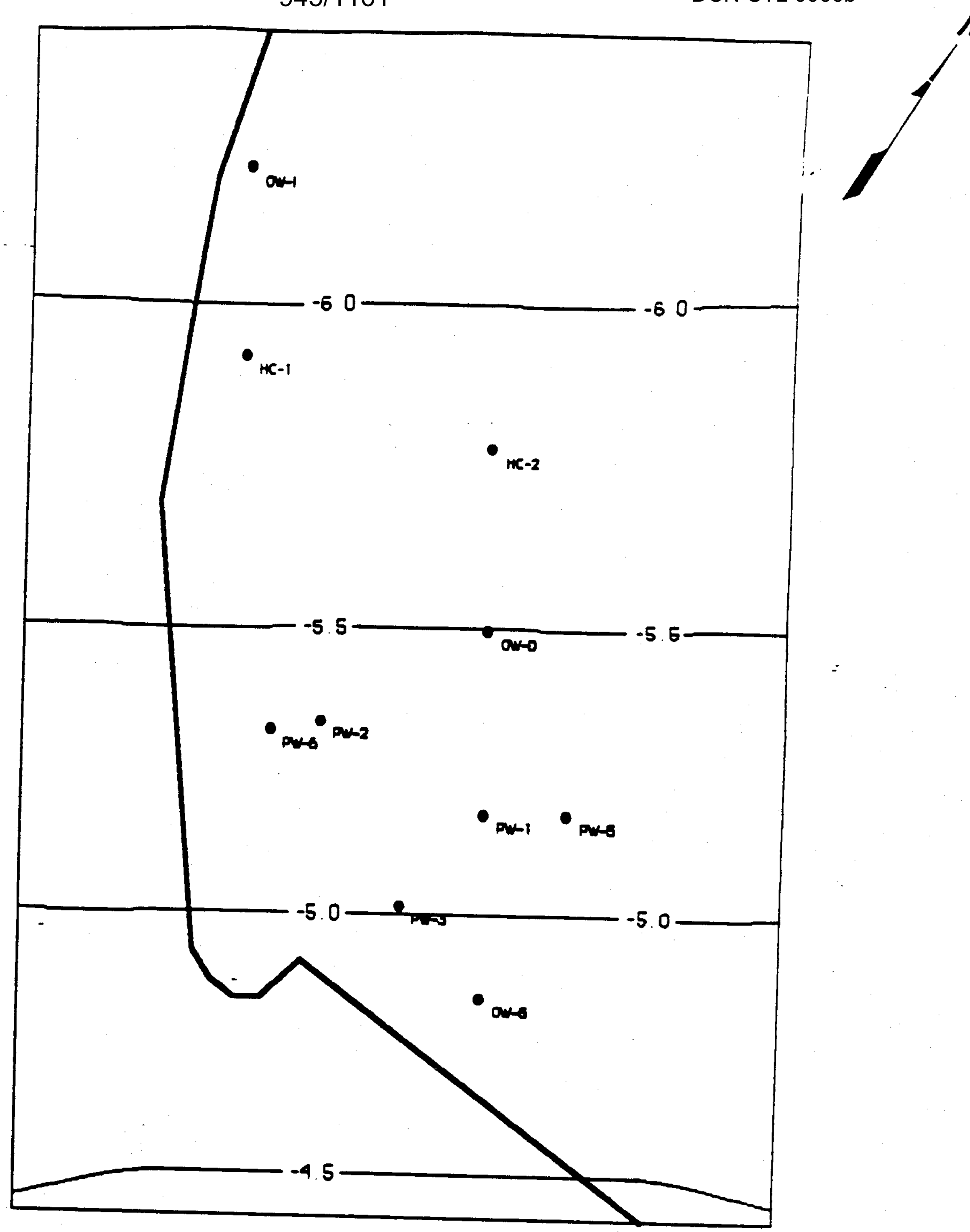
0 500 1,000 FEET

KEY:

—-5.0— PIEZOMETRIC CONTOUR IN FEET (M.S.L. DATUM)

Dames & Moore

FIGURE 38



CONTOURS OF ASSUMED INITIAL PIEZOMETRIC SURFACE OF THE UPPER RARITAN AQUIFER IN JANUARY 1976

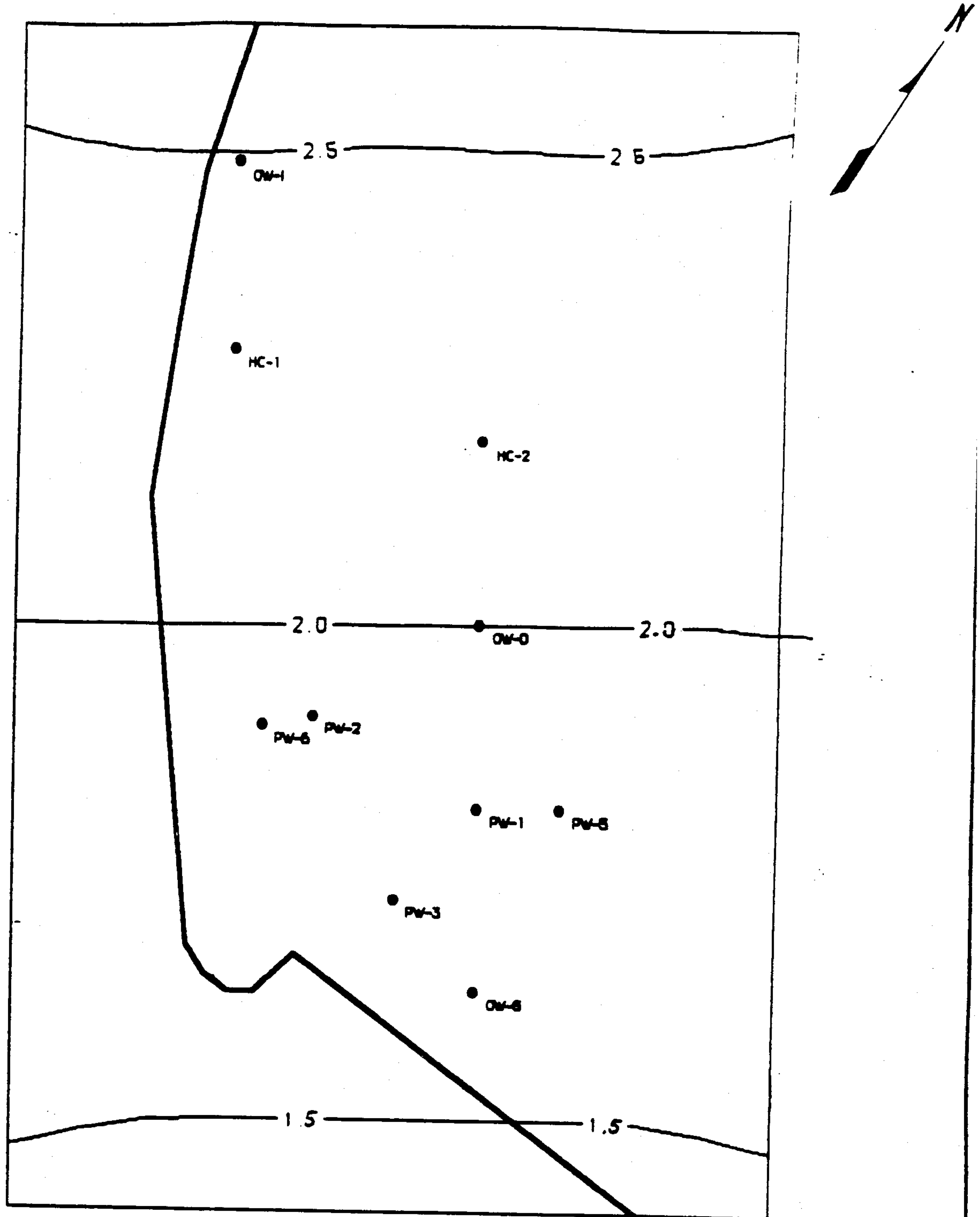
SALEM/HOPE CREEK GENERATING STATIONS PSE&G

0 500 1,000 FEET

KEY:
—-5.0— PIEZOMETRIC CONTOUR IN FEET (M.S.L. DATUM)

Dames & Moore

FIGURE 38



CONTOURS OF ASSUMED INITIAL PIEZOMETRIC SURFACE OF THE MT. LAUREL-WENONAH AQUIFER IN MARCH 1973

SALEM/HOPE CREEK GENERATING STATIONS PSE&G

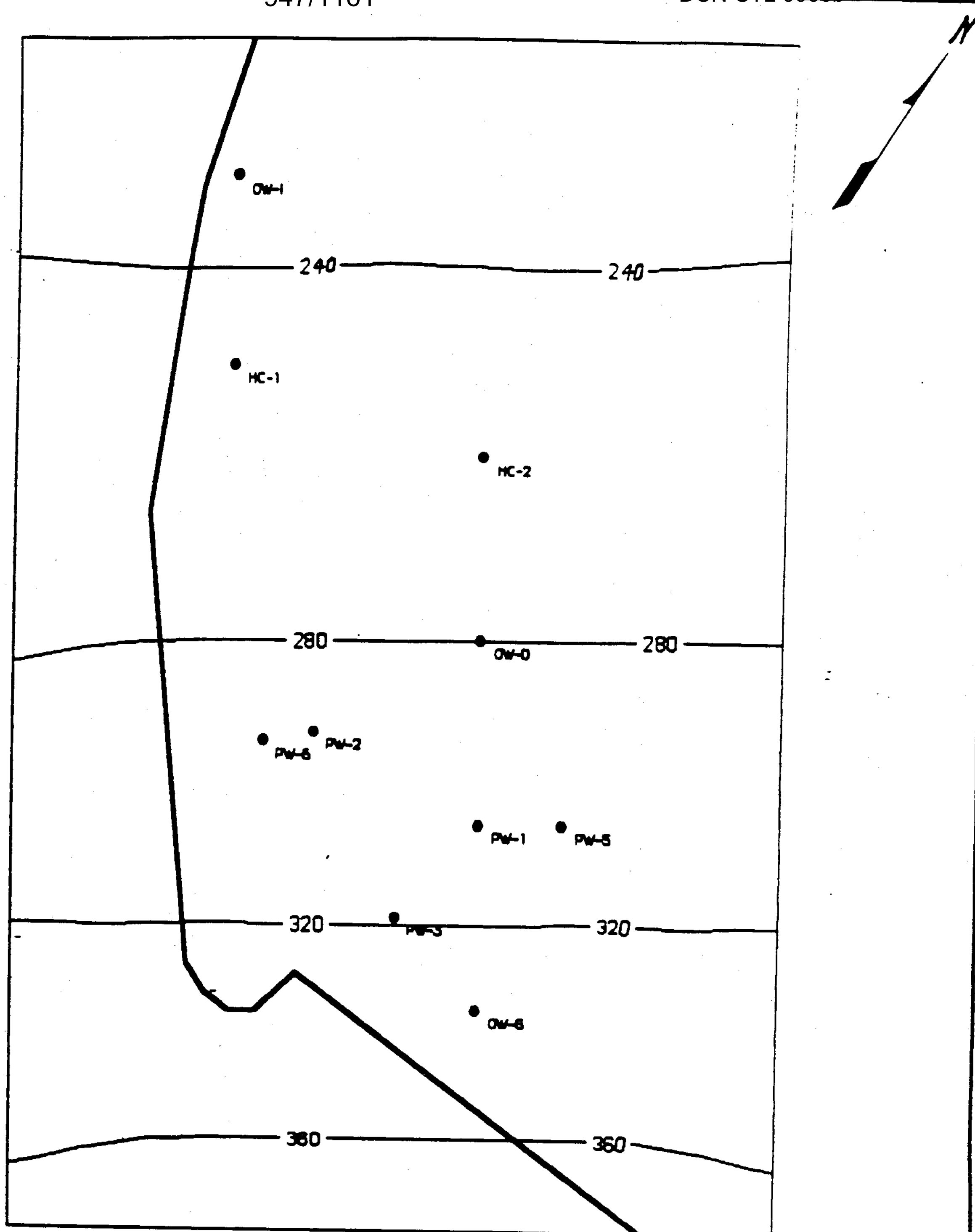
0 500 1,000 FEET

KEY:

—2.0— PIEZOMETRIC CONTOUR IN FEET (M.S.L. DATUM)

Dames & Moore

FIGURE 39



CONTOURS
OF ASSUMED INITIAL CHLORIDE CONCENTRATION OF THE MIDDLE RARITAN AQUIFER IN JUNE 1984

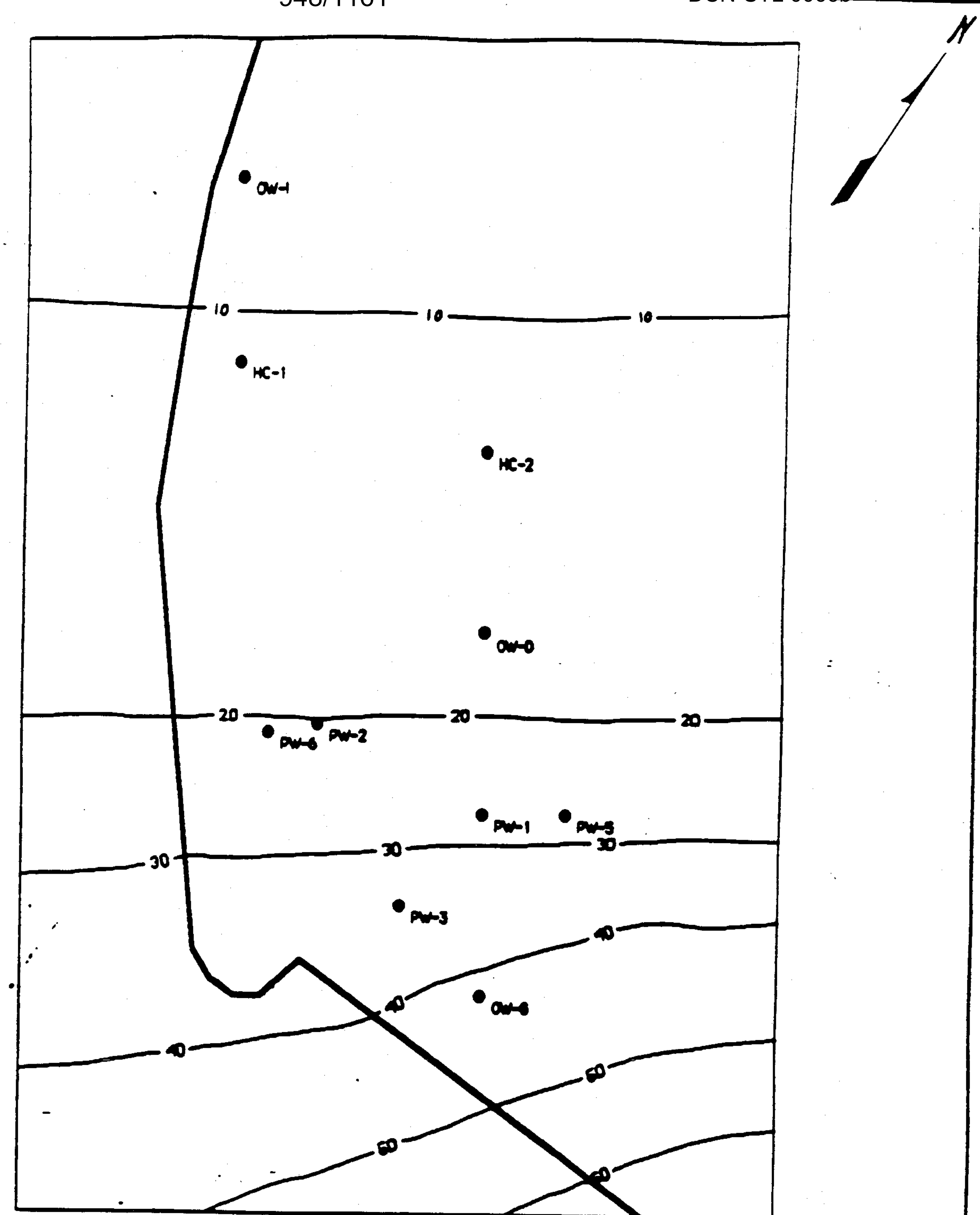
SALEM/HOPE CREEK GENERATING STATIONS
PSE&G

0 500 1,000 FEET

KEY:
—280— CHLORIDE CONTOUR IN mg/l

Dames & Moore

FIGURE 40



CONTOURS
OF ASSUMED INITIAL CHLORIDE CONCENTRATION OF THE UPPER RARITAN AQUIFER IN JANUARY 1976

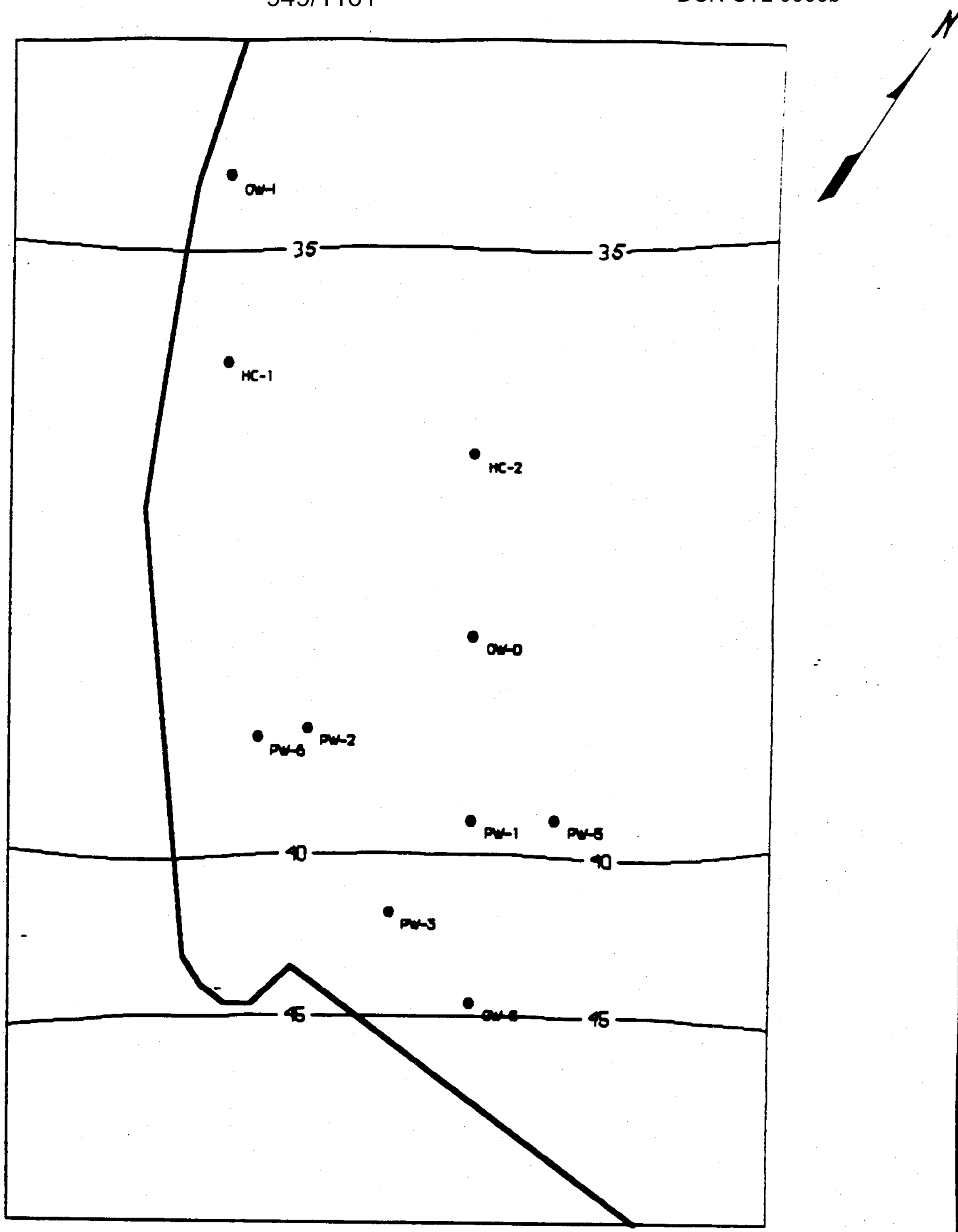
SALEM/HOPE CREEK GENERATING STATIONS
PSE&G

0 500 1,000 FEET

KEY:
—60— CHLORIDE CONTOUR IN mg/l

Dames & Moore

FIGURE 41



CONTOURS OF ASSUMED INITIAL CHLORIDE CONCENTRATION OF THE MT. LAUREL-WENONAH AQUIFER IN MARCH 1973

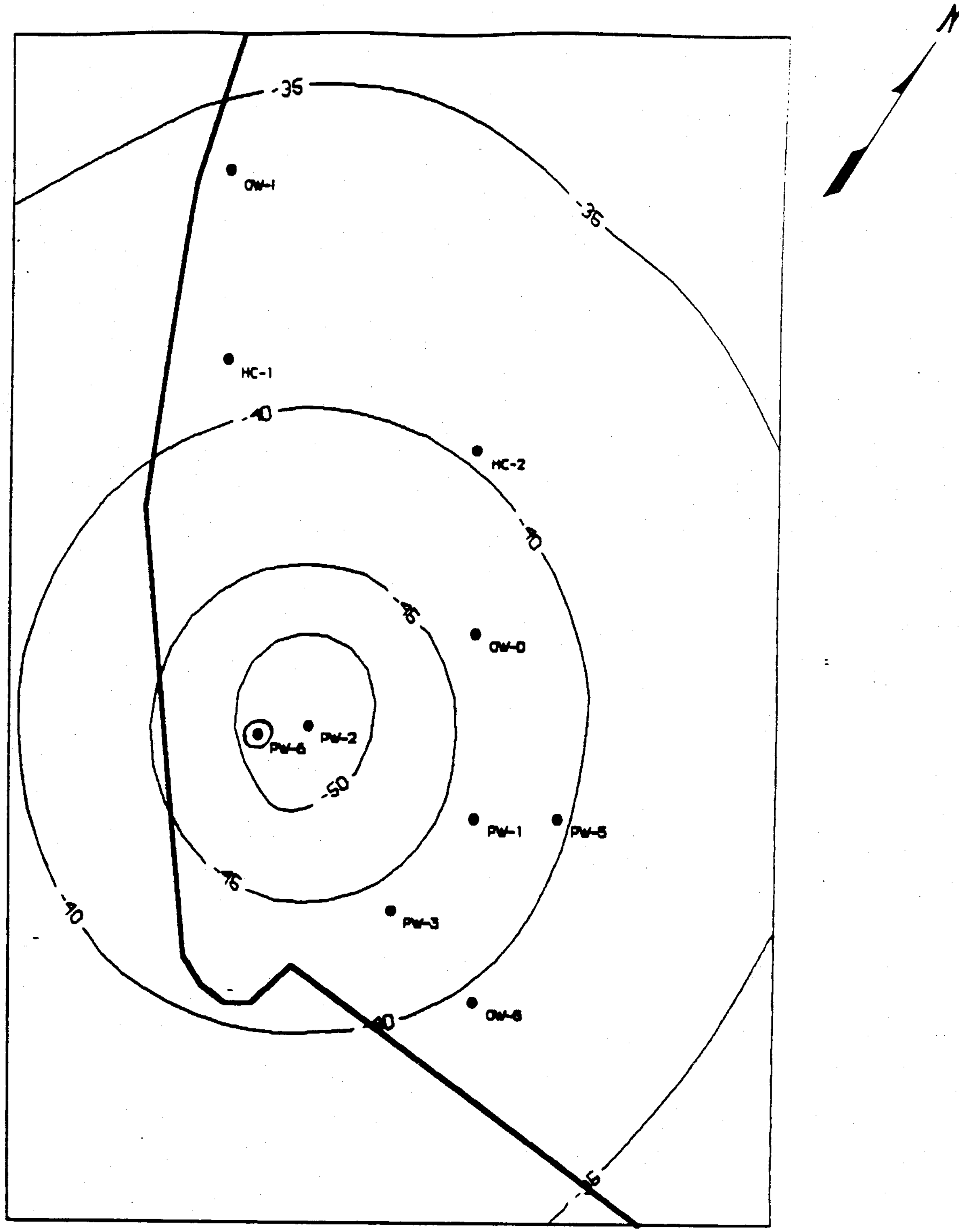
SALEM/HOPE CREEK GENERATING STATIONS
PSE&G

0 500 1,000 FEET

KEY:
—40— CHLORIDE CONTOUR IN mg/l

Dames & Moore

FIGURE 42



CONTOURS OF CALIBRATED PIEZOMETRIC SURFACE OF THE MIDDLE RARITAN AQUIFER FOR SUMMER 1987

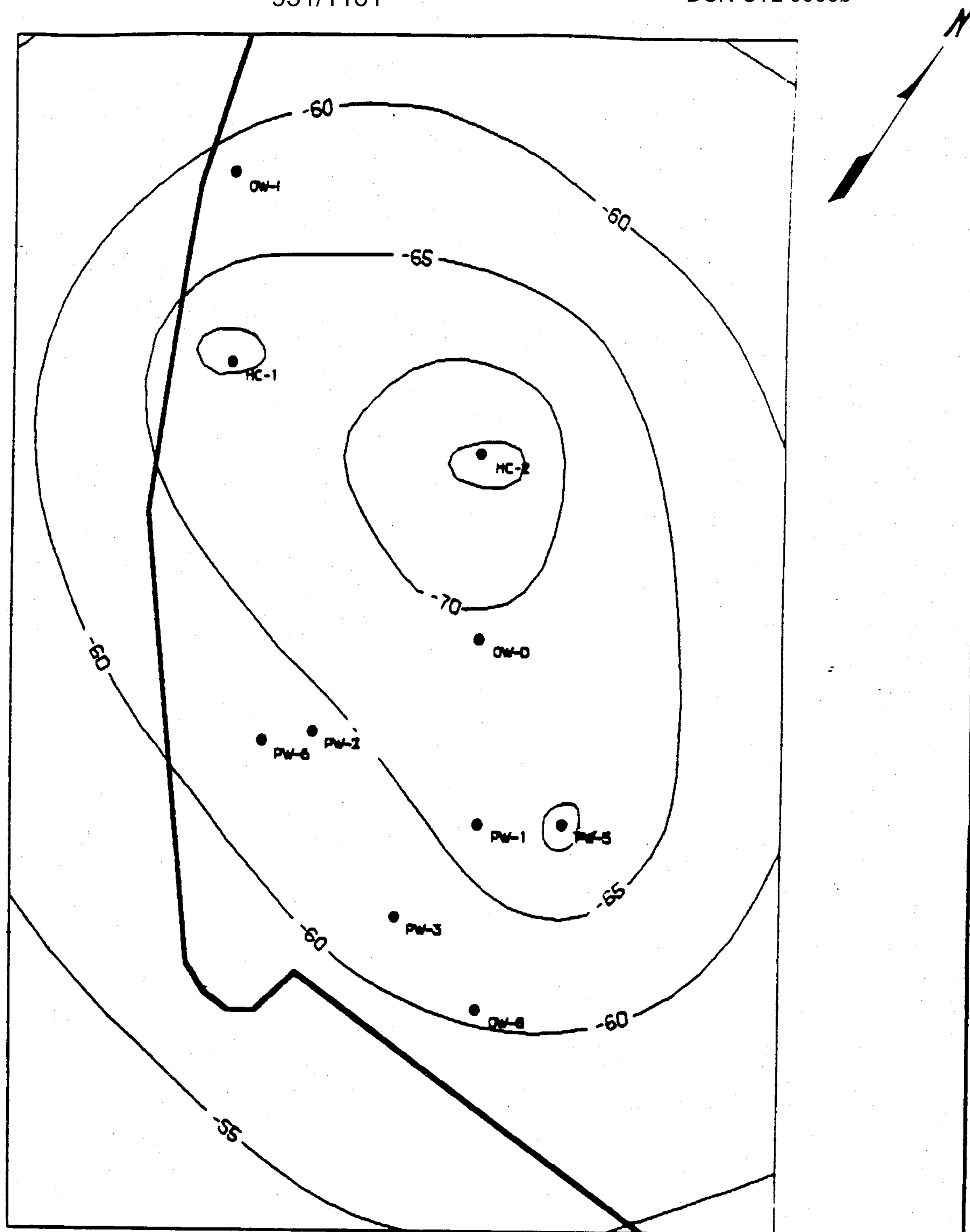
SALEM/HOPE CREEK GENERATING STATIONS
PSE&G

0 500 1,000 FEET

KEY:
-40.0 PIEZOMETRIC CONTOUR IN FEET (M.S.L. DATUM)

Dames & Moore

FIGURE 43



CONTOURS OF CALIBRATED PIEZOMETRIC SURFACE OF THE UPPER RARITAN AQUIFER FOR SUMMER 1987

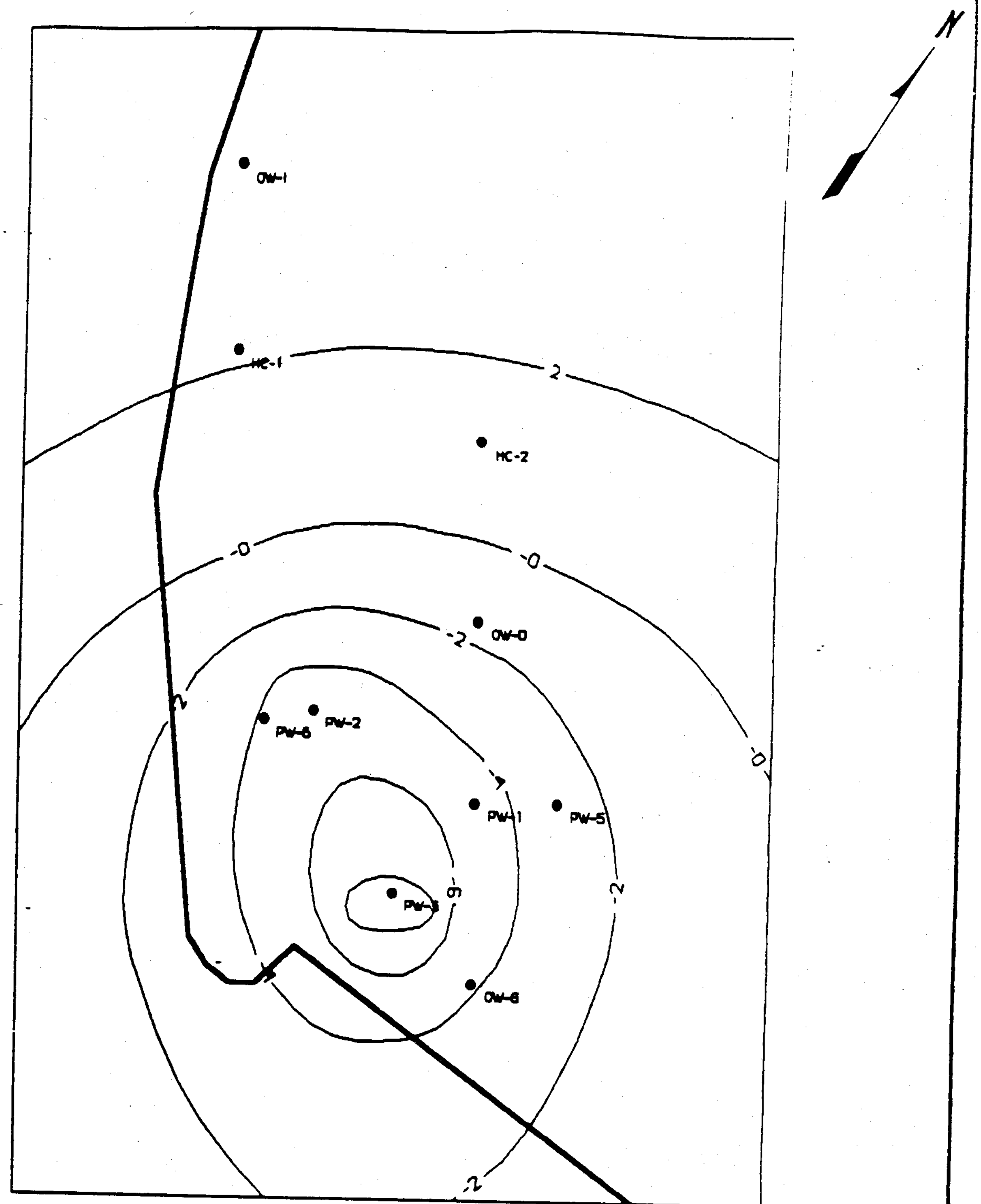
SALEM/HOPE CREEK GENERATING STATIONS
PSE&G

0 500 1,000 FEET

KEY:
—-65— PIEZOMETRIC CONTOUR IN FEET (M.S.L. DATUM)

Dames & Moore

FIGURE 44



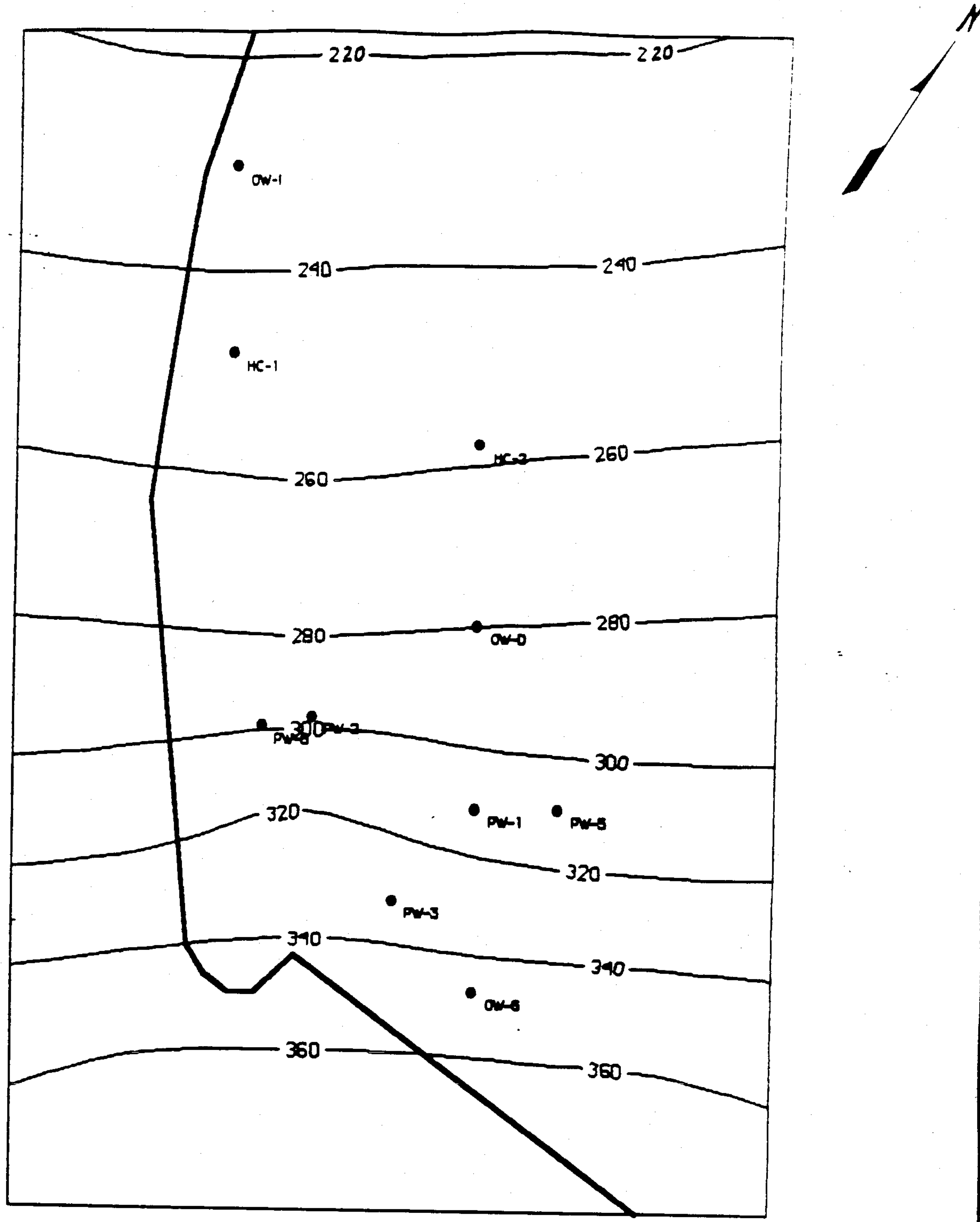
CONTOURS OF CALIBRATED PIEZOMETRIC SURFACE OF THE MT. LAUREL-WENONAH AQUIFER FOR SUMMER 1987

SALEM/HOPE CREEK GENERATING STATIONS
PSE&G

0 500 1,000 FEET

KEY:
—— -4 —— PIEZOMETRIC CONTOUR IN FEET (M.S.L. DATUM)

Dames & Moore



CONTOURS OF CALIBRATED CHLORIDE CONCENTRATION OF THE MIDDLE RARITAN AQUIFER FOR SUMMER 1987

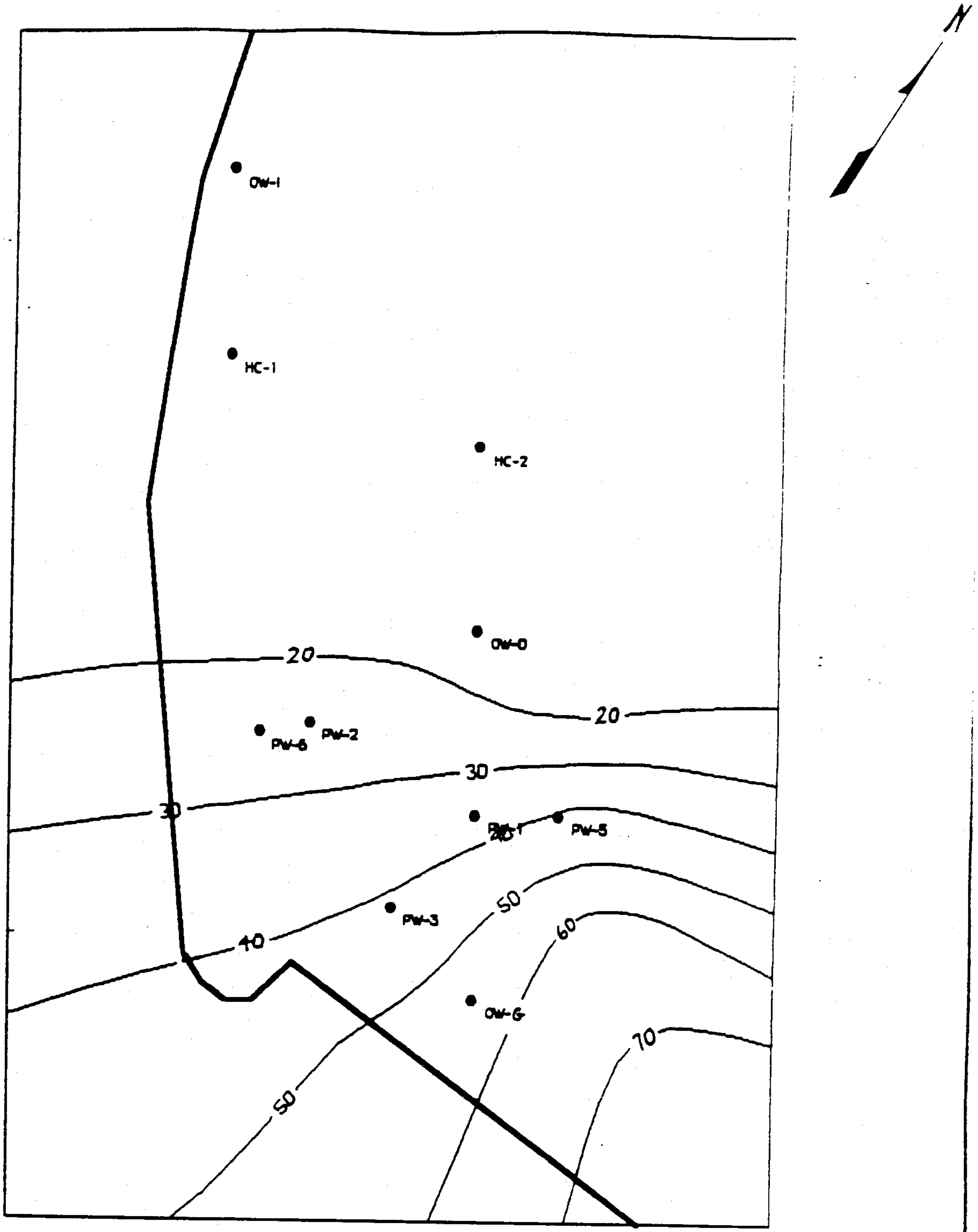
SALEM/HOPE CREEK GENERATING STATIONS
PSE&G

0 500 1,000 FEET

KEY:
—260— CHLORIDE CONTOUR IN mg/l

Dames & Moore

FIGURE 47



CONTOURS
OF CALIBRATED CHLORIDE CONENTRATION
OF THE UPPER RARITAN AQUIFER
FOR SUMMER 1987

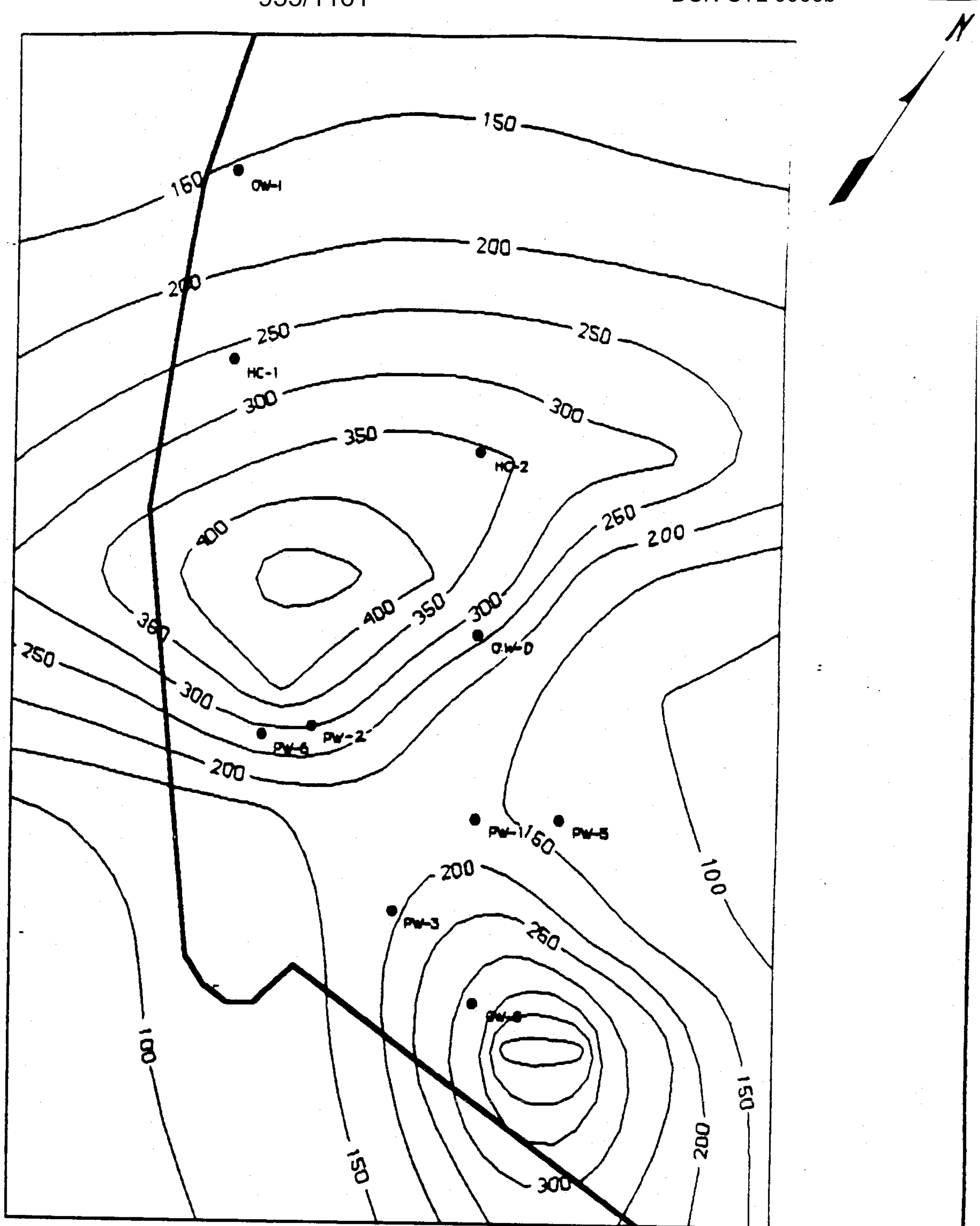
SALEM/HOPE CREEK GENERATING STATIONS
PSE&G

0 500 1,000 FEET

KEY:
—30— CHLORIDE CONTOUR IN mg/l

Dames & Moore

FIGURE 48



CONTOURS OF CALIBRATED CHLORIDE CONCENTRATION OF THE MT. LAUREL-WENONAH AQUIFER FOR SUMMER 1987

SALEM/HOPE CREEK GENERATING STATIONS

PSE&G

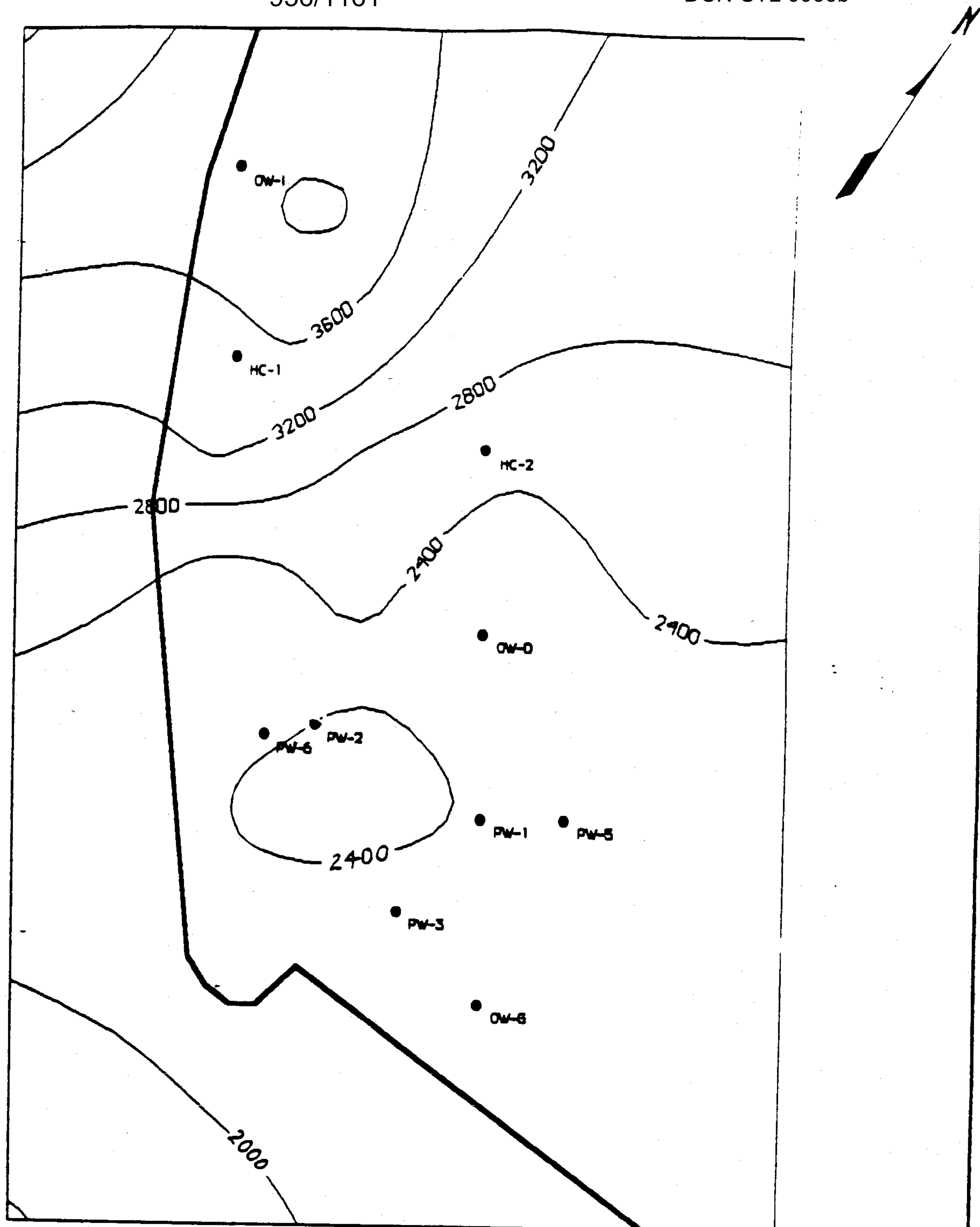
0 500 1,000 FEET

KEY:

—250— CHLORIDE CONTOUR IN mg/l

Dames & Moore

FIGURE 49



CONTOURS OF CHLORIDE CONCENTRATION OF THE VINCENTOWN AQUIFER FOR SUMMER 1987

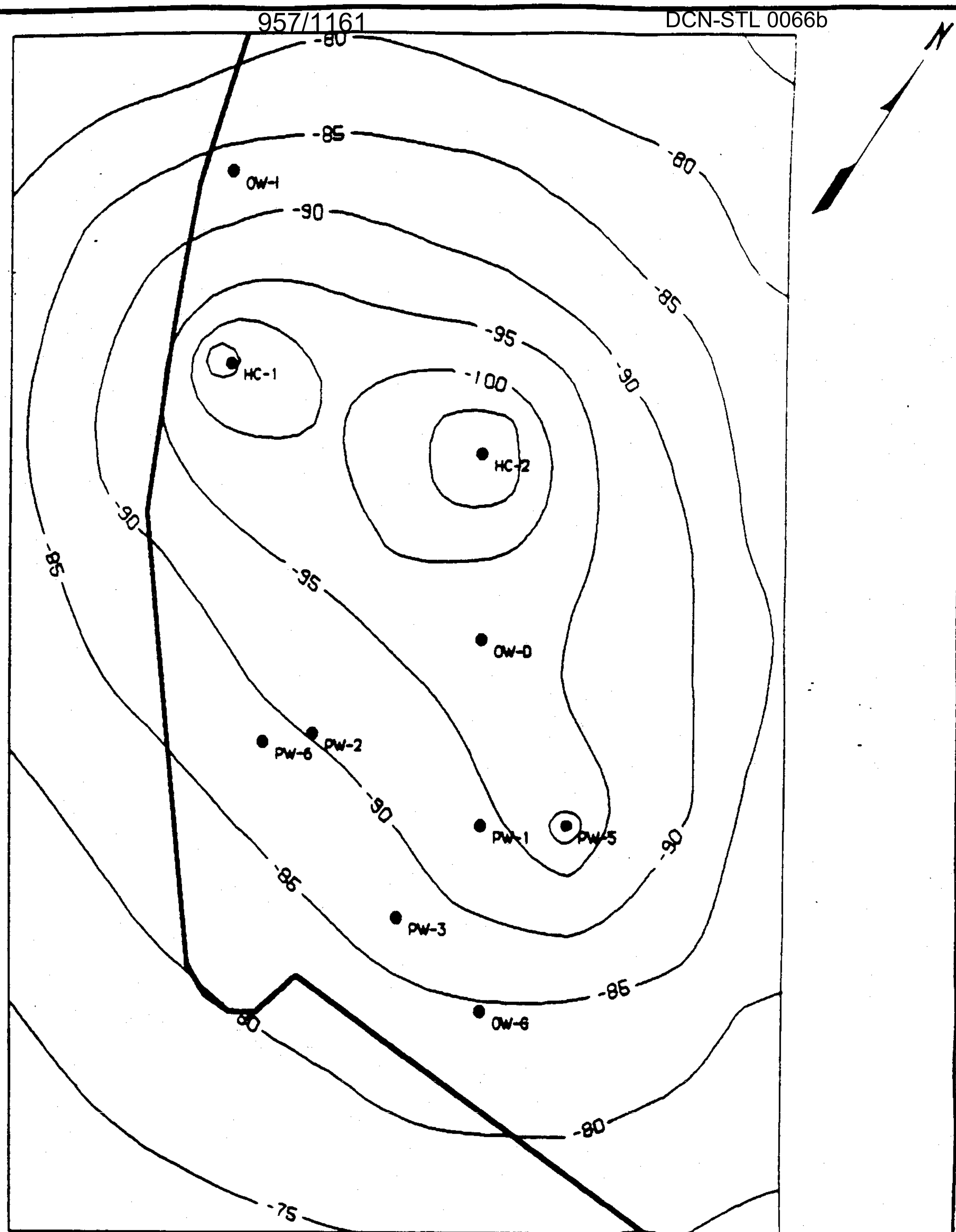
SALEM/HOPE CREEK GENERATING STATIONS PSE&G

0 500 1,000 FEET

KEY:
—2,400— CHLORIDE CONTOUR IN mg/l

Dames & Moore

FIGURE 50



PIEZOMETRIC CONTOURS IN UPPER RARITAN AQUIFER IN YEAR 2007 -PREDICTIVE RUN 4-

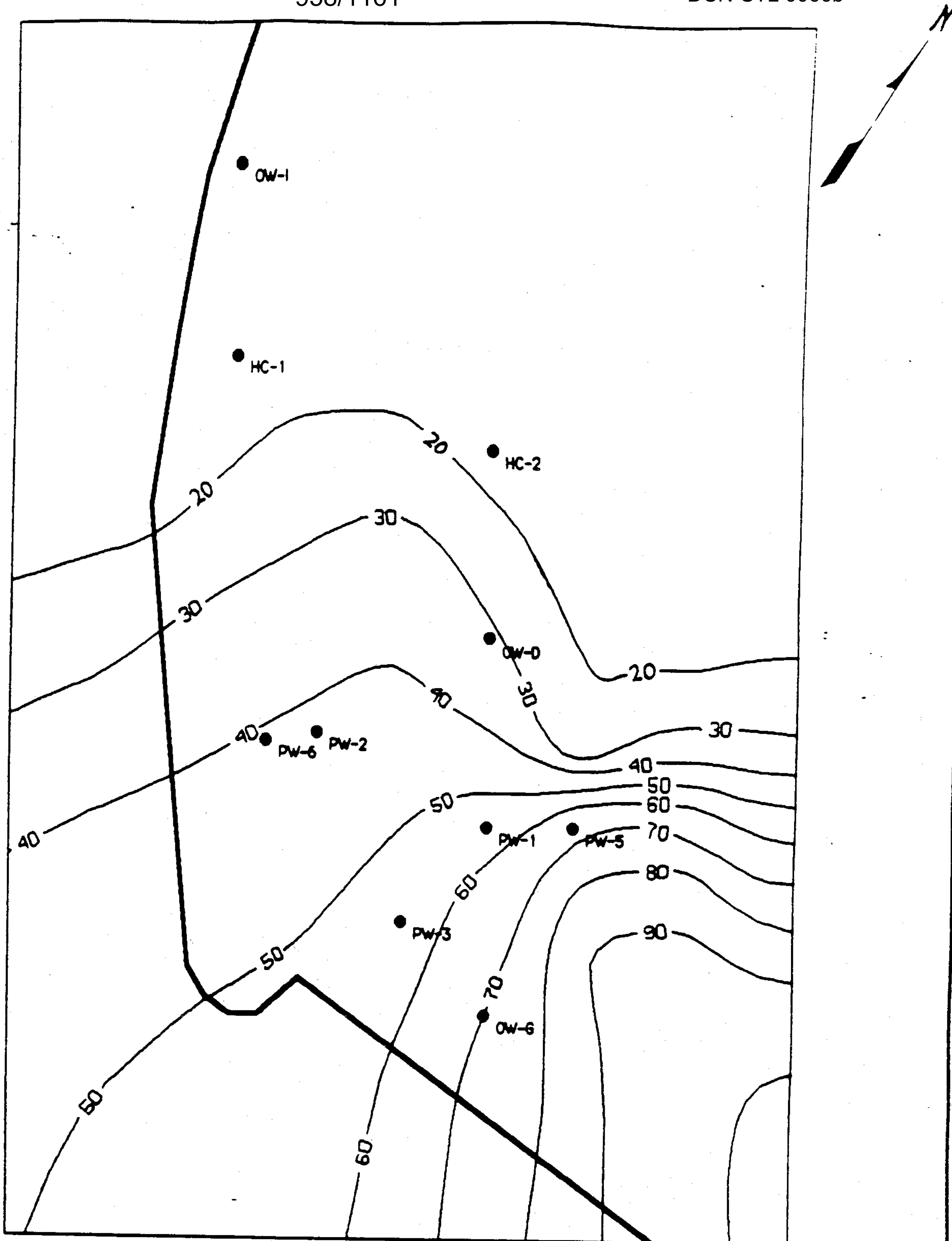
SALEM/HOPE CREEK GENERATING STATIONS
PSE&G

KEY:

— -90 — PIEZOMETRIC CONTOUR, FEET (M.S.L. DATUM)

Dames & Moore

FIGURE 51



CHLORIDE CONTOURS IN UPPER RARITAN AQUIFER IN YEAR 2007 -PREDICTIVE RUN 4-

SALEM/HOPE CREEK GENERATING STATIONS

PSE&G

KEY:

—80— CHLORIDE CONTOUR IN mg/l

Dames & Moore

FIGURE 52

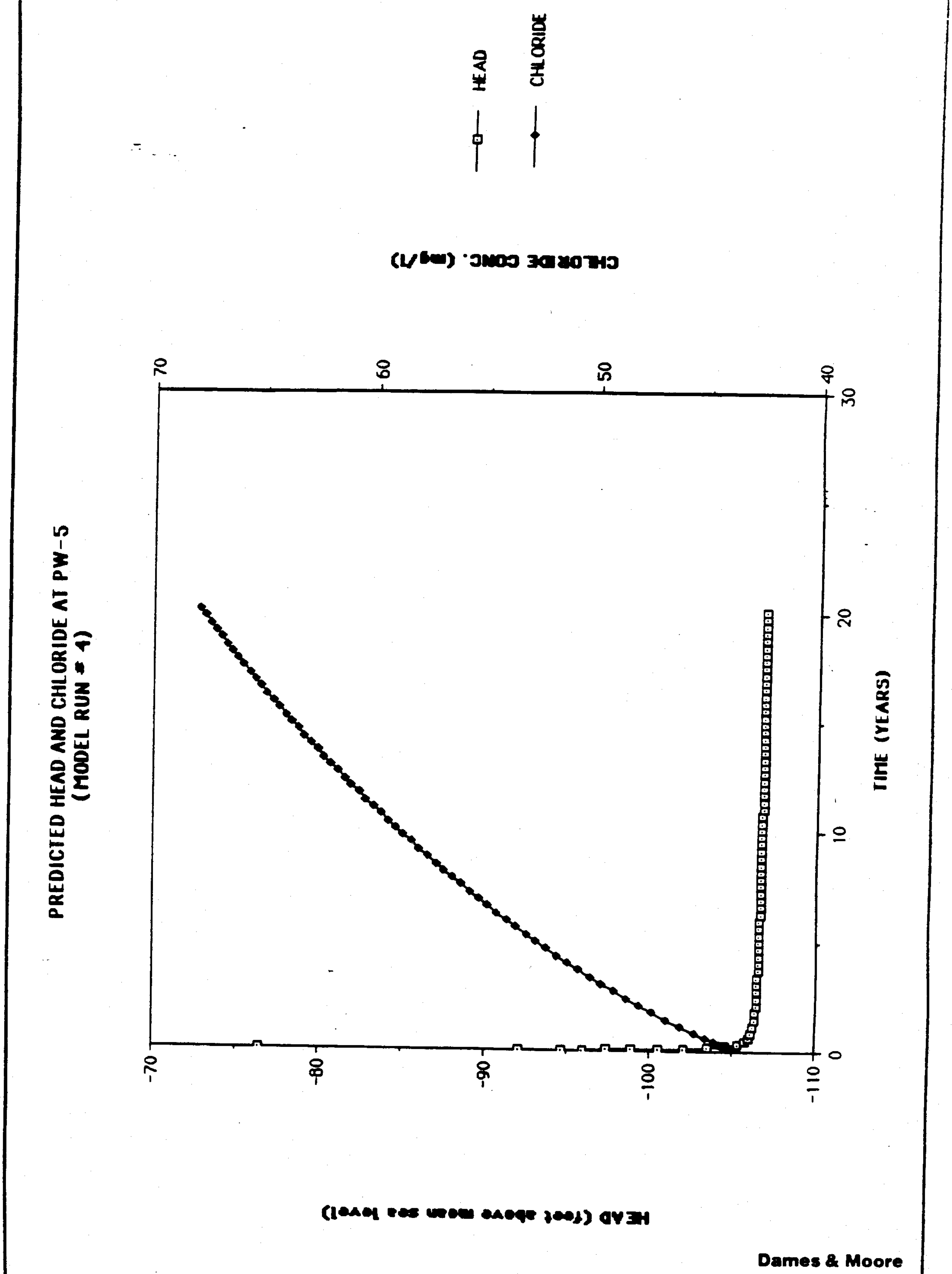
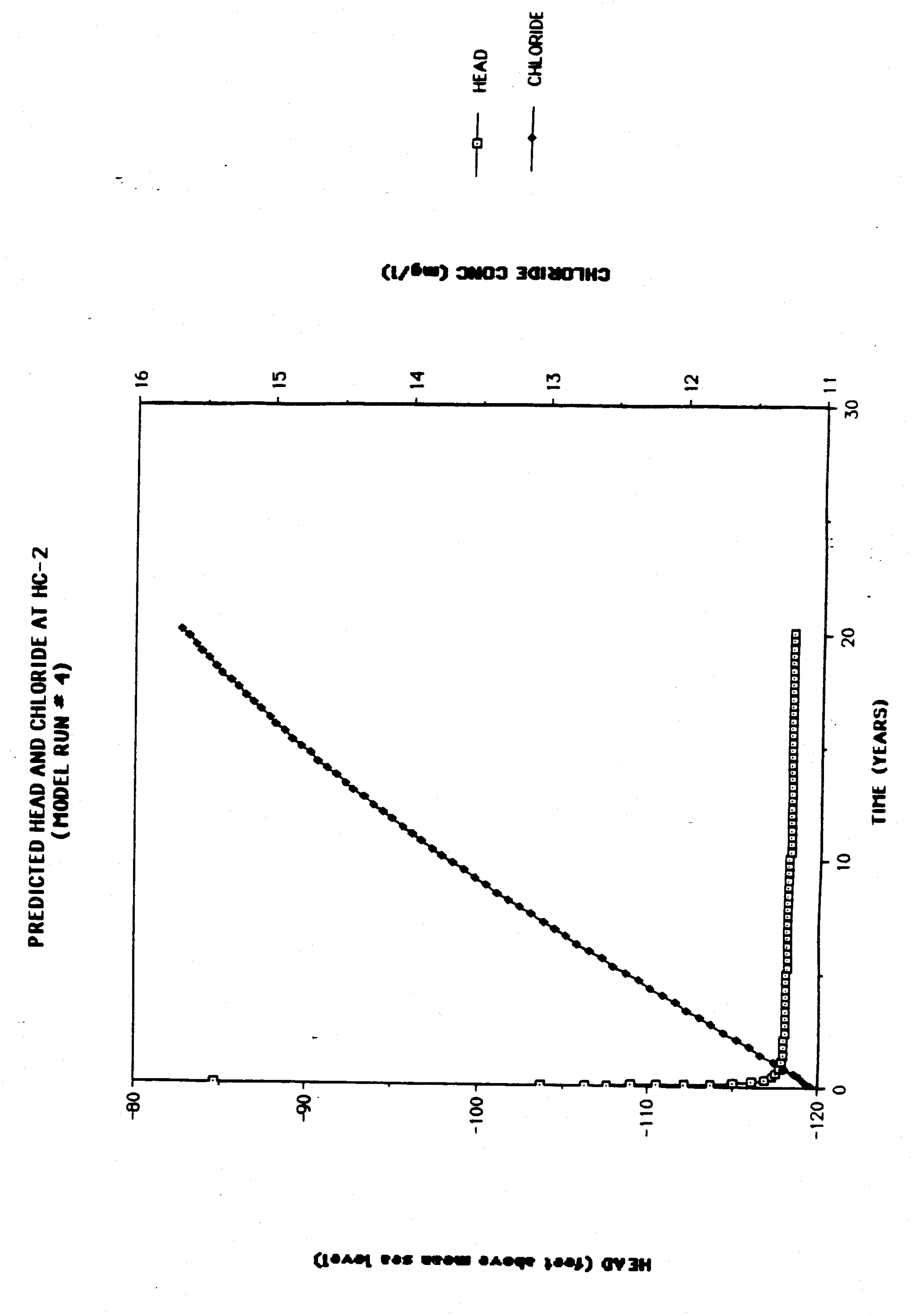
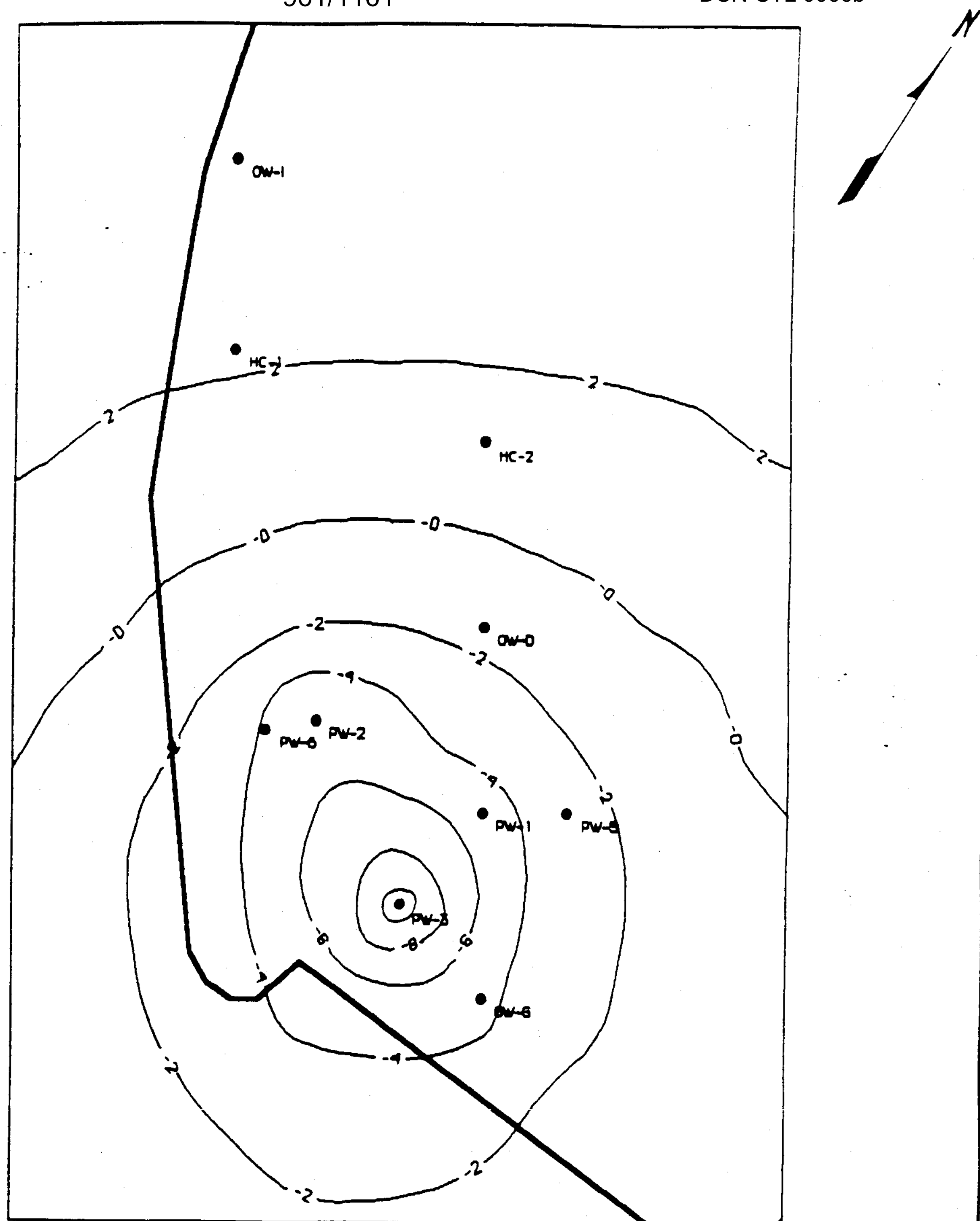

PREDICTED HEAD AND CHLORIDE AT PW-5
(MODEL RUN # 4)
HEAD
CHLORIDE
CHLORIDE CONC. (mg/l)
70
60
50
40
HEAD (feet above mean sea level)
-70
-80
-90
-100
-110
TIME (YEARS)
0
10
20
30
Dames & Moore

FIGURE 53



Dames & Moore

FIGURE 54



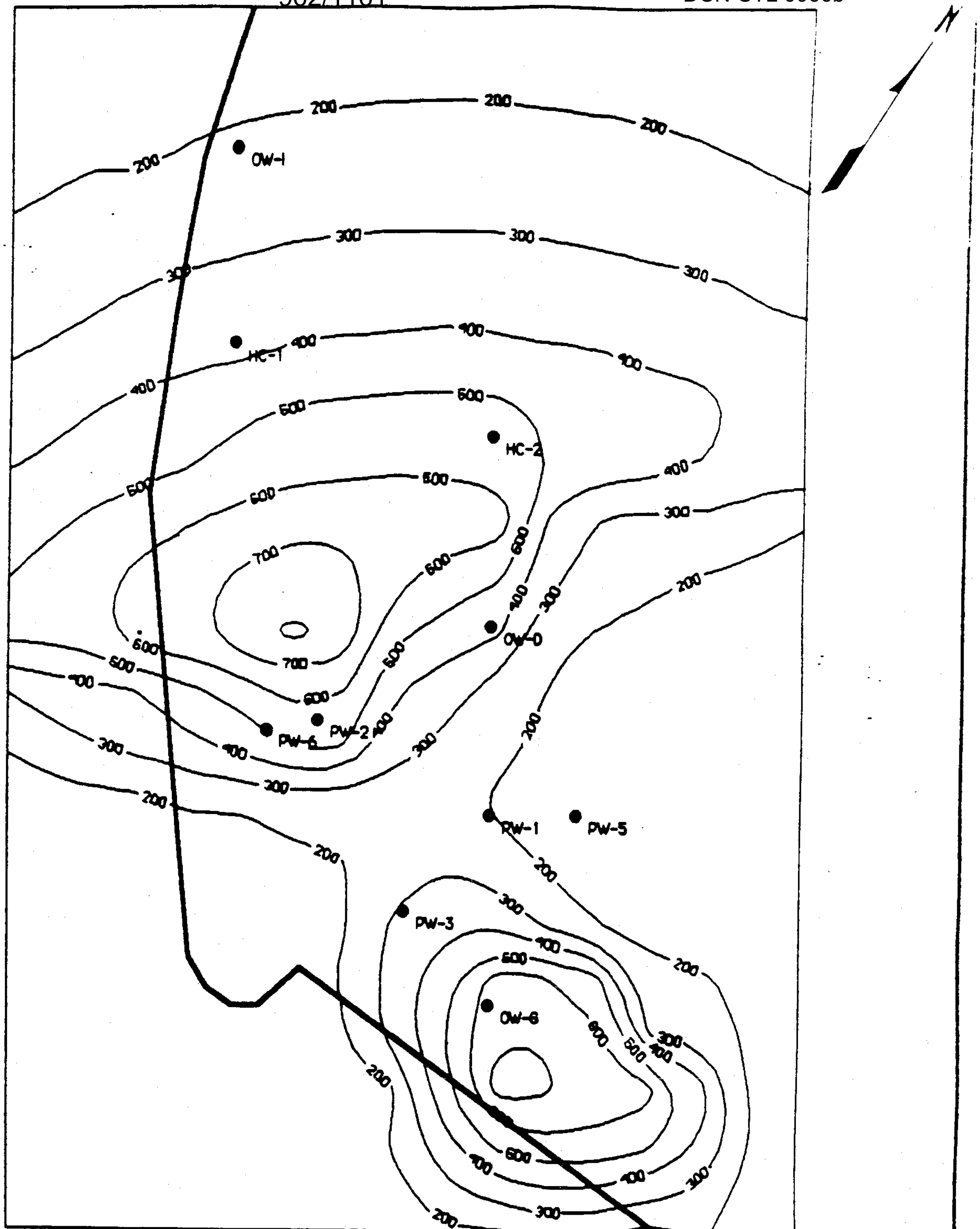
PIEZOMETRIC CONTOURS IN MT.LAUREL-WENONAH AQUIFER IN YEAR 2007 -PREDICTIVE RUN 1-

SALEM/HOPE CREEK GENERATING STATIONS PSE&G

KEY:

-2— PIEZOMETRIC CONTOUR, FEET (M.S.L. DATUM)

Dames & Moore



CHLORIDE CONTOURS IN MT.LAUREL-WENONAH AQUIFER IN YEAR 2007 -PREDICTIVE RUN 1-

SALEM/HOPE CREEK GENERATING STATIONS

PSE&G

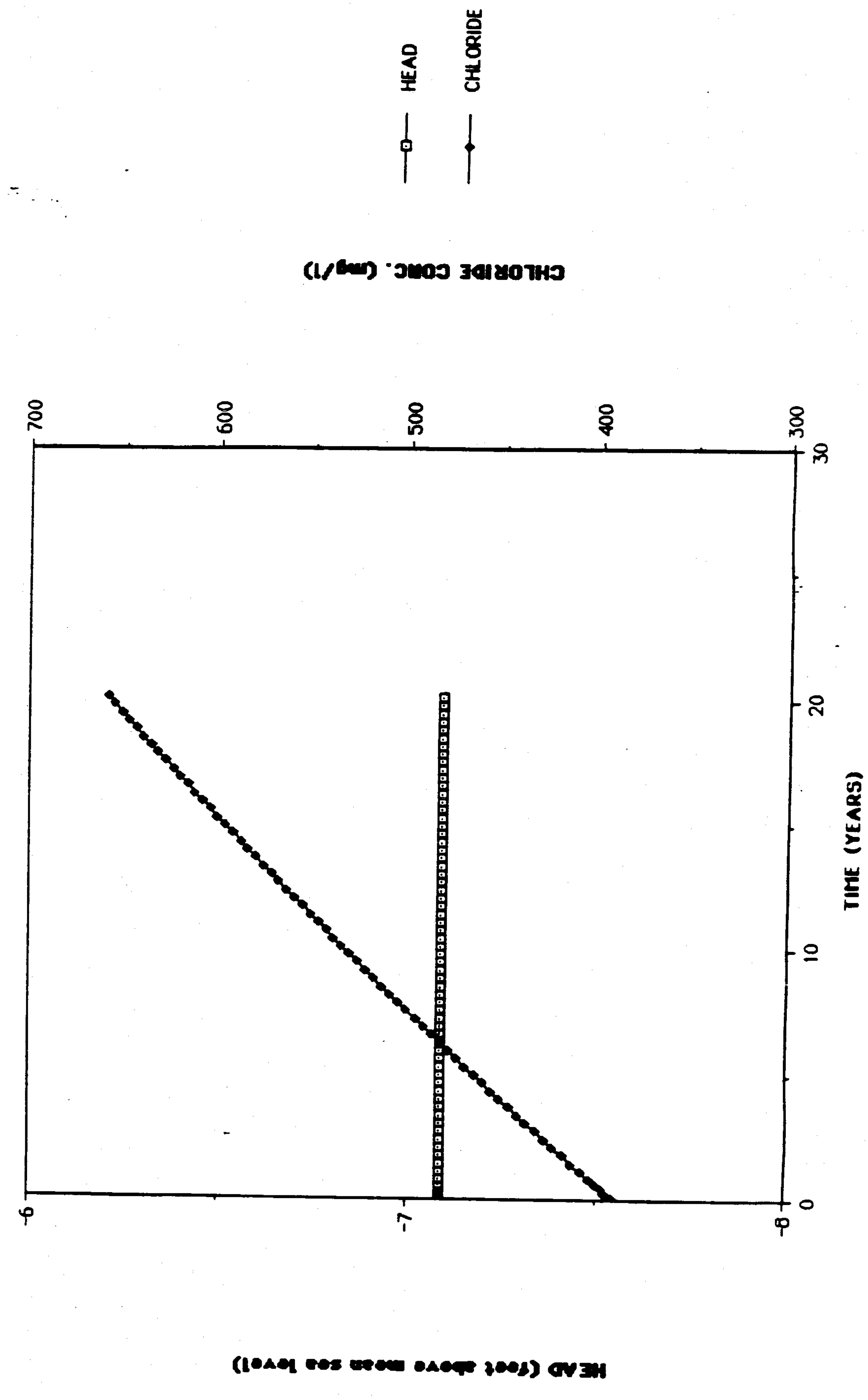
KEY:

—200— CHLORIDE CONTOUR IN mg/l

Dames & Moore

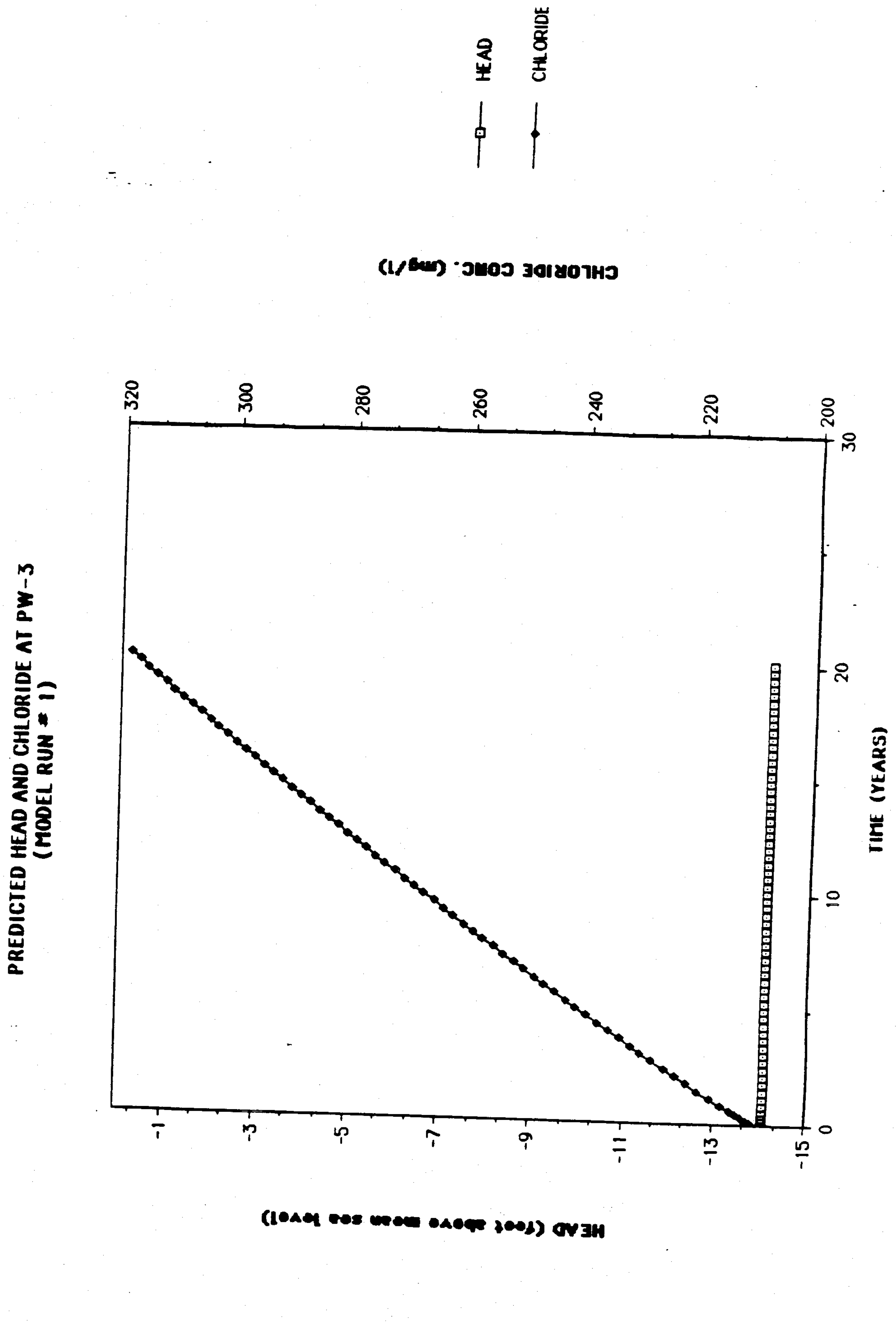
FIGURE 56

PREDICTED HEAD AND CHLORIDE AT PW-2
(MODEL RUN # 1)



Dames & Moore

FIGURE 57



Dames & Moore

FIGURE 58

SALEM/HOPE CREEK GENERATING STATIONS PSE&G

MAP OF PLANT AND VICINITY SHOWING LOCATION OF PROPOSED NEW OBSERVATION WELLS AND PRODUCTION WELLS

DAMES & MOORE

FIGURE 59