GROUNDWATER LEVELS AS AFFECTED BY SWINE WASTE LAGOONS IN HIGH WATER TABLE SOILS

by

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INTRODUCTION

The popularity of anaerobic lagoons for use with confinement swine operations in Southeast Virginia has been increasing in recent years. These lagoons are not difficult to build and maintain and have served as a feasible method of waste disposal in the region. This area typically has a high water table with sandy loam soils. There has been concern expressed by state officials that these units could possibly cause contamination of groundwater in the surrounding area due to infiltration from the lagoons to the water table. The deep aquifer in this area is a good potable source of water. Its low concentrations of minerals make it feasible for both private and industrial use.

This study was initiated to evaluate the possibility of a pollution hazard from anaerobic lagoons. The study involved two lagoons in Southeast Virginia. Both lagoons had heavy concentrations of ammonia, chlorides, and heavy metals, which could cause contamination of water supplies. Strict regulations prevent overflow from lagoons to protect surface waters, but there is a question as to the safety of the groundwater under the lagoons. Seepage could transport contaminants from the lagoon into the groundwater making large quantities of this important source of water unfit for use without special treatment. It may become necessary to reconsider the design and location of these types of lagoons in the future to prevent endangering natural resources if there is significant migration of dangerous contaminants from the lagoons to groundwater. Two swine waste lagoons were selected and instrumentation was placed to detect possible seepage by the observation of groundwater movement around them.

The objectives of this study were:

1) to measure groundwater levels around two selected swine waste lagoons, and

2) to determine if the lagoon affected the level of the water table.

LITERATURE REVIEW

Groundwater Mounds

A method of replenishing groundwater when surface supplies are available is recharge, which is ponding the water and allowing it to infiltrate into the ground. This has been done in the western United States where factors are favorable, as well as in other countries.

A mathematical equation derived from heat conduction problems was used by Bittinger and Treleace (1965) to describe the shape of a groundwater mound as it was developed and dissipated under a circular recharge basin. Actual data were compared with theoretical results by using a reservoir as a test basin with a resulting mound of several square miles.

Field observations by Bianchi and Haskell (1975) analyzed the Dupuit-Forchheimer theory of mound heights under a recharge basin. Varying the recharge resulted in rising and falling of the mound heights, which was compared to theoretical rates and changing shapes. The amount of moisture in the valdose zone[1/] was found to influence the rate of drainage from the basin through the soil to the water table. The mathematical treatment of groundwater seepage has also been studied by Khan (1973). He analyzed two- and three-dimensional groundwater mounds under a rectangular recharge basin on a permeable, homogeneous, and isotropic soil.

The presence of a groundwater mound under a water basin has been measured by Wilson and Cook (1968). Perforated observation wells were

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[1/] Groundwater between the ground surface and the water table placed 46 m below the ground in selected areas adjacent to a river, and a series of piezometers was installed around the wells at various depths. These wells suggested a direct correlation between the river stage and the water level in the observation wells. Possible deep water percolation from the river apparently influenced the groundwater level in the surrounding area. Considerable amounts of water were supplied to the groundwater from storage in the valdose zone after the surface supply ended, especially in cases of deep water tables.

Formation of groundwater mounds has been studied and observed by Bianchi and Haskell (1975) under artificial recharge basins by means of a series of observation wells placed in the bottom of the basin. There was a zone between the bottom of the basin and the groundwater table in which the groundwater mound was observed to rise and fall during and after recharge. Observations of wells at different depths under the basin indicated the existence of a perched water table above the normal groundwater level as a result of a constricting layer when the basin was filled with water. This rising and falling of the mound was also theoretically described by equations and by a graph of the actual results.

Groundwater Conditions

The groundwater conditions in the Suffolk, Virginia, area have been altered considerably in the last 50 years. Brown and Cosner (1974) prepared an atlas showing changes of the potentiometric surface of the deep aquifer of Southeastern Virginia. Groundwater once flowed to the surface in this area due to the potentiometric head being higher than the ground surface. Due to a large withdrawal of groundwater from the Franklin area, the groundwater flow has shifted and is moving down and toward Franklin in a large region of Southeast Virginia. This deep water movement is in the lower Cretaceous aquifer, which runs from the eastern Piedmont region to the coast, and is the source of groundwater for Southeast Virginia. Most of this aquifer is replenished by percolation from the shallower groundwater bodies that overlie this aquifer. Any contamination of upper groundwater supplies could therefore cause similar contamination of the aquifer.

Solid waste disposal has been a problem in central Florida (Stewart and Duerr, 1973), where improper disposal of this waste could cause contamination of Florida's fresh water supplies due to infiltration from a high water table and sandy soil in which the waste is disposed. This region has a deep aquifer that is supplied by percolation from sources of water around the high water table.

Lagoon Seepage

The mass transfer method was used by Fossum (1972) to determine the amount of evaporation and seepage loss from a lagoon. Seven sets of observation wells were installed starting at the sides of two municipal lagoons and extending outward 152 m. Samples were taken from these wells for chemical analysis, and the groundwater levels were recorded. By recording the stage of the lagoons it was possible to estimate seepage rates. It was apparent from the water table profiles that the lagoons had a significant effect on the water table 92 m to 122 m away from the lagoon. It had also been discovered that groundwater levels, which were normally 1 m or 2 m deep were raised enough around the lagoon to interfere with normal crop growth out to 92 m. Samples that were taken indicated a decrease in the concentration of natural chemicals in the groundwater as a result of horizontal movement of seepage from the lagoon which diluted the natural groundwater surrounding the lagoon. There was also a possibility of horizontal groundwater movement around the lagoons not related to the lagoon seepage.

The hydraulic conductivity of different soil types was analyzed by Chang et al. (1974). The soils, ranging from sand to clay, were placed in columns and installed at the bottom of a new lagoon. The lagoon was then filled with clean water and the first set of columns was recovered and analyzed for conductivity. The lagoon was then used for receiving wastewater and columns were taken out of the bottom of the lagoon in intervals over the next sixty four days. This analysis revealed an initial reduction of hydraulic conductivity, especially in the sandy soil due to compaction, followed by a gradually decreasing conductivity. Within thirty days water movement was no longer detectable under laboratory conditions except in the sand columns. The conductivity at the surface layer was less than the deeper layers, which suggested a restricting barrier at the surface zone was gradually extending downward with time. There was an initial mechanical sealing at the surface but it was not sufficient to stop water movement. The chemical changes in the soil did not influence the sealing process to any extent. From their results in the three different soil types used, the biological clogging sealed off the soil, stopping water movement completely. They suggested the seepage of the lagoon before sealing occurs could be very significant and could become a source of contamination to groundwater, especially in areas of shallow groundwater tables. The drying of the soil after it was submerged with wastewater caused the conductivity to return to its initial rate before submergence.

Nordstedt et al. (1971) analyzed the operation of multistage dairy waste lagoons for efficiency and environmental safety in handling effluent. One of their objectives was to ascertain the groundwater pollution potential of the lagoons in a sandy soil where the groundwater level was near the ground surface. There was also a clay layer under the lagoons, which possibly restricted vertical movement of water. Water samples were taken from wells at different distances from the lagoons and examined for pollutants as an indication of seepage. Some seepage was detected around the anaerobic lagoon as evidenced by a high concentration of nitrates, salts, and BOD_5[1/] in the sample groundwater. The effects of seepage were not observed in the wells 30 m and beyond.

Davis et al. (1972) measured the infiltration through the bottom of a new liquid manure pond in an area where the water table was fairly deep in the ground. Ponds were filled with clean irrigation water and the infiltration rate was measured. The ponds were then filled with wastewater and measurements of infiltration were taken. The results showed a 200-fold reduction in the infiltration rate after flooding with the wastewater. It was concluded that there was very little downward movement of dairy manure wastewater through the pond bottom. Their analysis indicated biological sealing of the pond soil to be the principal factor involved in stopping infiltration due to bottom slime and rapid depositions of biological sludge. Clean water infiltration rates

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[1/] The quantity of oxygen used in the biochemical oxidation of organic matter under specified conditions for five days averaged 122.0 cm per day while, after two weeks of adding manure water, it dropped to 5.8 cm per day and after four months, 0.5 cm per day.

Preul (1968) investigated the concentration levels and travel distances of contaminants in groundwater near ten lagoons used for holding wastewater for small municipalities. These sites were chosen for their high infiltration rates in a sandy or silty subsoil to study the travel of contaminants under extreme conditions. Observation wells were placed for sampling at various distances from the lagoons in the apparent direction of groundwater flow. At five of the lagoons, wells were placed in the bottom to take samples of groundwater directly under them. There was an increase in contaminants in the groundwater close to the lagoon, which generally decreased with the distance from the lagoon. Samples taken directly under the lagoon revealed contamination was considerably less than that in the lagoons, indicating absorption and biological transformation to be effective to some extent. Preul's results were to be used in determining safe distances between wastewater lagoons and shallow groundwater supplies in a silty or sandy soil.

A series of eight small lagoons 1.2 m in diameter was built by Hart and Turner (1965) to study dairy and poultry manure loading and decomposition in a lagoon treatment process. Large infiltration losses were noticed in these lagoons, and these losses were considered important. It was suggested that biological sealing alone would not stop loss of lagoon water by infiltration.

A study around the Suffolk area was begun to investigate possible groundwater contamination around three swine lagoons (Ciravolo, 1976b). Sampling wells were installed at various distances from the lagoons and at 3.0, 4.6, and 6.1 meter depths relative to the ground surface. Two series of wells were placed around two of the lagoons at 3, 15, and 30 meter distances, while one lagoon had three series of wells at 3 and 15 meter distances. Groundwater samples were tested primarily for NH_4, NO_3, Cl, and fecal coliform. The data at the time of their presentation indicated low levels in all wells for fecal coliform. Chloride measurements indicated some pollutants at the 3.0 m depth, 3 m distance, and much lower concentrations in the rest of the wells. There was little apparent movement of pollutants beyond the 3 meter wells at one lagoon. Limited data at the other two lagoons indicated a trend similar to this. These wells were left in place by Ciravolo (1976b), and were used in the work reported herein for determining conductivity rates at different depths.

PROCEDURE

Analytical Methods

Water flows, according to Darcy's law, from a higher to a lower elevation on an energy gradient described mathematically by the equation:

$$Q = kA \frac{d(z+p/\gamma+c)}{dl}$$

where: Q = water flow, cfs

k = hydraulic conductivity, ft/sec

A = area, ft^2

z = elevation of point from datum, ft

p = pressure, psf

γ = specific weight, lbs/ft^3

c = arbitrary constant, ft

l = length of flow path, ft

The energy term resulting from the velocity of groundwater flow may be neglected because of its small quantity relative to the total energy. If there is no water pressure in the aquifer, the equation reduces to a form where the velocity of groundwater is directly proportional to the difference in elevation of the water table. A change in water elevation around the lagoons would indicate a flow in the direction of steepest gradient. A series of wells perpendicular to the edge of the lagoon would reveal any change of the water table and any movement of water from or into the area of the lagoon. This method was used for determining the presence of seepage around the two lagoons studied.

Site Selection

The area selected for this study was in Southeast Virginia where there existed a need for the investigation of lagoons in sandy soils and located above a shallow water table. There are many lagoons[1/] in this region resulting from high swine production. Three of these lagoons were used by Ciravolo (1976b) in his study of potential groundwater contamination. Two of these lagoons were selected for this study after examining the local conditions at each. The first one selected was an anaerobic swine lagoon (Fig. 1) and was located at the Tidewater Research and Continuing Education Center (Holland Station). There was a built up embankment around this lagoon which would allow the water to rise approximately 1.2 m above the natural ground surface. This differential in elevation caused a potential hydraulic gradient between the lagoon and the water table, which was greater than the other lagoons. This lagoon was placed into service in the Fall of 1974. There was an overflow lagoon located directly to one side of this lagoon and a wooded area on the opposite side. The second lagoon chosen was operated by a private swine producer and was located 8 km away from Holland Station (Fig. 2). This site was characterized by a very sandy soil, a swampy area to one side of the lagoon, and swampy woodland directly behind. There were unusual nitrate readings recorded at this site by Ciravolo (1976a) which made further investigation of water movement desirable.

[1/] A lagoon is a water inpoundment in which organic wastes are stored or stabilized.

Fig. 1 Holland Station anaerobic lagoon on left and aerobic lagoon on right. Two series of wells are visible at top center of photograph.

Fig. 2 Private farm anaerobic lagoon.

Development of Wells

Design features for the wells were dependent on the local conditions encountered. The dominant soil in the Suffolk area is a sandy loam with randomly located lenses of silty clay. It was impossible to determine by checking soil and geology maps what conditions existed under and around each lagoon and to establish areas where subsurface water flow would tend to be restricted. Discussion with local scientists at Holland Station did not reveal any knowledge of a significant horizontal restriction involving a large area in the top 6 m of soil. Rainfall records were used to indicate when water would be entering the water table. In a study by Amos and Hallock (1976) the water table level was recorded at Holland Station at weekly intervals. The low levels were approximated from this chart, which provided an estimate of the water table level during summer drought. Ciravolo (1976a) also gave estimates of the local levels of the water table around the lagoons. A strong correlation existed between rainfall and water table (Amos and Hallock, 1976). The water table was sensitive to rainfall and drought. This indicated that the water table in this area had no restricting layers above it.

The spacing of each of the fifteen wells was planned according to the theoretical shape of a groundwater mound (Fig. 3). Since the change in slope is greater near the water source, the wells were spaced closer together near the lagoon and the spacing increased as the distance from the lagoon increased. The first six were placed 0.76 m apart, the next two were set 1.52 m apart, the next three, 3.0 m apart, the next two, 6.1 m apart, and the last well 36.6 m from the lagoon. The depths of

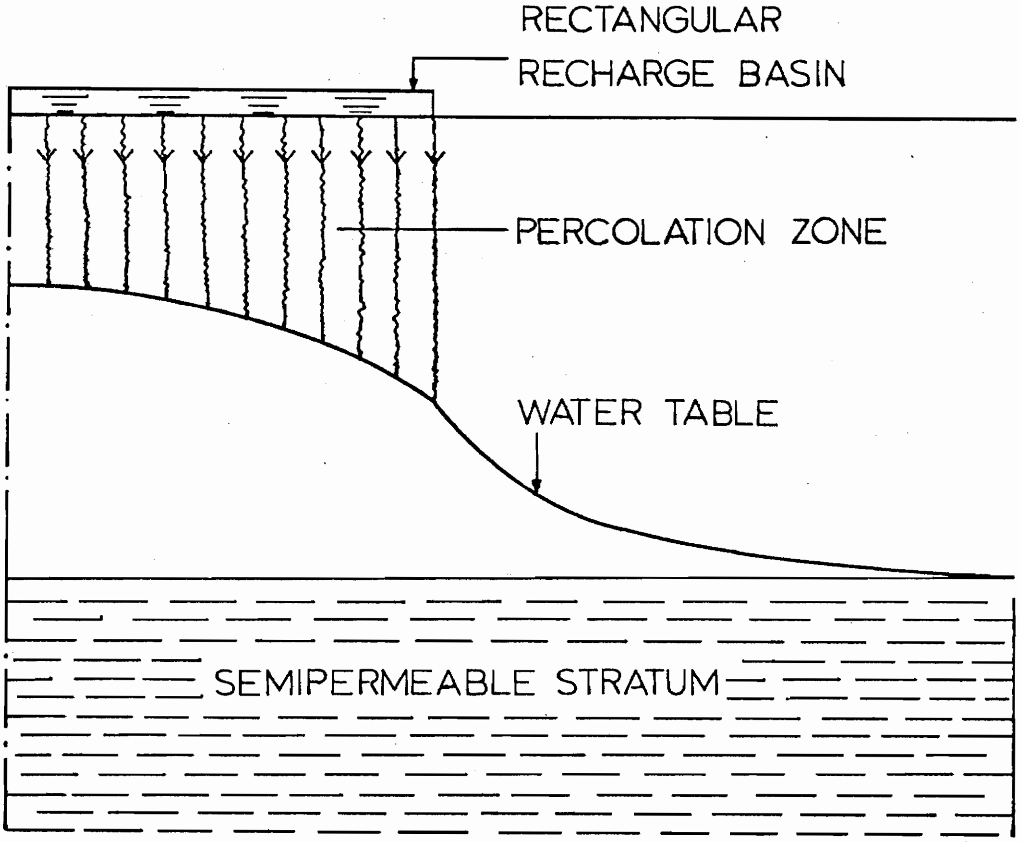

Fig. 3 Theoretical shape of groundwater mound under basin (Khan, 1973).

the wells were determined from estimated water table information. The first seven wells in all series were placed at a depth of 4.3 m to compensate for the height of the lagoon embankment and the next eight wells in three of the series were 3.7 m deep. The eight by the swampy land around the private farm were 2.4 m deep, which was sufficient under the driest conditions. All well depths were greater than necessary to allow for filling in of the pipe by sand and debris during the study. The well casings were perforated with 3 mm holes to allow free access of water at all levels. The holes were spaced at 2.5 cm on all sides of the casing. A piezometer effect was avoided and the free water table surface (where water pressure is equal to atmospheric pressure) was found in the well. The perforations ran from the bottom of the casing up to 0.3 m below the ground surface. This prevented seepage of surface water into the wells. The casings were 4 cm diameter PVC plastic pipe. This was large enough for a metering device to drop freely through the pipe.

Two series of wells were installed at each lagoon, with each series placed where it would not interfere with farm operations or be limited in length by a building or trees. The two series at both lagoons were placed as far apart as possible in the available space, but were parallel to abandoned sample wells used by Ciravolo (1976a) in a separate study. Ciravolo's wells were not perforated but were used for taking water samples for chemical analysis, and are referred to hereafter as sample wells. The wells installed specifically for this study are referred to as measuring wells. At the private farm there were two lines of sample wells, so each series of measuring wells was placed about 2 meters from the sample wells (Fig. 4). At Holland Station there were three series of sample wells, so the two measuring well series were placed between these three series as shown in Fig. 5. A water level pipe was also installed in each lagoon to record the water stage at each observation date. The series at the private farm in the swampy area was called series PW (Fig. 6), and the other, series PR (Fig. 7). The series nearest the woods at Holland Station was identified as HW, while the remaining series was named HR (Fig. 8). A water jet was used to open holes for well casings.

The water level in the wells was measured every two weeks. The travel distance to Suffolk was 430 km, which placed limitations on recording the levels at closer time intervals. Water levels were measured with an electrode-type sensor attached to a measuring tape (Fig. 9). When the electrode touched water, a potential was detected by a volt meter. The depth of the water was then read from the measuring tape (Fig. 10) to the nearest 2 mm. The well tops were extended 0.9 m above the ground for the first well and 0.64 m for the other fourteen wells in all series to provide sufficient space for measuring water levels. The elevation of each well top relative to a given datum was measured for determination of the ground surface profile and water table elevation.

Data Collection

Collection of data took place from September, 1975 to February, 1976. Thirteen sets of data were collected at two week intervals within this time. Each set of data consisted of the depth measurements from the four series of measuring wells. When the last five sets were

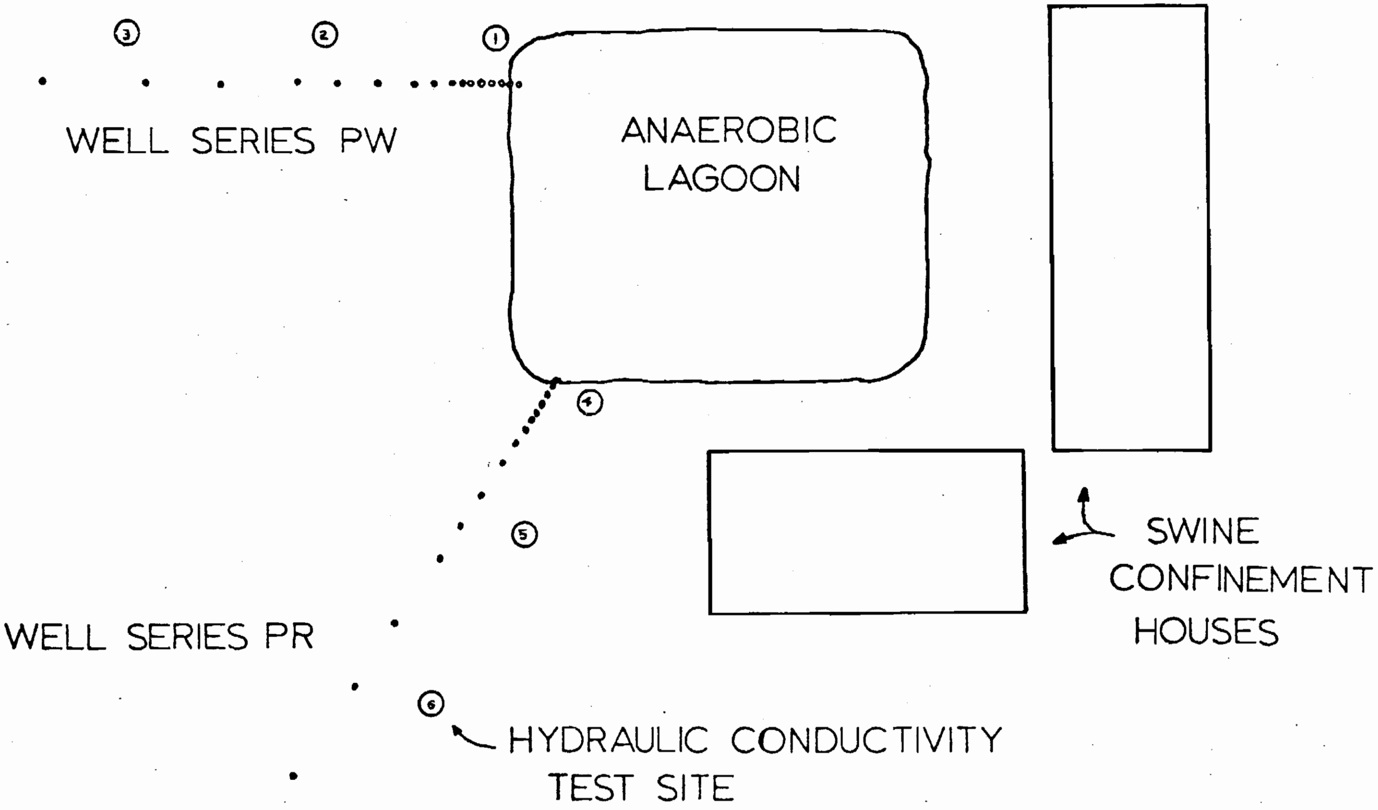

Fig. 4 Diagram of private farm showing well series.

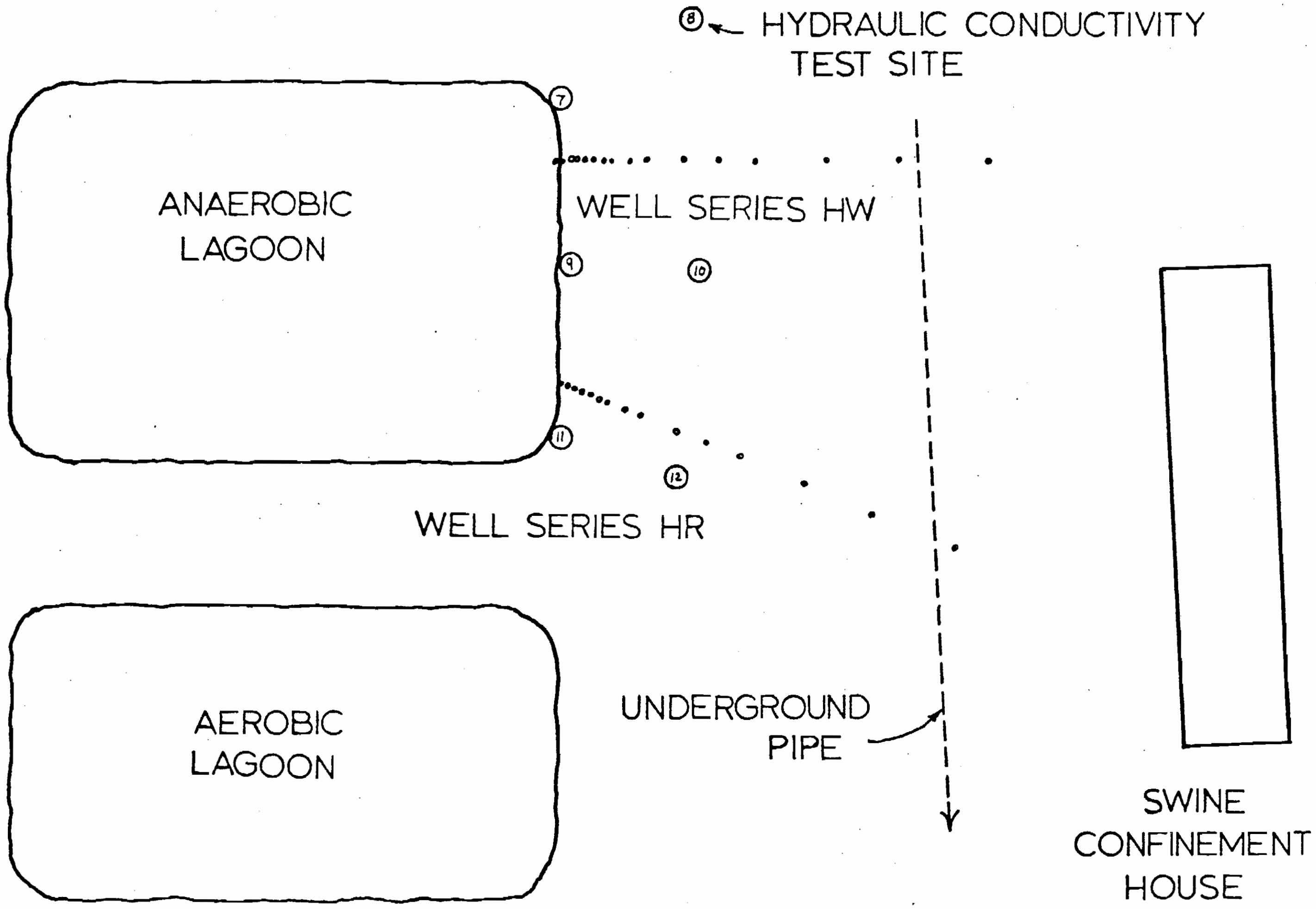

Fig. 5 Diagram of Holland Station showing well series.

Fig. 6 Series PW showing wells extending into the swampy area.

Fig. 7 Well series PR. Three sets of abandoned wells used for conductivity testing are visible on far side of well series.

Fig. 8 Well series HW in foreground with series HR visible beyond.

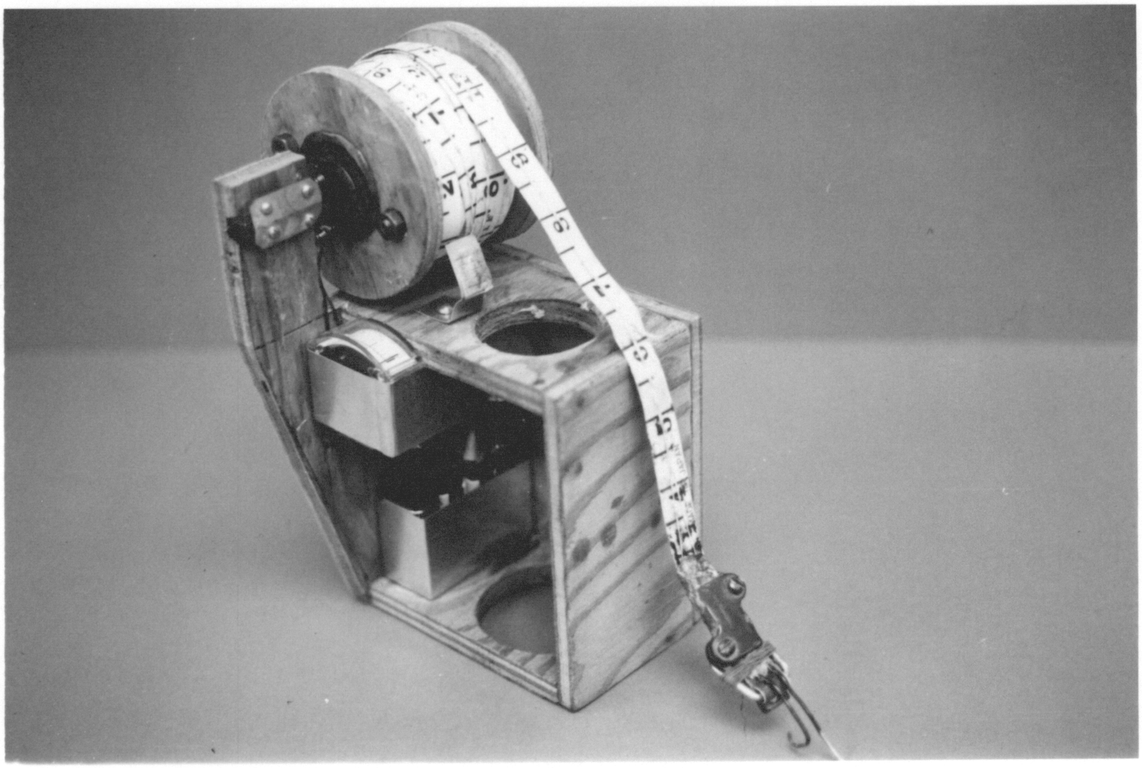

Fig. 9 Meter used for measuring water level in wells.

Fig. 10 Meter in place on well for taking a level reading.

collected, the levels of the abandoned sample wells were also recorded for an indication of water movement. Since the sample wells were unperforated, they acted as piezometers, which enabled differences in potential to be detected in the vertical direction.

Hydraulic conductivity was recorded using the tube method described by Boersma (1965) for each of the sample wells which gave an indication of the spatial variability of saturated hydraulic conductivity at each site.

RESULTS

Water table depths for the four series of wells are shown in Appendix II. These depths were plotted as shown in Appendix I. The elevation is relative to the base of the first well and the horizontal distance from the lagoon was also measured from this point. The wells were numbered one through fifteen, starting with one at the edge of the lagoon. Each well location on the plot is shown by a vertical arrow (Appendix I). The stage of the lagoon at the time of measurement is represented by a horizontal line just to the right of the elevation axis of the plot.

Private Farm

The ground surface at well series PR, which was primarily in loose sandy soil, did not show evidence of a high water table. Even though the water table came close to the surface at times, the land was not wet or swampy. Data obtained from this series of wells were the least variable of the four sites. A very slight slope in the water table was observed even during periods of low water tables around the lagoon. The second well in Appendix I, Fig. 7, showed a slight increase that did not correspond to the other well levels. This may have been caused by an error in measurement of the water level. A sharp increase was apparent in Appendix I, Fig. I, for the wells at 4.6 m and 6.1 m, which resulted from sand or silt that had collected in the wells during installation to a level above the water table. The measurements that were normally recorded clearly indicated a horizontal water table in the direction of the well series, with little influence from any possible lagoon seepage that might have occurred.

The PW series was unique because the last three wells were submerged past their base by the water table. The water table was above the ground surface during most of this study (Fig. 7 and Appendix I, Figs. 14-27). The well located 16.7 m from the lagoon was slightly higher in elevation than the well located at a distance of 22.9 m, and was located in a small ponded area which was at a higher elevation than the main body of water over the swampy land. This gave the graph an appearance of having a slope on the surface water during high water table periods, especially following rainy weather. The first nine wells in the embankment gave measurements with an irregular appearance inconsistent with any expected water table pattern. Each of the irregular measurements coincided with a rainfall the day before the measurements were taken (Table I). This pattern was possibly caused by rainfall infiltrating through the embankment with a tendency to seep at different rates through the soil. The measurements with a smooth regular pattern were taken after dry weather indicating the irregular measurements were a result of rainfall and not the lagoon.

These measurements gave no indication of continuous seepage from the side of the lagoon. Supporting evidence of seepage could not be obtained from the irregular water table profiles which were sometimes present following periods of rainfall. There was a hydraulic head at all times between the lagoon and the water table that should have caused the lagoon water to infiltrate through the sides of the lagoon since the lagoon level was normally above the water table from 1.0 m during low water tables to 0.3 m with high water tables. This head would have

TABLE 1

Daily Rainfall in cm for Holland Station, 1975-1976.[1]

Day	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.
1		3.56			0.08	2.18	
2		0.66			0.20	( )	3.56
3							0.05
4						0.25	
5							
6	0.64		0.38				
7	0.99	1.04					
8	0.03	0.15		( )	4.01	1.70	
9			1.70		(0.51)	0.33	
10		( )	0.08		0.43		
11			( )				
12	0.10	0.10		0.08		0.05	
13		2.01		3.76			( )
14				0.08		0.18	
15						( )	
16		0.13				0.23	
17		3.43				0.76	
18			3.00		0.91	0.05	
19		0.13	0.23				
20					( )		
21							
22		0.56		( )			0.15
23		0.05					0.10
24		1.37		1.75			
25	0.10	0.69	(0.05)	0.05			
26		2.74			2.08	0.18	
27		(1.32)	1.47		1.09	2.46	( )
28			0.03	0.28		4.83	
29						(0.03)	
30			0.08		0.05		
31					0.64		

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[1] Parentheses indicate well measurements taken this day.

caused a continuous movement of water had there been seepage.

The movement of groundwater not associated with the lagoon was possible during most of the season, especially when there was a high water table. The lagoon was located next to a topographical low, which collected surface water and formed a swampy area approximately 30 m in diameter. This plot of land was under water most of the year except for occasional dry weather in the summer, and it did not appear to have surface drainage away from the area. Well series PW extended partially across the swampy area with the last well in the center of the submerged area. During extremely dry weather the water table at both well series approached the same elevation (Appendix I, Figs. I and 14) indicating no groundwater level differential between the two series of wells at this time. During periods of recharge, the groundwater profile at series PR had a greater increase than series PW. A high water table during winter season resulted in up to a 0.6 m differential in the water table between the two locations, which should have caused movement toward the swampy area.

The saturated hydraulic conductivity in the vicinity of the lagoon ranged from a high of 120 cm/hr at the 3.0 m depth at PR (Table 2) to 0.5 cm/hr at a 6.1 m depth. Conductivities of 120 cm/hr are very high for a sandy soil, which indicated the possibility of underground flows of water or almost pure sand in the area. The soils around the PW series had conductivities ranging from 0.5 to 67 cm/hr. The conductivities around the lagoon were in general greatest at 3.0 m, and decreased with depth. The presence of silt and clay lenses most likely caused these wide variations. Locations of conductivity determinations are

TABLE 2

Hydraulic Conductivities in cm/hr at Measuring Sites.[1]

Depth, m	Site 1	2	3	4	5	6	7	8	9	10	11	12
3.0	40.1	18.9	4.9	36.4	120.3	15.1	8.7	0.5	15.6	25.5	5.2	35.5
4.6	17.8	13.5	67.6	6.6	58.5	14.9	2.7	0.6	4.5	2.5	8.8	6.7
6.1	60.7	0.6	2.2	0.5	1.7	22.4	1.3	0.5	2.2	3.0	6.5	6.8

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[1] Each site is identified with numbers in the circles on the figures.

shown in Table 2. Due to this extremely high conductivity of the soil it is possible a water table mound would not have been observed if there had been small amounts of seepage.

Holland Station

The Holland Station lagoon site was on flat terrain. The surface was usually dry even though the water table was normally less than 1 m below the surface. The two well series HR and HW were situated as shown in Fig. 5. A distinguishing feature of the series HR profile was the dip at 36.0 m, which dropped to 1.5 m below the surface. This corresponded to the location of a drainage pipe (Fig. 5) that passed through the line of wells. The exact depth of the water table over this drainage pipe was not known, but a definite effect was shown by the water table difference at 29 m and 36.6 m. The water table profile was drawn to the top edge of the pipe causing a dip on the graph, indicating that the effects on the water table were caused at this location. The water level changed very little between 22.9 m and 29.0 m, which may have been due to the soil strata at this location or from compacted soil resulting from lagoon construction the year before. There was also a tendency for the water tables to be at scattered levels over time near the lagoon and at distinct depths past 15.2 m, as if there were horizontal soil layers in this area. The embankment above the natural ground surface was sandy soil that was deposited during the construction of the lagoon while the original soil at the lagoon site was a mixture of silt-clay. The first well of series HR yielded results that were not expected relative to the other wells in the series. This sharp upward bend shown in Appendix I, Figs. 28-31, 35-36, and 38-39, was thought to be leakage around the well casing. When the wells were installed the lagoon was at its lowest seasonal level, and when the level rose the base of the first well was submerged for the remainder of the study. This condition then resulted in leaking since a complete seal around the casing could not be obtained. A seal of packed soil would have been satisfactory if it had not been continuously submerged. The second well involved similar problems, especially when the lagoon level reached the base of this well, (Appendix I, Fig. 37) and is shown by the unusually higher levels recorded at the 1.5 m distance. These profiles did not indicate any water table mounding from seepage although it was possible that small amounts of seepage could have occurred above the water table and entered the valdose zone in the ground. The biological sealing mechanism would not have taken effect for several months after the lagoon level rose above its old level leaving a portion of the lagoon side between the old and new water level susceptible to seepage.

It is possible that the water table at series HR may have been influenced by the aerobic lagoon beside the anaerobic lagoon (Fig. 1). The biological sealing mechanism would not have been as predominant in this aerobic lagoon which was used for overflow from the anaerobic lagoon, because of the lower organic loading.

Series HW was similar to HR in its variations in the water table profile. There was a dip in the water table at a distance of 31 m from the lagoon corresponding to the location of the drainage pipe. This dip resulted when the water table profile was drawn as at HR, the exact location of the water table over the pipe not being known. The effect of the pipe is visible on the water table profiles (Appendix I, Figs.

40-52). These profiles were similar to HR with a varying profile for the first 15.2 meters, and remaining relatively constant past 15.2 m. There was one rise in Appendix I, Fig. 41, which was not a result of the normal water table, but was most likely due to an error in measurement. The first two wells were subject to the same conditions as at HR with the base of the first well submerged throughout the study and the second well after December (Appendix I, Figs. 48-52). Several of the measurements at the first well indicated surface leakage around the well casing while other measurements indicated only minimal leakage. The leaking of the casing increased as the lagoon increased in depth over the base of the well. After December, there was extreme leakage around the casing of the second well when the lagoon had risen to this level. The water table profile during the study was sloped gently toward the drainage pipe but the origin of the groundwater there was not certain. There may have been a small amount of seepage contributing to the groundwater. The water table levels to the right of the pipe dip indicated the water table was almost as high around the lagoon as past the 36.6 m well, which indicated the water table was not rising significantly from lagoon seepage.

During wet seasons, a drainage channel in the woods located beside the lagoon emptied into the drain pipe one meter under the surface at the edge of the woods. This drain pipe began at the woods, passed through the lot and by the lagoon as shown in Fig. 5. There was no noticeable difference in water table elevations between HR and HW indicating no water flow between the two series. There was erosion around the pipe area at a junction just past the lagoon that indicated water was running along the side of the pipe. The soil around the side of the pipe most likely did not fill back in underneath the pipe due to its silty-clay content, leaving a cavity around the pipe for water flow.

Approximately 2 km past the lagoon in the direction of the pipe flow, a large barrow pit about 20 ha in area and 7.6 m deep was dug in Fall, 1975, for road construction (Fig. 11). This area was pumped dry, which should have caused a drawdown of the water table in the surrounding area. It was expected that the excavation would fill up and form a lake but it only filled to a depth of about 1.5 m and started draining into a swamp on the far side. This should have caused groundwater flow toward this area from the surrounding higher water table. Its effect in the vicinity of the lagoon was not known at the time of the study.

The saturated hydraulic conductivities around the Holland lagoon, as expected, were not high. This soil was composed of 50% sand, 25% silt, and 25% clay (Amos and Hallock, 1976). The highest saturated hydraulic conductivities were found at the 3 m depth in the center of the lot and ranged from 15 to 35 cm/hr (Table 2). At greater depths the range was 0.5 to 9 cm/hr. There was a definite decrease between the 3.0 and 4.6 meter depth in conductivity around the center of the lot adjacent to the lagoon. The conductivities below 3.0 m at each location were very similar. The conductivity rates in this area suggest the soil mixture given above with slow to medium infiltration through the soil.

Statistical Analysis

A statistical analysis was conducted on the well depth data collected from the two sites, including a new Duncan's multiple range test at the 5% level. The depth of the water at each well was taken as the

Fig. 11 Barrow pit 2 km beyond Holland Station showing low level of water due to drainage on far side.

variable, with two tests being run. The first test variation took the average depth of the wells in the series at each measuring time. These averages were ranked in order of average depth, and the correlation between each was indicated. The second test variation took the average of the thirteen measuring times at each well in the series, then ranked the average and indicated statistical correlation between each. The tests for the private farm did not indicate a significant change in the average water level in each well for each series. The average level for all wells in each series for each data collection time indicated the water table was largely dependent on the season. The Holland Station wells did not indicate differences in average levels between the wells for the first 11 m. Past 11 m, a slope toward the drain pipe was indicated. Water table levels for each series were highly dependent upon season.

SUMMARY AND CONCLUSIONS

Two swine waste lagoons in Southeast Virginia were investigated for evidence of seepage to the surrounding groundwater. One lagoon was located at the VPI&SU Tidewater Research and Continuing Education Center at Holland Station, Virginia, and the other was located on a private farm near the Holland Station. Two series of wells were installed at each lagoon and groundwater levels were recorded. The water table was then plotted to determine the presence or absence of a groundwater mound around the lagoon, which would indicate seepage from the lagoon. A statistical analysis was used to evaluate the significance of temporal and spatial variations of the water table.

The following conclusions were made based on findings from the study.

1) Based on the data collected there were no significant water table changes that could be attributed directly to seepage from the lagoons.

2) Many variables affected the profile of the water table in the vicinity of the lagoon which made an evaluation of the water table levels more difficult.

3) There was an indication of independent groundwater movement around the lagoons.

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APPENDIX I

WATER TABLE PROFILES FOR WELL SERIES

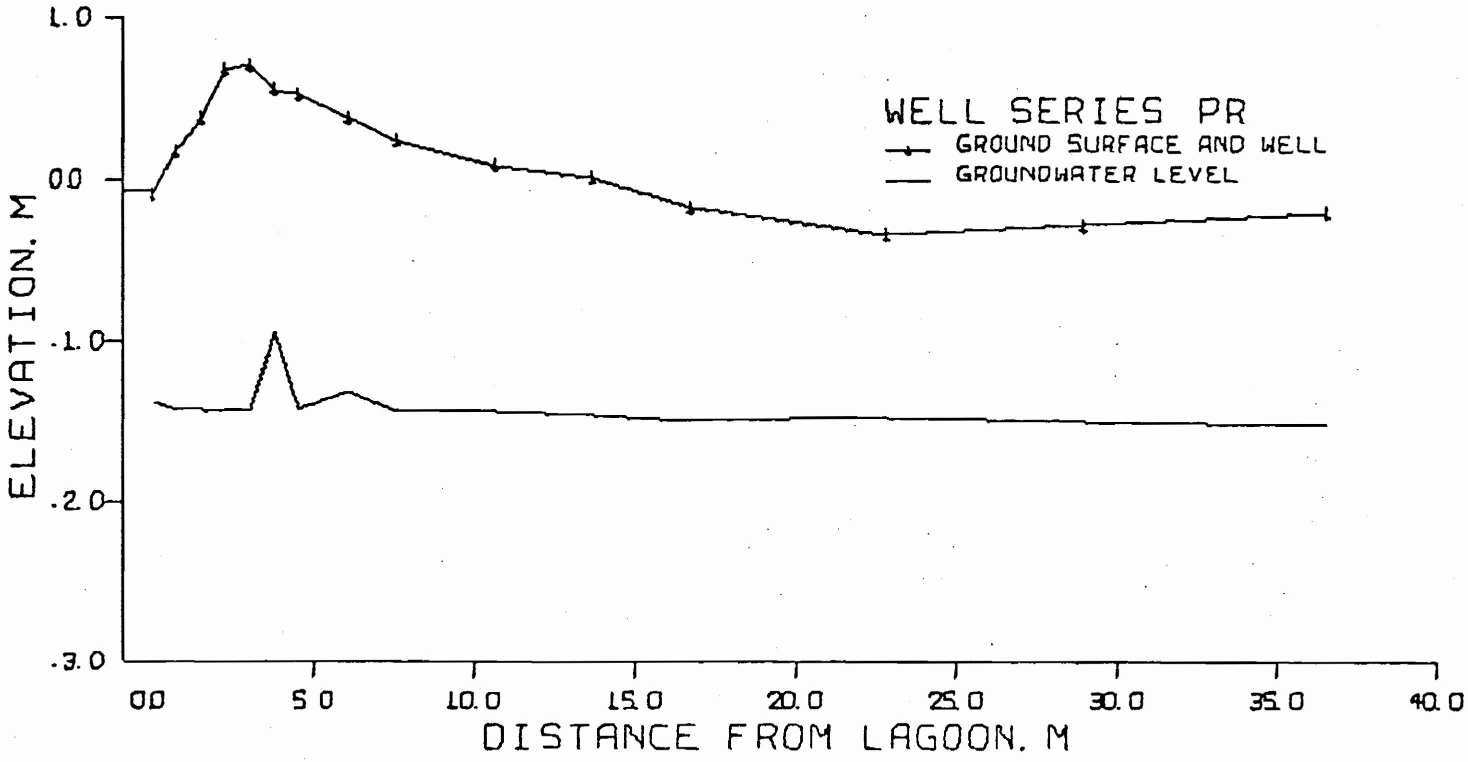


FIG. 1 WATER TABLE PROFILE SEP 10, 1975

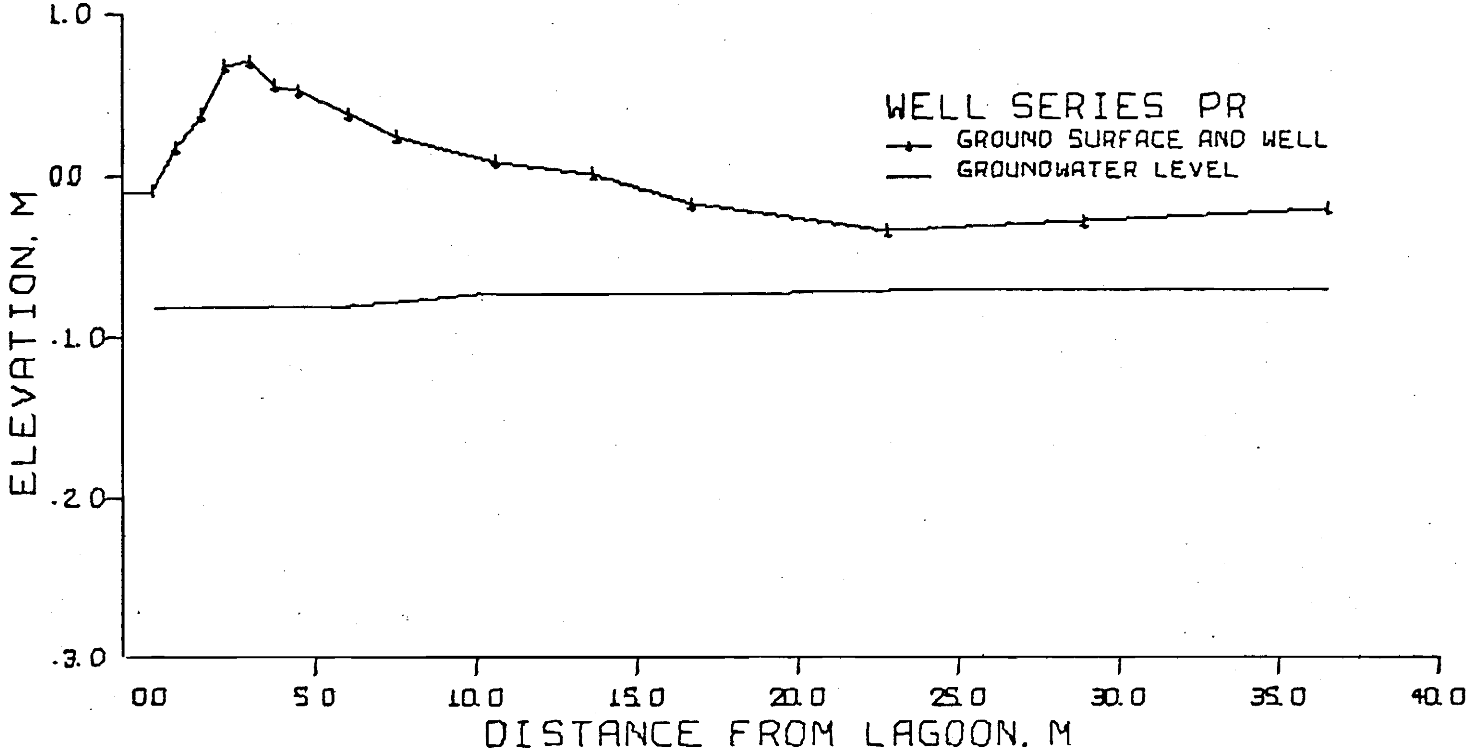


FIG. 2 WATER TABLE PROFILE SEP 27. 1975

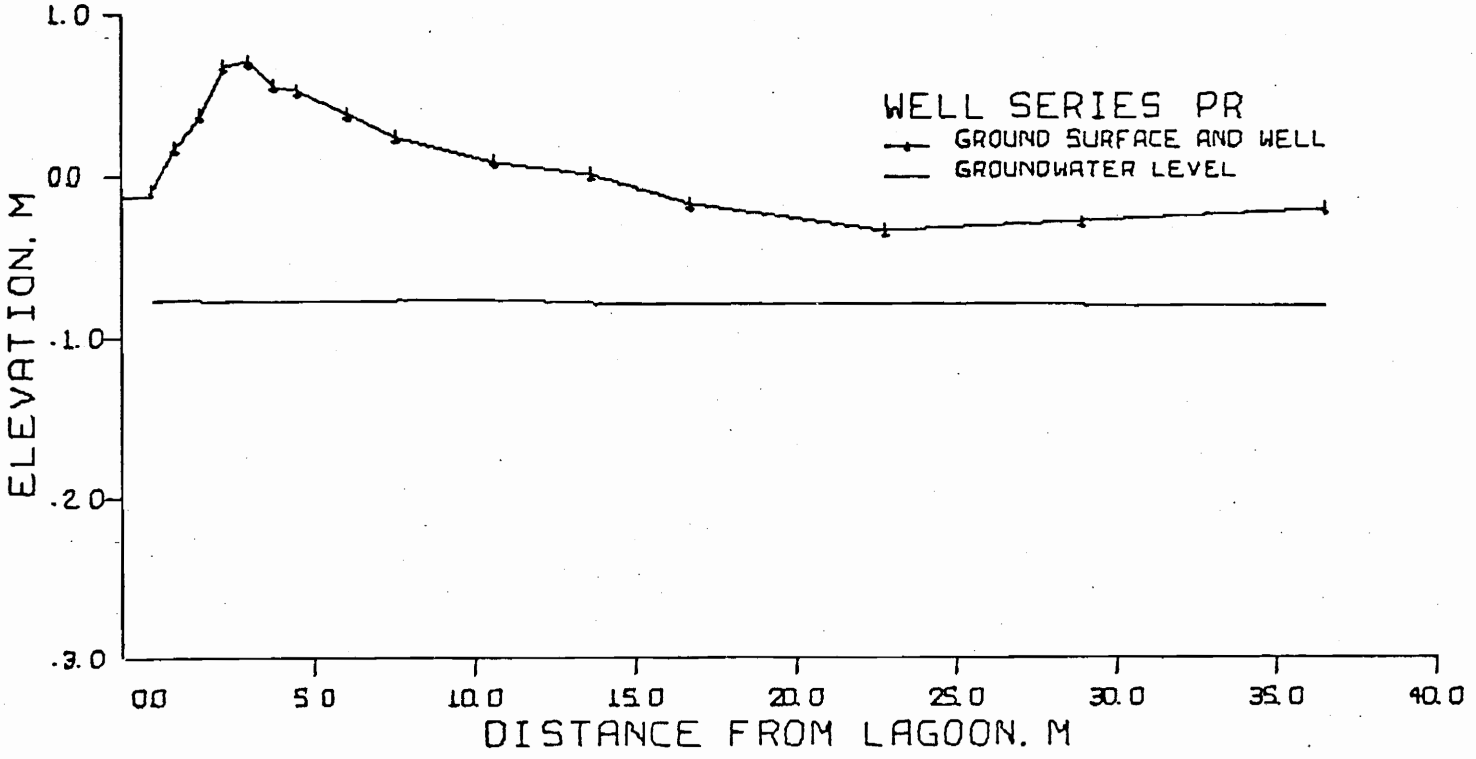


FIG. 3 WATER TABLE PROFILE OCT. 11. 1975

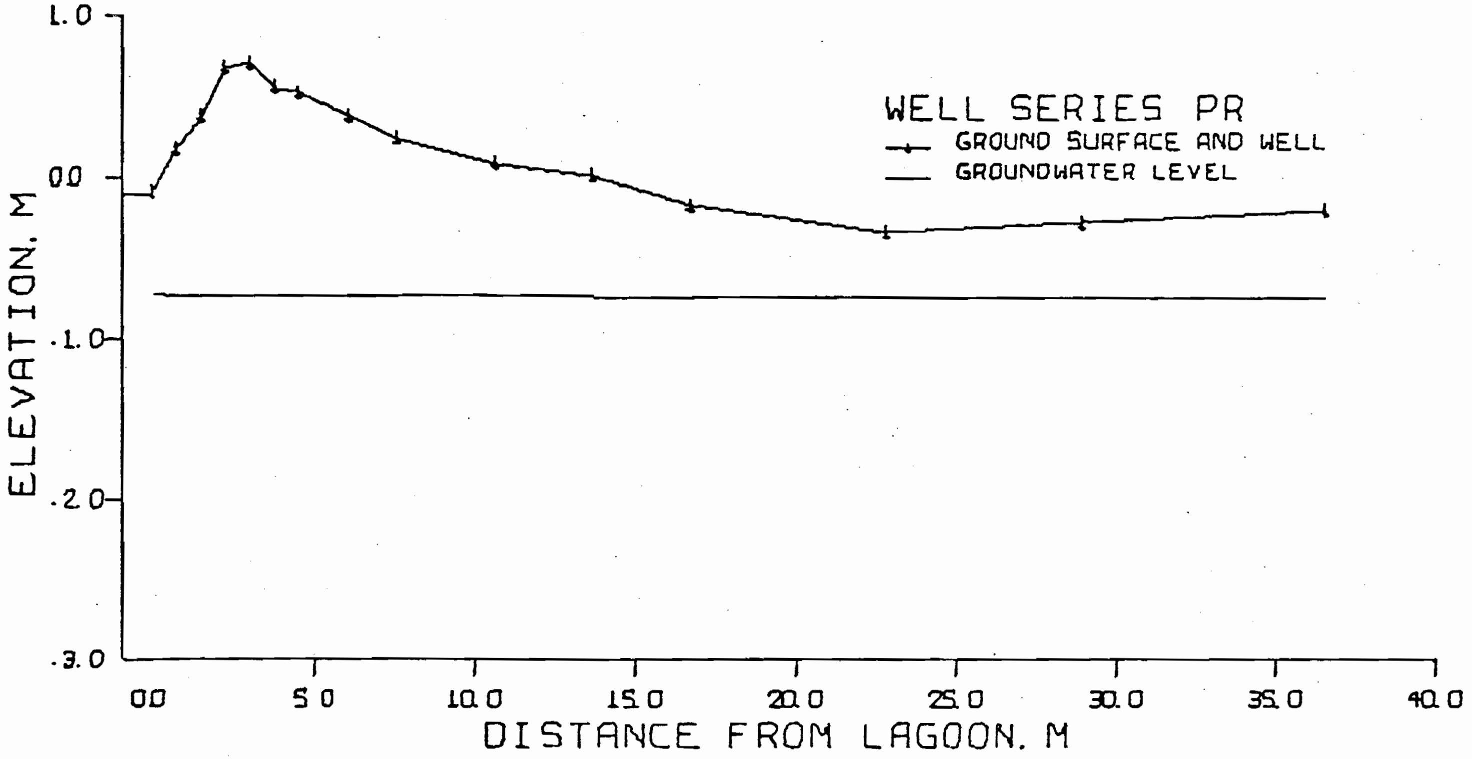


FIG. 4 WATER TABLE PROFILE OCT. 25. 1975

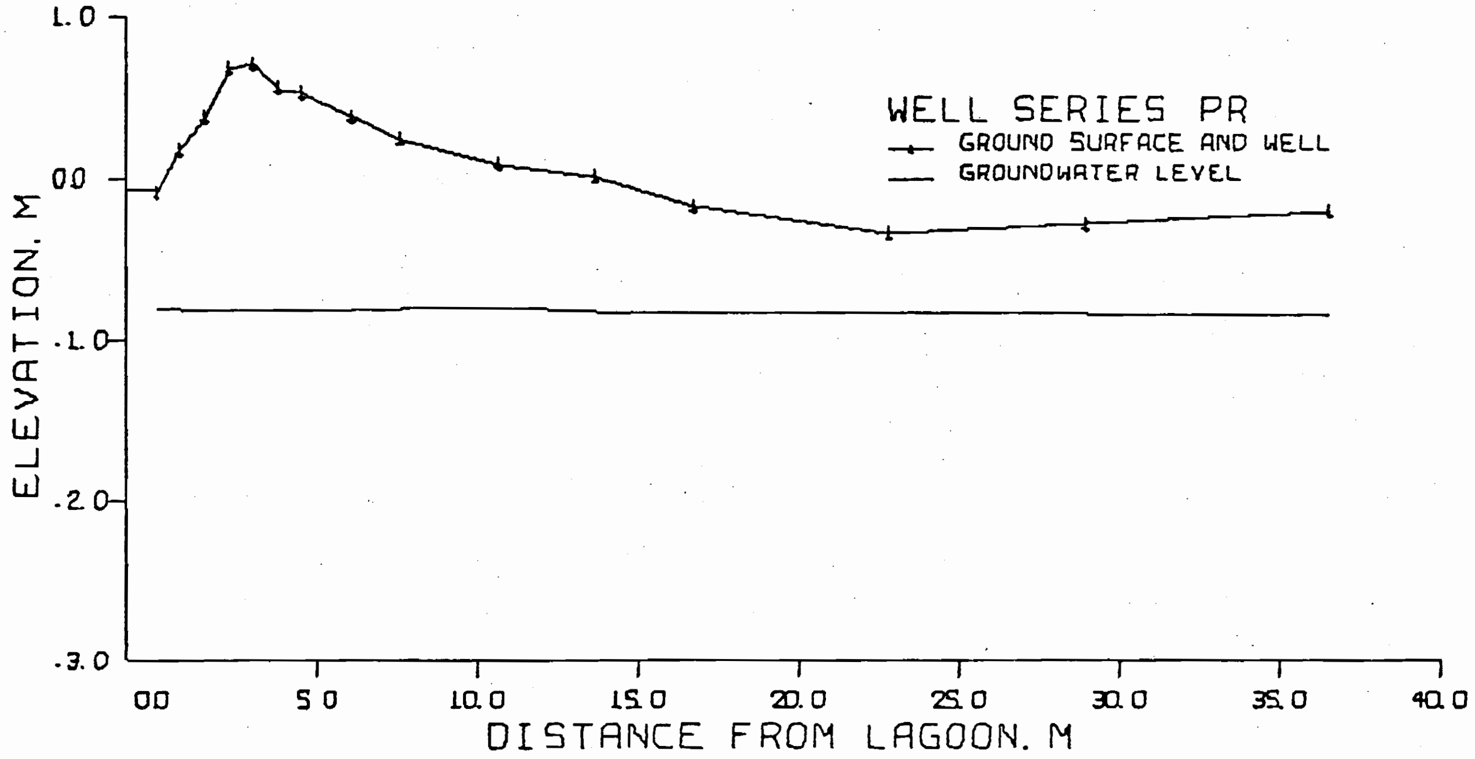


FIG. 5 WATER TABLE PROFILE NOV. 08. 1975

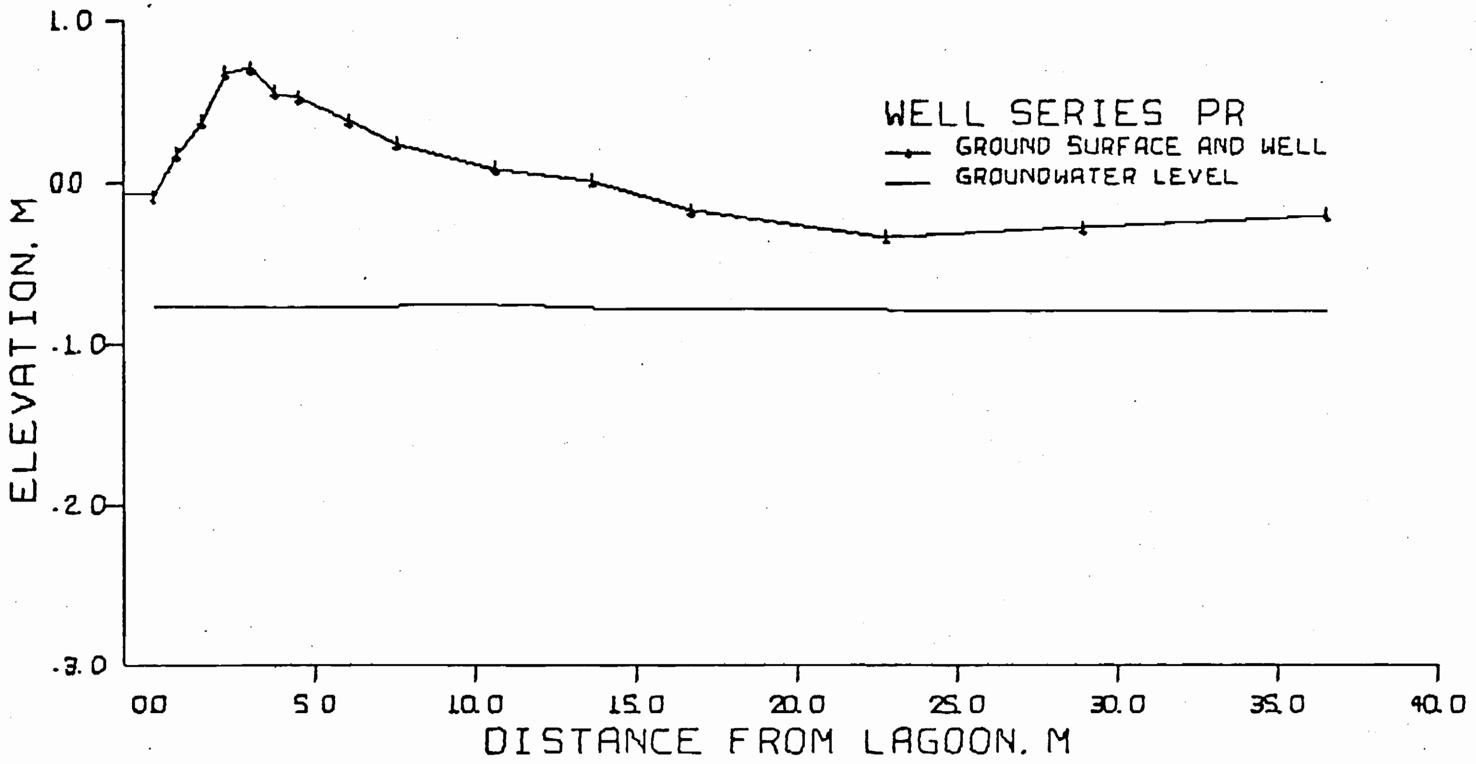


FIG. 6 WATER TABLE PROFILE NOV. 22. 1975

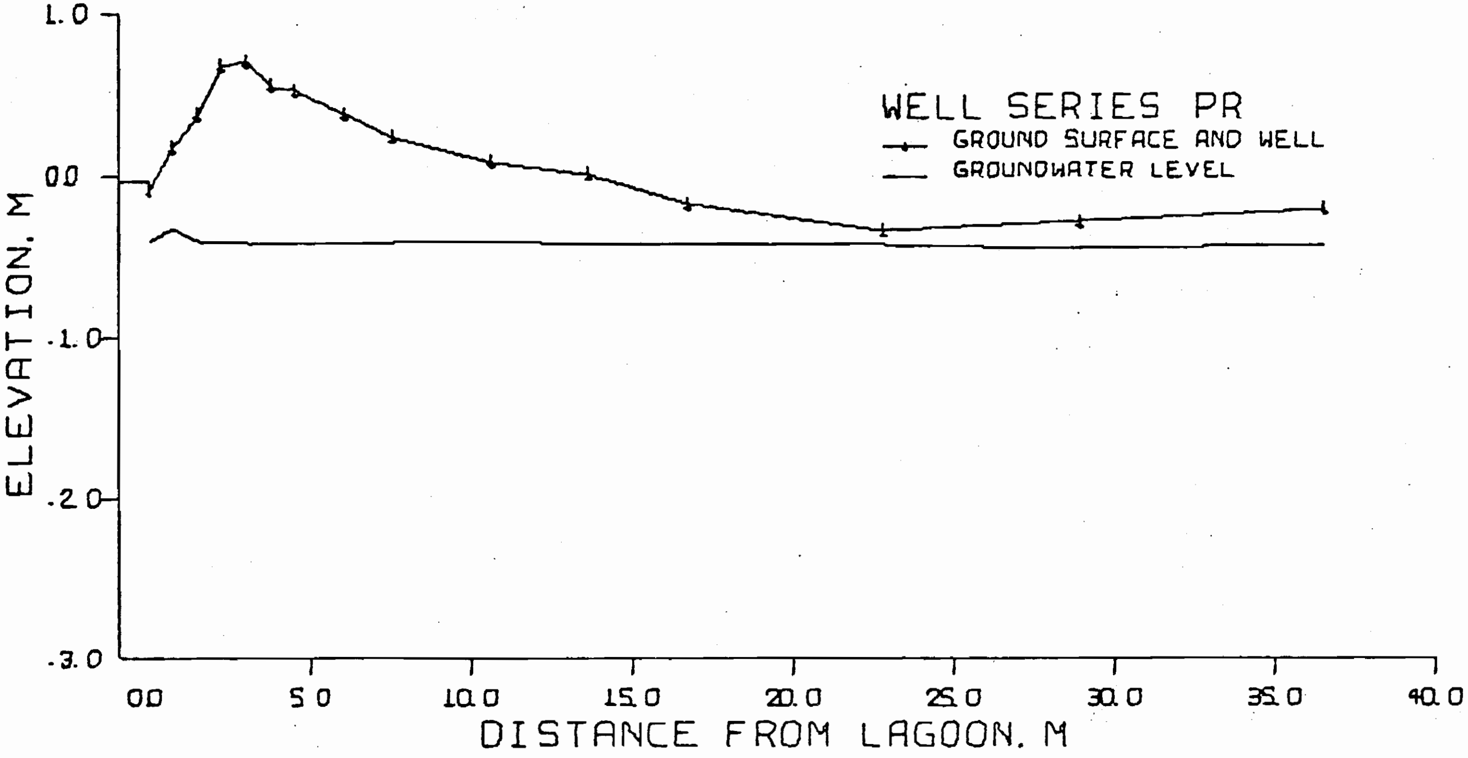


FIG. 7 WATER TABLE PROFILE DEC. 09. 1975

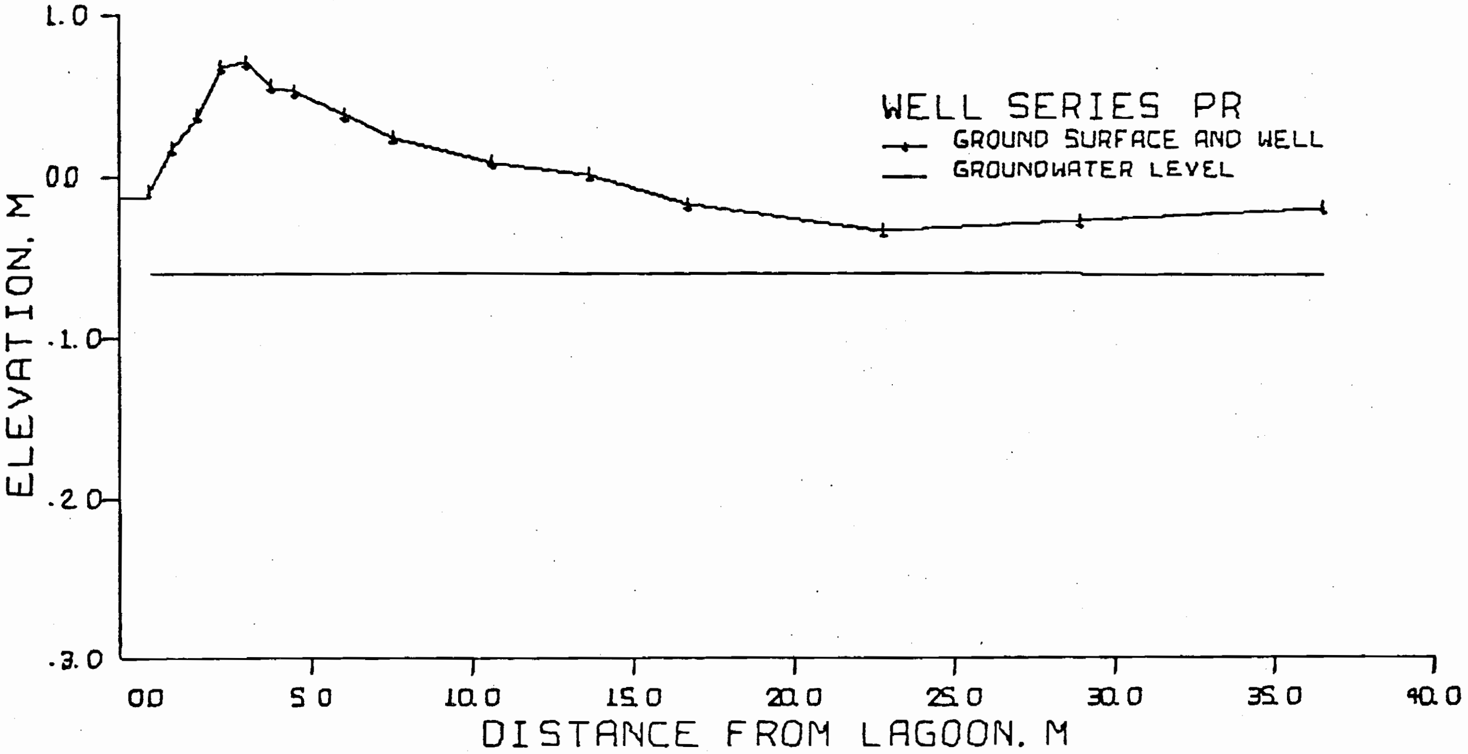


FIG. 8 WATER TABLE PROFILE DEC. 20. 1975

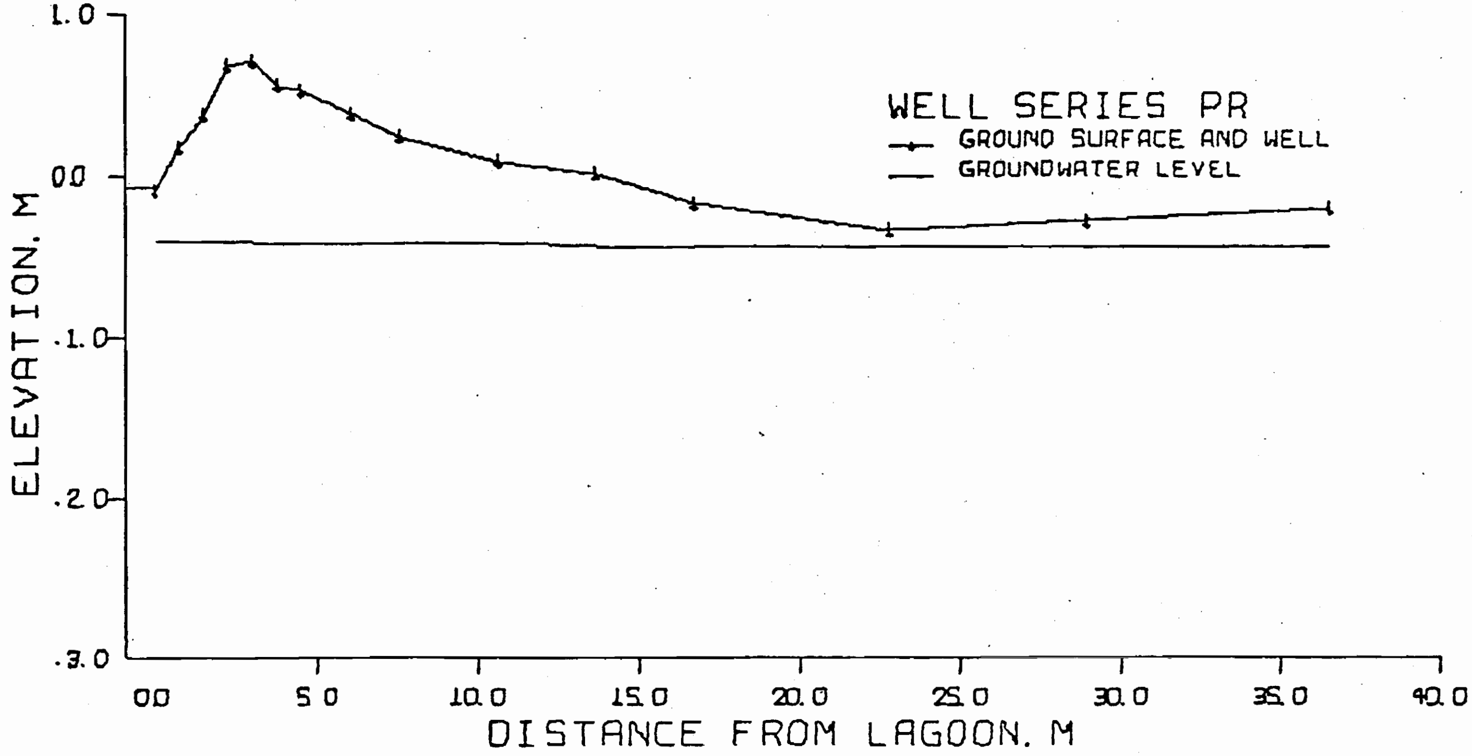


FIG. 9 WATER TABLE PROFILE JAN. 02. 1976

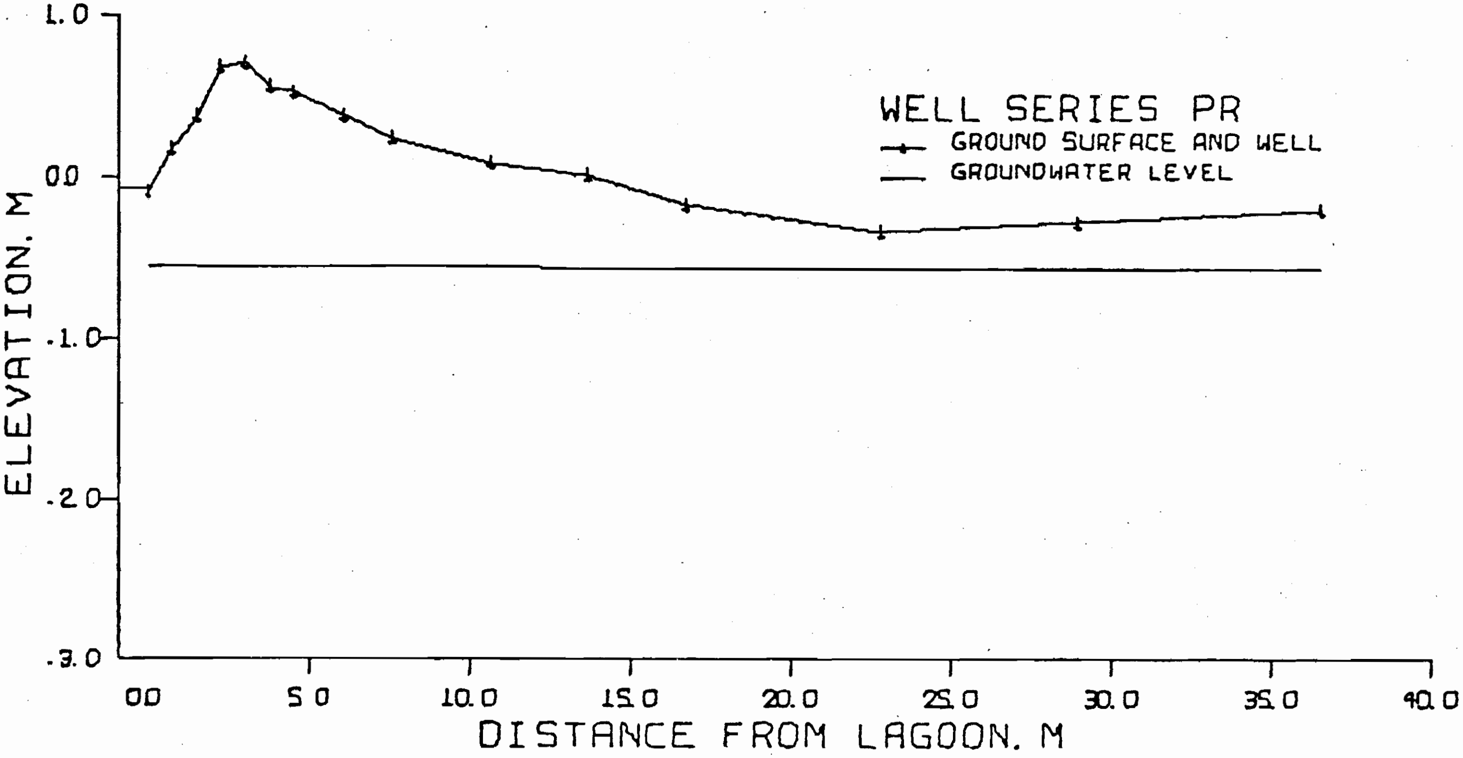


FIG. 10 WATER TABLE PROFILE JAN. 15. 1976

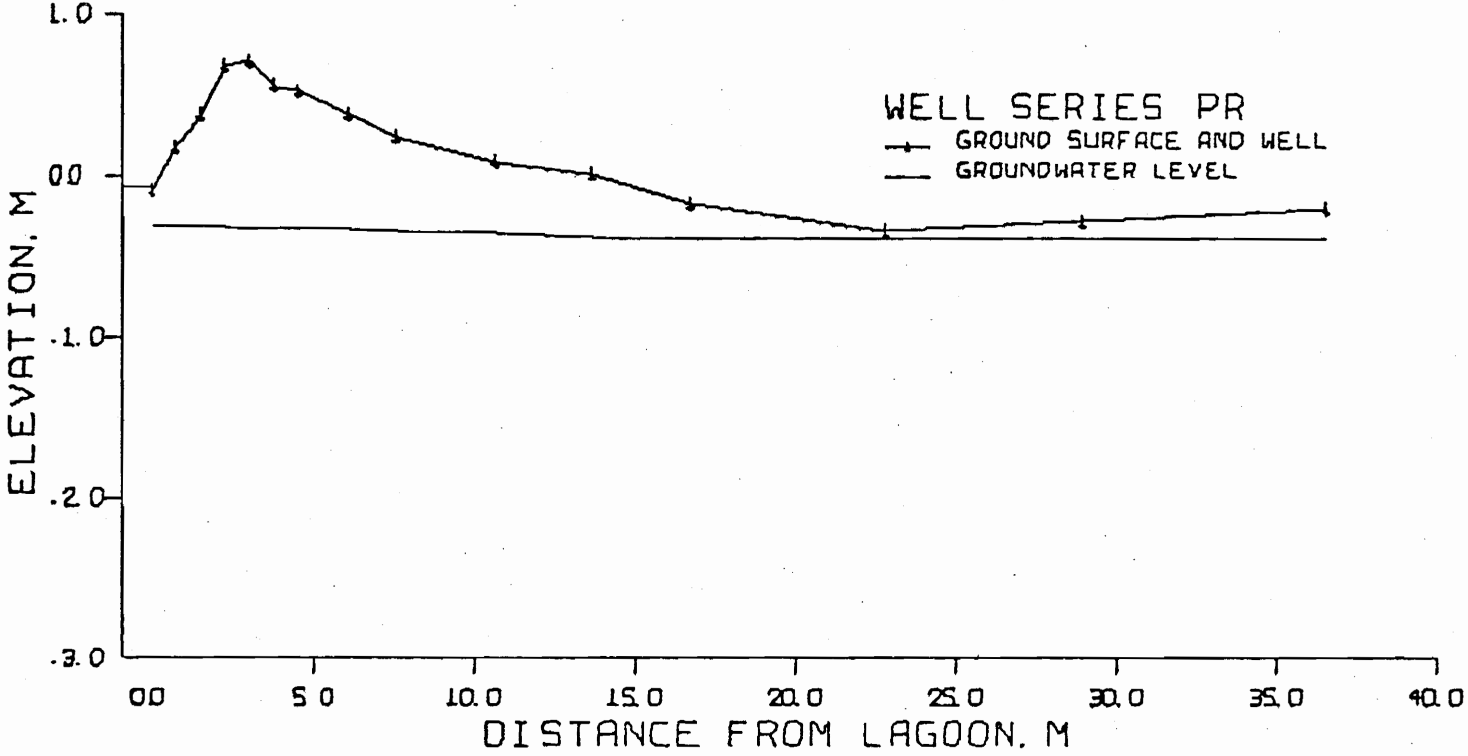


FIG. 11 WATER TABLE PROFILE JAN. 29. 1976

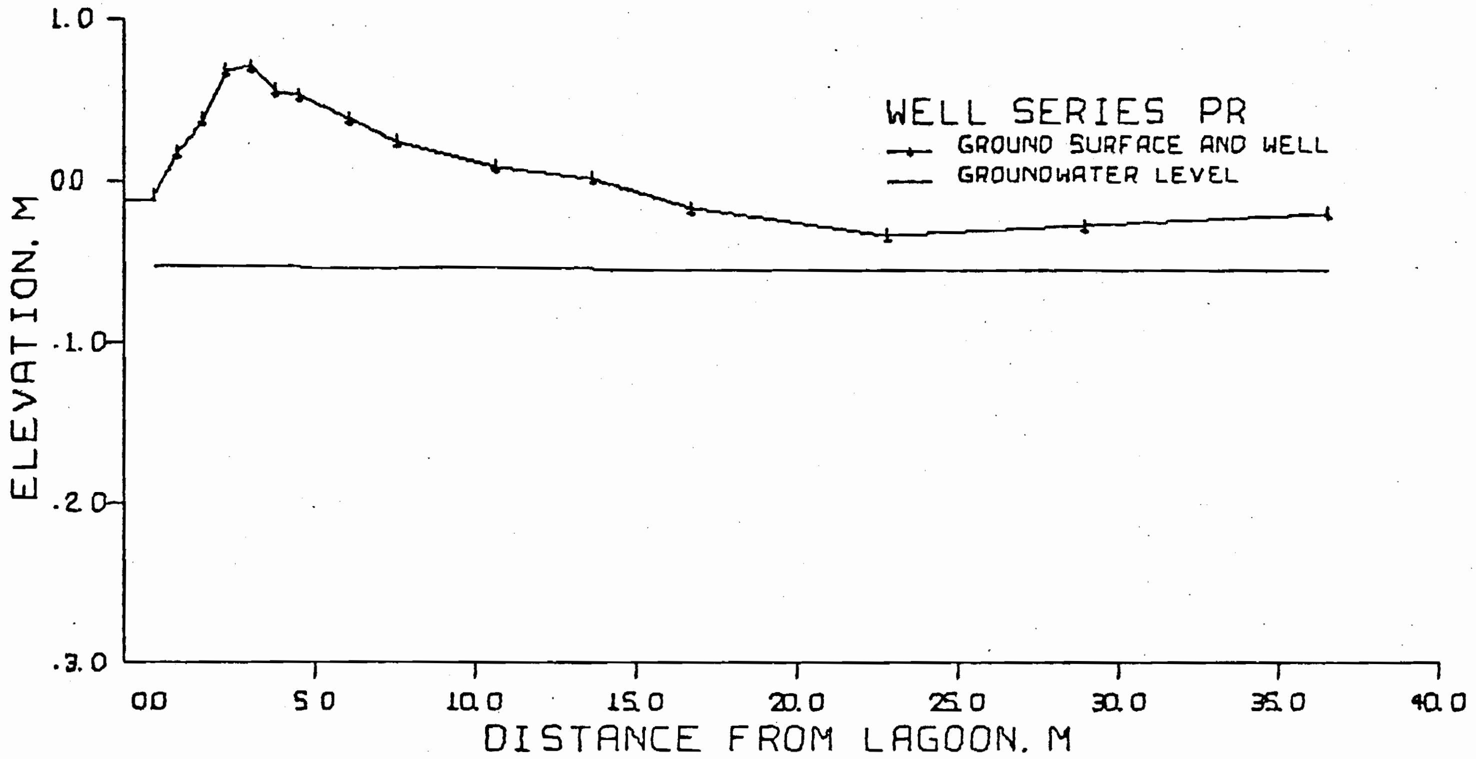


FIG. 12 WATER TABLE PROFILE FEB. 13. 1976

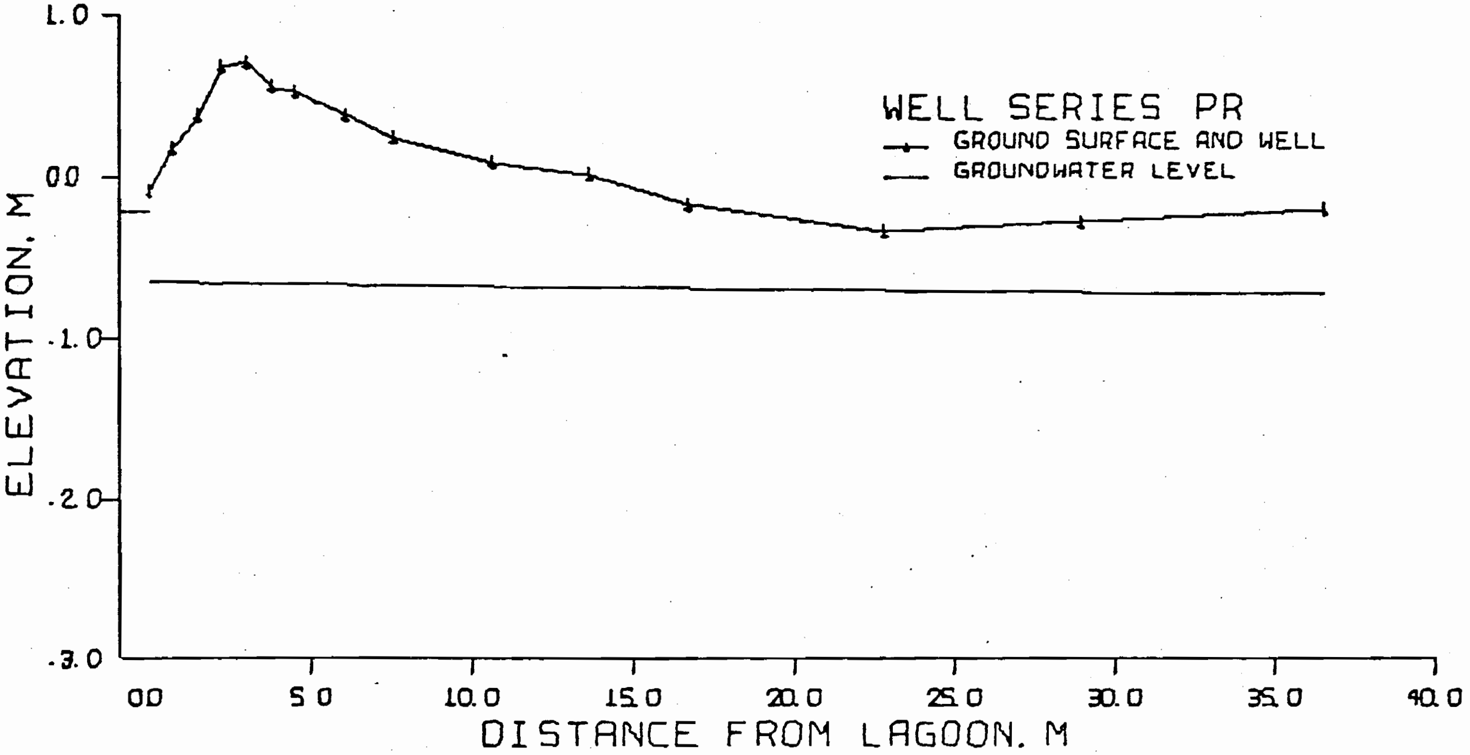


FIG. 13 WATER TABLE PROFILE FEB. 27. 1976

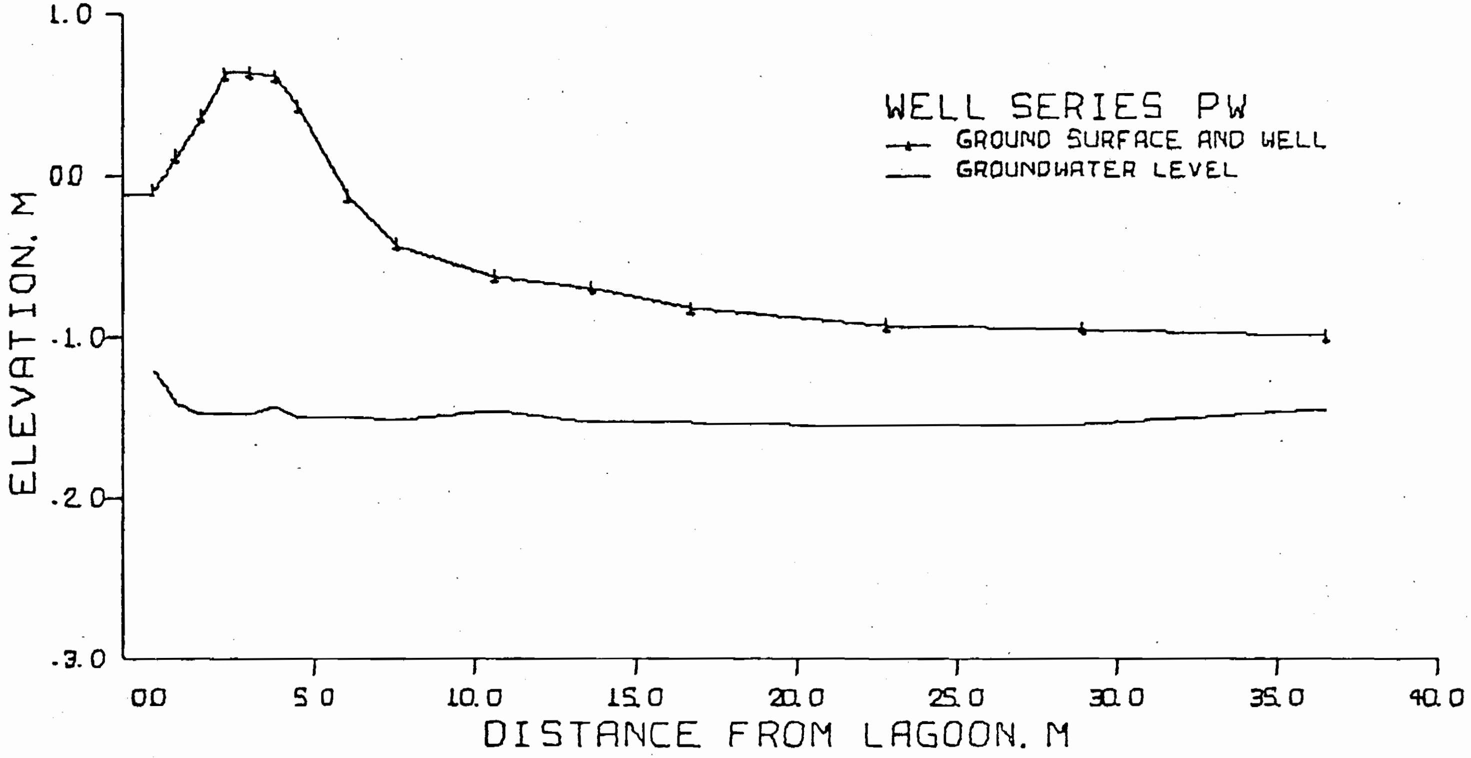


FIG. 14 WATER TABLE PROFILE SEP 10, 1975

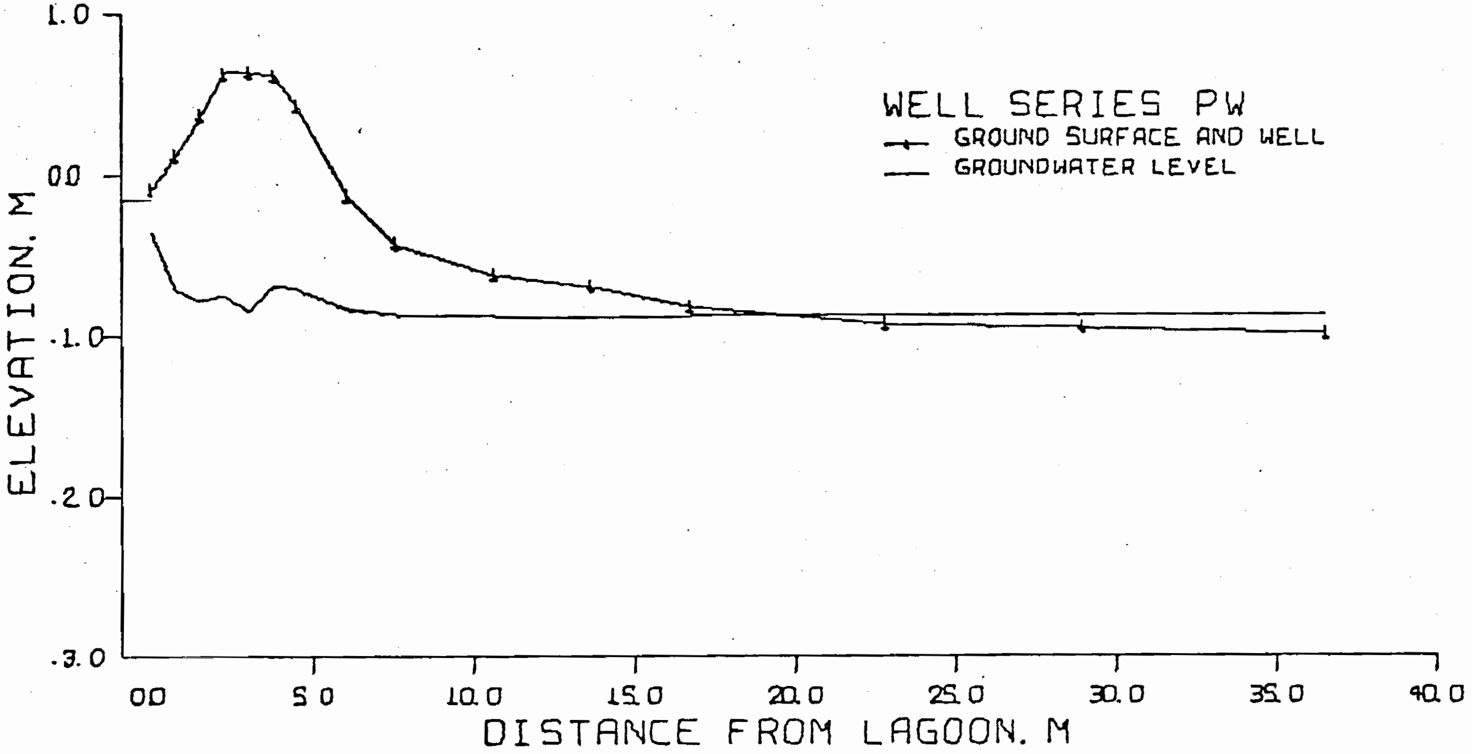


FIG. 15 WATER TABLE PROFILE SEP 27, 1975

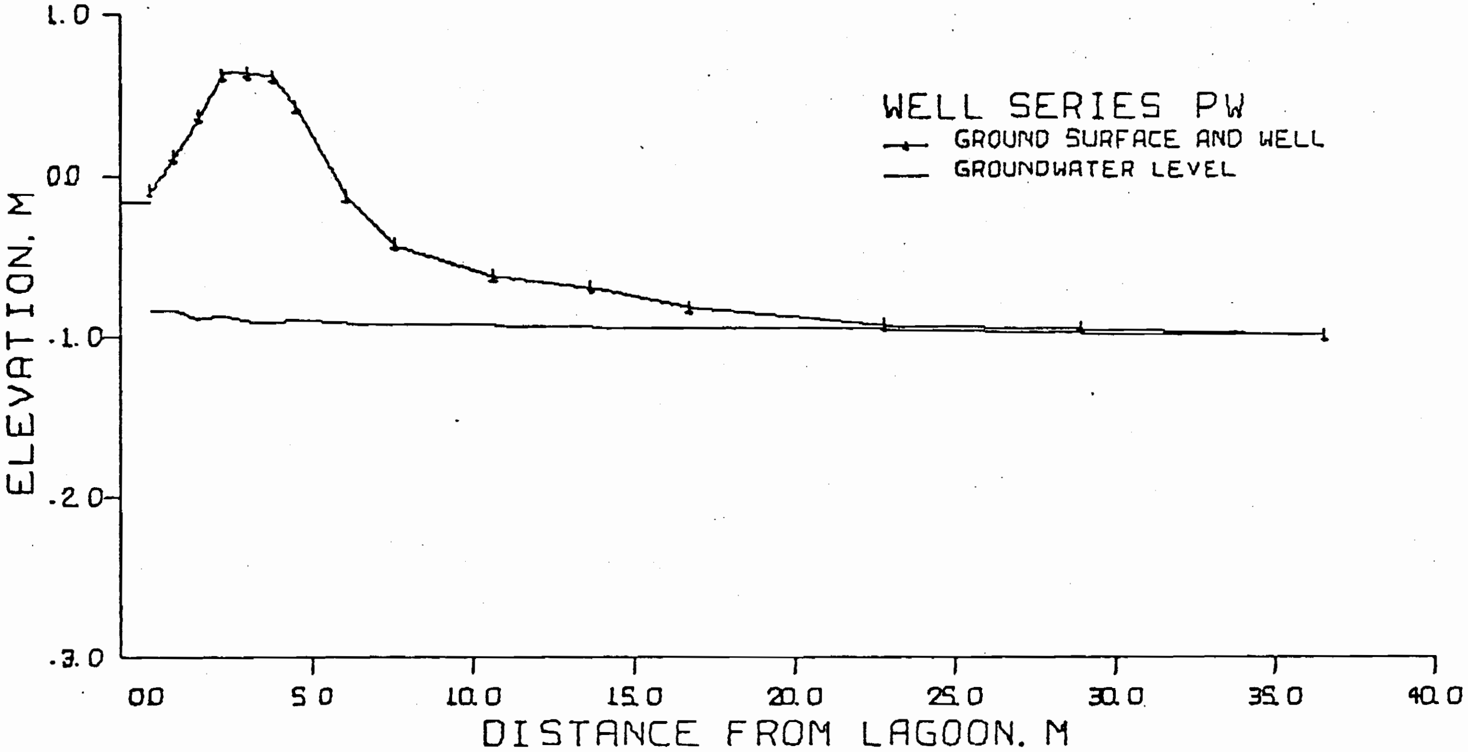


FIG. 16 WATER TABLE PROFILE OCT. 11. 1975

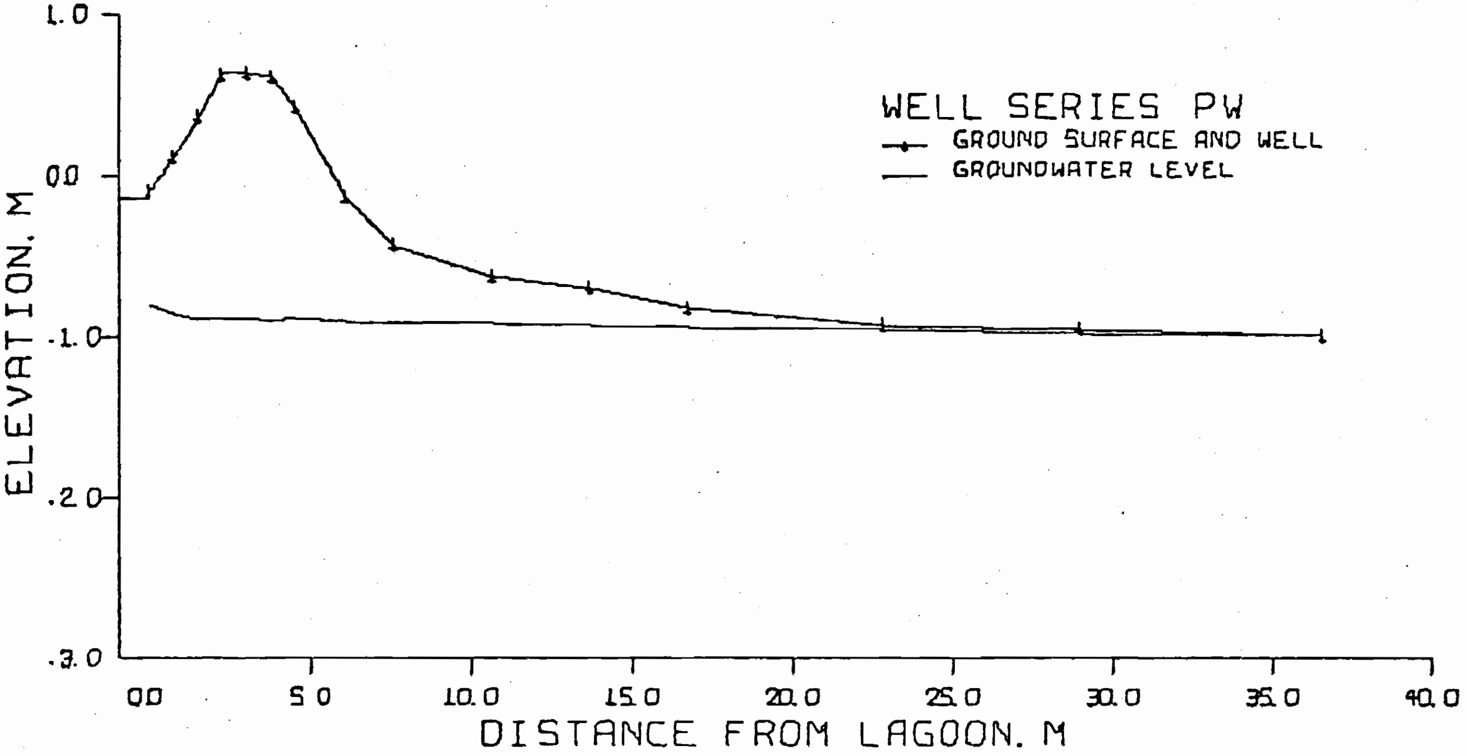


FIG. 17 WATER TABLE PROFILE OCT. 25. 1975

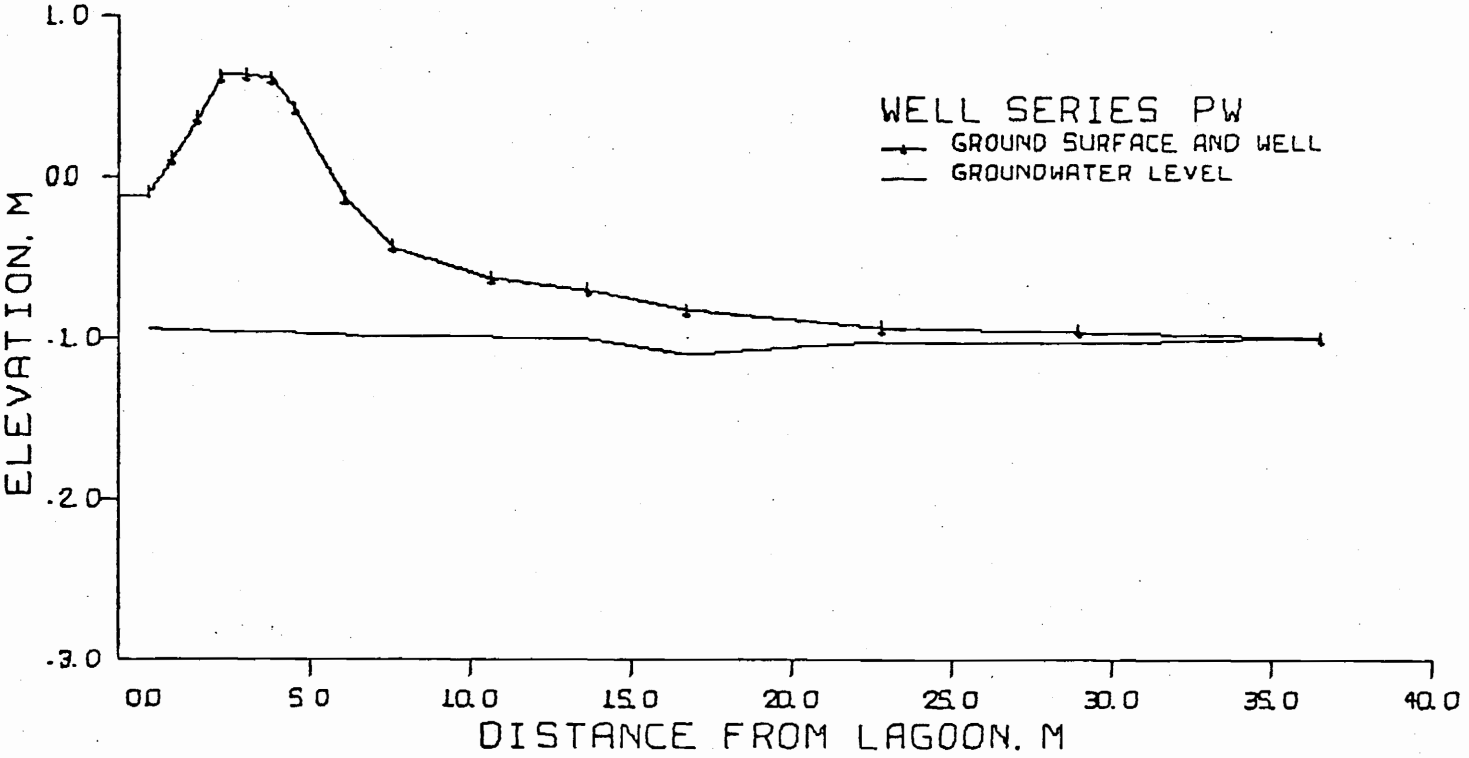


FIG. 18 WATER TABLE PROFILE NOV. 08. 1975

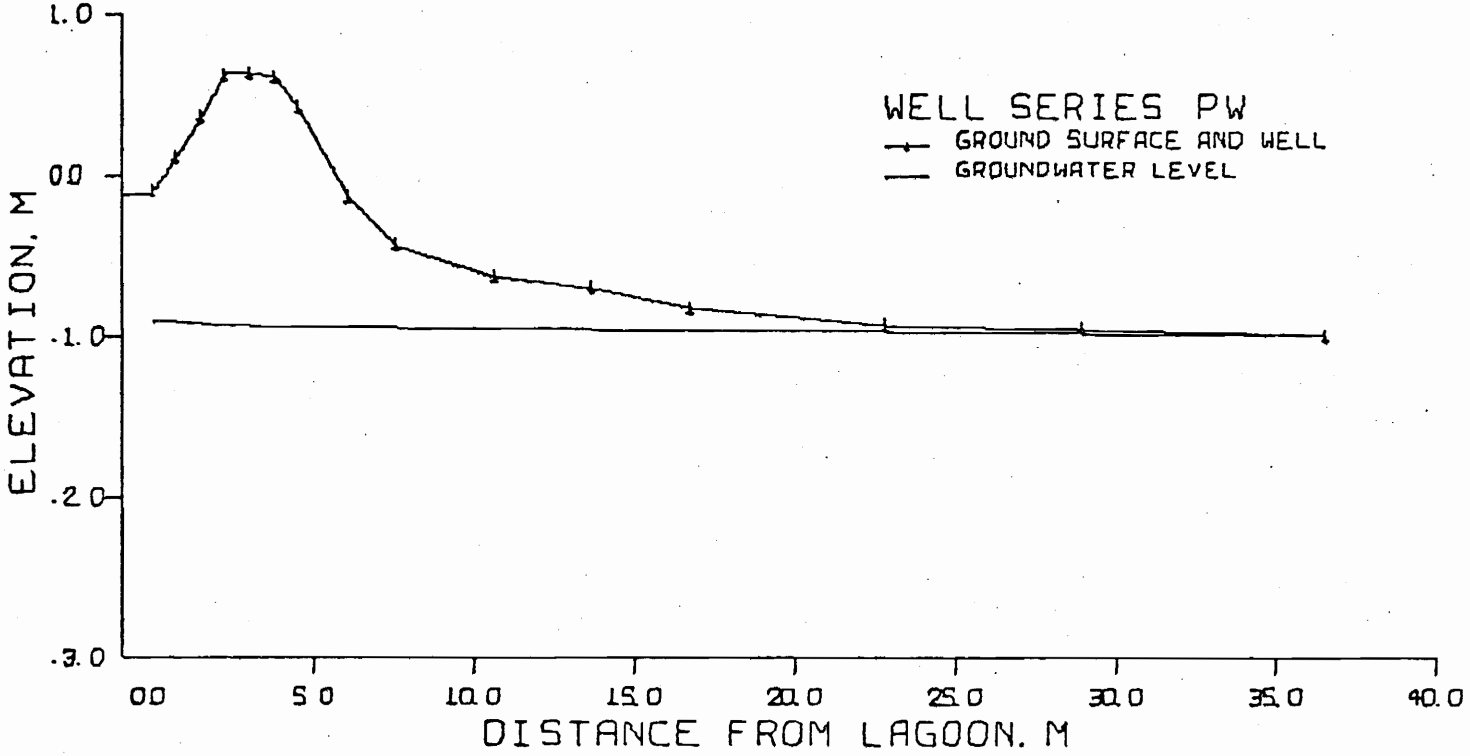


FIG. 19 WATER TABLE PROFILE NOV. 22. 1975

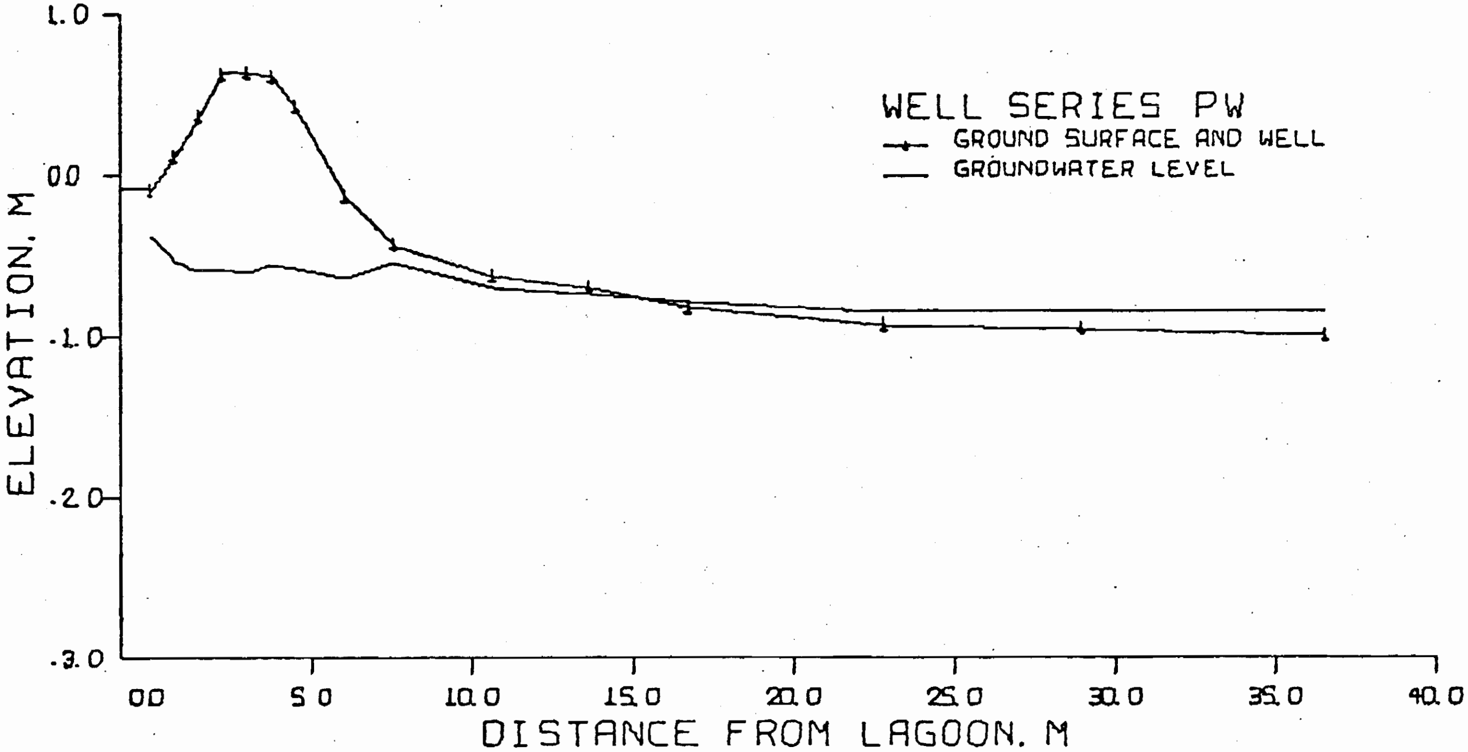


FIG. 20 WATER TABLE PROFILE DEC. 09, 1975

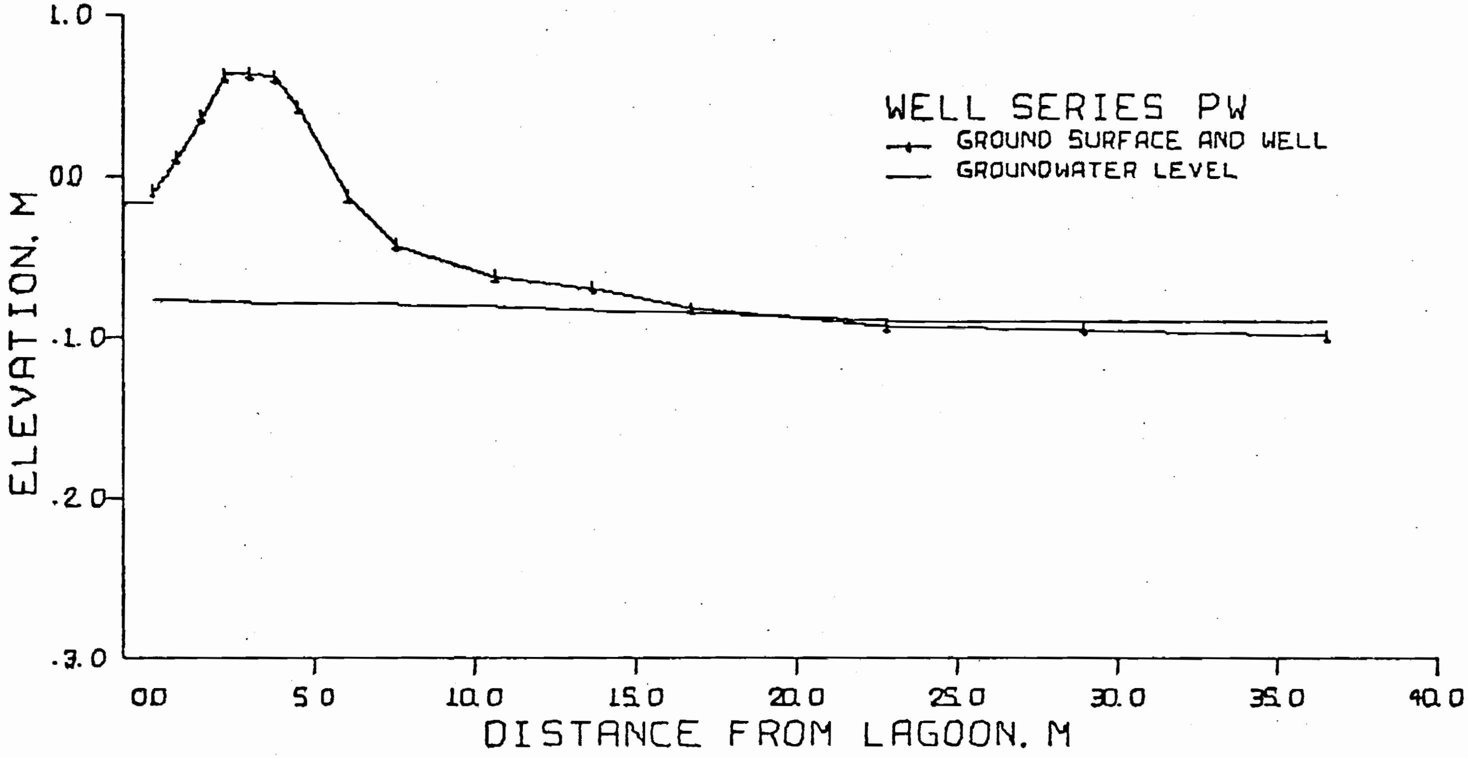


FIG. 21 WATER TABLE PROFILE DEC. 20. 1975

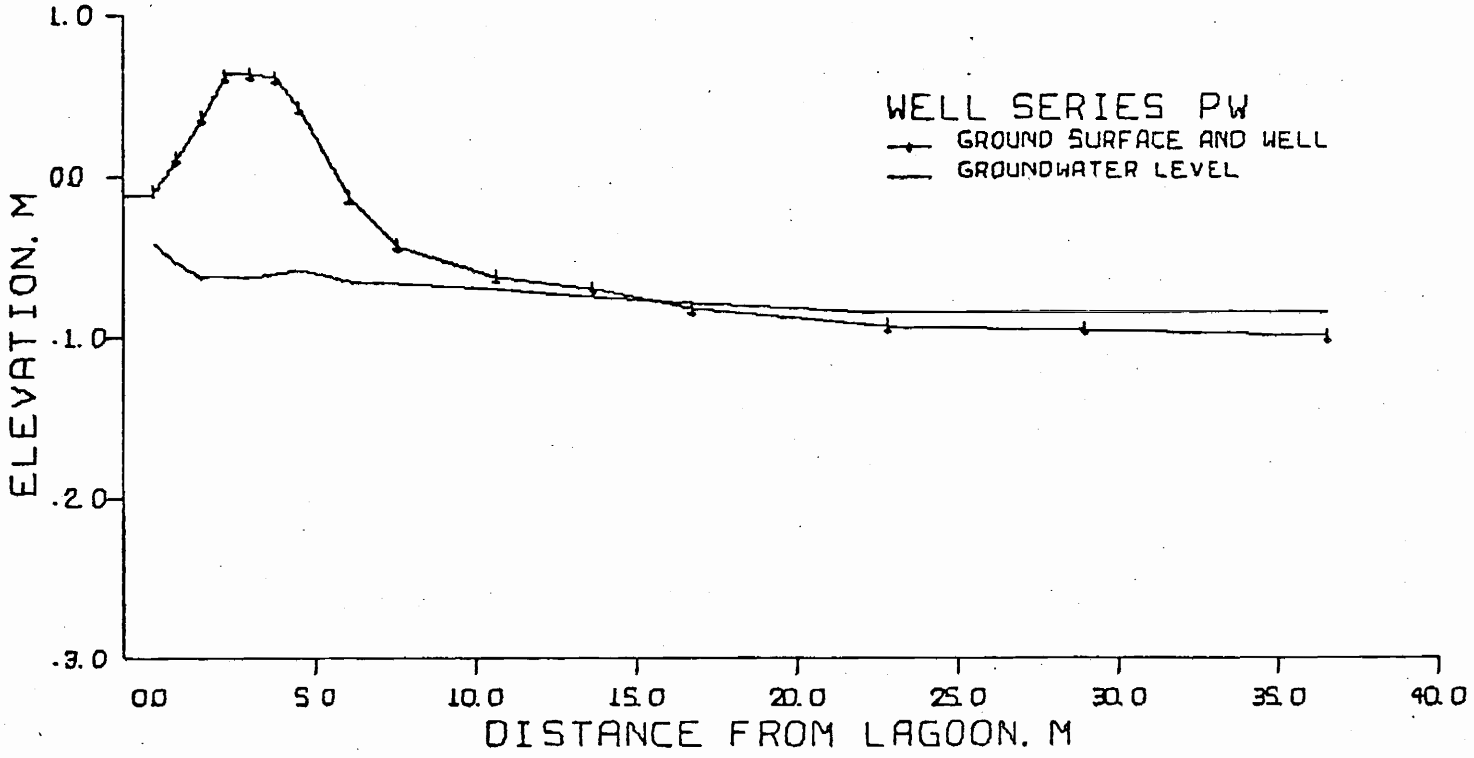


FIG. 22 WATER TABLE PROFILE JAN. 02. 1976

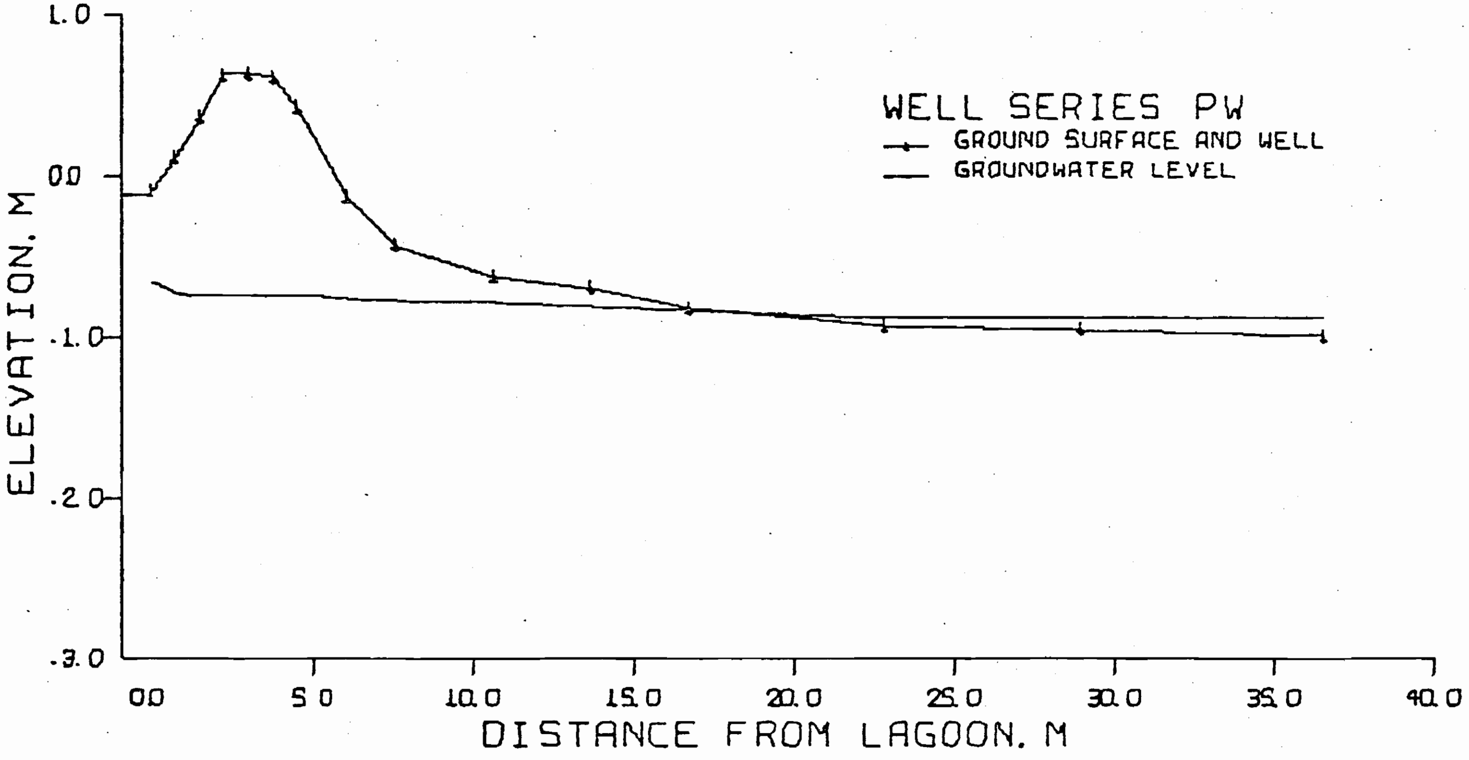


FIG. 23 WATER TABLE PROFILE JAN. 15. 1976

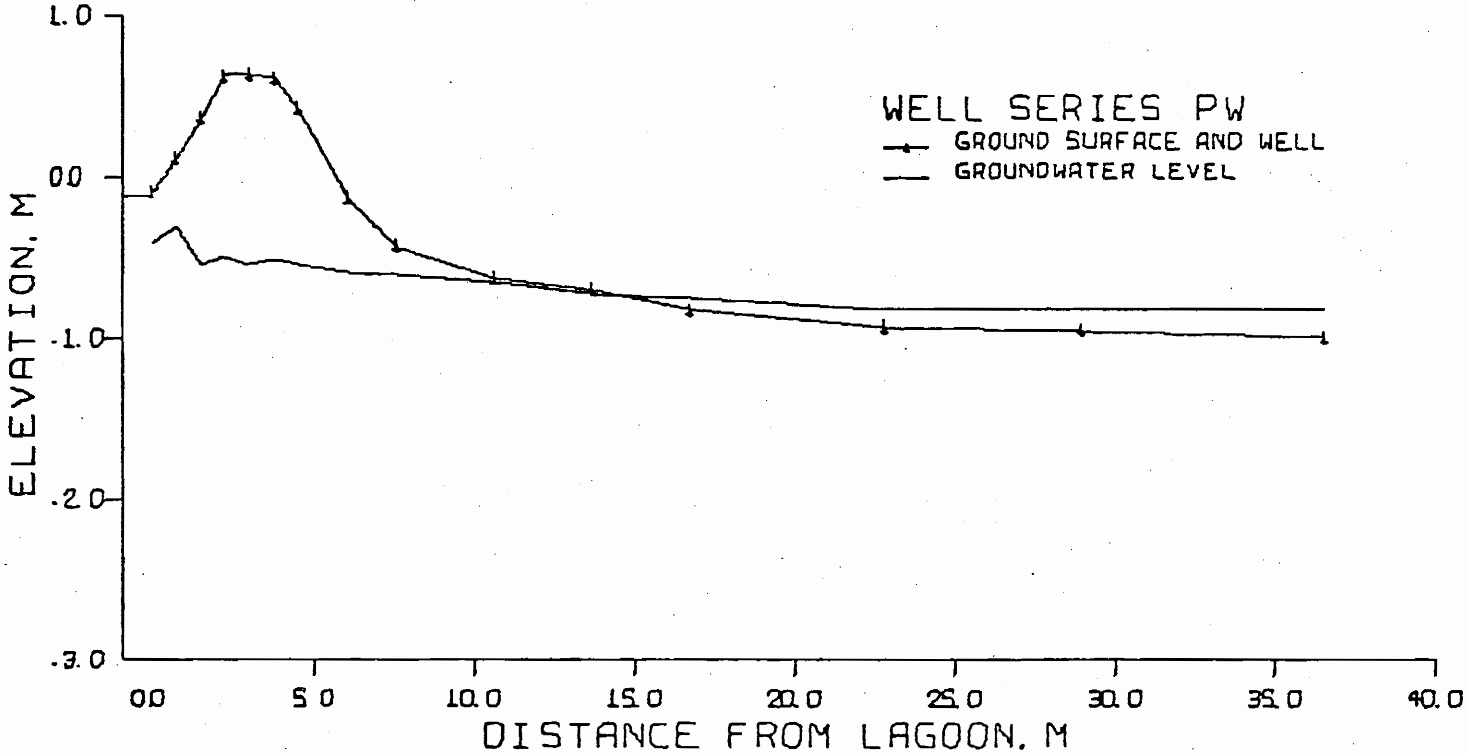


FIG. 24 WATER TABLE PROFILE JAN. 29. 1976

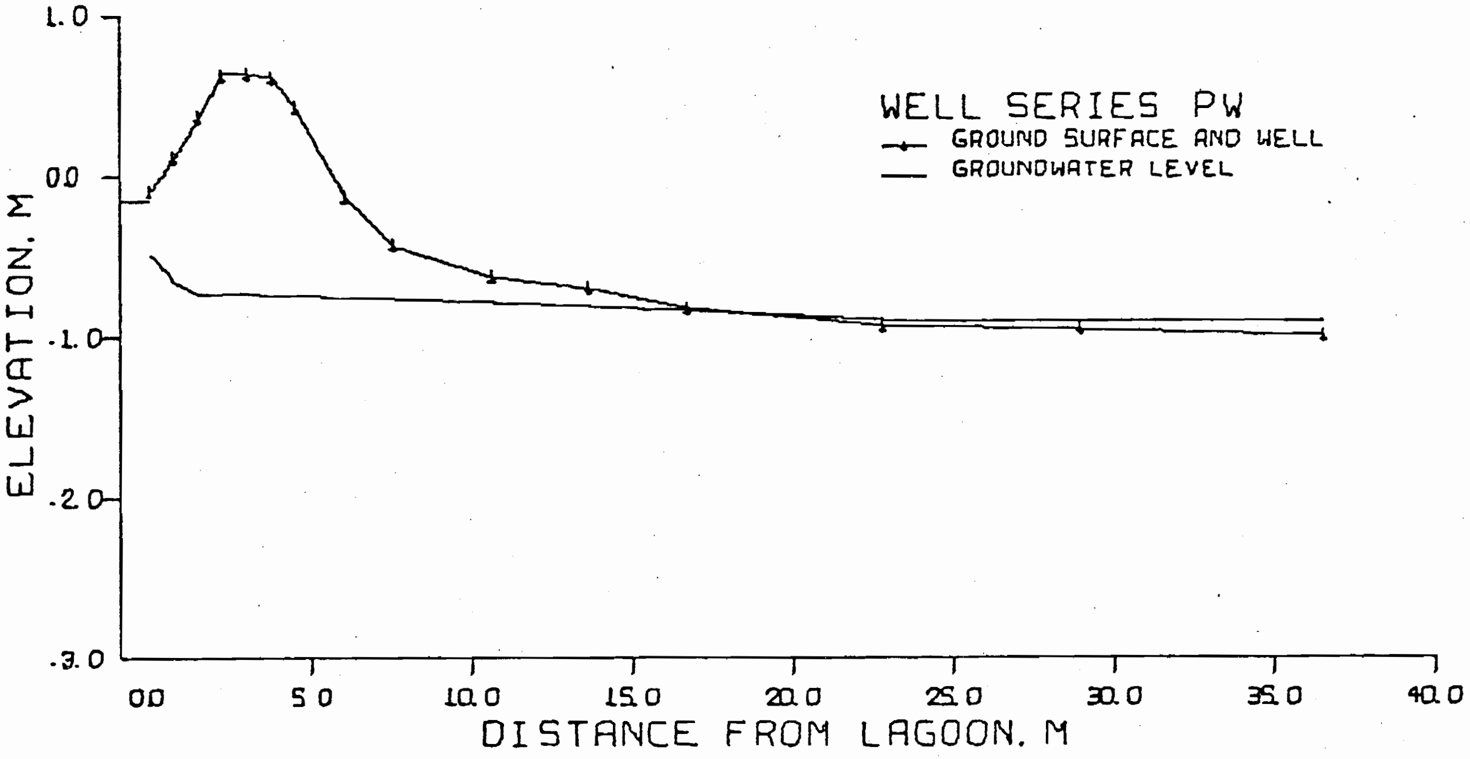


FIG. 25 WATER TABLE PROFILE FEB. 13. 1976

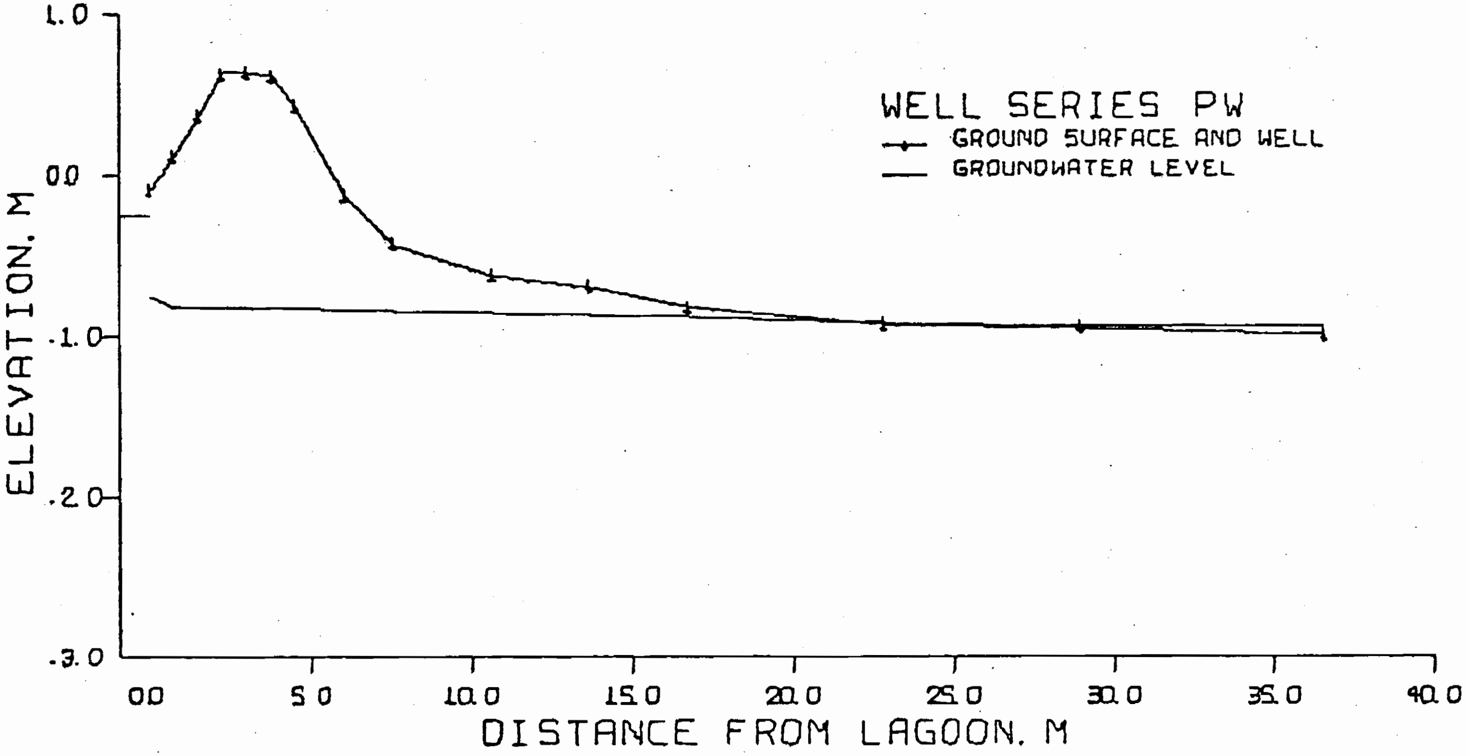


FIG. 26 WATER TABLE PROFILE FEB. 27, 1976

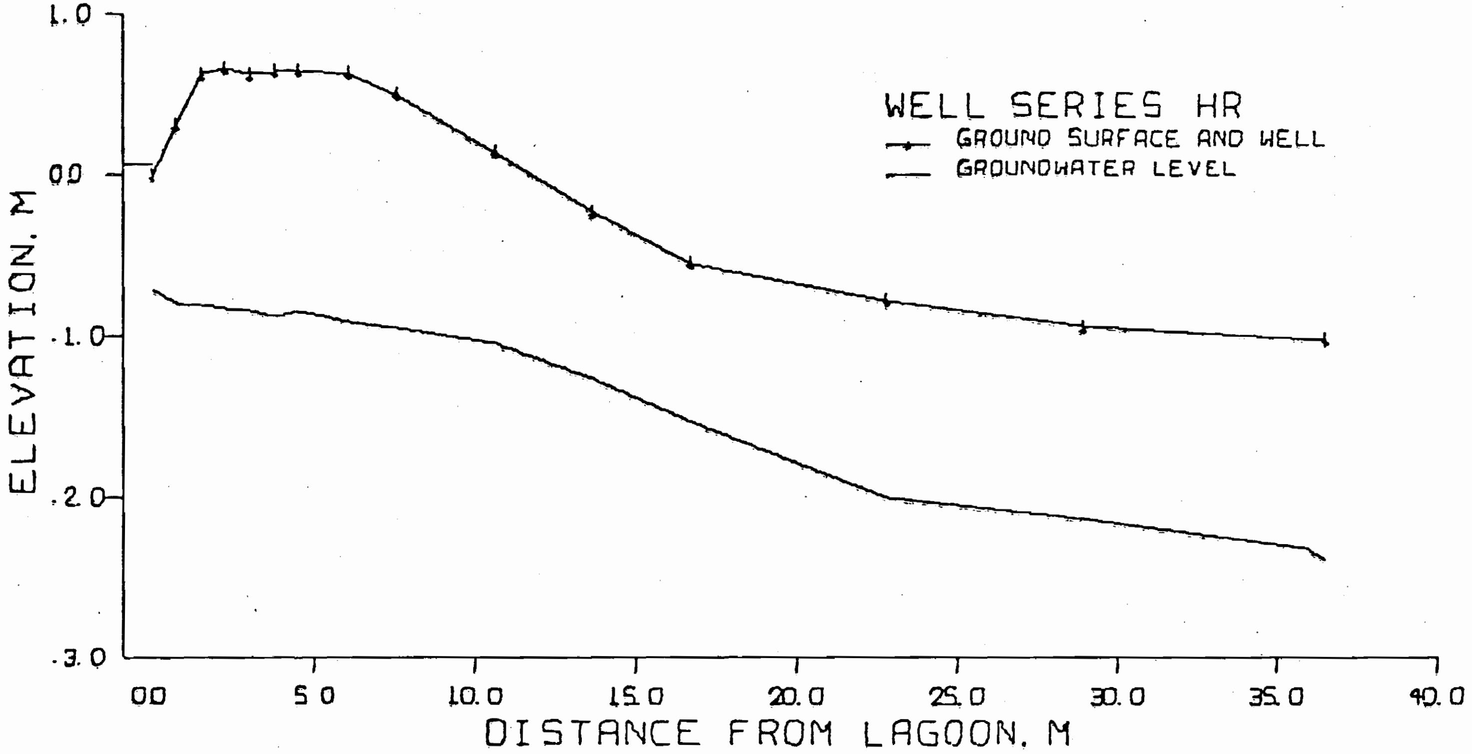
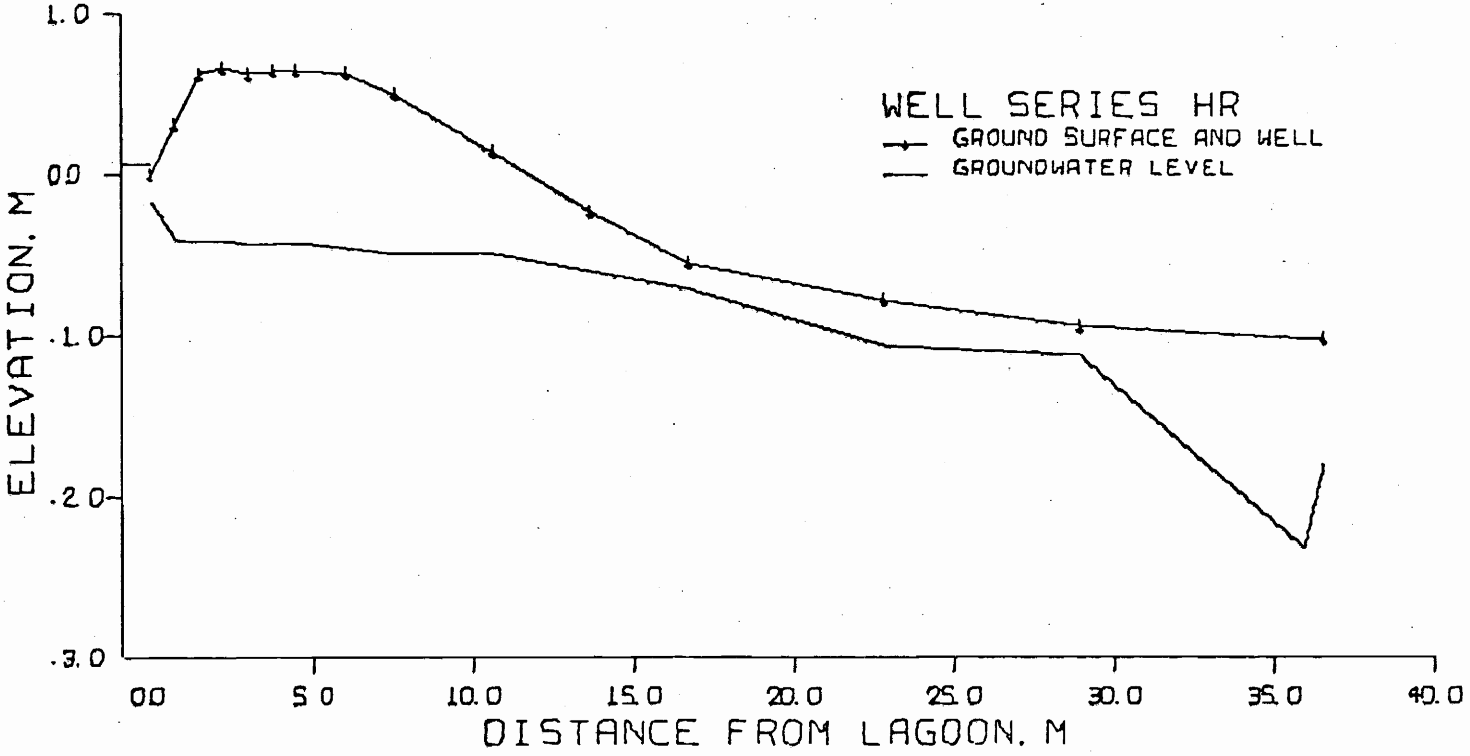


FIG. 27 WATER TABLE PROFILE SEP 10. 1975



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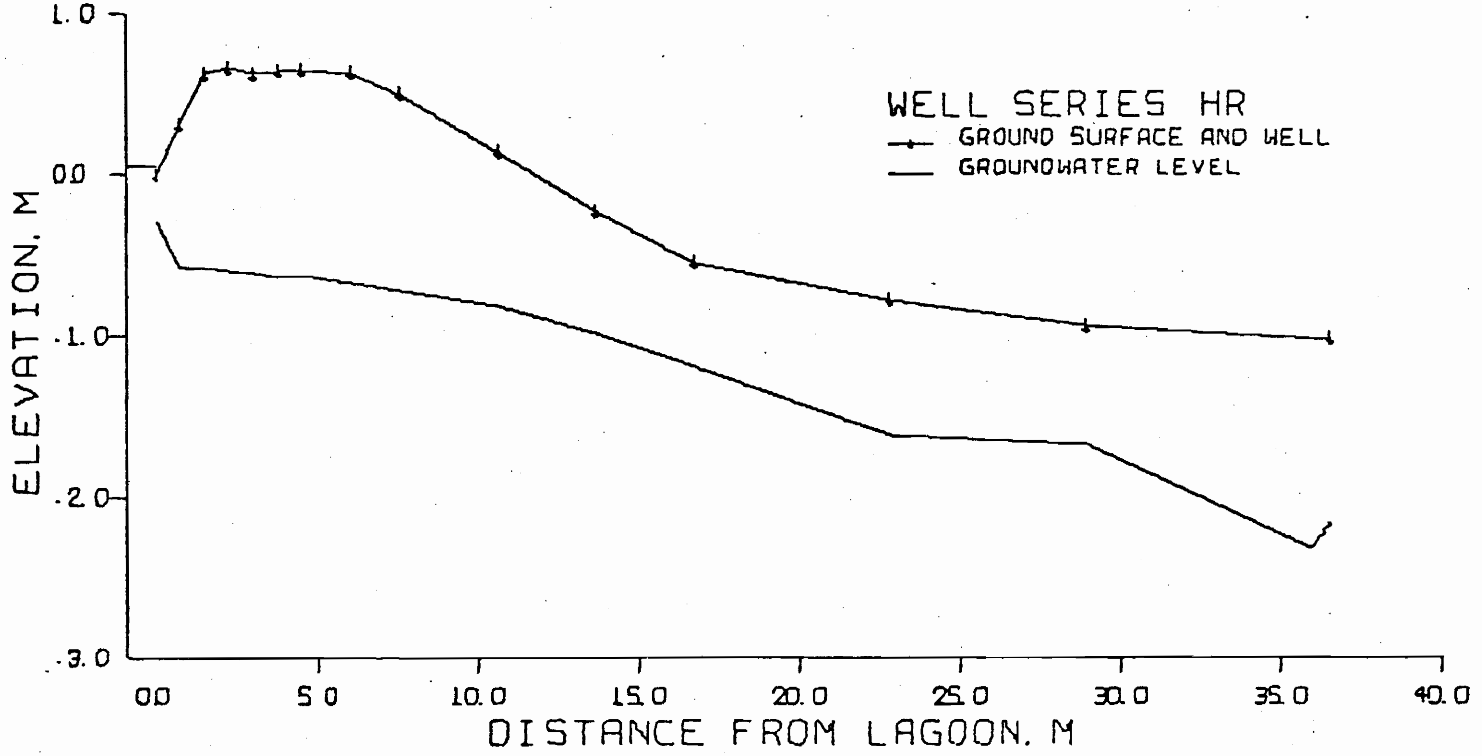


FIG. 29 WATER TABLE PROFILE OCT. 11. 1975

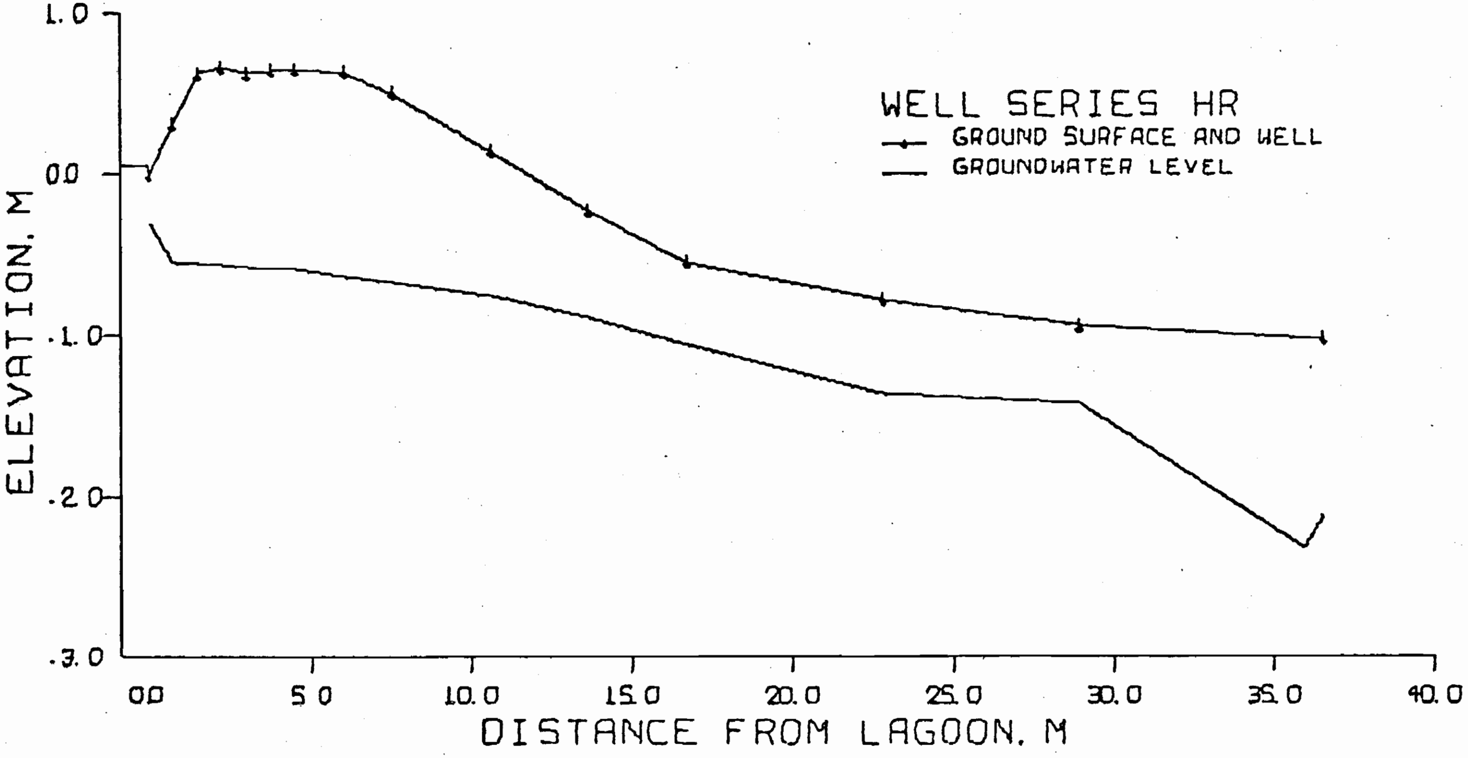


FIG. 30 WATER TABLE PROFILE OCT. 25. 1975

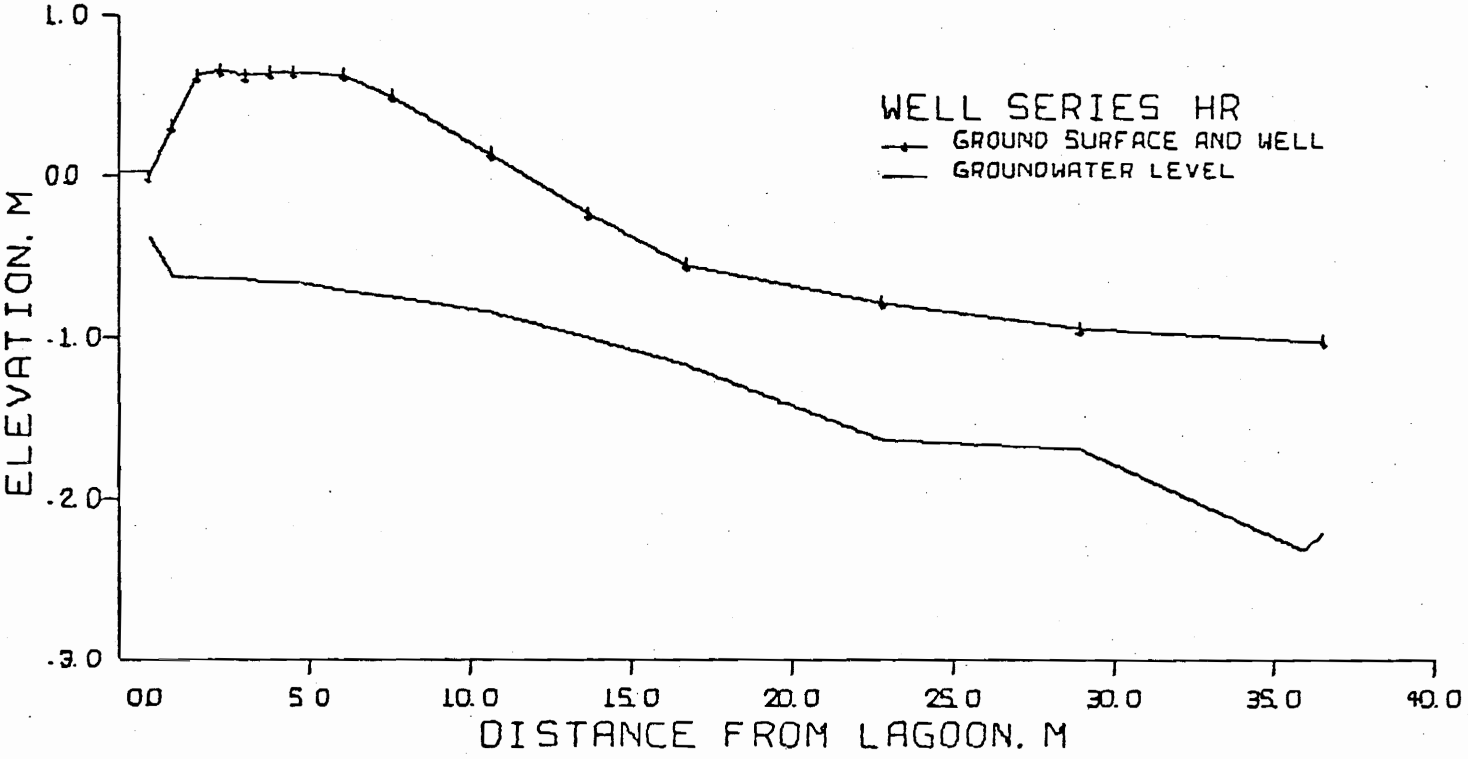
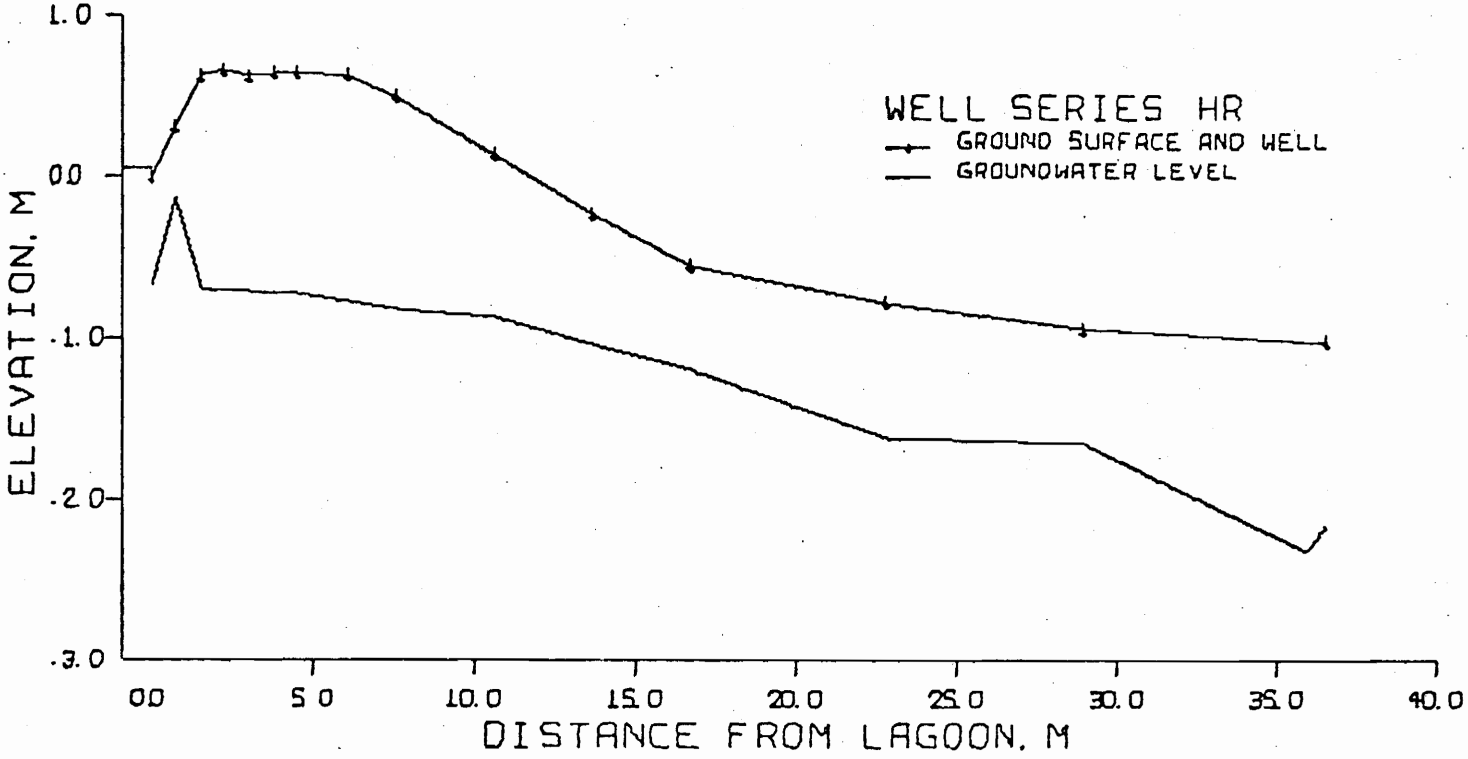


FIG. 31 WATER TABLE PROFILE NOV. 08. 1975



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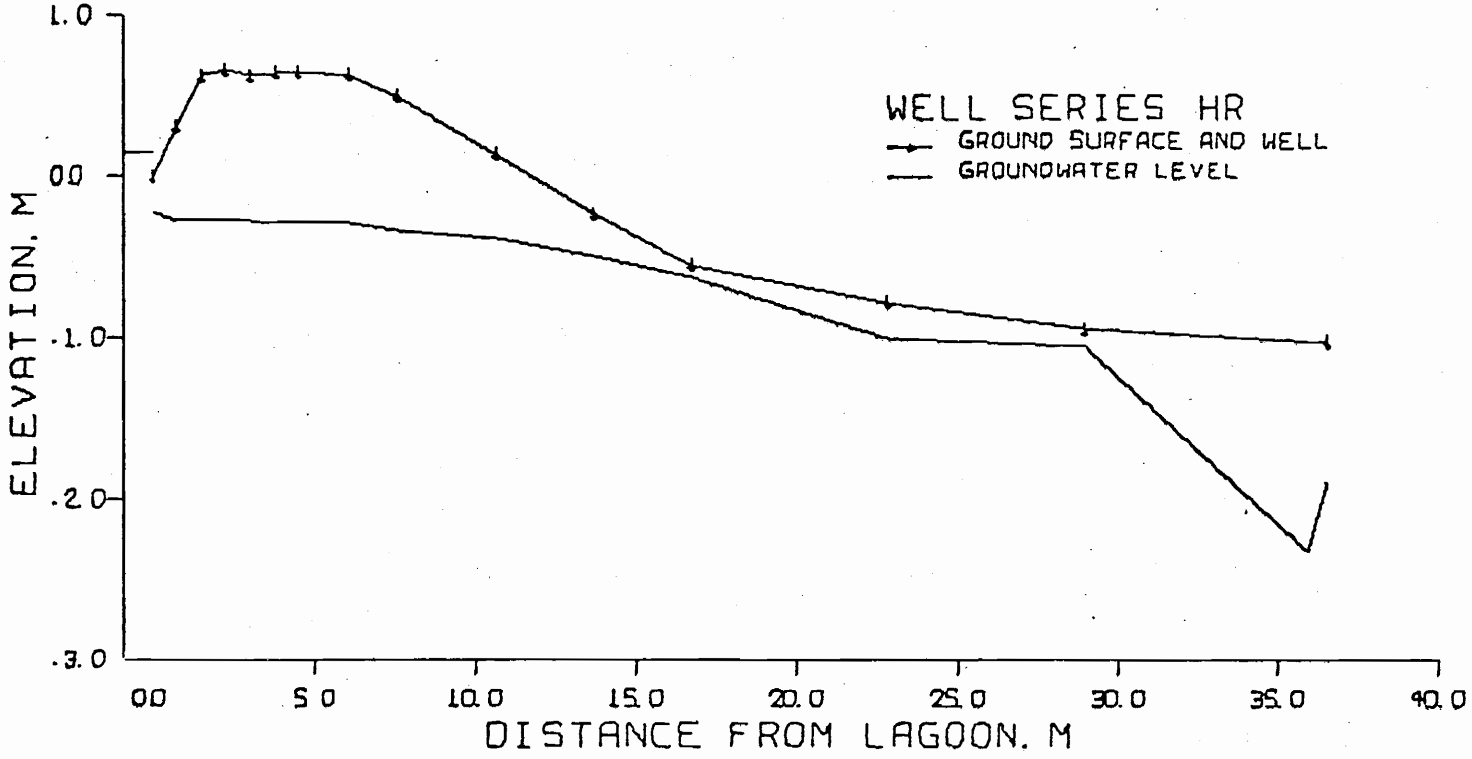

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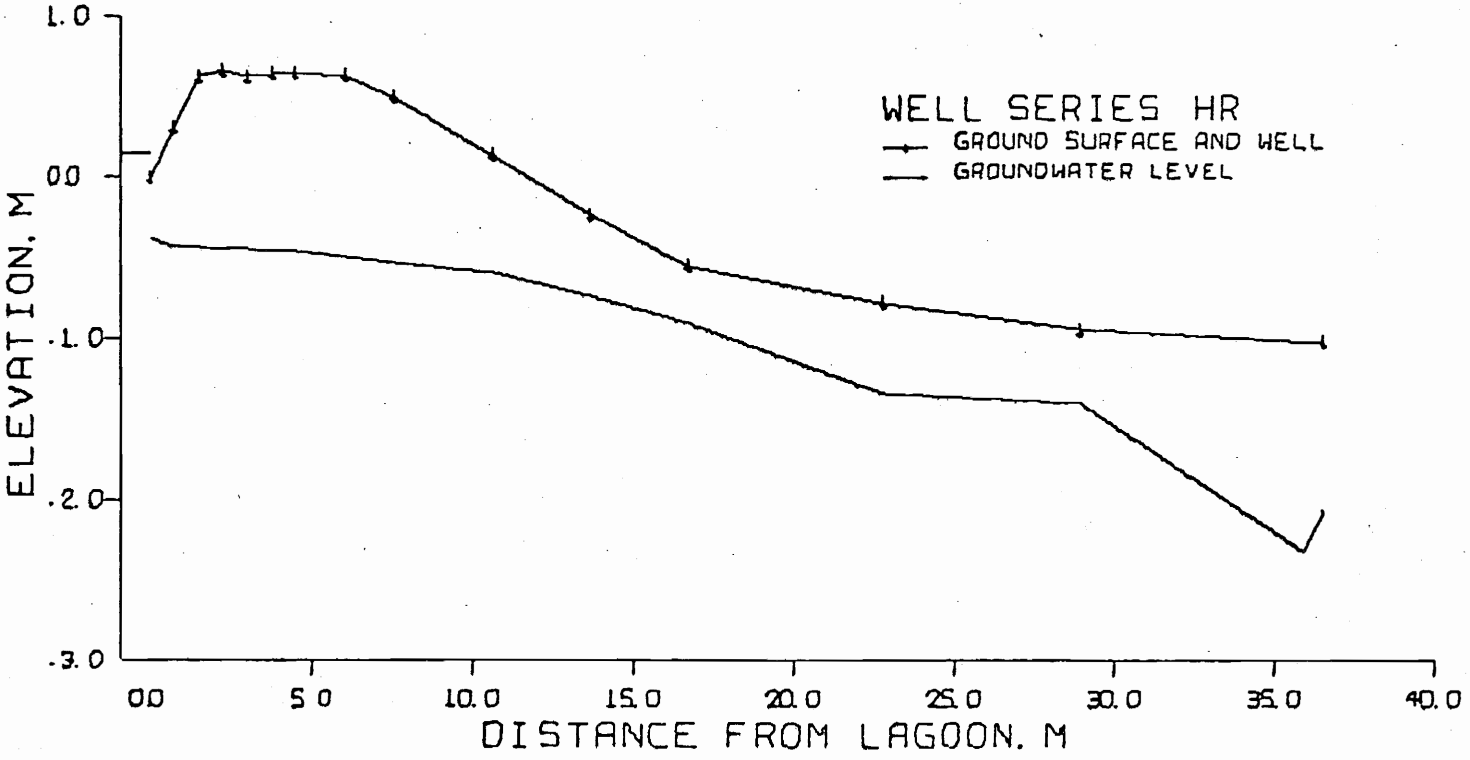

FIG. 34 WATER TABLE PROFILE DEC. 20. 1975

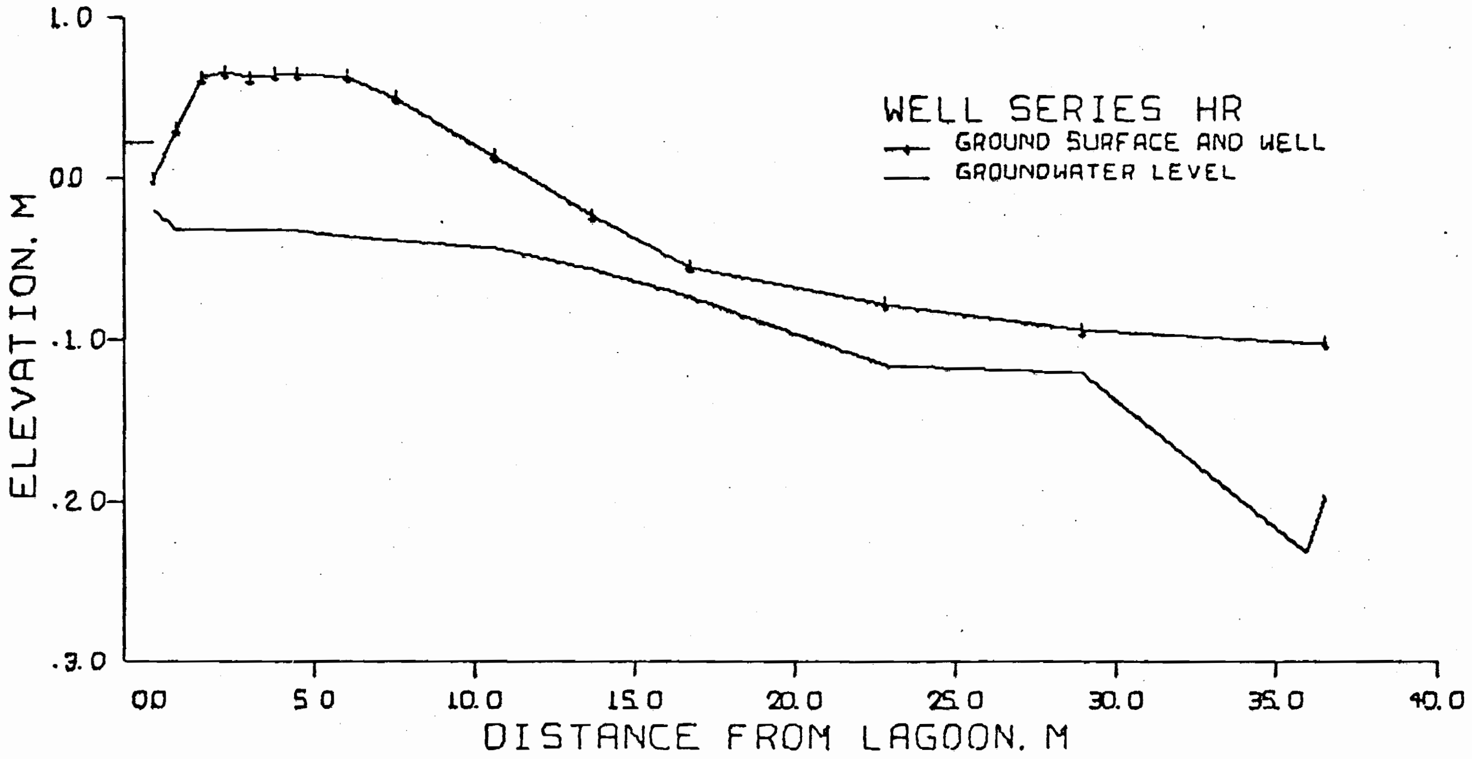

FIG. 35 WATER TABLE PROFILE JAN. 02. 1976

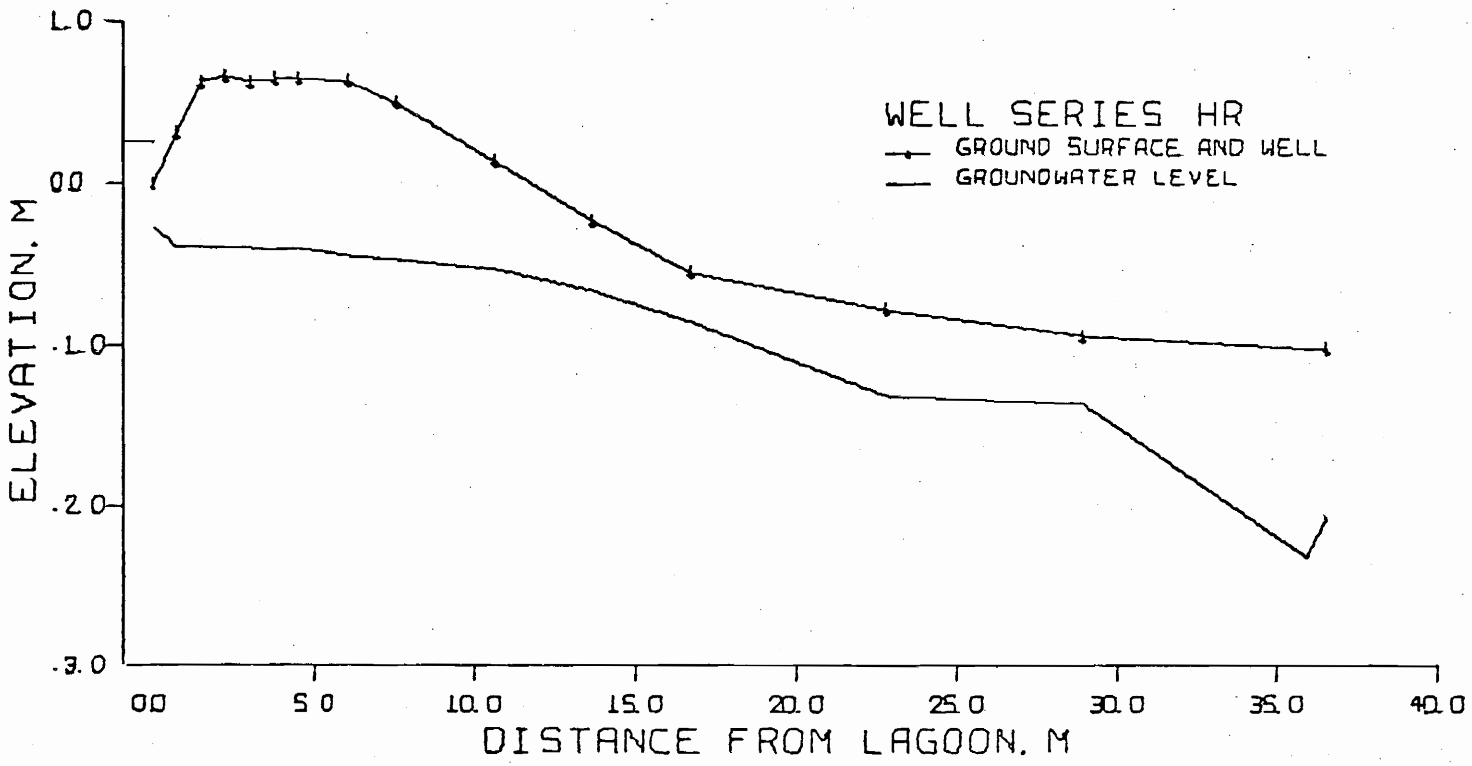

FIG. 36 WATER TABLE PROFILE JAN. 15. 1976

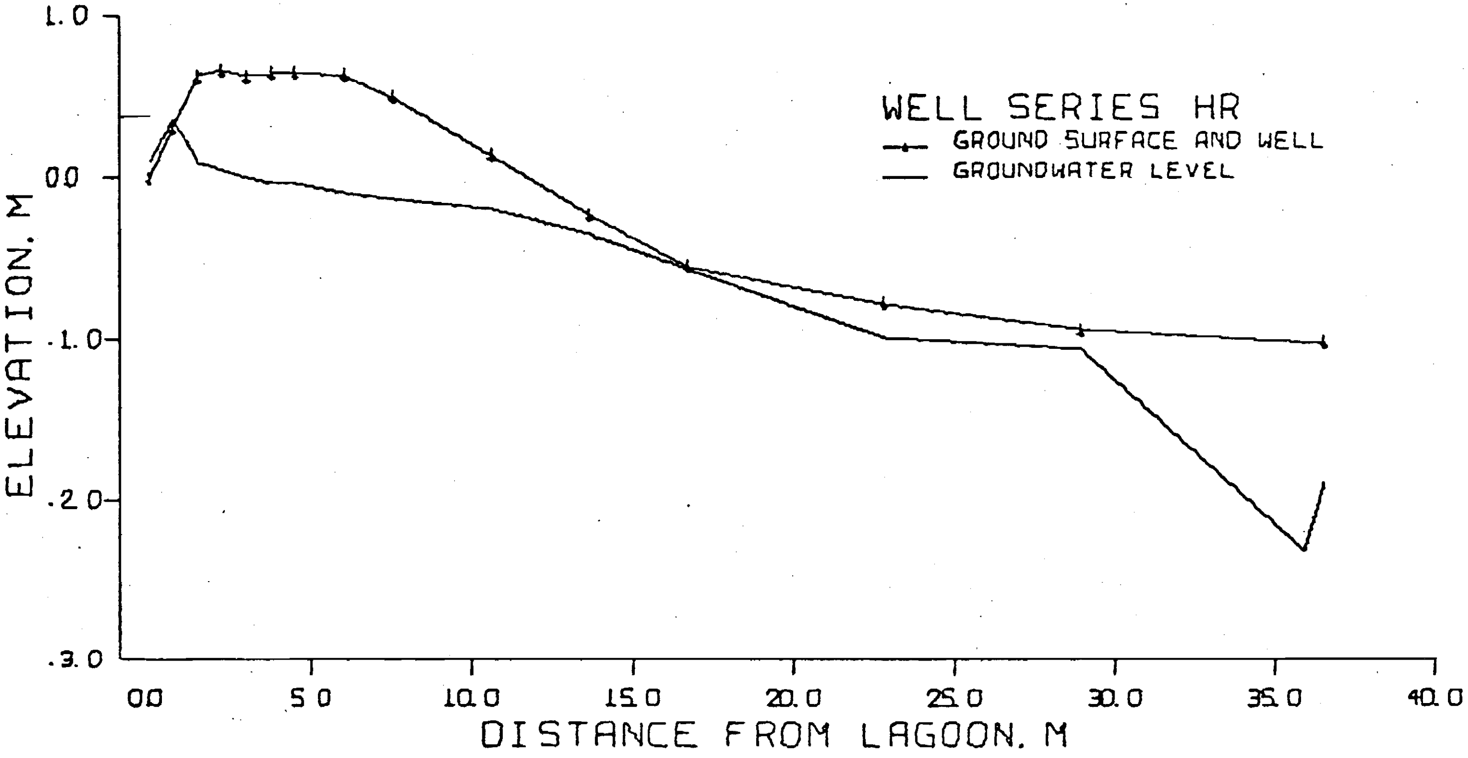

FIG. 37 WATER TABLE PROFILE JAN. 29, 1976

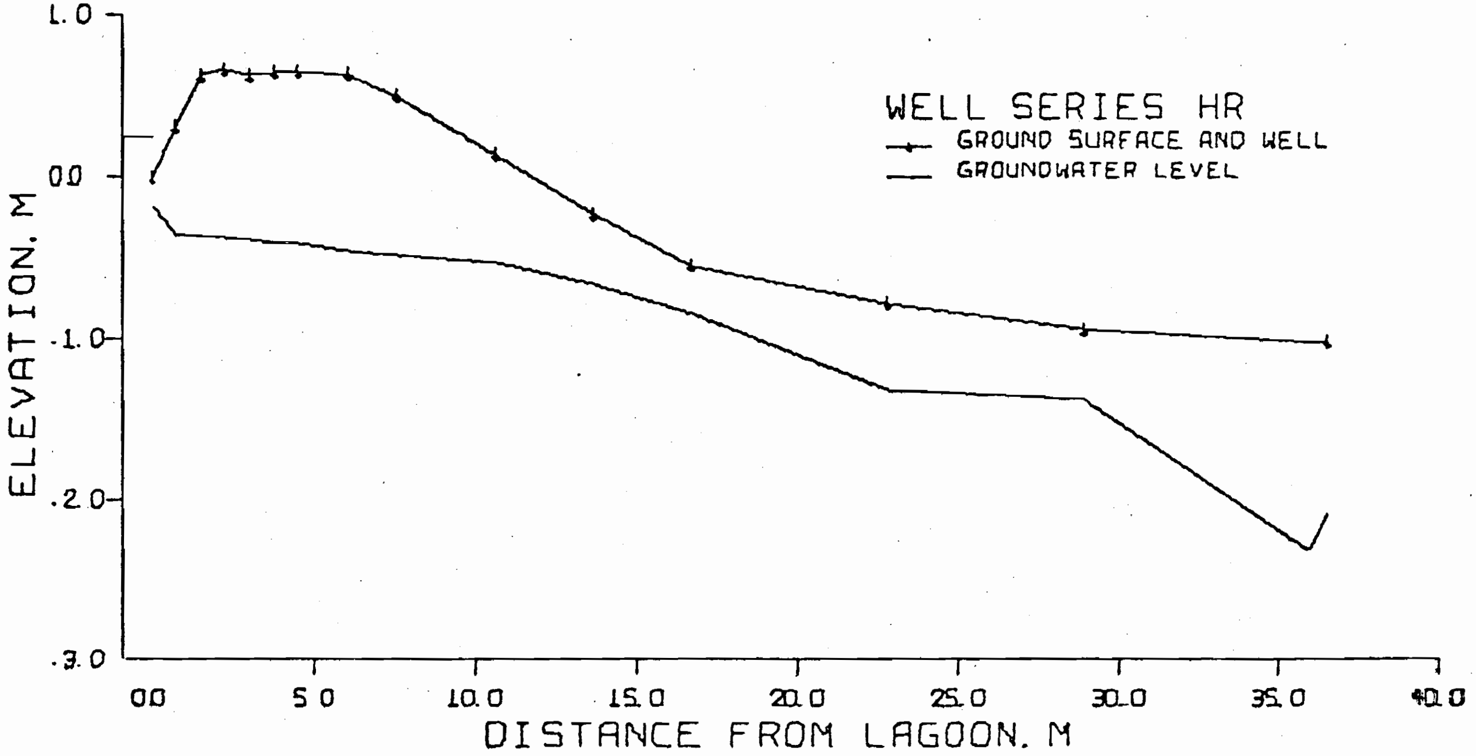

FIG. 38 WATER TABLE PROFILE FEB. 13. 1976

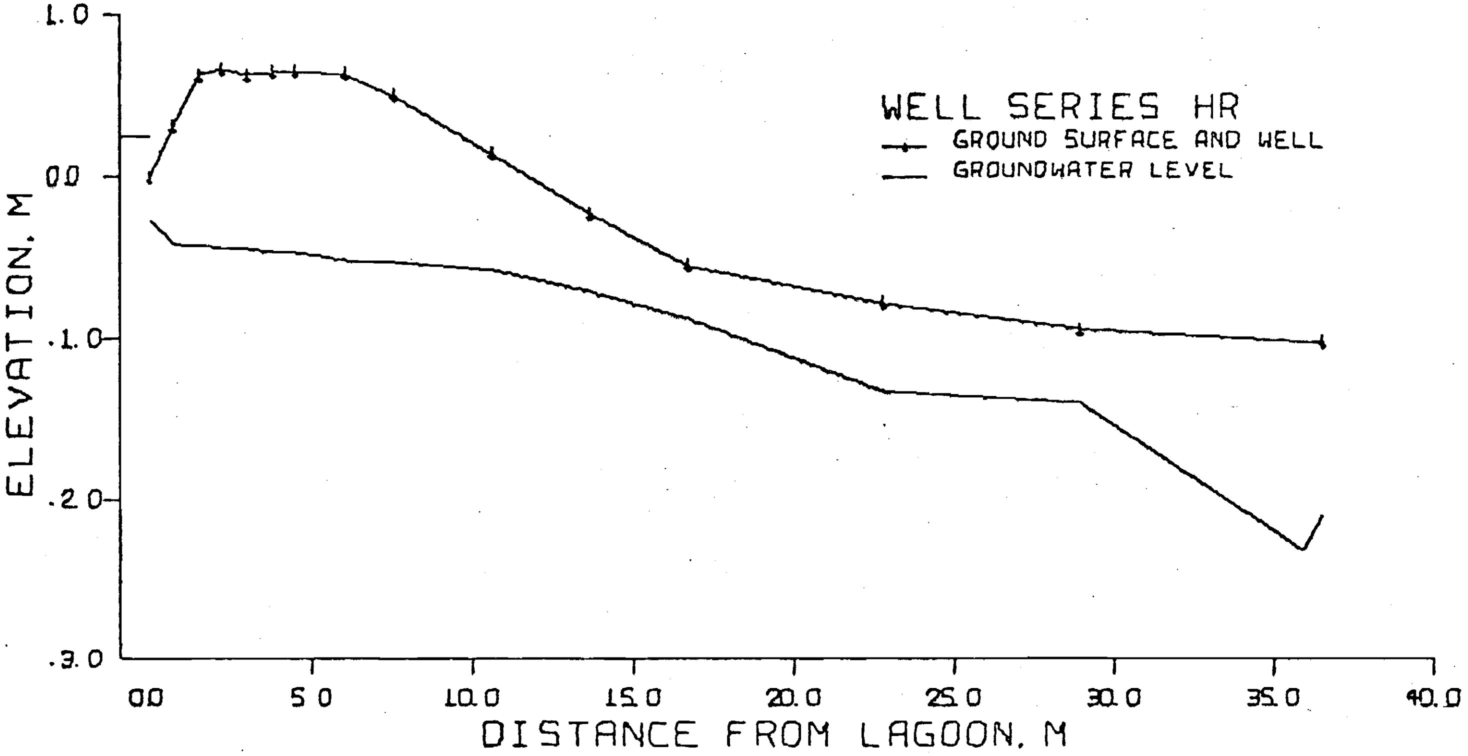

FIG. 39 WATER TABLE PROFILE FEB. 27. 1976

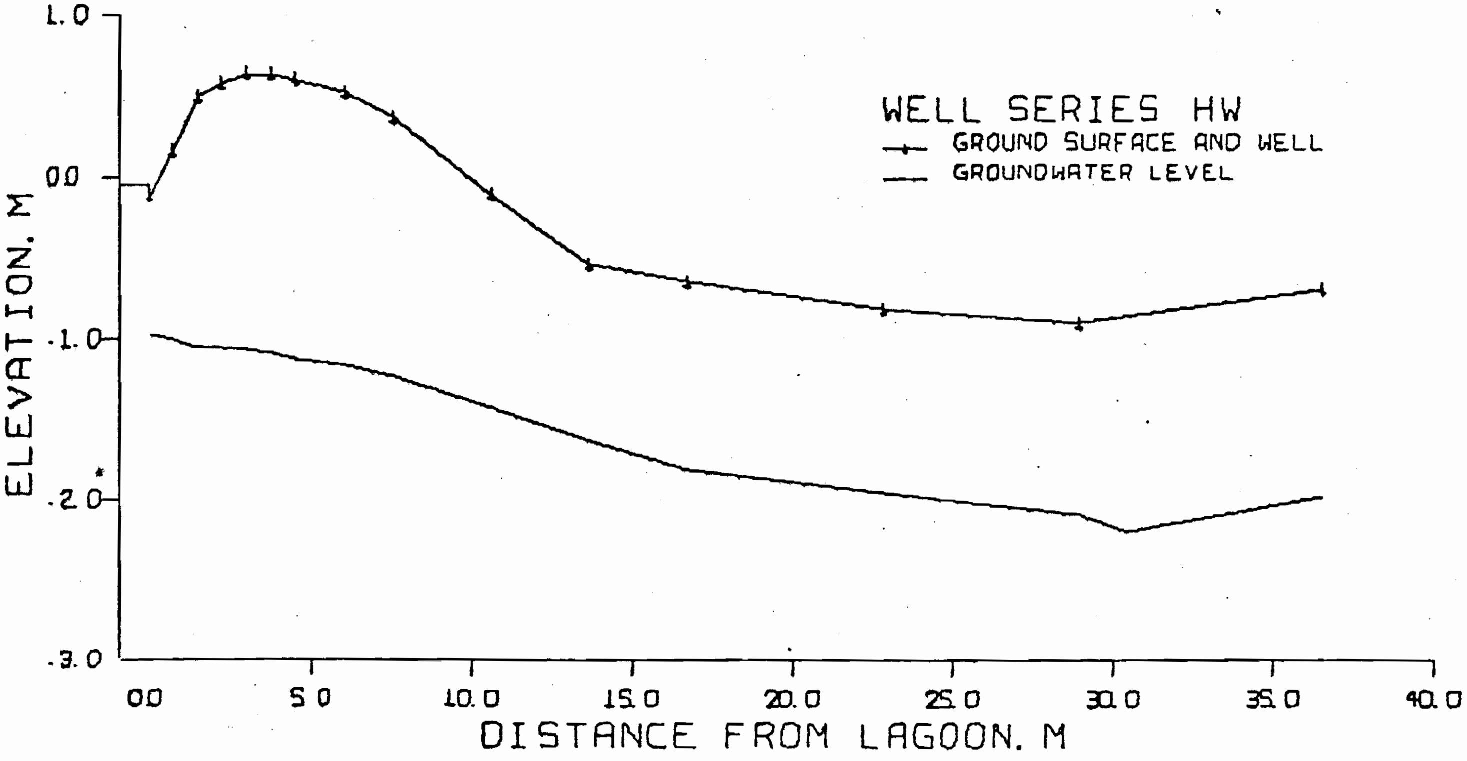

FIG. 40 WATER TABLE PROFILE SEP 10. 1975

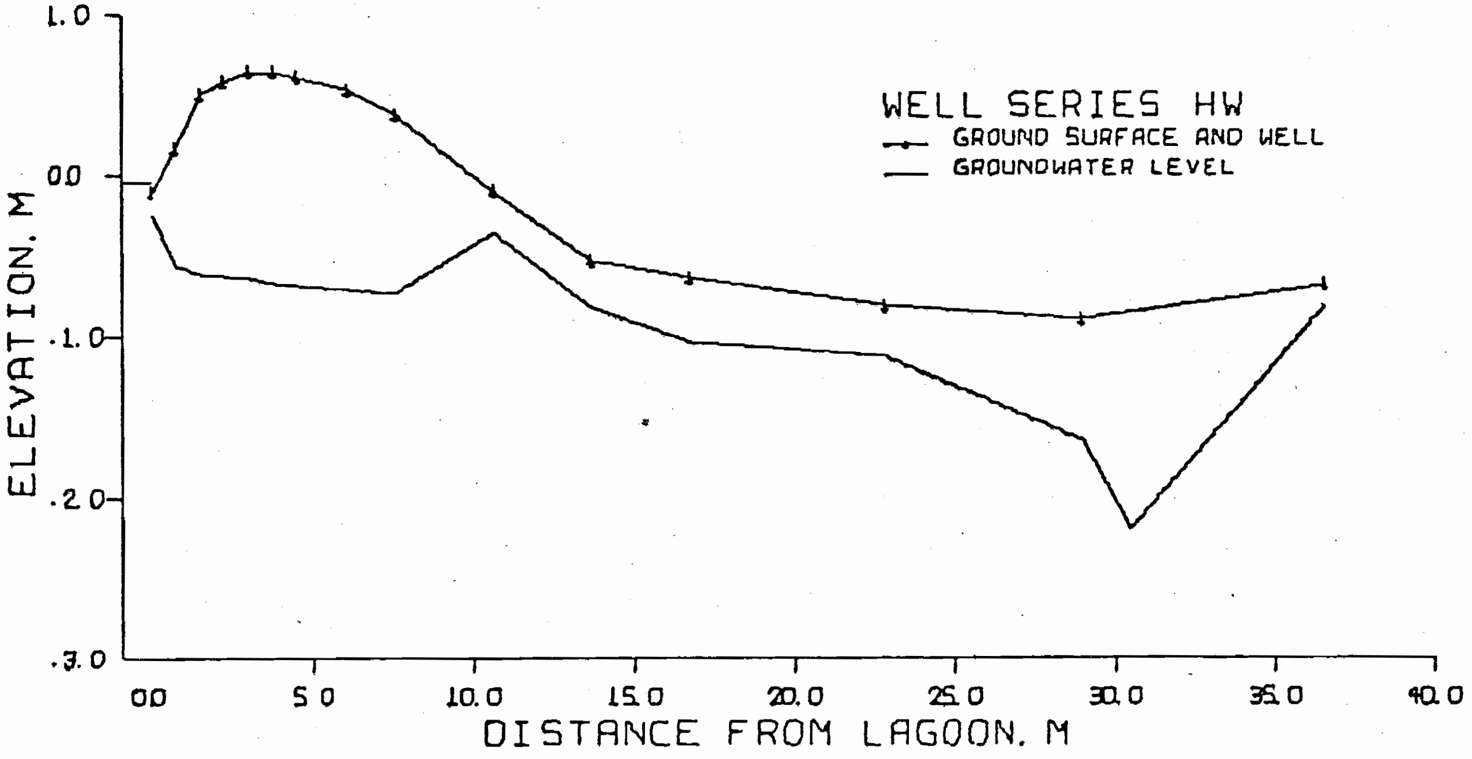

FIG. 41 WATER TABLE PROFILE SEP 27. 1975

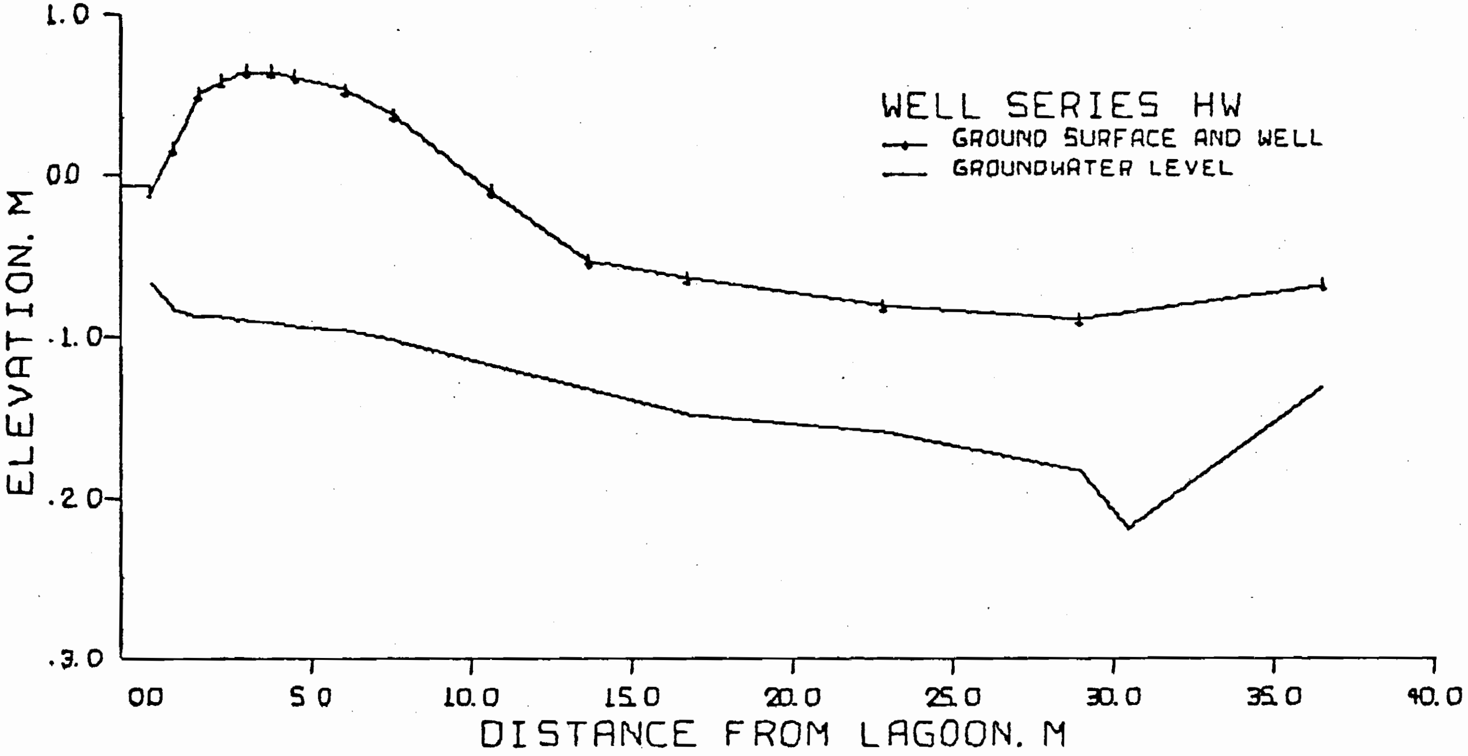

FIG. 42 WATER TABLE PROFILE OCT. 11. 1975

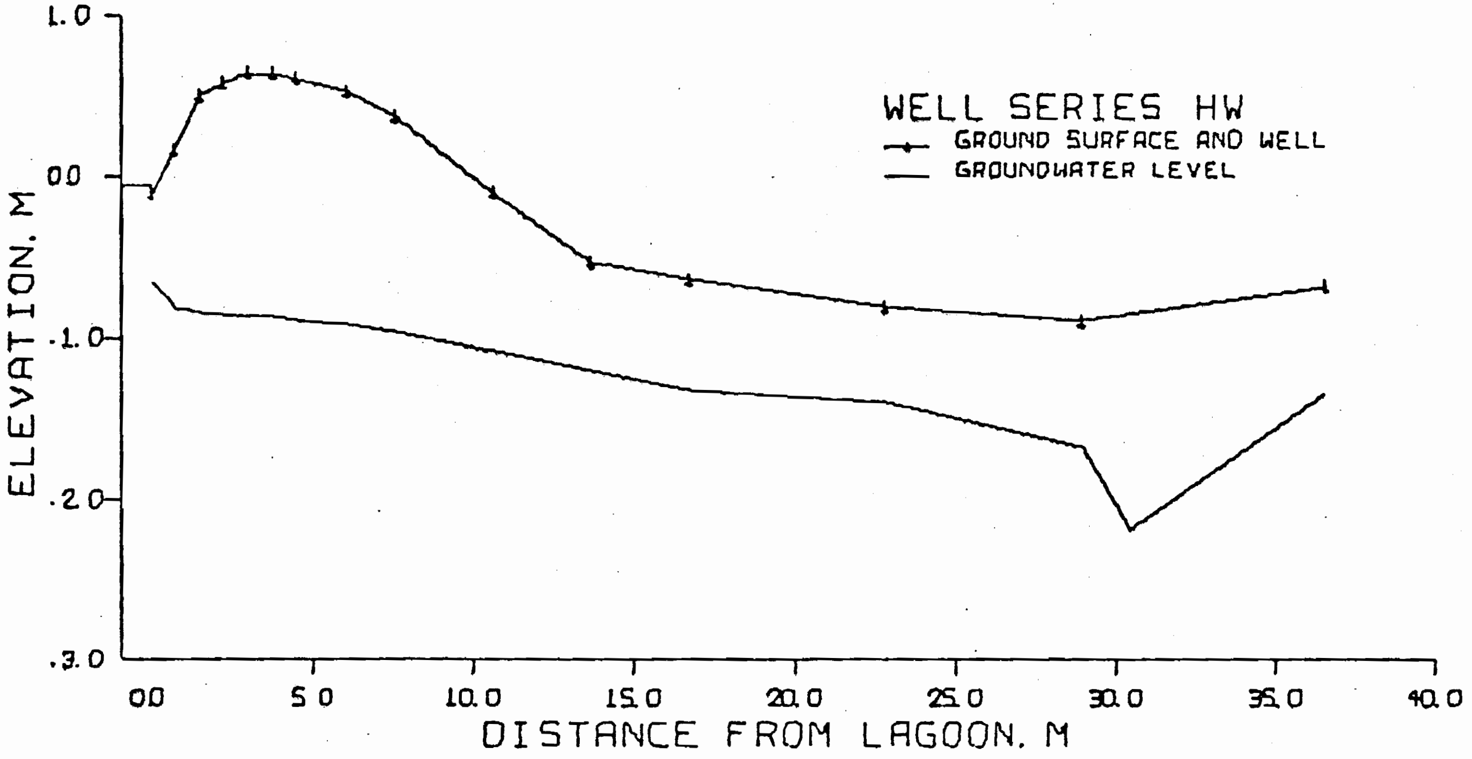

FIG. 43 WATER TABLE PROFILE OCT. 25. 1975

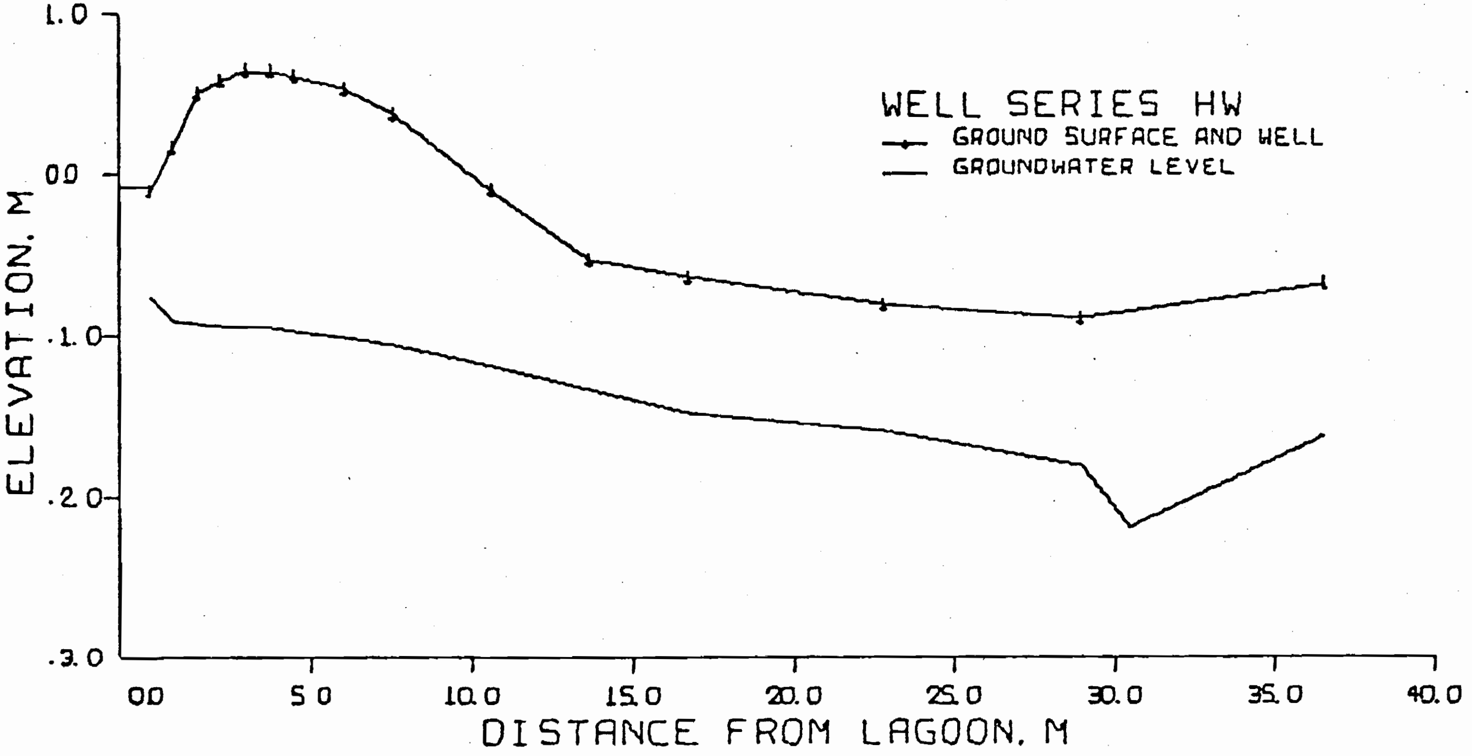

FIG. 44 WATER TABLE PROFILE NOV. 08. 1975

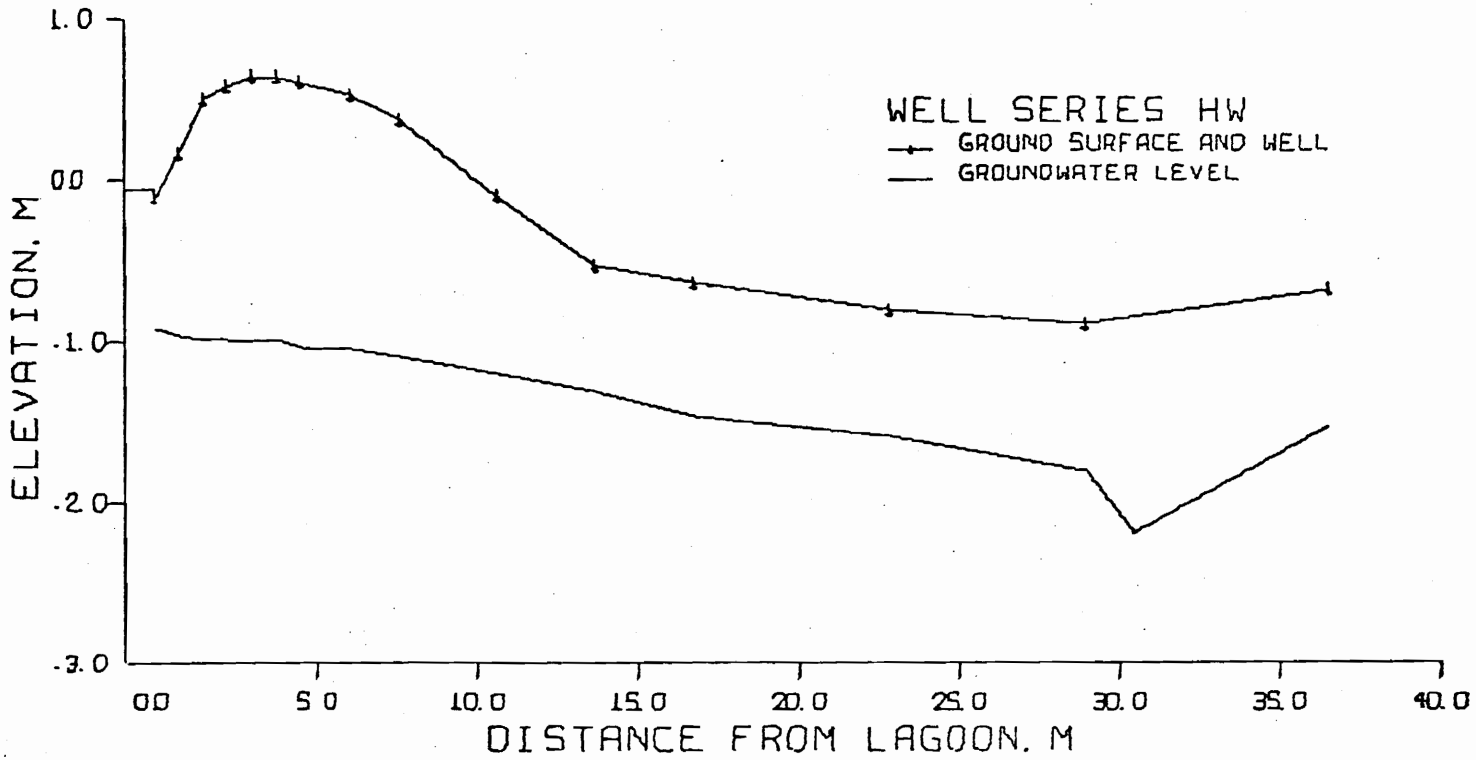

FIG. 45 WATER TABLE PROFILE NOV. 22. 1975

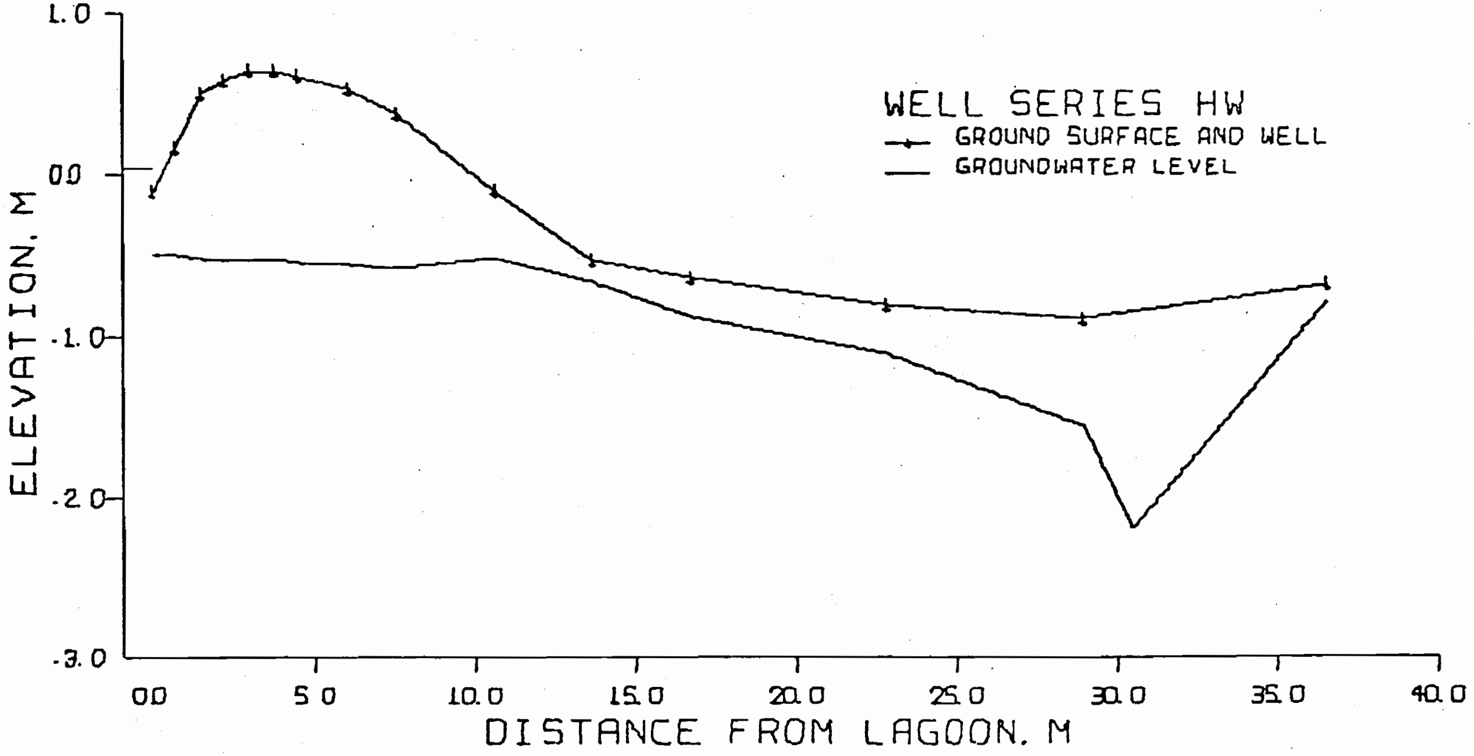

FIG. 46 WATER TABLE PROFILE DEC. 09, 1975

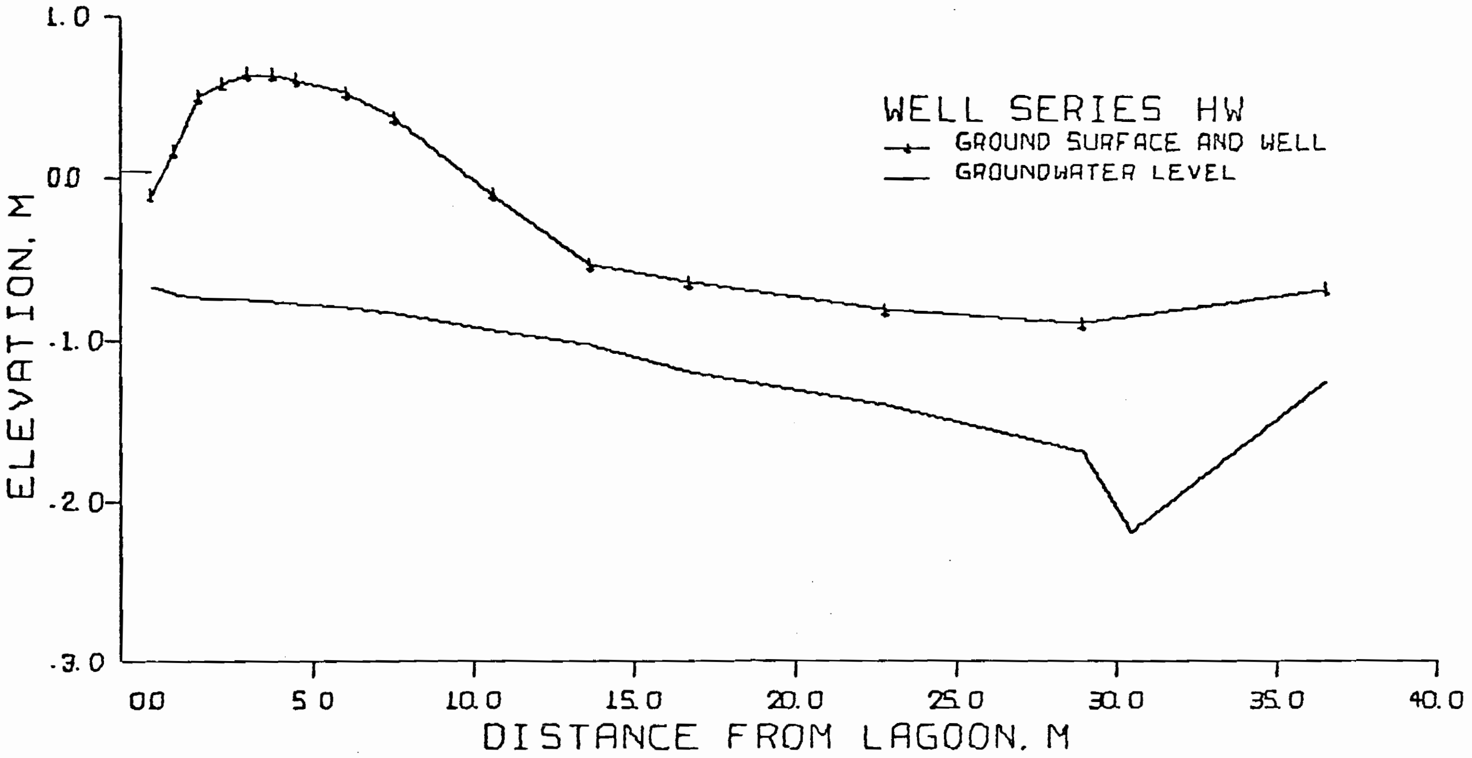

FIG. 47 WATER TABLE PROFILE DEC. 20. 1975

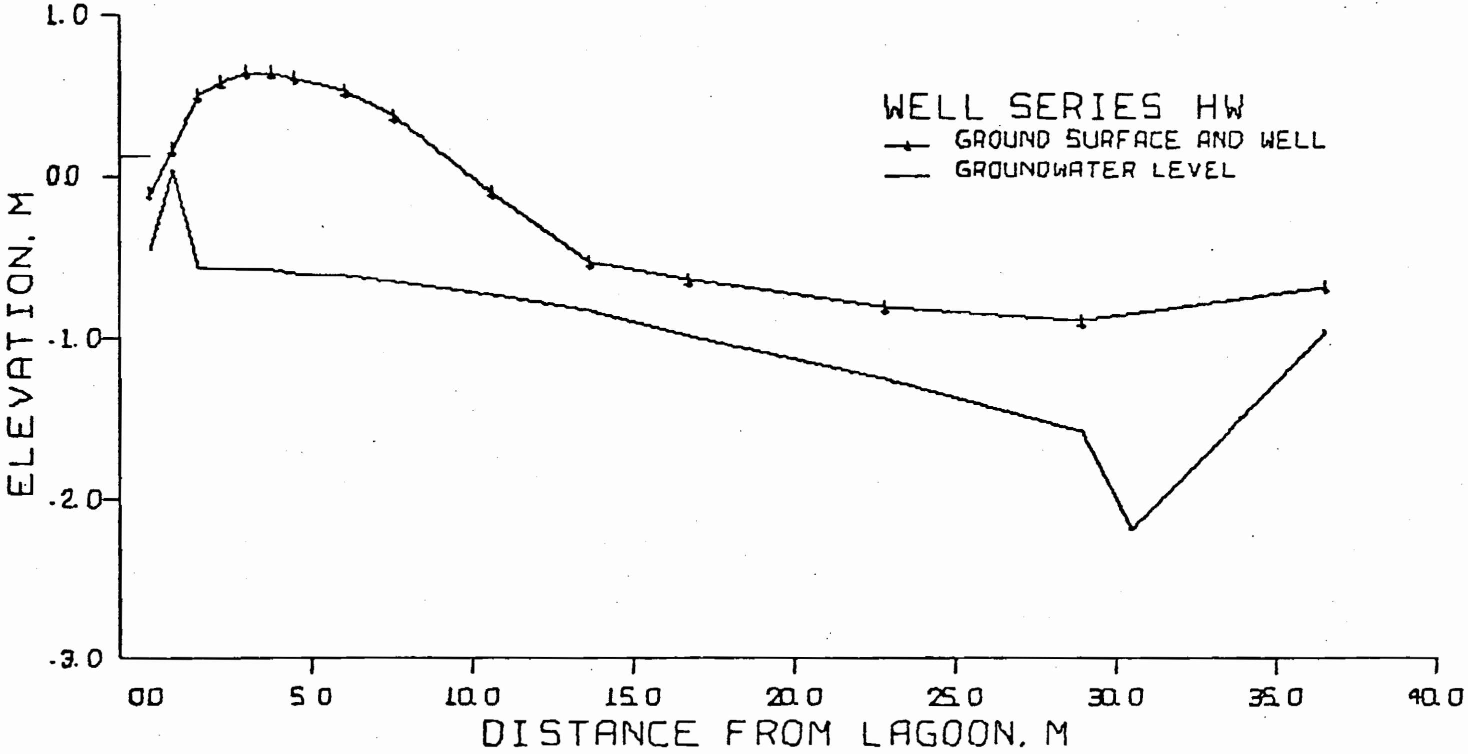

FIG. 48 WATER TABLE PROFILE JAN. 02. 1976

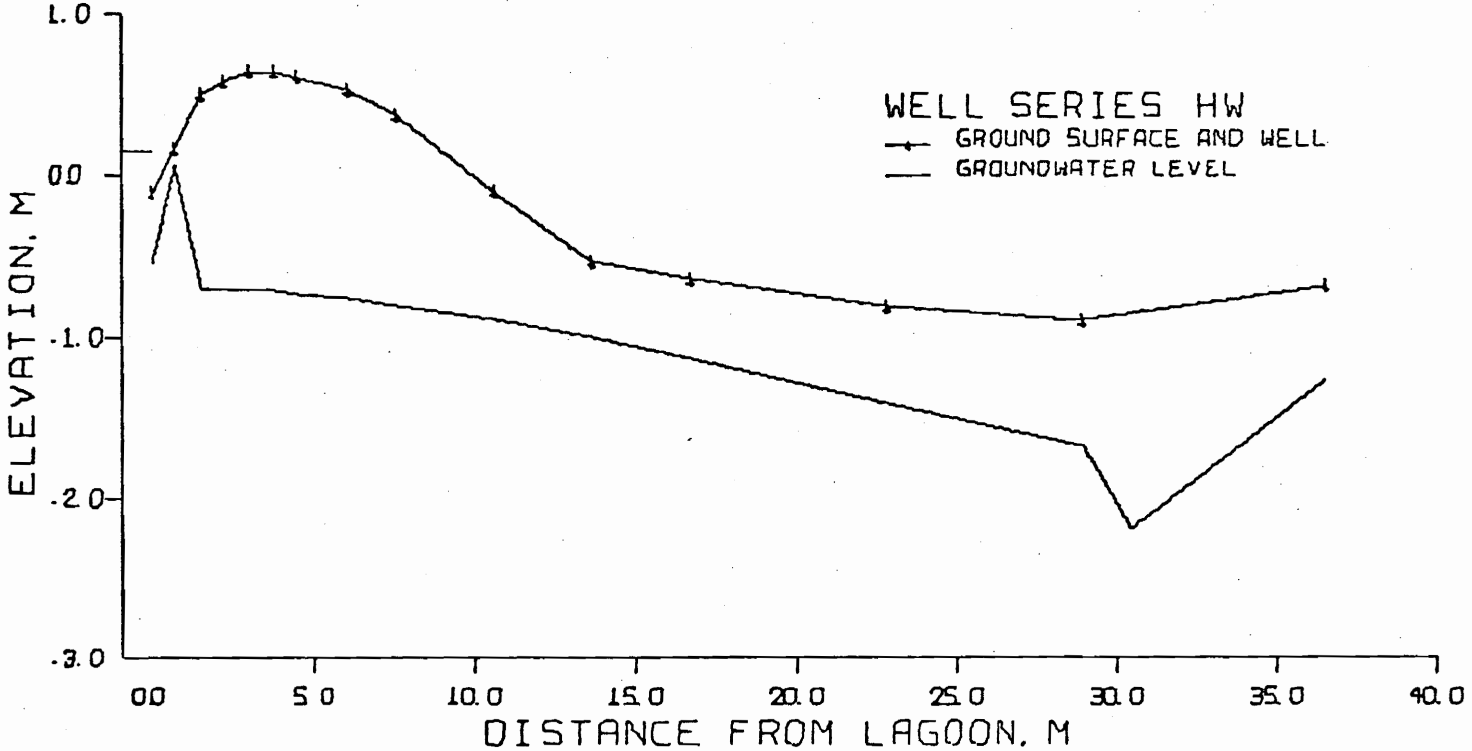

FIG.49 WATER TABLE PROFILE JAN. 15. 1976

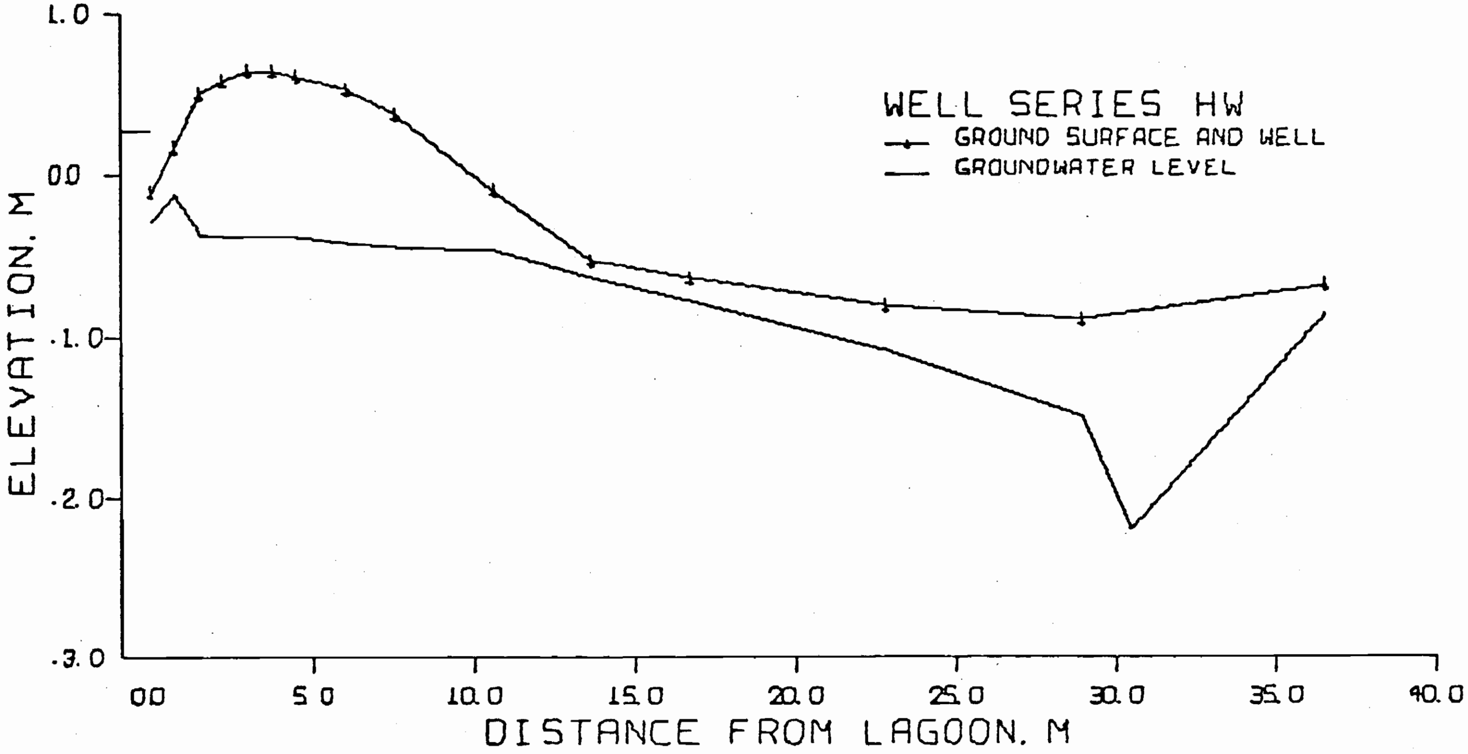

FIG. 50 WATER TABLE PROFILE JAN. 29, 1976

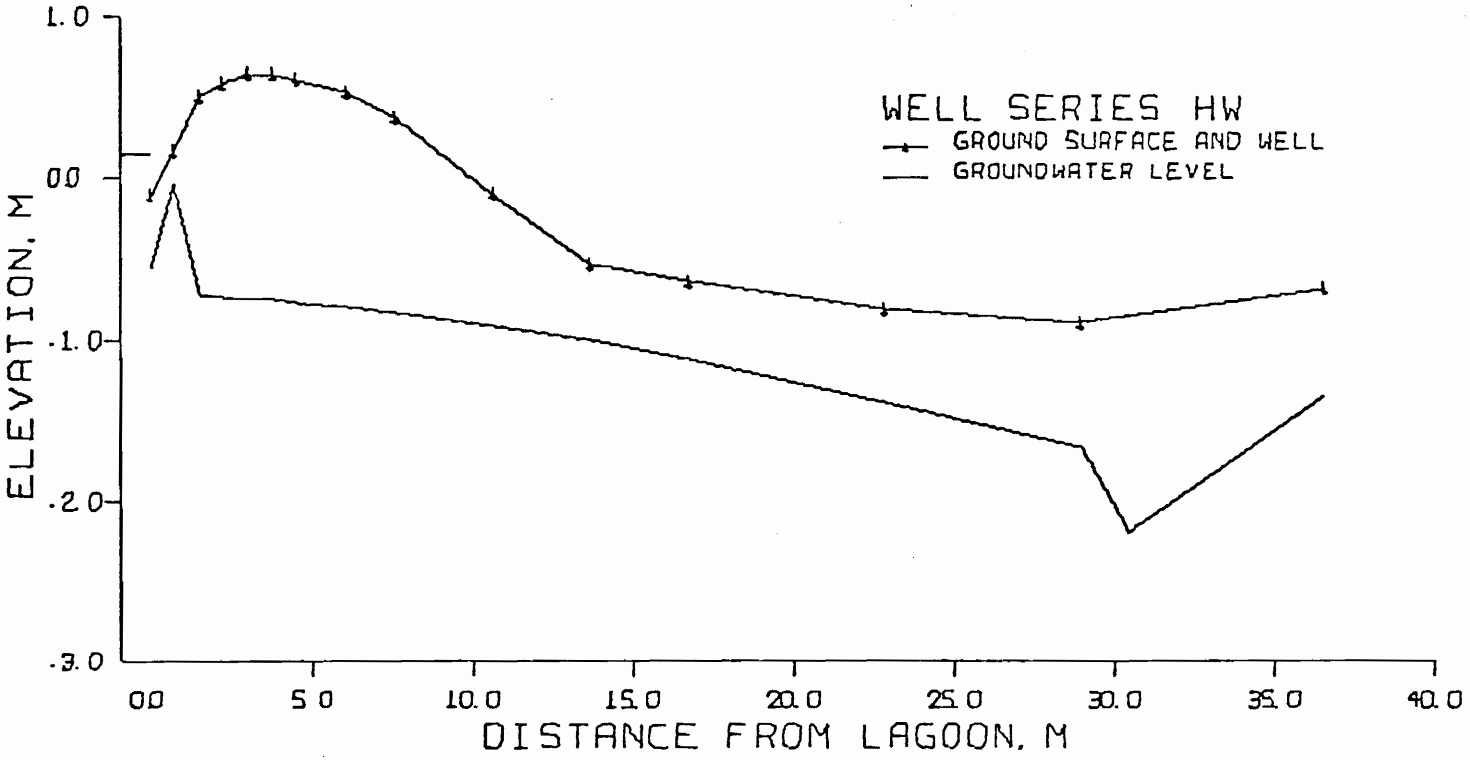

FIG. 51 WATER TABLE PROFILE FEB. 13, 1976

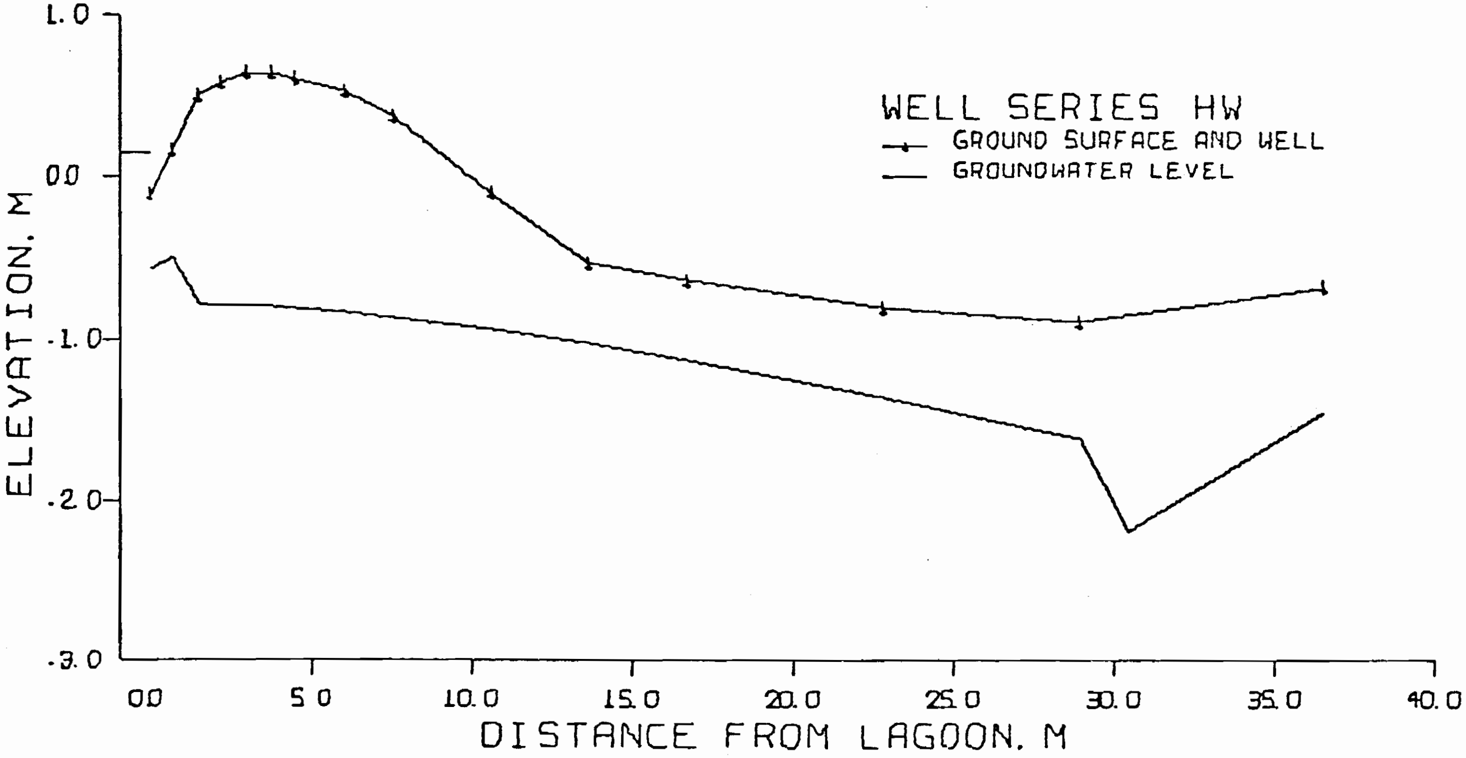

FIG. 52 WATER TABLE PROFILE FEB. 27. 1976

APPENDIX II

WATER TABLE DEPTH DATA FOR WELL SERIES

TABLE 1

ELEVATION OF GROUND SURFACE AT EACH WELL LOCATION RELATIVE TO A FIXED DATUM.

WELL NO.	SERIES PR	PW	HR	HW
1	9.52	9.50	9.80	9.46
2	10.39	10.18	10.82	10.36
3	11.05	11.01	11.85	11.45
4	12.03	11.86	11.97	11.71
5	12.13	11.90	11.86	11.92
6	11.64	11.82	11.92	11.91
7	11.54	11.20	11.93	11.80
8	11.06	9.38	11.88	11.54
9	10.60	8.40	11.44	11.03
10	10.10	7.76	10.26	9.47
11	9.85	7.53	9.05	8.07
12	9.25	7.11	8.01	7.71
13	8.71	6.77	7.26	7.16
14	8.90	6.71	6.72	6.87
15	9.15	6.56	6.47	7.57

TABLE 2

SERIES PR

ELEVATION OF THE WATER TABLE IN EACH WELL AND LAGOON RELATIVE TO FIXED DATUM.

		WELL NC.					
DATE	LAGOON	1	2	3	4	5	6
SEP. 10, 1975	9.56	5.29	5.16	5.15	5.13	5.15	6.74
SEP. 27, 1975	9.44	7.15	7.12	7.13	7.15	7.15	7.17
OCT. 11, 1975	9.39	7.34	7.29	7.27	7.26	7.27	7.26
OCT. 25, 1975	9.46	7.47	7.40	7.39	7.39	7.40	7.39
NOV. 08, 1975	9.57	7.22	7.15	7.14	7.14	7.15	7.14
NOV. 22, 1975	9.57	7.30	7.33	7.29	7.29	7.30	7.29
DEC. 09, 1975	9.68	8.45	8.73	8.51	8.46	8.46	8.44
DEC. 20, 1975	9.39	7.83	7.83	7.84	7.83	7.85	7.84
JAN. 02, 1976	9.56	8.46	8.52	8.47	8.45	8.45	8.43
JAN. 15, 1976	9.56	8.01	8.04	8.02	8.00	8.01	8.00
JAN. 29, 1976	9.56	8.77	8.84	8.80	8.78	8.76	8.74
FEB. 13, 1976	9.43	8.06	8.11	8.07	8.08	8.06	8.06
FEB. 27, 1976	9.11	7.66	7.69	7.66	7.65	7.66	7.64

TABLE 2 -- CONTINUED

WELL NO.								
7	8	9	10	11	12	13	14	15
5.14	5.49	5.12	5.12	5.03	4.93	4.98	4.92	4.83
7.17	7.18	7.25	7.43	7.40	7.42	7.47	7.53	7.52
7.26	7.27	7.29	7.31	7.23	7.22	7.21	7.20	7.17
7.39	7.39	7.42	7.46	7.39	7.38	7.39	7.38	7.35
7.14	7.14	7.17	7.20	7.11	7.10	7.10	7.08	7.04
7.28	7.30	7.31	7.35	7.27	7.25	7.24	7.22	7.19
8.44	8.45	8.45	8.51	8.41	8.41	8.43	8.35	8.42
7.84	7.84	7.85	7.88	7.83	7.82	7.84	7.84	7.81
8.44	8.43	8.42	8.47	8.38	8.35	8.37	8.38	8.40
8.01	8.00	8.00	8.03	7.96	7.97	7.97	7.97	7.95
8.75	8.74	8.69	8.68	8.58	8.55	8.54	8.53	8.54
8.06	8.04	8.05	8.07	8.02	8.01	8.01	8.00	8.00
7.63	7.63	7.60	7.61	7.57	7.55	7.52	7.50	7.46

TABLE 3

SERIES PW

ELEVATION OF THE WATER TABLE IN EACH WELL AND LAGOON RELATIVE TO FIXED DATUM.

		WELL NO.					
DATE	LAGOON	1	2	3	4	5	6
SEP. 10, 1975	9.42	5.86	5.20	4.94	4.95	4.97	5.13
SEP. 27, 1975	9.30	8.67	7.48	7.24	7.36	7.06	7.57
OCT. 11, 1975	9.25	7.10	7.08	6.88	6.96	6.86	6.82
OCT. 25, 1975	9.32	7.20	7.00	6.90	6.92	6.93	6.84
NOV. 08, 1975	9.43	6.78	6.70	6.72	6.67	6.68	6.64
NOV. 22, 1975	9.43	6.87	6.83	6.79	6.78	6.77	6.74
DEC. 09, 1975	9.54	8.57	8.09	7.86	7.91	7.83	7.99
DEC. 20, 1975	9.25	7.30	7.31	7.26	7.27	7.26	7.22
JAN. 02, 1976	9.42	8.47	8.08	7.75	7.81	7.76	7.84
JAN. 15, 1976	9.42	7.67	7.45	7.38	7.39	7.40	7.37
JAN. 29, 1976	9.42	8.47	8.78	8.03	8.18	8.04	8.16
FEB. 13, 1976	9.29	8.25	7.66	7.39	7.40	7.44	7.38
FEB. 27, 1976	8.97	7.35	7.13	7.11	7.11	7.14	7.10

TABLE 3 -- CONTINUED

WELL NO.								
7	8	9	10	11	12	13	14	15
4.88	4.90	4.83	5.03	4.80	4.79	4.70	4.77	5.08
7.48	7.08	6.98	6.93	6.89	6.91	6.98	6.97	6.97
6.88	6.79	6.76	6.77	6.73	6.71	6.69	6.62	6.59
6.93	6.83	6.80	6.80	6.77	6.72	6.68	6.62	6.59
6.67	6.60	6.58	6.58	6.55	6.21	6.49	6.46	6.56
6.75	6.74	6.73	6.71	6.68	6.67	6.65	6.61	6.59
7.92	7.70	8.02	7.53	7.39	7.26	7.04	7.08	7.05
7.25	7.20	7.19	7.15	7.10	7.03	6.88	6.84	6.83
7.91	7.67	7.62	7.51	7.36	7.23	7.05	7.05	7.06
7.40	7.31	7.30	7.25	7.18	7.09	6.92	6.91	6.92
8.05	7.88	7.82	7.66	7.43	7.37	7.12	7.13	7.14
7.40	7.33	7.33	7.24	7.18	7.08	6.87	6.86	6.86
7.12	7.06	7.05	7.00	6.96	6.91	6.79	6.73	6.75

TABLE 4

SERIES HR

ELEVATION OF THE WATER TABLE IN EACH WELL AND LAGOON RELATIVE TO FIXED DATUM.

DATE	LAGOON	WELL NO.					
		1	2	3	4	5	6
SEP. 10, 1975	10.00	7.48	7.21	7.16	7.07	7.04	6.94
SEP. 27, 1975	10.00	9.27	8.49	8.48	8.46	8.39	8.37
OCT. 11, 1975	9.95	8.85	7.92	7.90	7.84	7.79	7.73
OCT. 25, 1975	9.96	8.81	8.00	8.00	7.95	7.92	7.86
NOV. 08, 1975	9.89	8.57	7.78	7.77	7.71	7.71	7.64
NOV. 22, 1975	9.96	7.60	9.37	7.57	7.53	7.50	7.46
DEC. 09, 1975	10.28	9.08	8.92	8.95	8.94	8.91	8.88
DEC. 20, 1975	10.28	8.59	8.38	8.38	8.36	8.33	8.31
JAN. 02, 1976	10.55	9.19	8.79	8.80	8.79	8.76	8.74
JAN. 15, 1976	10.66	8.95	8.54	8.54	8.52	8.51	8.48
JAN. 29, 1976	11.06	10.12	11.01	10.14	9.95	9.81	9.70
FEB. 13, 1976	10.65	9.23	8.61	8.64	8.58	8.54	8.47
FEB. 27, 1976	10.63	8.96	8.47	8.41	8.35	8.33	8.26

TABLE 4 -- CONTINUED

WELL NO.								
7	8	9	10	11	12	13	14	15
7.03	6.81	6.71	6.36	5.65	4.78	3.24	2.82	1.99
8.41	8.30	8.19	8.21	7.84	7.48	6.34	6.15	3.92
7.75	7.58	7.44	7.14	6.57	5.91	4.52	4.34	2.75
7.88	7.71	7.59	7.32	6.87	6.35	5.34	5.14	2.87
7.66	7.48	7.35	7.03	6.55	5.98	4.49	4.29	2.56
7.45	7.28	7.14	6.95	6.43	5.91	4.53	4.39	2.74
8.89	8.85	8.71	8.53	8.18	7.75	6.53	6.37	3.62
8.32	8.18	8.07	7.87	7.40	6.86	5.41	5.25	3.07
8.75	8.61	8.53	8.39	7.94	7.42	6.02	5.87	3.37
8.49	8.35	8.27	8.08	7.62	7.00	5.51	5.35	3.04
9.68	9.50	9.38	9.19	8.67	7.95	6.56	6.34	3.62
8.47	8.30	8.23	8.06	7.64	7.03	5.50	5.30	2.99
8.27	8.11	8.07	7.91	7.50	6.94	5.46	5.24	2.94

TABLE 5

SERIES HW

ELEVATION OF THE WATER TABLE IN EACH WELL AND LAGOON RELATIVE TO FIXED DATUM.

DATE	LAGOON	WELL NO. 1	2	3	4	5	6
SEP. 10, 1975	9.64	6.64	6.54	6.38	6.39	6.35	6.26
SEP. 27, 1975	9.64	9.03	7.98	7.78	7.76	7.70	7.60
OCT. 11, 1975	9.59	7.62	7.08	6.94	6.91	6.86	6.82
OCT. 25, 1975	9.60	7.66	7.15	7.05	7.02	6.98	6.96
NOV. 08, 1975	9.53	7.34	6.86	6.77	6.72	6.69	6.68
NOV. 22, 1975	9.60	6.79	6.64	6.59	6.57	6.52	6.58
DEC. 09, 1975	9.92	8.23	8.20	8.11	8.07	8.08	8.12
DEC. 20, 1975	9.92	7.64	7.49	7.41	7.37	7.37	7.34
JAN. 02, 1976	10.19	8.30	9.91	7.97	7.94	7.90	7.91
JAN. 15, 1976	10.30	8.02	10.01	7.55	7.51	7.49	7.47
JAN. 29, 1976	10.70	8.85	9.40	8.61	8.57	8.55	8.58
FEB. 13, 1976	10.29	8.01	9.68	7.50	7.40	7.36	7.36
FEB. 27, 1976	10.27	7.94	8.19	7.30	7.26	7.22	7.20

TABLE 5 -- CONTINUED

WELL NO. 7	8	9	10	11	12	13	14	15
6.15	6.01	5.80	5.15	4.50	3.89	3.43	2.97	3.34
7.54	7.47	7.42	8.62	7.13	6.41	6.12	4.43	7.15
6.73	6.64	6.45	5.95	5.47	4.96	4.61	3.82	5.49
6.89	6.81	6.66	6.26	5.86	5.48	5.24	4.32	5.38
6.60	6.51	6.34	5.92	5.43	4.96	4.59	3.87	4.49
6.43	6.36	6.20	5.85	5.50	5.00	4.60	3.89	4.79
8.02	7.98	7.93	8.12	7.62	6.93	6.16	4.72	7.23
7.29	7.22	7.07	6.75	6.44	5.92	5.23	4.27	5.70
7.85	7.78	7.67	7.42	7.07	6.58	5.72	4.64	6.70
7.41	7.31	7.16	6.87	6.52	6.09	5.21	4.32	5.65
8.54	8.44	8.33	8.27	7.70	7.25	6.26	4.92	7.00
7.30	7.22	7.09	6.82	6.52	6.14	5.26	4.38	5.37
7.17	7.09	6.97	6.74	6.47	6.11	5.35	4.51	5.05

VITA

Oscar Thomas Bucklew, Jr. was born at Bethesda, Maryland, on September 21, 1952, the son of Oscar Thomas and Alice Sabota Bucklew, Sr. He attended Quantico High School and graduated from Fairfax High School in June, 1970.

He entered Virginia Polytechnic Institute and State University in the Fall of 1970 and completed requirements for a Bachelor of Science in Agricultural Engineering in 1974. He was registered in Spring, 1974, as a Professional Engineer in Training after passing the required exam. Graduate studies began in Fall, 1974, with a half-time research assistantship. Requirements for the Master of Science in Agricultural Engineering were completed in July, 1976, with emphasis in the area of soil and water.

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GROUNDWATER LEVELS AS AFFECTED BY SWINE WASTE LAGOONS IN HIGH WATER TABLE SOILS

by

Oscar Thomas Bucklew, Jr.

(ABSTRACT)

Confinement swine operations have been increasing recently in Southeast Virginia due to its economic feasibility. The presence of anaerobic lagoons to store the waste water from these operations in a region with high water tables in a sandy loam soil has come under question by state authorities as to their environmental impact on state waters.

A study was initiated to determine if the lagoons affect levels of the groundwater table in their vicinity. A change in the levels of the water table around the lagoon would indicate the possibility of seepage through the sides of the lagoon into the surrounding groundwater.

Observation wells were installed in series radiating from two lagoons in Southeast Virginia. Water table levels were recorded to determine the presence of any slope in the water table. The data collected did not detect a variability in the water table levels that could be attributed to seepage from the lagoons.