STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES
Randolph Hodges, *Executive Director*

DIVISION OF INTERIOR RESOURCES
Robert O. Vernon, *Director*

BUREAU OF GEOLOGY
Charles W. Hendry, Jr., *Chief*

Information Circular No. 74

CONSTRUCTION OF WASTE-INJECTION MONITOR WELLS NEAR PENSACOLA, FLORIDA

By
James B. Foster and Donald A. Goolsby

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with
BUREAU OF GEOLOGY
FLORIDA DEPARTMENT OF NATURAL RESOURCES

TALLAHASSEE
1972

Completed manuscript received
December 13, 1971
Printed for the Florida Department of Natural Resources
Division of Interior Resources
Bureau of Geology
by Rose Printing Company
Tallahassee, Florida

Tallahassee
1972

CONTENTS

ILLUSTRATIONS

(Figures 8 through 16 are at end of text)

TABLES

(at end of text)

CONSTRUCTION OF WASTE-INJECTION MONITOR WELLS NEAR PENSACOLA, FLORIDA

By

James B. Foster and Donald A. Goolsby

ABSTRACT

The effects of injection of liquid chemical waste into the lower Floridan aquifer at the Monsanto Company plant near Pensacola, Florida, have been monitored since July 1963. Near the end of 1968, high concentrations of waste were found in water samples from the monitor well that tapped the aquifer receiving the waste. This monitor well was plugged in February 1969 to eliminate the possibility that acid waste might corrode the well casing and escape from the injection zone into the fresh water strata of the sand-and-gravel aquifer. In order that the monitoring program might be continued, two additional monitor wells were drilled during the period December 1969-January 1970 at distances 1.5 miles south and 1.9 miles north of the injection wells.

This report compiles the geologic and hydrologic data that pertain to the two monitor wells and were collected during the period of construction of these wells. Included are records of drill cuttings, water samples, temperatures, rates of artesian flow, aquifer tests, geophysical logs, and chemical analyses.

Results of the chemical analyses of water from the two monitor wells confirm that the water of the lower Floridan aquifer is highly saline and that it becomes increasingly saline with depth in the aquifer. Water samples taken during the construction period are believed to represent native aquifer water. Dissolved chemical constituents that would indicate the presence of injected chemical waste in the immediate areas of the monitor wells were not detected.

INTRODUCTION

BACKGROUND

In July 1963 Monsanto Company began injecting liquid chemical waste from its plant near Pensacola, Florida, into the limestone of the lower Floridan aquifer (Barraclough, 1966, pp. 22-24). The first injection well was completed in March 1963; a second well was completed in July 1964. The combined injection capacity of the two wells is about 2,200 gpm (gallons per minute) at an operating pressure of about 190 psi (pounds per square inch) at the well head.

The lower Floridan aquifer contains water that is naturally saline. This aquifer is overlain by a thick and impermeable layer of Bucatunna clay that confines the saline water and the added chemical waste to the lower Floridan aquifer. The water of the upper Floridan aquifer, which overlies the Bucatunna clay, is not potable.

The original monitor well was drilled into the lower Floridan aquifer to detect movement of chemical waste and changes in hydrostatic pressure that

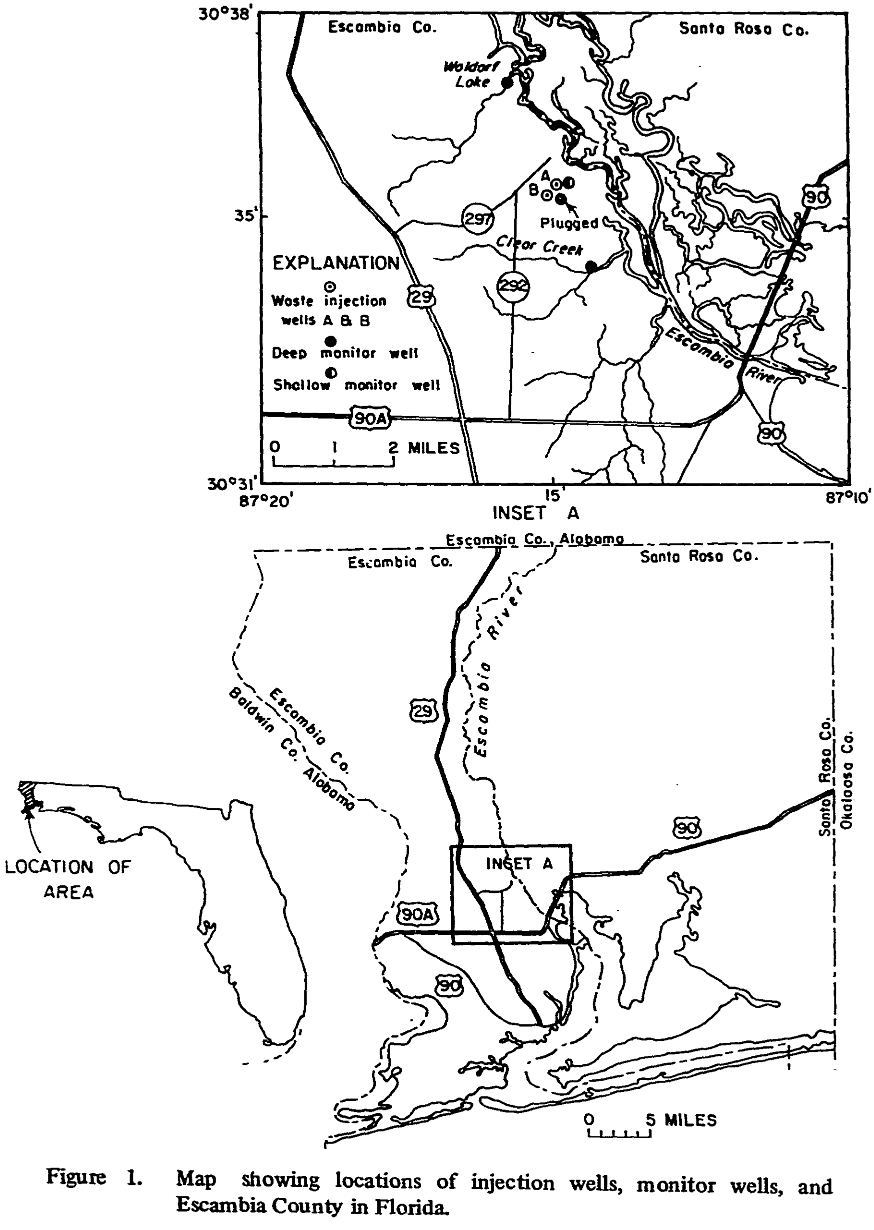


Figure 1. Map showing locations of injection wells, monitor wells, and Escambia County in Florida.

resulted from the injection process. This well was about 1,300 feet south of the immediate area of the two injection wells. Another monitor well was drilled into the upper Floridan aquifer to detect possible leakage of waste through the layer of Bucatunna clay. This well is near injection well A, as shown in figure 1.

From July 1963 to April 1968 the liquid chemical waste was treated with ammonia to increase the pH of the waste from about 3.0 to 5.5 before injection into the aquifer. Signs of chemical waste were detected in the original monitor well about 10 months after injection began. In April 1968, the ammonia treatment was stopped; thereafter, liquid waste was injected at a pH of from 3 to 3.5. About 5 months later the chemical effects of this waste were noted at the monitor well and in January 1969, acidic waste was detected. The steel casing of this well was subject to corrosion by the acidic waste. Such corrosion and failure of the casing might have led to the release of acidic waste from the injection zone through the monitor well. As a precautionary measure, in February 1969 the original monitor well was completely filled with cement.

In order that the monitoring program might be continued, two monitor wells were drilled from December 1969 to February 1970. One well is about 1.5 miles south of the injection wells, near Clear Creek, and the other is about 1.9 miles north of the injection wells, near Waldorf Lake (fig. 1).

As a part of the cooperative program between the Bureau of Geology of the Florida Department of Natural Resources and the U.S. Geological Survey, a fairly complete suite of hydrologic and geologic data were obtained during the period of construction of the two wells.

PURPOSE AND SCOPE

The purpose of this report is to provide a record of the geology, hydraulic conditions, and chemical quality of the water found during construction of two monitor wells.

Details of the well design and drilling procedures are discussed. Hydrogeologic data collected during the construction of the wells are presented in tables, graphs, and diagrams. These data include lithologic logs describing drill cuttings, drilling time logs, field and laboratory analyses of water samples, temperatures, rates of artesian flow from different zones of the aquifer, static water levels, aquifer tests, and geophysical logs.

ACKNOWLEDGMENTS

The courtesies and assistance extended by the personnel of the Monsanto Company and Layne-Central Company are greatly appreciated. The support provided by the following individuals who were most closely associated with the

drilling is especially appreciated: B.T. Dean, C.P. Neiswender, Jr., and Arthur Zabinski of the Monsanto Company; A.G. Symons, J. Turner, and J.C. Armstrong of the Layne-Central Company.

WELL CONSTRUCTION

DRILLING EQUIPMENT AND SET UP

A hydraulic rotary drilling machine was used to construct the two monitor wells, as seen in figure 2. The machine had a drilling platform, a 68-foot tower with fingers for stacking drill pipe, a rotary table, and a transfer housing with controls. An industrial engine fueled by propane gas was used to drive the rotary

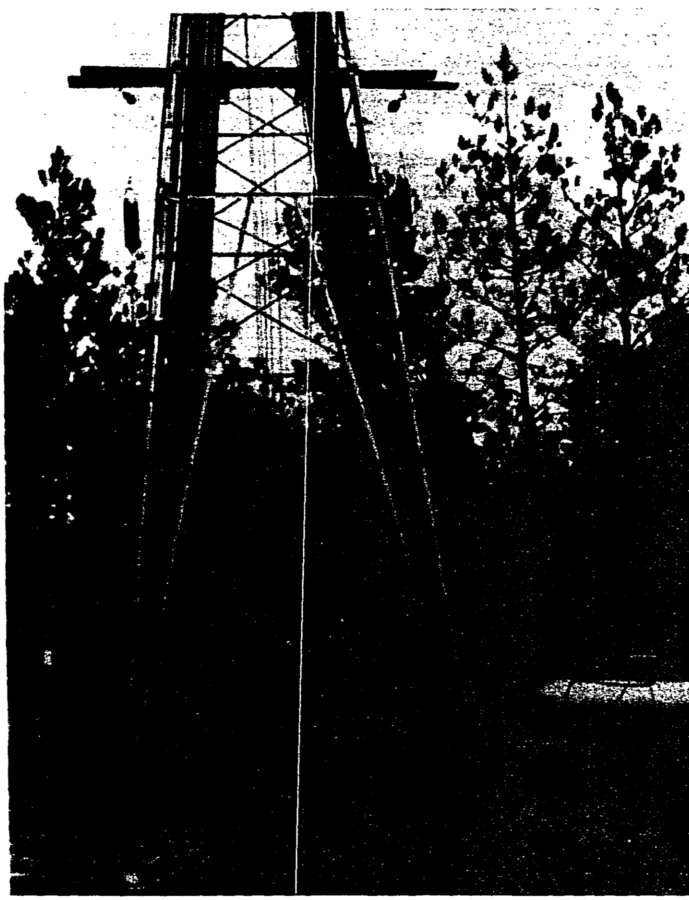


Figure 2. Photograph of rotary drilling machine showing tower and work platform.

table and other associated equipment.

Two mud pits were dug, one to contain the drill cuttings which settled out of the drilling fluid, and the other to store drilling fluid which was recirculated through the well by the mud pump. The mud ditch from the drill hole to the settling pit was floored with neat cement to facilitate cleaning the ditch and the collection of drill cuttings.

The drilling fluid used to complete the hole from the land surface to the top of the lower Floridan aquifer was a suspension of drilling mud (clay) mixed in water. The mix water, obtained from a nearby stream, was acidic (pH 5.5 to 6) so that it was necessary to raise the pH by adding caustic soda so that the drilling mud would stay in suspension. The density of the drilling fluid was maintained at about 12 to 14 pounds per gallon.

DRILLING PROCEDURE

A pilot hole 7-7/8 inches in diameter was drilled from land surface through slightly more than 100 feet of sand and gravel interbedded with clay lenses into the first significant clay bed. This part of the hole was then reamed at a diameter of 21 inches to a depth of about 100 feet and a 16-inch steel casing was installed from the surface to about 100 feet and grouted in place with cement. From the bottom of the 16-inch casing, a 9-7/8-inch pilot hole was drilled to the top of the lower Floridan aquifer and reamed to 15 inches in diameter. An 8-inch steel casing was installed from land surface to the top of the lower Floridan aquifer and grouted in place with cement. The hole was completed by drilling a 7-7/8-inch diameter hole into the consolidated limestone of the lower Floridan aquifer. One hundred and sixty-six feet of the aquifer were penetrated by the Clear Creek well and 183 feet by the Waldorf Lake well. Drilling was terminated when flow from the lower Floridan aquifer no longer increased with added well depth. Flow was measured at the land surface by use of a 6-inch Parshall flume. Use of drilling mud was not required for drilling in the lower Floridan aquifer because the flow of water from the aquifer was sufficient to carry the cuttings from the hole. For each well, however, fresh water from a nearby creek was circulated as drilling fluid. Construction details of the Clear Creek and Waldorf Lake monitor wells are shown in figures 3 and 4.

CASING

The 16-inch diameter steel casing was installed in both wells to depths of about 100 feet to prevent caving of the unconsolidated sand and gravel. Eight-inch nominal casing (ASTM A-53, Grade A, welded construction, 0.322-inch wall) was installed from land surface to 1,430 feet and 1,340 feet in the Clear Creek and Waldorf Lake wells, respectively. Guides to center the casing

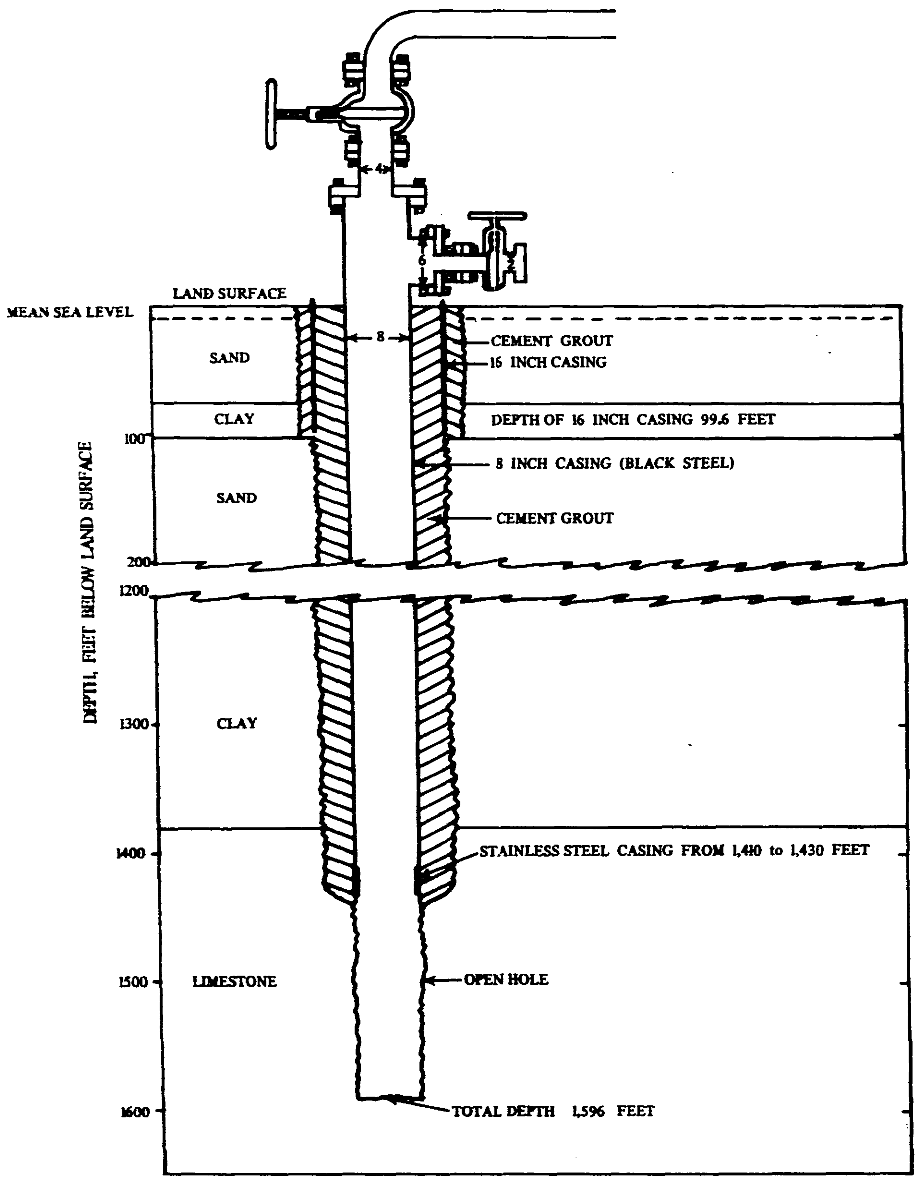


Figure 3. Diagram showing construction details of Clear Creek monitor well.

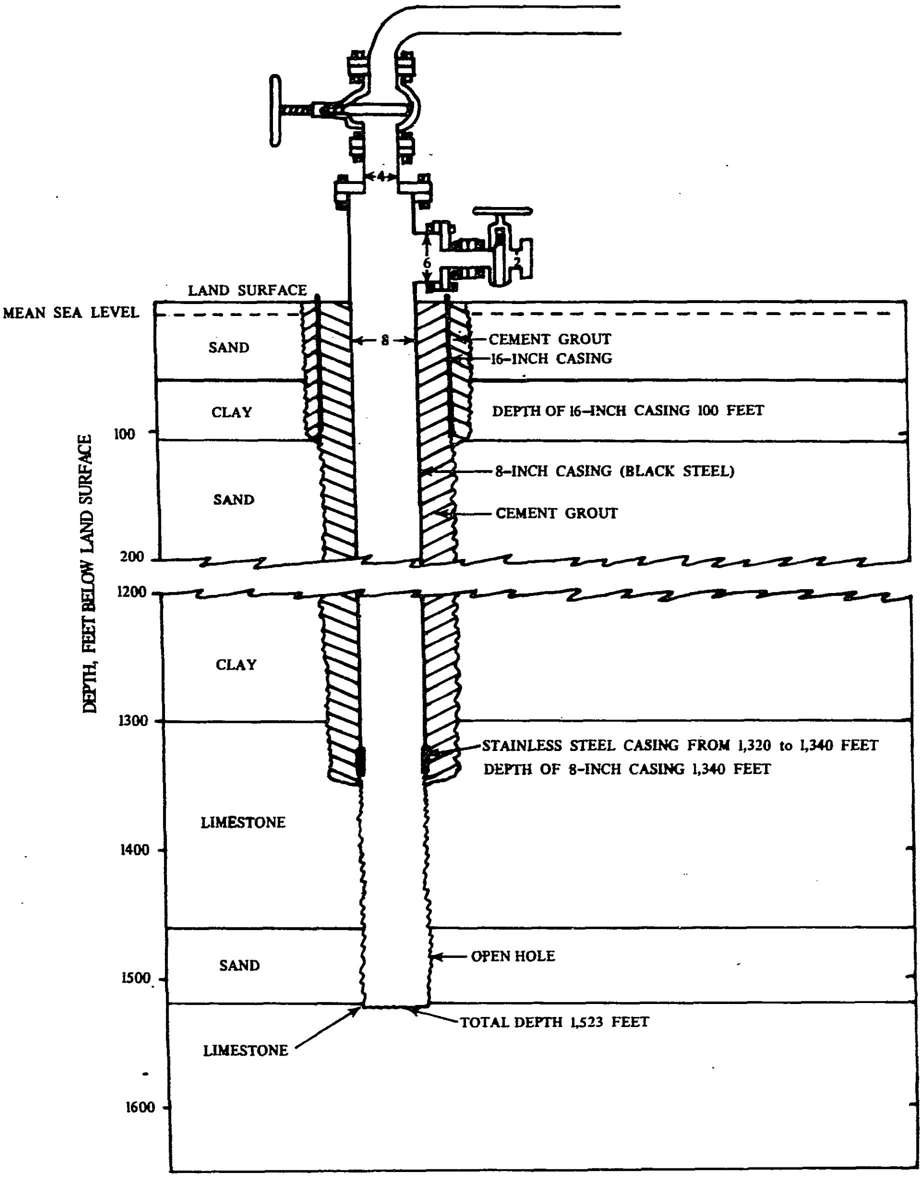


Figure 4. Diagram showing construction details of Waldorf Lake monitor well.

were welded on both the 16-inch and 8-inch casings, as shown in figure 5, to insure that the cement grout would encircle the casing and completely fill the voids around the casing. Joints were butt welded as the casing was installed. The bottom 20-foot section of the 8-inch casing was stainless steel (ASTM - 312, type 304, welded construction, 0.322-inch wall).

Figure 5. Photograph showing 8-inch steel casing with centering guides.

CEMENT GROUTING

Both the 16-inch and 8-inch casings were grouted in place using standard commercial cement with no additives. In each case, cement grout was introduced from inside the casing at the bottom and forced by pump pressure up the annular space around the casing. The process was continued until the grout had displaced all the drilling mud outside the casing and flowed freely at the surface. The line through which the cement was injected was lowered to within about 2 feet of the bottom of the casing and sealed at the top of the casing with a dresser coupling which is welded in the top of the bradenhead. The casing was filled with drilling mud before cement was fed into the bottom of the well.

The highly fluid cement grout settled appreciably as it set, so that the upper 100 feet of the 8-inch casing had to be regrouted from the top. Part of the equipment used for grouting is shown in figures 6 and 7. Grouting Clear Creek well required 125 bags of cement for the 16-inch casing and 1,340 bags for the 8-inch casing. Grouting Waldorf Lake well required 125 bags of cement for the 16-inch casing and 1,368 bags for the 8-inch casing.

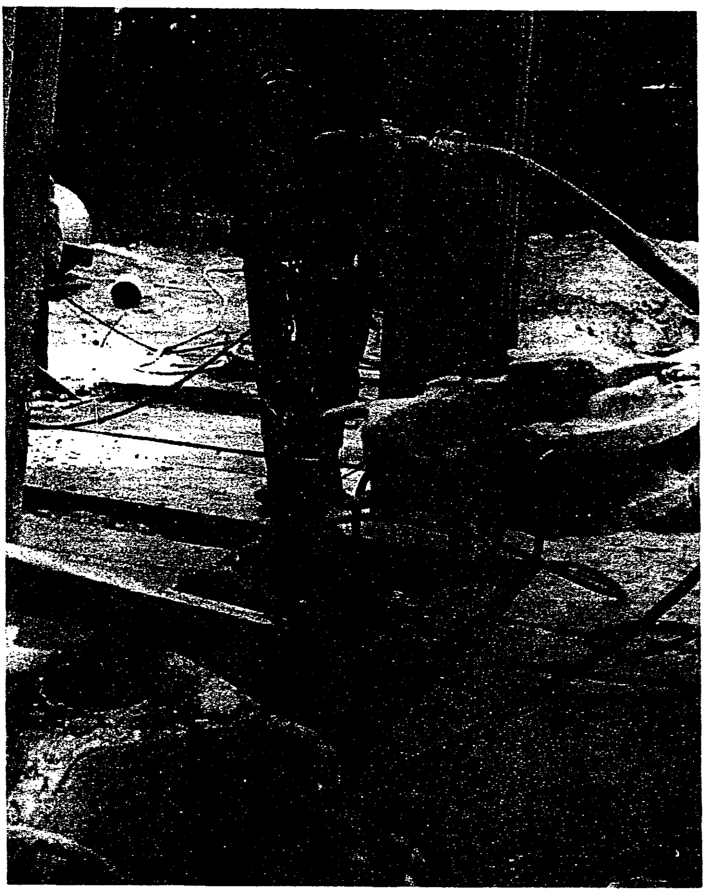


Figure 6. Photograph showing hookup of bradenhead and cement line used to grout well casing.

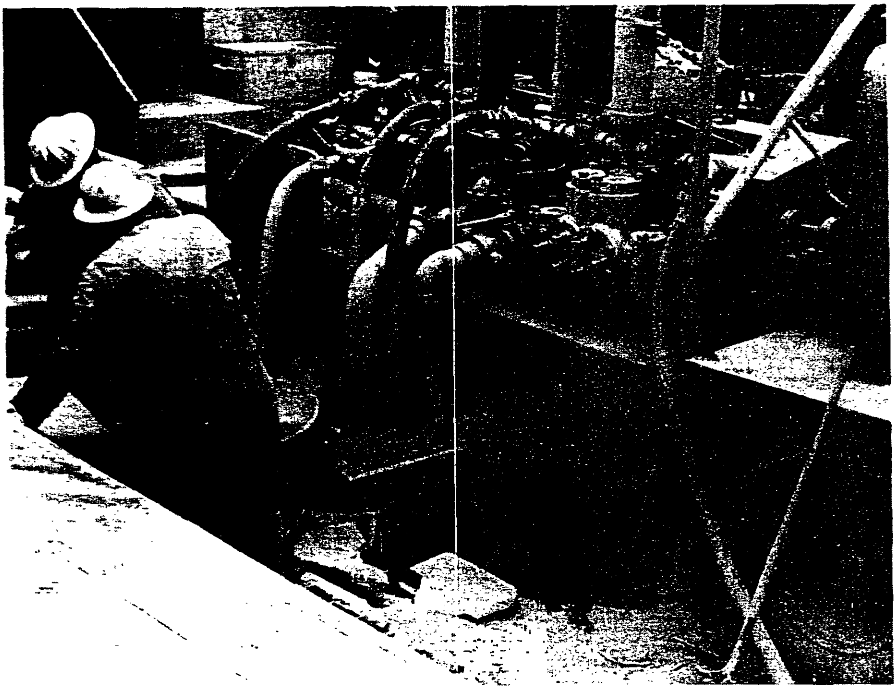


Figure 7. Photograph showing trailer-mounted cement-grout pump. Two men feed cement to mixing box where water is added.

HYDROGEOLOGIC DATA

A fairly complete suite of hydrologic and geologic data were obtained during construction of the two monitor wells. These data, which include drill cuttings and related lithologic logs, measurements of the potentiometric level of water and related aquifer tests, rates of flow, geophysical logs, and water samples and related chemical analyses, are presented in tables 1-7 and figures 8-16 at the end of the text. The lithologic log for injection well A is included in the report because it represents comparable data that were not previously published. Because the significance of some of the data collected depends on the sampling techniques used, these techniques are explained in some detail.

DRILL CUTTINGS

Drill cuttings were collected from the mud ditch when drilling was interrupted to add increments of drill stem. Drill stem units ranged from 22 to

32 feet nominal length. Circulation of drilling fluid was continued at these times until all or almost all of the drill cuttings were removed from the well bore. After each sampling period, drill cuttings were cleaned from the mud ditch. Each sample therefore represents a composite of rock material removed from successively deeper sections of the well.

At the end of drilling each increment of hole, the driller recorded the depth as determined from careful measurement of the length of each drill stem added to the string. Depth of drilling was recorded also at times when drilling action reflected distinct changes of lithology. Rate of drilling progress in different zones of the aquifer is indicated for the two monitor wells by drilling time logs shown in figure 8. Lithologic logs are given for the two monitor wells and for injection well A in tables 1-3.

POTENTIOMETRIC LEVEL AND FLOW OF WATER

In the area of the monitor wells, water in the lower Floridan aquifer is under pressure that results partly from natural artesian pressure of water in the aquifer and partly from pressurized injection of chemical waste into the aquifer. On completion of the wells, the potentiometric level of water in the aquifer recovered to 228 feet above land surface at Clear Creek well and to 233 feet above land surface at Waldorf Lake well. These levels were determined by use of a pressure gage.

During the construction period the rate of water flow from the lower Floridan aquifer was measured at times when drilling was interrupted to add drill stem. A 6-inch Parshall flume in the mud ditch was used. Each successive increase in the total flow from the well is attributable to flow added by the last drilled section of the aquifer.

Flow from the aquifer was impeded to some degree by the drill stem in the well bore. At Clear Creek well, total flow from the completed well increased from 603 gpm with drill stem in place to 688 gpm with drill stem removed. At Waldorf Lake well, flow from the completed well increased from 412 gpm with drill stem in place to 435 gpm with drill stem removed.

Most of the flow in each case was derived from the uppermost zones of the aquifer penetrated. Contribution of flow from different parts of the aquifer with drill stem in place is indicated for the two monitor wells in figures 13 and 14. The relative distribution of flow from the aquifer probably was not changed appreciably by removal of the drill stem.

AQUIFER TESTS

Drawdown and recovery tests were made at both wells to determine the transmissivity of the lower Floridan aquifer. The monitor wells normally are not allowed to flow. During the drawdown test, a uniform rate of flow was maintained by regulation of a 6-inch valve on the well. Rates of flow–503 gpm at Clear Creek well and 350 gpm at Waldorf Lake well–were determined by use of a 5-inch circular orifice on a 6-inch discharge pipe. A pressure gage was used to measure the drawdown or decline of pressure of water in the aquifer as flow continued.

The recovery test began with the end of the drawdown test when the 6-inch valve was closed to stop the flow from the aquifer. The pressure recovery was measured by use of pressure gage. Results of the aquifer tests are given for the two wells in figures 9-12.

GEOPHYSICAL LOGS

Electric, fluid-resistivity, caliper, and current meter (velocity) logs were obtained at the open-hole section of the lower Floridan aquifer for each of the two monitor wells. A gamma-ray log of the entire well also was obtained. These logs are reproduced in figures 8, 13 and 14. Instruments used to obtain the geophysical logs were operated by personnel of the U.S. Geological Survey.

WATER SAMPLES

Beginning with drilling in the lower Floridan aquifer, water from the well was collected when drilling was interrupted to add drill stem. In drilling this part of the hole, drill-stem sections in nominal lengths of 32 feet were used. For each sampling, after each increment of drilling, the bit was raised about 30 feet from the bottom of the hole. Water flowing into the 30 feet of well bore below the drill bit flowed upward by artesian pressure through the hollow drill stem. Water that entered the well bore above the drill bit moved upward through the annular space between the drill stem and the wall of the well bore or casing. Separate samples were taken of water flowing from the drill stem and from the casing. The total flow of the completed well was sampled after the drill stem was removed.

Zones of the aquifer sampled and conditions of flow in the well bore at time of sampling are indicated in figures 13 and 14.

CHEMICAL ANALYSES OF WATER SAMPLES

Water samples collected from Clear Creek and Waldorf Lake monitor wells were analyzed for major and minor chemical constituents at the U.S. Geological Survey District Laboratory in Ocala, Florida. Analytical methods used by the laboratory are given in table 4. Results of chemical analyses of 26 water samples from the two wells are listed in table 5. Results of a spectographic analysis, made to detect the present level of metallic ions in the water of Clear Creek monitor well, are shown in table 6.

After completion of the monitor wells, analyses were made at the well sites for several unstable chemical constituents and physical properties of the water. The pH and oxidation-reduction potential were measured at the well head by use of a flow-through chamber. These measurements were taken before the water came in contact with the atmosphere. Ferrous iron was determined by complexing with 2,2' bipyridine. Results of these analyses are shown in table 7. In connection with the field analyses at both wells, small gas bubbles were noted to collect on the walls of the sample containers. The source and nature of the bubbles were not determined.

Results of chemical analyses of water taken from the drill stem show that all major chemical constituents of water in the lower Floridan aquifer, except bicarbonate, become increasingly concentrated with depth (figs. 15 and 16). The concentration of bicarbonate decreases with depth. Results of chemical analyses of water taken from the well casing show similar but much less pronounced trends of concentration for the same constituents. The effect of change in concentration with depth is diminished in this case because the flow from different zones of the aquifer is mixed with a disproportionately large part of the total flow coming from the uppermost part of the aquifer (figs. 13 and 14).

At the time of construction, water of the lower Floridan aquifer in the immediate areas of the two monitor wells probably was native to the aquifer. Chemical changes of the water that would result from injection of chemical waste materials were not apparent in the results of chemical analyses made. These changes would include increased concentration of total organic carbon, organic and ammonia nitrogen, calcium, total hardness, and total alkalinity. A slight decrease of pH also might be expected.

REFERENCES

Barraclough, J. T.
1966 *Waste injection into deep limestone in northwestern Florida:* Ground Water Jour., Tech. Div., Natl. Water Well Assoc., v. 4, no. 1, p. 22-24.

Barraclough, J. T.
1962 (and Marsh, O. T.) *Aquifers and quality of ground water along the Gulf Coast of western Florida:* Florida Geol. Survey, Rept., Inv. 29, 28p.

Ferris, J. G.
1962 (Knowles, D. B., Brown, R. H., and Stallman, R. W.) *Theory of aquifer tests:* U.S. Geol. Survey Water-Supply Paper 1536-E, 174 p.

Goolsby, D. A.
1971 *Hydrogeochemical effects of injecting wastes into a limestone aquifer near Pensacola, Florida:* Ground Water Jour., Tech. Div., Natl. Water Well Assoc., v. 9, no. 1, p. 13-19.

Jacob, C. E.
1950 *Flow of ground water, Engineering Hydraulics:* chap. 5 in Rouse, Hunter, New York, John Wiley and Sons, New York, p. 321-386.

Marsh, O. T.
1962 *Relation of the Bucatunna Clay Member (Bryam Formation Oligocene) to geology and ground water of westernmost Florida:* Geol. Soc. America Bull., v. 73, p. 243-252.

Musgrove, R. H.
1965 (Barraclough, J. T., and Grantham, R. G.) *Water resources of Escambia and Santa Rosa counties, Florida:* Florida Geol. Survey Rept. Inv. 40, 102 p.

Table 1. Lithologic log of Clear Creek monitor well.
(Florida Bureau of Geology No. W-10490)
(USGS No. 303417N0871417.1)
(Lithologic description by J. B. Foster)

Owner: Monsanto Company
Location: On Clear Creek
Driller: Layne-Central Company
James C. Armstrong
Date drilled: December 1969
Total depth: 1,596 ft
Depth of casing: 1,430 ft
Casing diameter: 8 in
Well finish: Open hole
Method of drilling: Hydraulic rotary

Aquifer: Lower Floridan
Altitude (land surface): 15.23 ft.
Water level: 229 ft above land surface 12/24/69
Yield: 686 gpm (flow)
Transmissivity: 8,000 gpd/ft
Storage coefficient: –
Chloride concentration: 8,150 mg/1
Temperature: 35°C

Lithology	Thickness (feet)	Depth (feet)
Sand, white to orange, quartz, very fine to very coarse; clay, white and orange; few heavy mineral grains.	12.0	12.0
Same as above. Fragments limonite.	10.0	22.0
Same as above. White kaolinitic clay.	10.0	32.0
Sand, white to yellow, quartz, very fine to granule, froster; clay, white and yellow; limonite.	6.0	38.0
Same as above. Orange clay. Increased granule size of sand.	10.0	48.0
Sand, tan to pink, quartz, medium to 60% granule; clay, 40% white, yellow, and lavender; black heavy mineral.	28.5	76.5
Clay, tan to lavender, 70%; sand, 30%.	25.0	101.5
Clay, gray, some white and red streaks; some sand, very fine to medium; mica.	6.0	107.5
Sand, gray, medium to very coarse, quartz; clay, gray to white, 20%; black organic material.	6.5	114.0
Same as above. Less clay; grains of heavy minerals.	23.1	137.1
Same as above. Limonite grains.	23.0	160.1
Sand, white to gray, quartz, fine to granule; some clay; black phosphorite.	22.9	183.0
Same as above. 75% fine to medium sand.	16.0	199.0
Clay, light gray, 60%; sand, 40%, fine to coarse; few granules.	30.0	229.0
Sand, gray, quartz fine to coarse; clay, 20%, gray; black phosphorite.	23.0	252.0
Sand, tan to white, quartz, fine to very coarse, 70% coarse, frosted; clay, white to pink; black phosphorite.	23.0	275.0
Sand, light gray, quartz, fine to coarse; some white clay.	23.0	298.0
Sand, light gray to white, quartz, medium to very coarse; black phosphorite.	23.0	321.0
Same as above. Black phosphorite.	23.1	344.1
Same as above. Less very coarse sand. Heavy mineral fragments.	23.0	367.1
Sand, gray, quartz, very fine to coarse; clay, 20%, gray; black phosphorite grains; mica.	22.9	390.0

Lithology	Thickness (feet)	Depth (feet)
Same as above. Increased mica.	22.9	412.9
Sand, light gray, quartz, coarse silt to medium; some clay; mica; heavy mineral; black phosphorite; few shells.	22.9	435.8
Same as above. 10% gray clay.	23.0	458.8
Clay, gray; sand, coarse silt to fine; shells; black phosphorite; mica.	68.4	527.2
Same as above. Clay, waxy, dense, bluish-gray.	136.4	663.6
Sand, light gray, quartz, very fine to medium, some coarse grains; clay, gray; black phosphorite.	45.2	708.8
Same as above. Shells.	44.3	753.1
Clay, gray; sand, coarse silt to medium; shells; mica; black phosphorite.	44.8	797.9
Sand as above. Increased sand.	88.7	886.6
Sand, gray, quartz, fine to medium, frosted; clay, gray; shells; black phosphorite; slightly calcareous.	22.2	908.8
Limestone, gray; foraminifers; few sand grains; limonite fragments; black phosphorite.	22.4	931.2
Clay, gray, dense, calcareous; some sand; shells.	22.1	953.3
Limestone, white, finely crystalline; few foraminifers.	44.2	997.5
Limestone, light gray, finely crystalline; shells; some sand; black phosphorite; some clay; mica.	153.6	1151.1
Same as above. Lense of crystalline dolomitic limestone.	21.0	1172.1
Clay, gray, dense, waxy, calcareous; coarse silt; shells.	110.2	1282.3
Same as above. Limestone fragments.	99.8	1382.1
Limestone, white, finely crystalline; abundant foraminifers; shell; green glauconite; fragments of silty clay; magnetite fragments.	33.0	1417.1
Limestone, light gray, finely crystalline, bioclaustic; 80% foraminifers; green glauconite; shells.	22.9	1440.0
Limestone, white, fine grained, sandy; sand fone to medium; green glauconite; black phosphorite; calcite; foraminifers; shell fragments.	31.9	1471.9
Same as above. Brownish dolomitic limestone fragments; increased calcite; iron stain.	124.1	1596.0

Table 2. Lithologic log of Waldorf Lake monitor well.
(Florida Bureau of Geology No. W-10487)
(USGS No. 303657N0871543.1)
(Lithologic description by J. B. Foster)

Owner: Monsanto Company
Location: On Waldorf Lake
Driller: Layne-Central Company
James C. Armstrong
Date drilled: February 1970
Total depth: 1,523 ft
Depth of casing: 1,340 ft
Casing diameter: 8 in
Well finish: Open hole
Method of drilling: Hydraulic rotary

Aquifer: Lower Floridan
Altitude (land surface): 7.73 ft
Water level: 233 ft above land surface 03/17/70
Yield: 433 gpm (flow)
Transmissivity: 3,000 gpd/ft
Storage Coefficient: –
Chloride concentration: 7,100 mg/l
Temperature: 35°C

Lithology	Thickness (feet)	Depth (feet)
Sand, white to yellow, quartz, fine to granule, froster; clay fragments, white to yellow; heavy mineral grains.	38.4	38.4
Sand, white to tan, quartz, medium to granule, froster; some clay.	23.0	61.4
Clay, light gray; sand, fine to coarse; grains of heavy minerals.	23.0	84.4
Clay, gray; sand; heavy mineral.	23.0	107.4
Sand, light gray to tan, quartz, coarse to very coarse; clay, gray; mica; grains of heavy minerals.	27.7	135.1
Sand, white to yellow, quartz, fine to very coarse; clay, white to orange; limonite; black phosphorite grains.	23.0	158.1
Same as above. Some purple clay coating sand grains.	69.0	227.1
Same as above. Increased black phosphorite.	46.0	273.1
Sand, light gray to gray, quartz, medium to granule; clay, gray; black phosphorite granules; mica.	23.0	296.1
Sand, tan to light gray, quartz, fine to coarse; shells; few foraminifers; black phosphorite; some gray clay.	23.0	319.1
Same as above. Increased gray clay.	23.0	342.1
Same as above. Increased shell.	22.9	365.0
Clay, gray, silty; sand, fine to coarse; shells; black phosphorite.	22.9	387.9
Same as above. Increased clay.	45.9	433.8
Clay, bluish-gray, dense, waxy; sand, fine to coarse; black phosphorite.	22.8	456.6
Same as above. Increased sand.	22.8	479.4
Sand, light gray, quartz, very fine to medium; clay, light gray; fine grained black phosphorite; mica.	91.1	570.5
Same as above. Increased clay.	22.7	593.2
Clay, gray, waxy, silty; sand, fine to coarse; shells; fine black phosphorite.	22.6	615.8
Clay, gray, waxy, silty; few sand grains; black phosphorite; shell.	22.5	638.3
Same as above. Some sand.	67.8	706.1
Same as above. 30% sand.	22.2	728.3

Lithology	Thickness (feet)	Depth (feet)
Sand, light gray, quartz, silt to coarse; clay, gray, 30%, waxy; some shell; fine black phosphorite.	44.7	773.0
Clay, gray, calcareous; sand; shell; black phosphorite; limestone lenses; mica.	90.7	863.7
Limestone, gray, finely crystalline; some clay; silt; sand; shells; black phosphorite.	44.6	906.7
Same as above. 25% sand.	44.2	950.9
Same as above. Increased clay.	22.1	973.0
Limestone, gray, dense, hard; black phosphorite; shells.	66.2	1039.2
Same as above. Increased shells; foraminifers.	22.1	1061.3
Same as above. Lenses of brownish-gray dolomitic limestone.	22.2	1083.5
Clay, gray, waxy, calcareous; sand; limestone.	22.0	1105.5
Sand, light gray, quartz, silt to medium, few granules; clay, gray; black phosphorite; limestone; foraminifers.	21.1	1126.6
Same as above. Shells.	21.0	1147.6
Clay, gray, dense, waxy; sand; limonite; limestone fragments.	132.9	1280.5
Limestone, gray to white, finely crystalline; black phosphorite.	22.7	1303.2
Limestone, light gray to cream; foraminifers; shells; black phosphorite; green glauconite.	38.0	1341.2
Limestone, white, granular; green glauconite; foraminifers; shells; black phosphorite; limonite stains.	119.7	1460.9
Sand, white, quartz, fine; limestone fragments; foraminifers; shell; green glauconite filling fossil tests.	60.8	1521.7
Limestone, white; foraminifers; shells; green glauconite.	2.0	1523.7

Table 3. Lithologic log of injection well A.
(Florida Bureau of Geology No. W-6225)
(USGS No. 303537N0871456.1)
(Lithologic description by J. B. Foster)

Owner: Monsanto Company
Location: At plant
Driller: Layne-Central Company
James C. Armstrong
Date drilled: March 1963
Total depth: 1,808 ft
Depth of casing: 1,390 ft
Casing diameter: 12 in
Well finish: Open hole
Method of drilling: Air reverse rotary

Aquifer: Lower Floridan
Altitude (land surface): 32.2 ft
Water level: 36.6 ft above land surface 04/01/63
Yield: 128 gpm (flow)
Transmissivity: 6,300 gpd/ft April 1963
Storage coefficient: 0.0001, April 1963
Chloride concentration: 7,350 mg/l
Temperature: 35°C

Lithology	Thickness (feet)	Depth (feet)
Sand, light brown, quartz, very fine to very coarse; tan to orange clay; black organic material.	20.0	20.0
Sand, tan to white, quartz, medium to very coarse, frosted; orange clay coating some grains.	20.0	40.0
Sand, tan to white, quartz, fine to granule, frosted; tan to orange clay coating grains; few black phosphorite granules.	57.0	97.0
Sand, light gray, very fine to coarse, quartz; clay, 35%, light gray; mica; black phosphorite grains; limonite fragments.	22.0	119.0
Sand, light gray, fine to coarse, quartz, frosted; clay 20%, white; heavy mineral.	23.0	142.0
Sand, tan, fine to coarse, quartz, frosted; clay, orange to white; black phosphorite; mica; heavy mineral.	22.0	164.0
Same as above. 60% coarse to very coarse sand.	53.0	217.0
Sand, light gray, quartz, very fine to coarse, frosted; clay, light gray, coating sand grains; black phosphorite; heavy mineral; mica.	15.0	232.0
Same as above. Some coarse sand; increased clay.	22.0	254.0
Sand, white, quartz, very fine to coarse, frosted; black phosphorite grains.	23.0	277.0
Same as above. Some white clay.	24.0	301.0
Same as above. Sand coarse to very coarse.	20.0	321.0
Sand, light gray to white, quartz, very fine to granule, frosted; clay, light gray to white; black phosphorite; black carbonaceous material.	23.0	344.0
Same as above. Fine to coarse sand.	22.0	366.0
Sand, light gray, quartz, medium to granule, frosted; clay, light gray, coating sand grains; granule size black phosphorite.	10.0	376.0
Same as above. Some shell.	11.0	387.0
Sand, gray, quartz, very fine to very coarse, frosted; shell, abundant; clay, gray; black phosphorite; mica.	25.0	412.0
Same as above. Less shell.	23.0	435.0

Lithology	Thickness (feet)	Depth (feet)
Sand, light gray, quartz, fine to medium; clay, gray; few shell; mica; fine black phosphorite.	22.0	457.0
Same as above. Wood fragments.	22.0	479.0
Same as above. Increased wood fragments.	46.0	525.0
Sand, light gray, quartz, fine to coarse, frosted; few shells; mica; fine black phosphorite.	44.0	569.0
Clay, gray; sand, fine to coarse, 20% of sample.	24.0	593.0
Same as above. Few shells.	21.0	614.0
Sand, light gray, quartz, very fine to medium, frosted; clay, light gray; fine black phosphorite.	23.0	637.0
Same as above. Some very coarse sand; clay, gray.	46.0	683.0
Same as above. Few shell.	69.0	772.0
Same as above. Increase in very fine sand.	22.0	794.0
Same as above. Mica flakes.	21.0	815.0
Same as above. Few foraminifers; increase fine black phosphorite.	68.0	883.0
Clay, gray; sand, fine to coarse; shell, abundant.	45.0	928.0
Sand, light gray, quartz, fine to coarse, frosted; limestone, white; shell; some clay.	23.0	951.0
Limestone, gray to white, fine crystalline; sand, fine to coarse; shell; foraminifers.	21.0	972.0
Sand, light gray, quartz, fine to medium; limestone, white to gray; shell; foraminifers.	16.0	988.0
Limestone, light gray to tan, fine crystalline; some sand; shell; foraminifers; black phosphorite.	31.0	1019.0
Same as above. Some brown crystalline dolomitic limestone.	24.0	1043.0
Limestone, light gray to white, fine crystalline; few sand grains; foraminifers; pyrrhotite grains.	29.0	1072.0
Limestone, dolomitic, brown, crystalline; few shells.	32.0	1104.0
Limestone, white, crystalline; some foraminifera; few sand grains; some shells.	29.0	1133.0
Sand, white, quartz, very fine to fine; limestone, white; few foraminifers.	22.0	1155.0
Clay, gray; sand, fine to very coarse; mica; pyrrhotite; some shells.	77.0	1232.0
Clay, gray, dense; few sand grains.	138.0	1370.0
Limestone, white to light gray, finely crystalline; clay, gray; few sand grains.	20.0	1390.0
Limestone, white to light gray, fine grained to dense, gray color from glauconite or phosphorite; some shells.	26.0	1416.0
Same as above. Some foraminifers.	23.0	1439.0
Same as above. Abundant foraminifers.	23.0	1462.0
Limestone, white, dense to fine crystalline; foraminifers; shells; some black phosphorite or glauconite particles.	23.0	1485.0
Same as above. Pyrrhotite flakes.	55.0	1540.0
Limestone, white, fine crystalline, 70% calcite crystal structure; abundant green glauconite; shells; foraminifers.	29.0	1569.0

Lithology	Thickness (feet)	Depth (feet)
Limestone, white, finely crystalline; abundant foraminifers, 60%; green glauconite; shells; some sand grains.	41.0	1610.0
Sand, white, quartz, very fine to medium; limestone, 40%, white, finely crystalline; green glauconite; foraminifers; shell.	23.0	1643.0
Limestone, light gray, finely crystalline; sand, quartz, 15%; few foraminifers; green glauconite.	30.0	1673.0
Same as above. Increased foraminifers.	27.0	1700.0
Clay, greenish-gray, calcareous, dense; limestone fragments; foraminifers; green glauconite.	83.0	1783.0
Same as above. Few quartz sand grains.	25.0	1808.0

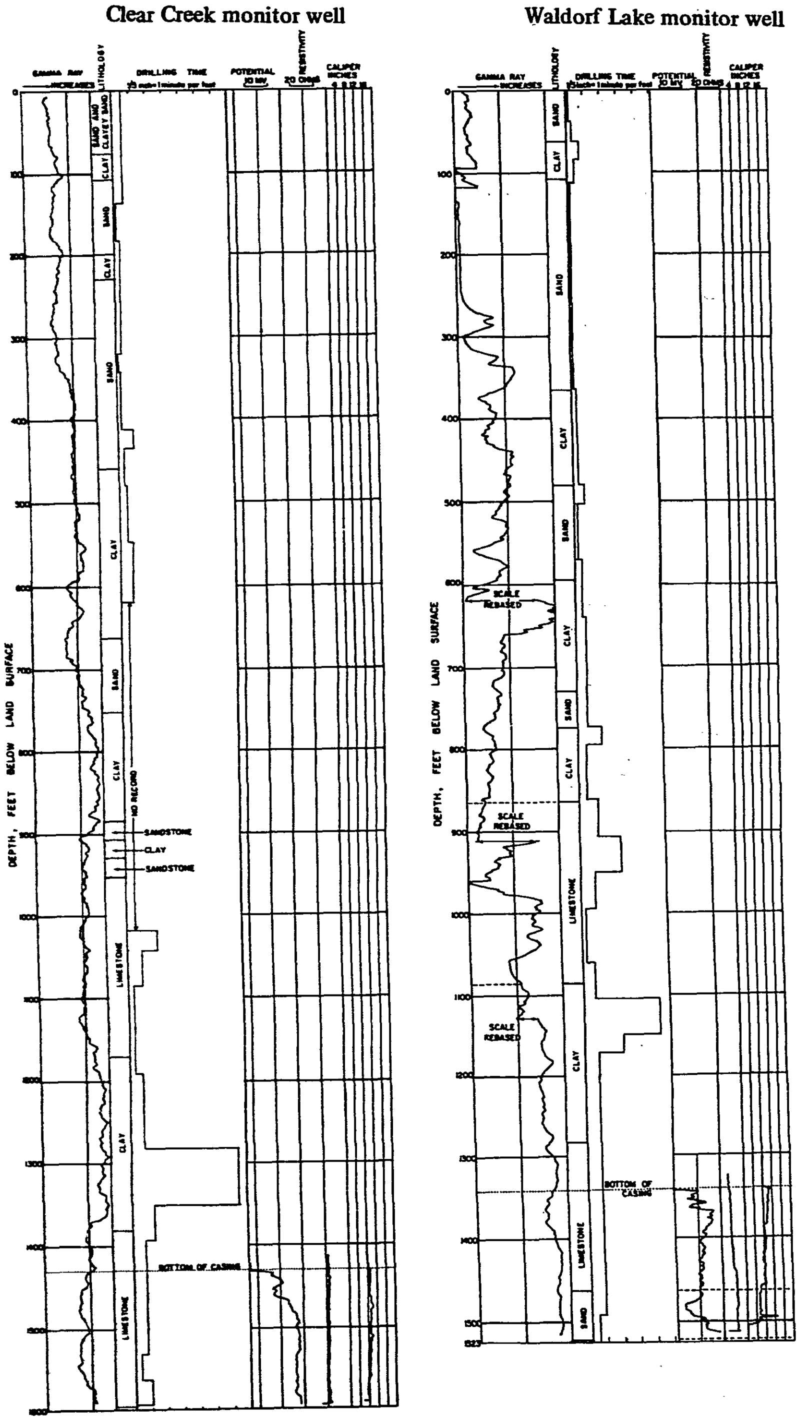


Figure 8. Geophysical and drilling time logs.

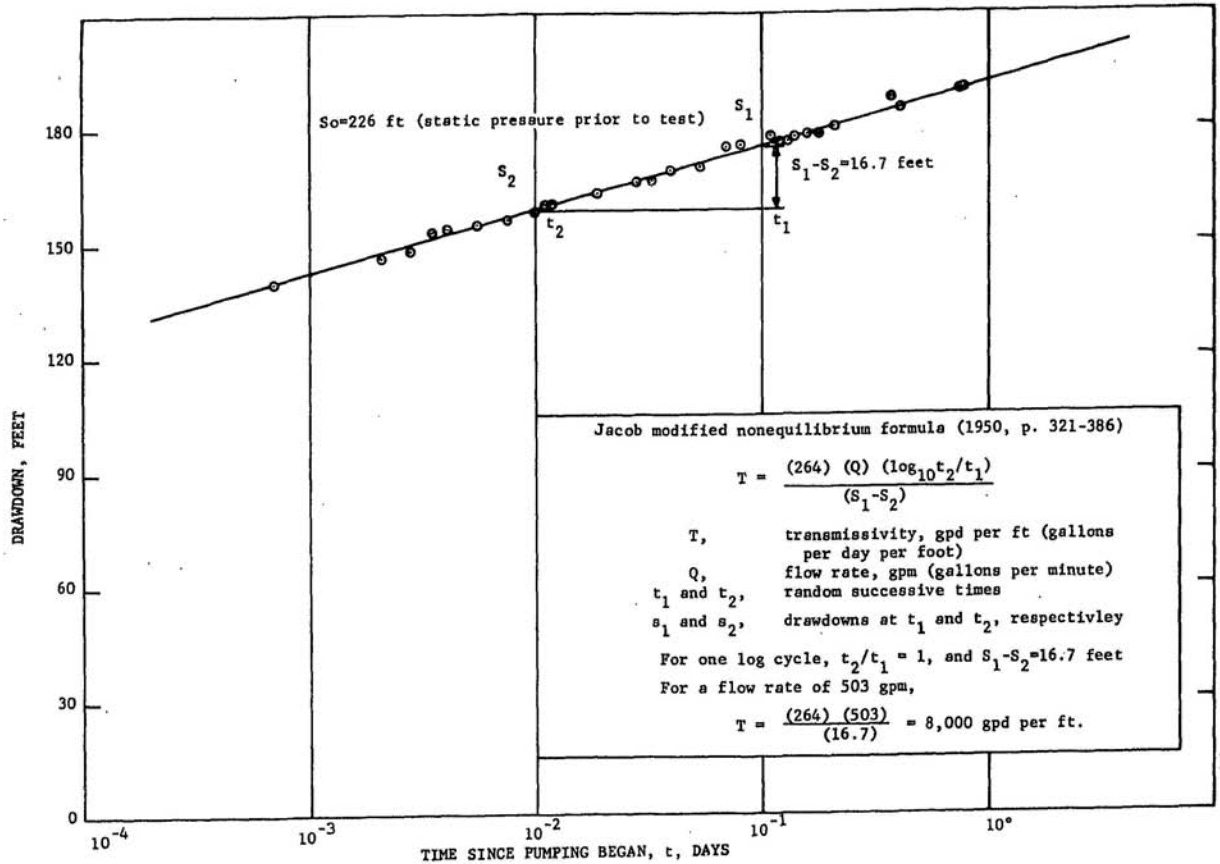


Figure 9. Graph showing computation of transmissivity of lower Floridan aquifer at Clear Creek monitor well. Data represents decline of water pressure in aquifer during period that well flowed at constant rate of 503 gpm.

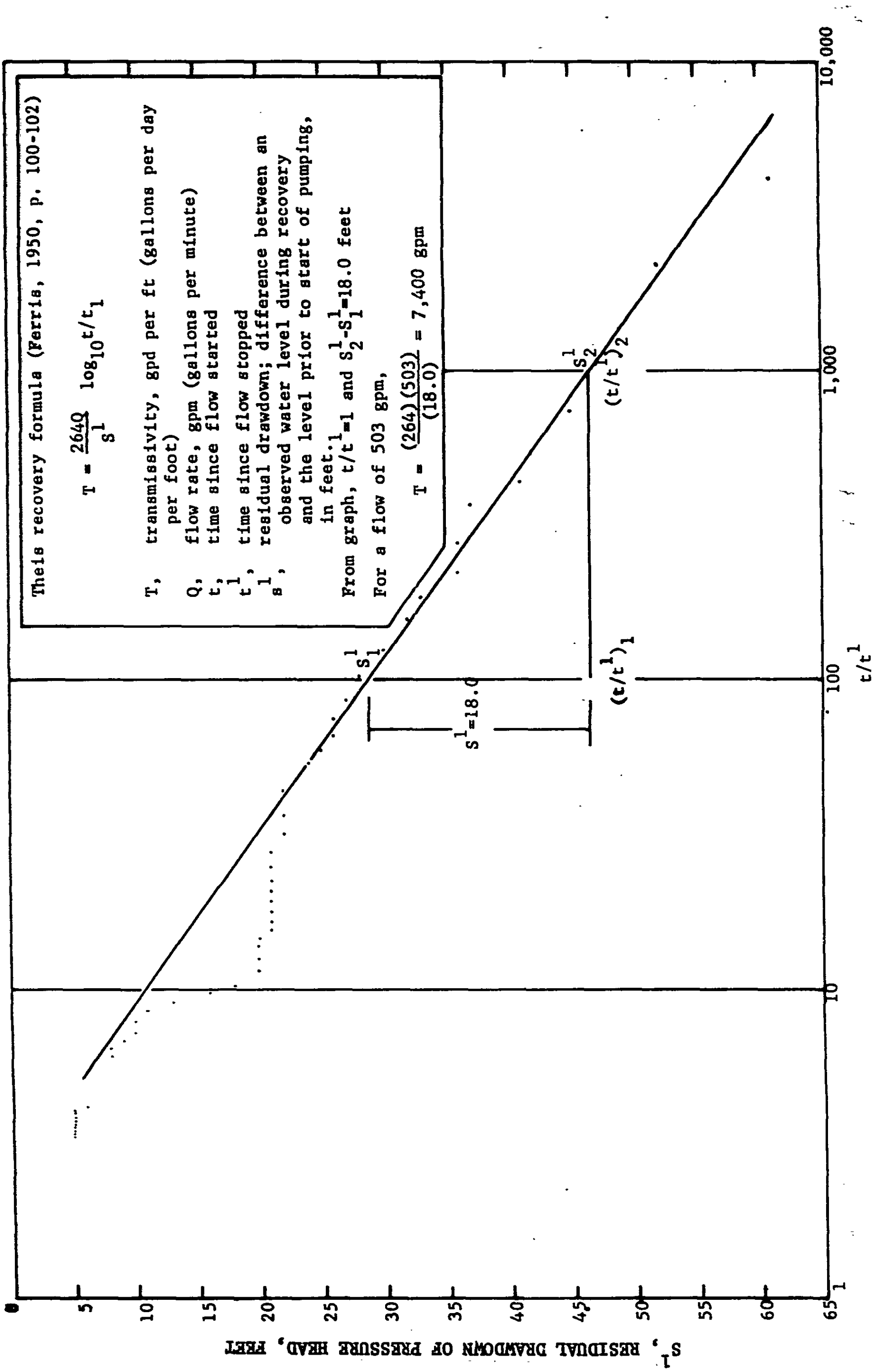


Figure 10. Graph showing computation of transmissivity of lower Floridan aquifer at Clear Creek monitor well. Data represent recovery of water pressure in aquifer following a period of constant flow from well.

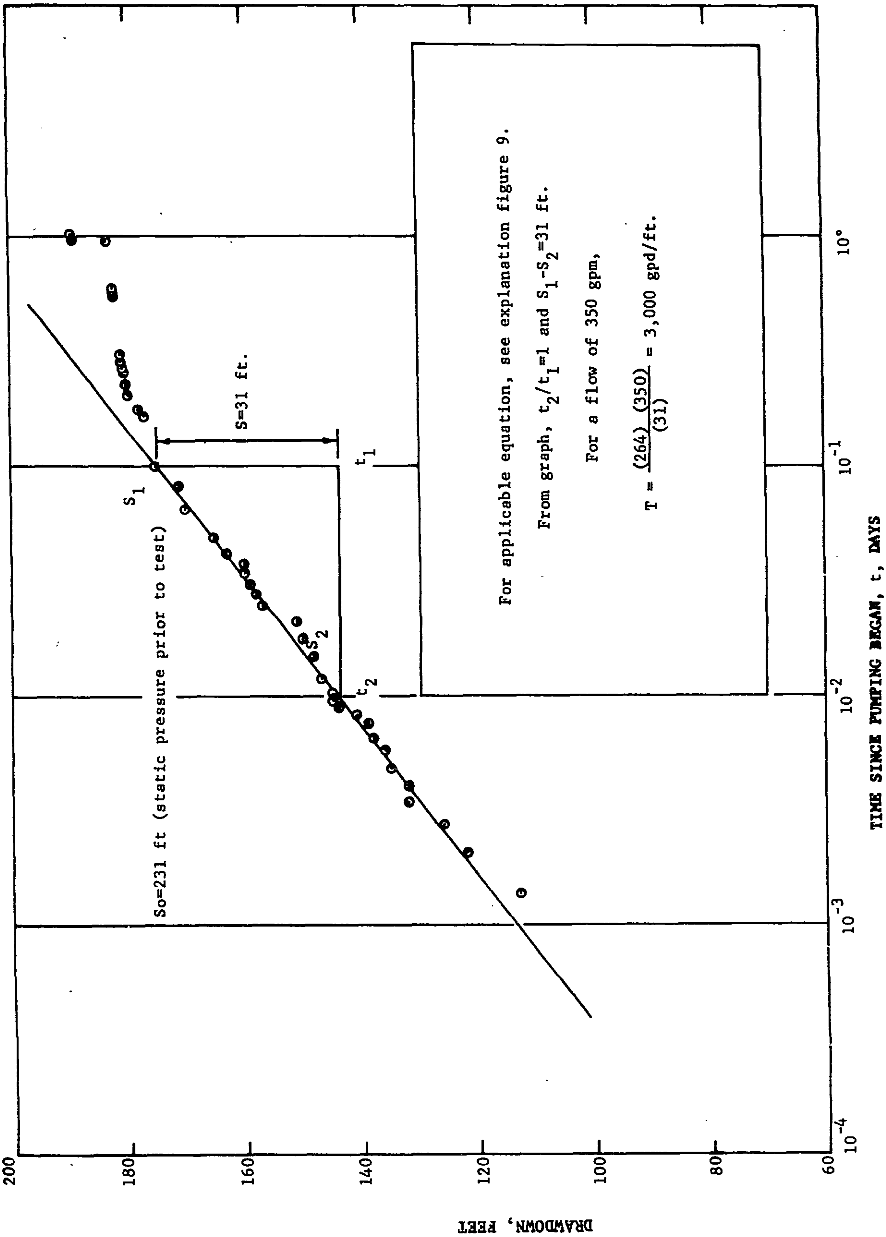


Figure 11. Graph showing computation of transmissivity of lower Floridan aquifer at Waldorf Lake monitor well. Data represent decline of water pressure in aquifer during period that well flowed at constant rate of 350 gpm.

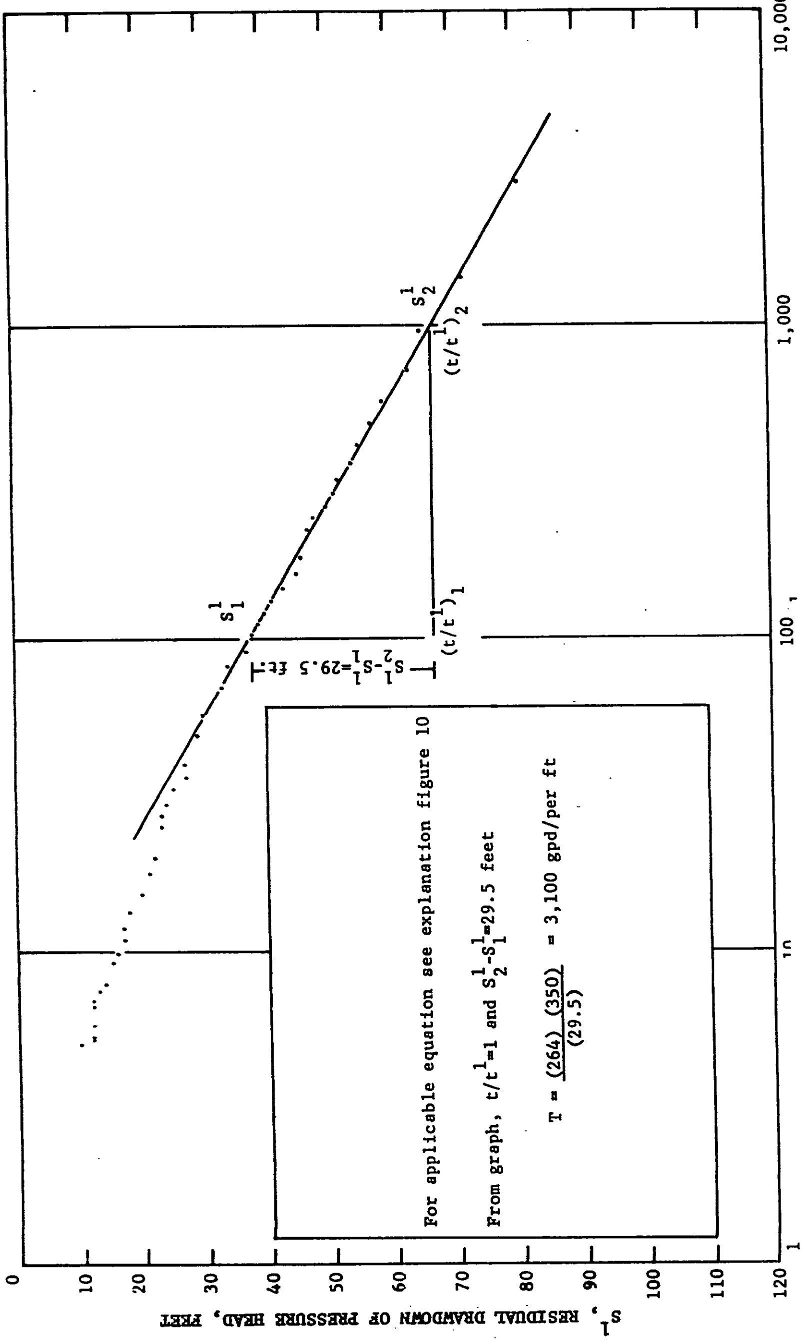


Figure 12. Graph showing computation of transmissivity of lower Floridan aquifer at Waldorf Lake monitor well. Data represent recovery of water pressure in aquifer following a period of constant flow from well.

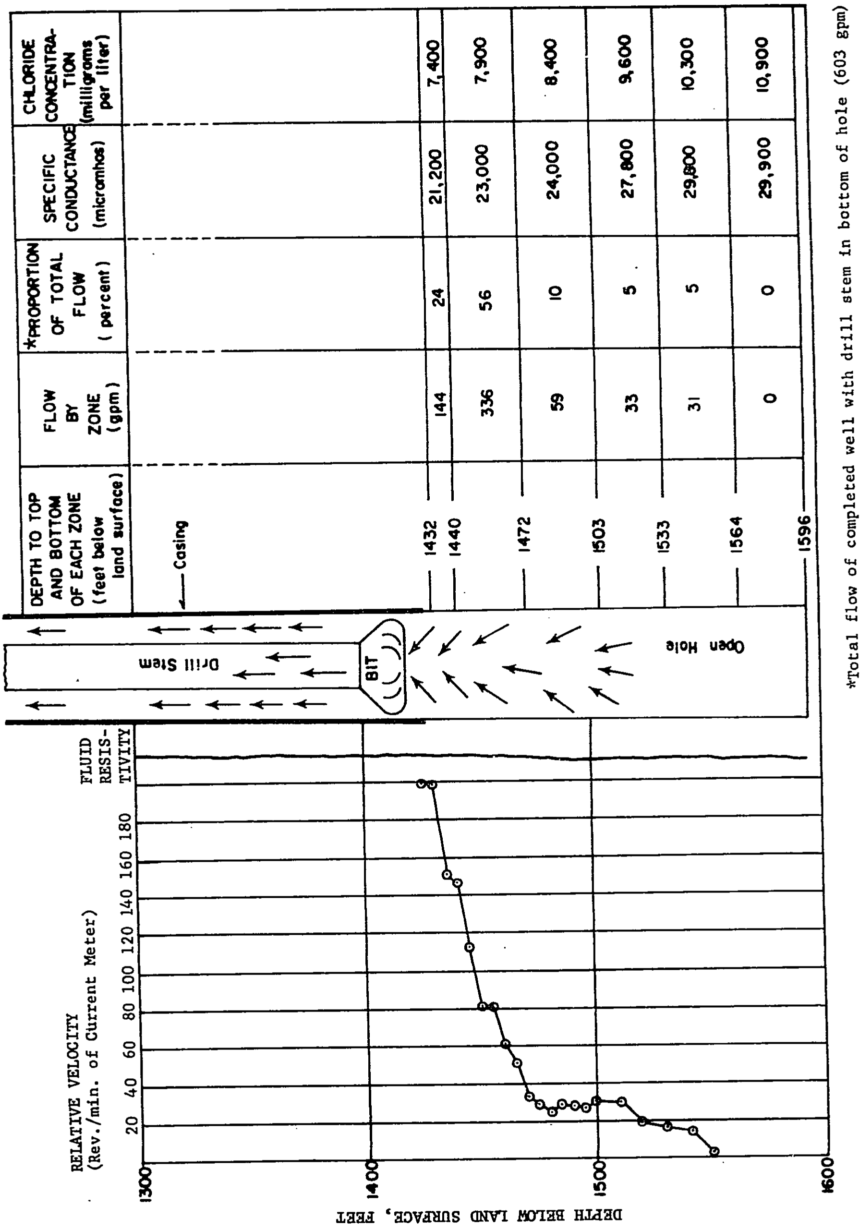
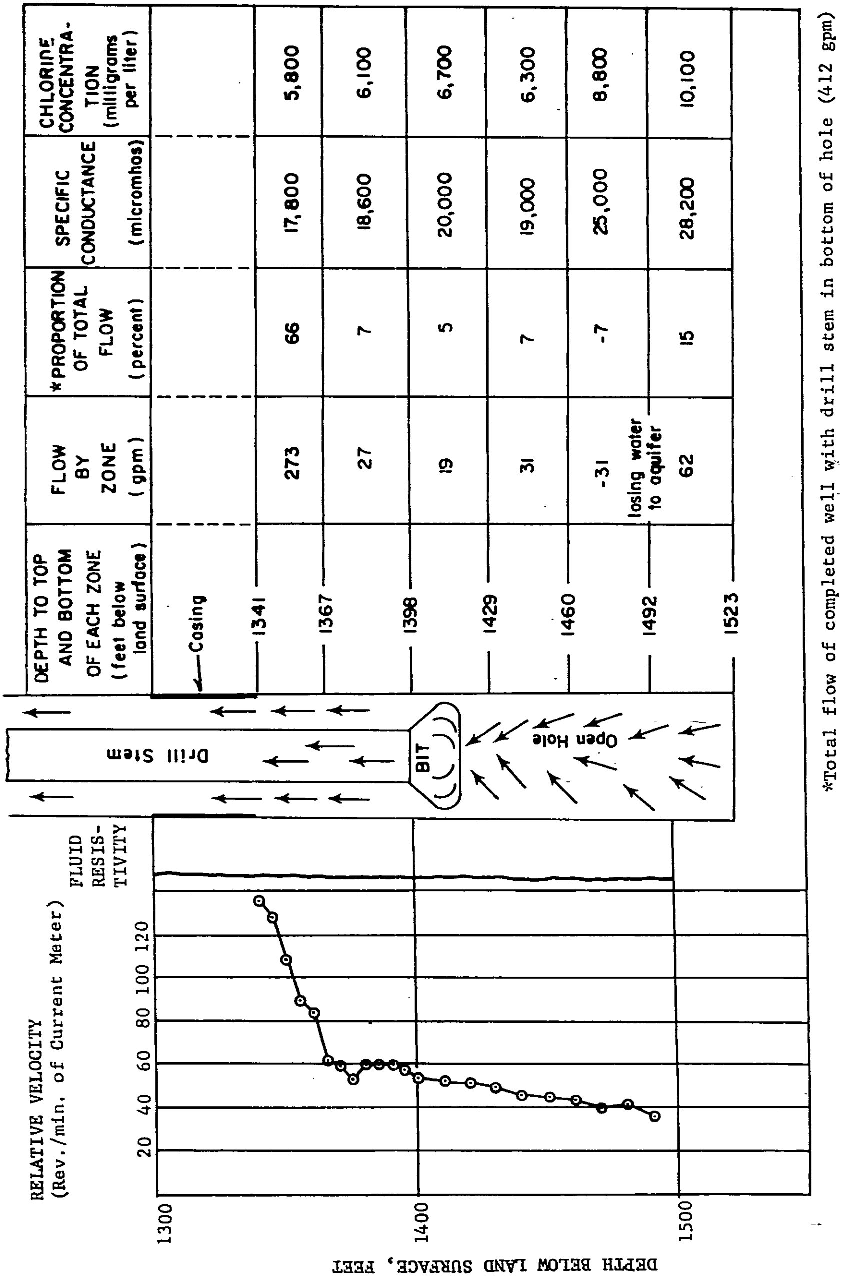


Figure 13. Graph showing quantity and chemical quality of water flow from different zones of the lower Floridan aquifer at Clear Creek monitor well.



DEPTH TO TOP AND BOTTOM OF EACH ZONE (feet below land surface)	FLOW BY ZONE (gpm)	*PROPORTION OF TOTAL FLOW (percent)	SPECIFIC CONDUCTANCE (micromhos)	CHLORIDE CONCENTRATION (milligrams per liter)
Casing				
1341–1367	273	66	17,800	5,800
1367–1398	27	7	18,600	6,100
1398–1429	19	5	20,000	6,700
1429–1460	31	7	19,000	6,300
1460–1492	-31 losing water to aquifer	-7	25,000	8,800
1492–1523	62	15	28,200	10,100

*Total flow of completed well with drill stem in bottom of hole (412 gpm)

Figure 14. Graph showing quantity and chemical quality of water flow from different zones of the lower Floridan aquifer at Waldorf Lake monitor well.

Table 4. Methods used to analyze water samples from Clear Creek and Waldorf Lake monitor wells.

Constituent	Analytical Method
Silica	Molybdate blue
Calcium	Atomic Absorption Spectroscopy
Magnesium	Atomic Absorption Spectroscopy
Strontium	Atomic Absorption Spectroscopy
Sodium	Atomic Absorption Spectroscopy
Potassium	Atomic Absorption Spectroscopy
Bicarbonate	Potentiometric Titration
Sulfate	Turbidimetric
Chloride	Visual Mercuric Nitrate
Fluoride	Spectrophotometric-Eriochrome Cyanine R
Dissolved Solids	Calculated from sum of determined constituents
Total Hardness	Calculated from Calcium, Magnesium, and Strontium
Non-Carbonate Hardness	Calculated
Alkalinity as $CaCO_3$	Calculated
Specific Conductance	Conductivity meter
pH	Potentiometric
Nitrate	Cadmium reduction-Technicon Autoanalyzer
Nitrite	Diazotation-Technicon Autoanalyzer
Ammonia	Distillation-Titration
Organic Nitrogen	Kjeldahl digestion-distillation-titration
Total Combined Nitrogen	Calculated
Total Organic Carbon	Beckman Carbon Analyzer
Color	Color-comparitor
Orthophosphate	Single reagent-Technicon Autoanalyzer
Total Phosphorus	Persulfate digestion-single reagent-Technicon Autoanalyzer
Bromide	Oxidation
Iodide	Oxidation
Arsenic 1/	Silver diethyldithiocarbamate
Boron	Carmine
Chromium 1/	Atomic Absorption Spectroscopy
Copper 1/	Atomic Absorption Spectroscopy
Iron 1/	Atomic Absorption Spectroscopy
Managanese 1/	Atomic Absorption Spectroscopy
Lead 1/	Solvent Extraction-Atomic Absorption Spectroscopy
Zinc 1/	Atomic Absorption Spectroscopy
Lithium	Atomic Absorption Spectroscopy
Oxidation-Reduction Potential	Potentiometric-platinum electrode
Hydrogen Sulfide	Iodiometric
Ferrous Iron	Spectrophotometric-Bipyridine

1/ Filtered through a 0.45 micron-membrane filter and acidified to pH2 with double distilled nitric acid at time of collection.

Table 5.–Results of chemical analyses of water samples from Clear Creek and Waldorf Lake monitor wells. Dissolved constituents in milligrams per liter.

Date of Collection	Time	Depth of well (feet)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (So_4)	Chloride (Cl)	Fluoride (F)	Dissolved Solids (calculated)	Total Hardness ($CaCO_3$)	Non-Carbonate Hardness ($CaCO_3$)	Alkalinity as $CaCO_3$	Specific Conductance (micromhos at 25° C)
CLEAR CREEK WELL – DRILL STEM FLOW																	
12-23-69	0854	1,472	19	163	141	16	4,900	71	272	0	7.900	3.0	13,400	1,010	783	223	23,000
12-23-69	0955	1,503	21	181	154	18	5,100	72	264	0	8,400	3.0	14,100	1,110	890	217	24,000
12-23-69	1012	1,503	21	181	151	18	5,100	75	260	0	8,400	2.9	14,100	1,090	881	213	24,000
12-23-69	1110	1,533	21	237	196	23	5.780	80	242	0	9,600	3.0	16,100	1,420	1,230	198	27,800
12-23-69	1213	1.564	24	300	243	30	6,230	86	216	0	10,300	3.0	17,300	1,780	1,610	177	29,800
12-23-69	1331	1,596	26	302	234	31	6,540	90	216	0	10,900	3.0	18,200	1,750	1,580	177	29,900
CLEAR CREEK WELL – CASING FLOW																	
12-23-69	0700	1,440	24	132	116	13	4,500	64	288	0	7,400	2.9	12,400	822	586	236	21,200
12-23-69	1015	1,503	20	140	122	14	4,700	67	276	0	7,500	3.0	12,700	868	642	226	21,500
12-23-69	1111	1,533	20	144	124	14	4,610	70	274	0	7,500	3.0	12,600	886	662	225	21,700
12-23-69	1214	1,564	20	149	129	14	4,720	70	276	0	7,700	3.0	12.900	919	693	226	21,900
12-23-69	1332	1,596	20	155	131	15	4,730	70	272	0	7,800	3.0	13,100	943	720	223	22,200
12-24-69	1022	1.596	20	172	146	16	5,030	75	264	0	8,200	3.0	13,800	1,050	832	217	23,200
03-11-70	1625	1.596	18	181	142	22	4,920	65	266	0	8,150	2.9	13,700	1,060	843	218	23,500
WALDORF LAKE WELL – DRILL STEM FLOW																	
02-02-70	1300	1,367	18	110	102	15	3,450	54	304	0	5,800	2.5	9,690	716	462	249	17,800
02-02-70	1402	1,398	18	121	111		3,530	55	300	0	6,100	3.1	10,100	767	520	246	18,600
02-02-70	1508	1.429	17	152	132	20	3,970	58	284	0	6,700	3.2	11,200	946	713	233	20,000
02-03-70	0850	1,460	17	138	118	21	3,660	56	296	0	6,300	3.2	10,400	855	612	243	19,000
02-03-70	0914	1,492	18	223	191	32	5,090	75	248	0	8,800	3.2	14,500	1,380	1,180	203	25,000
02-03-70	1106	1,523	18	282	223	42	5,950	82	228	0	10,100	3.1	16,800	1,670	1,480	187	28,200
WALDORF LAKE WELL – CASING FLOW																	
02-02-70	1300	1,367		104	93	15	3,720	52	312	0	5,600			660	404	256	17,000
02-02-70	1402	1,398		100	95	14	3,340	50	308	0	5,600			657	404	253	17,000
02-02-70	1508	1,429		101	95	14	3,290	50	328	0	5,700			659	390	269	17,000
02-03-70	0850	1,460		108	95	18			312	0				681	425	256	17,000
02-03-70	0913	1,492		115	101		3,520	51	328	0	5,800			709	440	269	17,500
02-03-70	1106	1,523	18	149	126	22	4,000	58	292	0	6,700	3.1	11,200	916	676	239	19,900
03-12-70	1600	1,523	18	159	132	19	4,280	55	288	0	7,100	3.1	11,900	962	726	236	20,800

*Contamination suspected

		Nitrogen Species																			
pH (Laboratory)	Temperature (°C)	Nitrate (NO_3)	Nitrite (NO_2)	Ammonia (NH_4)	Organic Nitrogen (N)	Total combined Nitrogen as N	Total Organic Carbon (C)	Color (pt-co scale)	Orthophosphate (PO_4)	Total Phosphorus (as PO_4)	Bromide (Br)	Iodide (I)	Arsenic (As)	Boron (B)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lithium (Li)	Manganese (Mn)	Lead (Pb)	Zinc (Zn)
8.0		0.0	0.01	11	0.00	9.0	.2	5	0.01					5.8				0.29			
8.0	35.0	.0	.01	11	.00	9.0		5	.01					6.2				.30			
8.0	35.0	.0	.03	10	2.0	10.2	31*	5	.01					6.2				.30			
8.0	35.0	.0	.01	12	.00	9.9	2	5	.01					6.5				.33			
7.9	35.0	.0	.01	14	.00	11.5	4	5	.01					6.6				.36			
8.0	35.0	.0	.04	8.2	2.1	8.8	1	5	.01					7.1				.36			
8.1	34.0	.0	.02	11	.00	9.0		5	.01					6.4				.28			
8.1		.0	.01	10	.55	8.8		5	.01									.27			
8.2	35.0	.0	.01	9.7	1.5	9.5		5	.01									.28			
8.2	35.0	.0	.01	9.9	.45	8.6		5	.01									.28			
8.1	35.0	.0	.01	11	.00	9.0	1	5	.01									.29			
8.0		.0	.02	9.7	2.7	10.7		5	.01									.29			
7.8	35.2	.0	.01	9.3	2.1	9.8	3	0	.00	0.01	28	1.5	.00	5.1	.02	.03	1.7	.31	.01	.01	.03
7.7	34.4	.0	.01	9.3	.82	8.5	3	5	.02	.03	23	.93		4.9				.24			
7.5	34.4	.0	.01	9.8	1.4	9.5	1	5	.01	.03	30	.97		5.2							
7.8	34.4	.0	.01	9.1	1.6	9.1	2	5	.01	.05	27	.93		5.2				.26			
7.6	35.0	.0	.01				1							5.2				.25			
7.7	35.0	.0	.01	9.0	2.7	10.1	2		.00	.02	40	1.1		6.0				.39			
7.8	35.3	.0	.01	6.8	5.4	11.0	2		.02	.03	32	.82		6.3				.43			
7.5	34.4																		.23		
7.7	34.4																		.23		
6.9	34.4																		.23		
7.6	35.0																		.23		
7.6	35.0																		.23		
7.7	35.3	.0	.01	9.6	.94	8.8	1		.02	.03				5.4				.26			
7.9	34.8	.0	.01	8.6	1.5	8.5	2	0	.00	.01	22	2.0	.01	4.5	.02	.02	1.6	.28	.01	.00	.02

Table 6. Results of spectrographic analysis of water sample taken from Clear Creek monitor well after completion.

Date of collection – March 11, 1970

Element	Concentration micrograms/liter
Aluminum (Al)	460
Barium (Ba)	140
Beryllium (Be)	< 45
Bismuth (Bi)	< 220
Cadmium (Cd)	ND
Cobalt (Co)	< 200
Gallium (Ga)	ND
Germanium (Ge)	< 220
Molybdinum (Mo)	< 90
Nickel (Ni)	< 220
Rubidium (Rb)	< 30
Silver (Ag)	< 22
Tin (Sn)	< 220
Titanium (Ti)	< 220
Vanadium (V)	< 220
Zirconium (Zr)	ND

< – Less than figure shown
ND – Specifically sought, not detected

Table 7. Results of field analyses of water from completed monitor wells.

	Clear Creek Monitor Well	Waldorf Lake Monitor Well
Date of Analysis	March 11, 1970	March 12, 1970
Time of Analysis	1500-1600	1600-1700
Specific Conductance (Micromhos at 25°)	22,320	19,350
Temperature °C	35.2	34.8
pH (Field measurement in closed system)	7.31	7.37
Oxidation-reduction potential at observed temperature (volts)	– 0.032	+ 0.023
Bicarbonate (HCO_3), mg/l	270	302
Hydrogen Sulfide (H_2S), mg/l	1.0	0.8
Ferrous Iron (Fe^{+2})	1.6	1.2

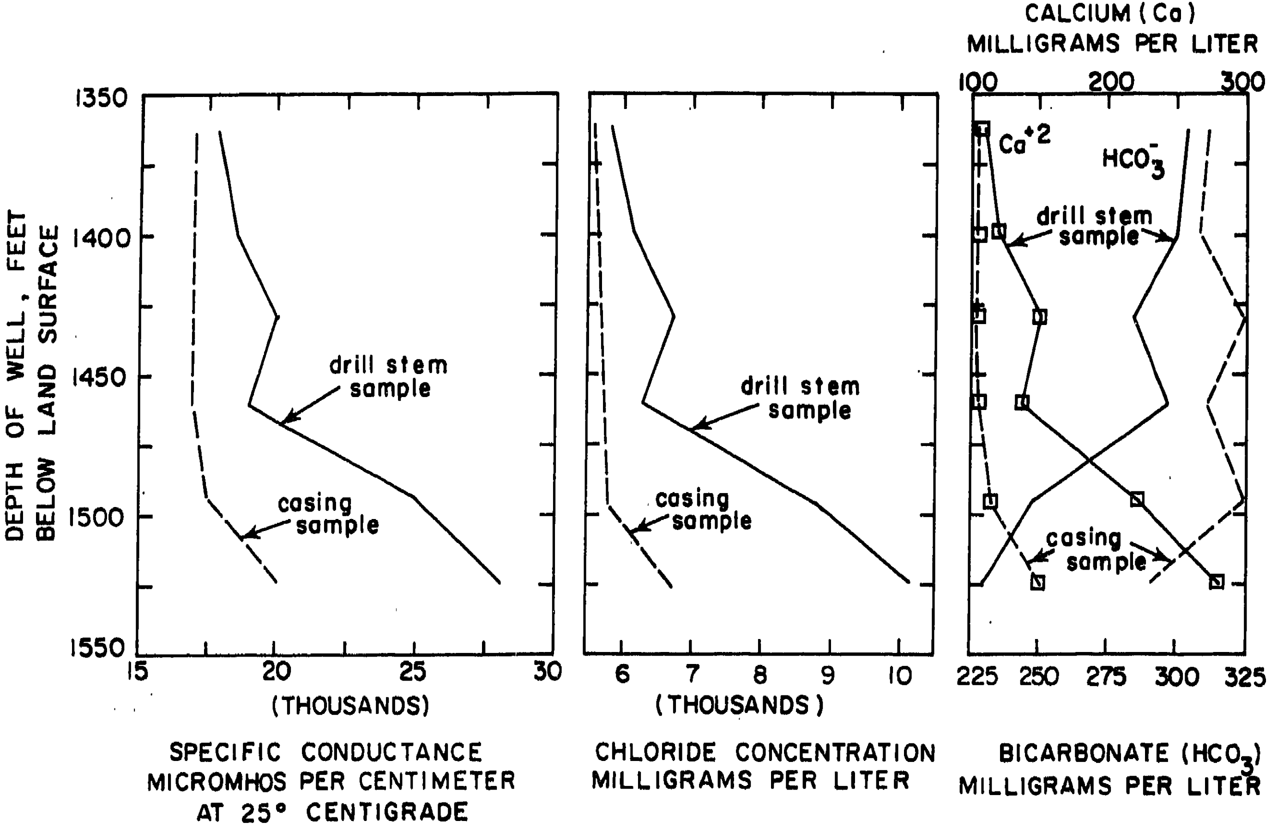


Figure 15. Graphs showing variation of chemical constituents with depth in lower Floridan aquifer at Clear Creek monitor well.

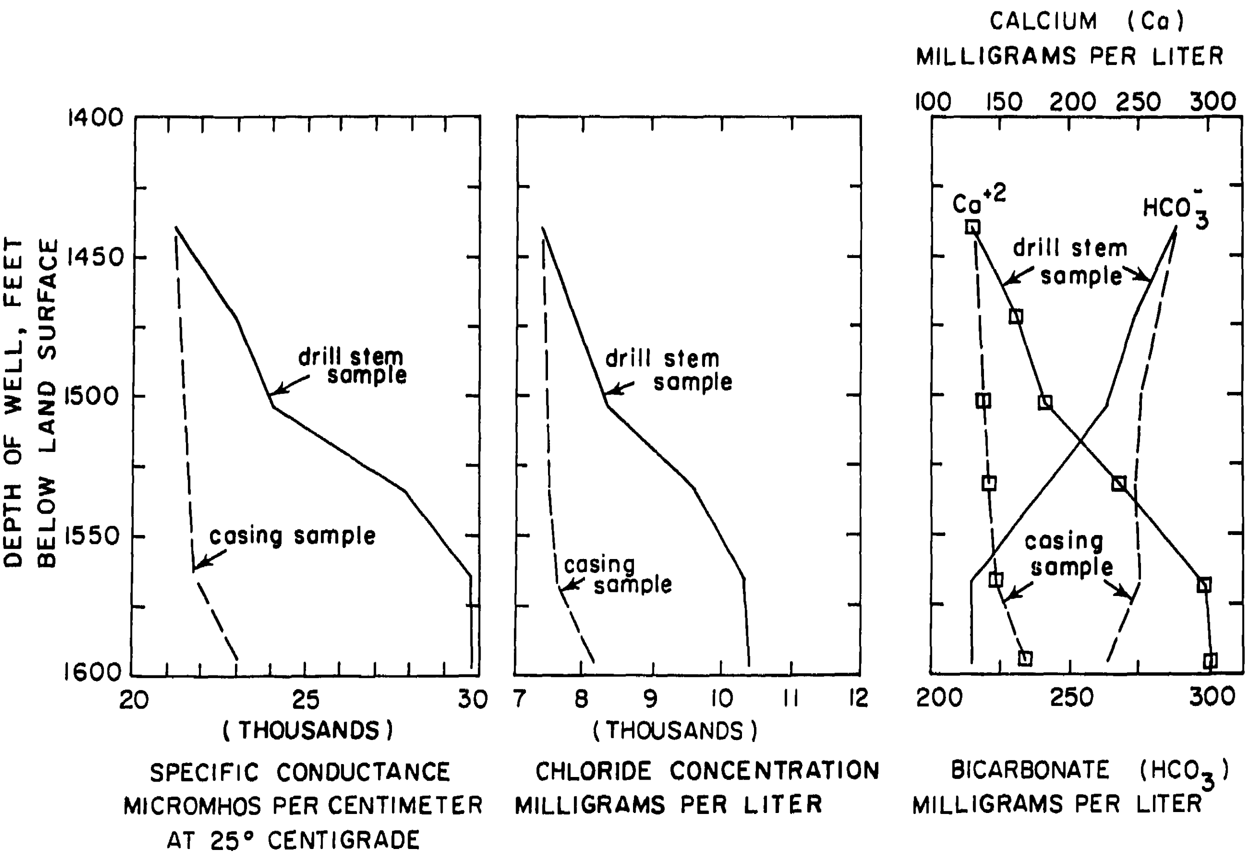


Figure 16. Graphs showing variation of chemical constituents with depth in lower Floridan aquifer at Waldorf Lake monitor well.