STATE OF FLORIDA
STATE BOARD OF CONSERVATION
DIVISION OF GEOLOGY

FLORIDA GEOLOGICAL SURVEY

Robert O. Vernon, Director

REPORT OF INVESTIGATIONS NO. 38

POSSIBILITY OF SALT-WATER LEAKAGE FROM PROPOSED INTRACOASTAL WATERWAY NEAR VENICE, FLORIDA WELL FIELD

By
William E. Clark
U. S. Geological Survey

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
FLORIDA GEOLOGICAL SURVEY

Tallahassee
1964

FLORIDA STATE BOARD
OF
CONSERVATION

LETTER OF TRANSMITTAL

Florida Geological Survey

Tallahassee

January 21, 1964

Honorable Farris Bryant, *Chairman*
Florida State Board of Conservation
Tallahassee, Florida

Dear Governor Bryant:

The Division of Geology is publishing, as Florida Geological Survey Report of Investigations No. 38, an evaluation of the "Possibility of Salt-Water Leakage from Proposed Intracoastal Waterway near Venice, Florida Well Field." The report is the result of a cooperative study between the U. S. Geological Survey and this department, during which the details of the well field were determined in considerable detail by electric logging, studies of rock cuttings, and mapping of surface formations by personnel of the State Survey. Both state and federal personnel cooperated in several detailed pumping tests to determine the hydrologic characteristics of the three aquifers present in the well field and to determine the possibilities of salt-water leakage into the well field.

The report has been compiled by Mr. W. E. Clark, engineer with the U. S. Geological Survey, and we are pleased to make this timely study available.

Respectfully yours,

Robert O. Vernon
Director and State Geologist

Completed manuscript received
December 11, 1963

Published for the Florida Geological Survey
By E. O. Painter Printing Company
DeLand, Florida
1964

TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

POSSIBILITY OF SALT-WATER LEAKAGE FROM PROPOSED INTRACOASTAL WATERWAY NEAR VENICE, FLORIDA WELL FIELD

By
William E. Clark

ABSTRACT

The proposed route C-1 of the intracoastal waterway passes a few hundred feet west of the Venice well field. One of the questions involved in constructing the waterway along this route is whether salt water will enter the well field from the waterway. In investigating the problem, the construction of the wells was determined, the geology was studied, water from wells was analyzed, and pumping tests were run.

There are three comparatively shallow aquifers at the well field: the water-table aquifer, the first artesian aquifer, and the second artesian aquifer. The water from the Venice well field is drawn from the first and second artesian aquifers. The water from the first artesian aquifer is of a better quality than the water from the second artesian aquifer. The water from the first artesian aquifer contains about 30 ppm (parts per million) of sulfate and about 50 ppm of chloride; whereas, the water from the second artesian aquifer contains more than 400 ppm sulfate and about 100 ppm chloride. The water from both aquifers is very hard. The poorer quality of water in the second artesian aquifer may be caused, in part, by the intrusion of highly mineralized water from a deeper aquifer, the Floridan aquifer.

The proposed waterway will cut into the water-table aquifer. If the well field is pumped too intensively, salt water will leak downward from the waterway into the producing aquifers. The downward leakage of the salt water, however, will be impeded by beds of relatively low permeability that lie below the waterway and above the first artesian aquifer. Estimates indicate that 6 or 7 million gallons per month may be pumped from the well field without causing salt-water leakage. Salt-water leakage may be kept within tolerable limits by reducing the pumpage from the field or by redistributing the pumping so that it is further from the waterway.

INTRODUCTION

PURPOSE AND SCOPE

The River and Harbor Act, approved by the U. S. Congress in 1945, provided for the construction of a section of the Intracoastal Waterway in southwestern Florida. The act authorized the route through Venice, Florida, close to and approximately parallel to the shore of the Gulf of Mexico. The authorization included provisions that local interests furnish the necessary lands to construct the waterway through Venice. To meet the requirements of this provision, the State, by legislative act in 1947, created a special taxing district, known as the West Coast Inland Navigation District. By 1951, the property development along the route in the vicinity of Venice had increased so much that the route as initially planned was abandoned.

An alternate route near Venice, known as Alternate Route C-1, trends landward through Roberts Bay and parallels the Seaboard Air Line Railroad, and then trends gulfward to rejoin the original route. The route encircles a large part of the city of Venice and approximately parallels, within a few hundred feet, the west line of wells of the Venice well field.

The proximity of Alternate Route C-1 to the well field threatens the Venice water supply by bringing salt water nearer the well field. The Florida Geological Survey, recognizing the threat, began an investigation to determine the effect of the construction of the waterway upon the well field and requested the assistance of the U. S. Geological Survey in the study. The investigation led to this report, which describes the hydrologic conditions at the well field and relates these conditions to the proposed waterway.

The field work for the investigation, which was done in June and July 1962, included: an inventory of the existing wells in the Venice well field and at the Venice water plant; running electric logs in 32 wells; studying well cuttings; collecting and analyzing water samples; and running pumping tests.

The investigation was made under the general supervision of Clyde S. Conover, district engineer, Ground Water Branch, U. S. Geological Survey.

ACKNOWLEDGMENTS

Thanks are especially due members of the Florida Geological Survey, who did a major part of the field work. In particular, thanks are due Dr. R. O. Vernon, state geologist, who arranged

for the investigation and furnished advice, personnel, and logging equipment. Cuttings from the wells in the Venice well field were described by Dr. R. O. Vernon and by Mr. Charles W. Hendry, Jr., assistant state geologist, of the Florida Geological Survey. Mr. Charles R. Sproul, assisted by Mr. H. C. Eppert, Jr. and Mr. James N. Davis, all of the Florida Geological Survey, and Mr. H. J. Woodard of the Florida Department of Water Resources collected data on the construction of the wells in the well field and made electric and gamma-ray logs of many of the wells. In addition, Messrs. Sproul and Hendry provided information on the geology of the area and aided in the delineation and description of the hydrologic units. Messrs. Hendry, Sproul, Woodard, Eppert, and Davis assisted in the pumping tests.

Mr. Orville L. Ives, waterworks superintendent for the city of Venice, furnished data on the well field and provided assistance in the gathering of additional data.

PREVIOUS INVESTIGATIONS

The geology and ground water of Sarasota County and the relation of the fresh ground water and salt water near the coast were described in a report by Stringfield (1933a). The report included data on the Venice public water supply. Another report by Stringfield (1933b) gave the results of a current-meter exploration of some artesian wells in Sarasota County, most of which are located 3 or 4 miles east of the Venice well field. A brief reconnaissance of the well field was made by G. G. Parker and N. D. Hoy in December 1942 (Parker, G. G., 1943, written communication).

GEOGRAPHY

LOCATION AND GENERAL FEATURES

Venice is on the gulf coast of southwestern Florida in Sarasota County (fig. 1). Venice was named in 1888 by Franklin Higel, who felt that the blue waters of the bays, rivers, and gulf gave the place a resemblance to the famous Italian city.

The Venice well field is in the city limits, lying about 1½ miles east of the Gulf of Mexico, between Hatchett Creek on the east and U. S. Highway 41 on the west. Just to the north and northwest of the well field, Roberts Bay extends about 2 miles back into the land. The land is low and flat, the entire area being less than 20 feet above sea level.

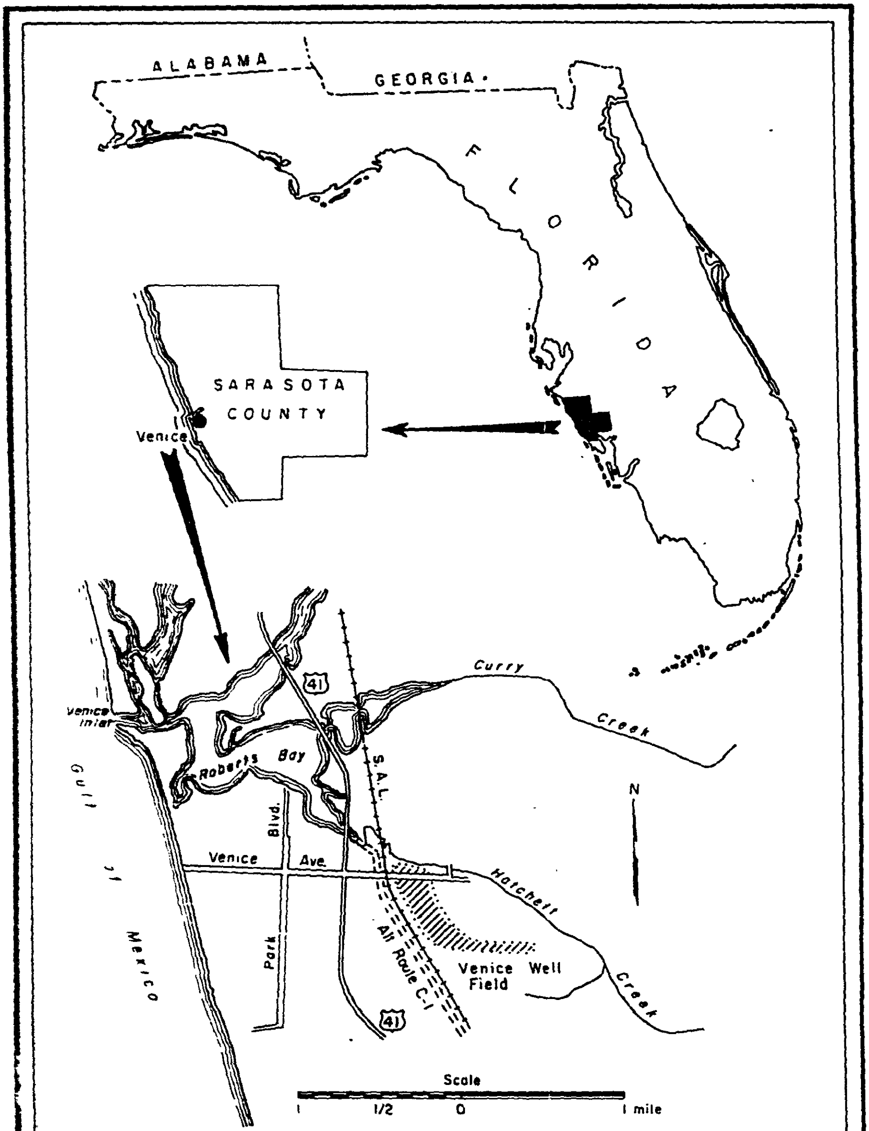


Figure 1. Florida showing locations of Sarasota County, Venice, and the Venice well field.

CLIMATE

Venice has a subtropical climate. The monthly and yearly averages of temperatures and rainfall at the U. S. Weather Bureau station at Venice are shown in table 1. The average annual temperature is 72.4°F. July and August are the warmest months; whereas January is the coldest.

TABLE 1.
Average Monthly Temperature, in Degrees Fahrenheit, and Average Monthly Rainfall, in Inches, at Venice, 1952-62.

Month	Temperature	Rainfall
January	60.0	3.04
February	64.4	3.10
March	66.0	4.02
April	71.3	4.31
May	76.6	2.74
June	79.8	4.23
July	81.5	7.77
August	81.4	6.49
September	80.5	7.34
October	75.6	4.78
November	68.9	1.06
December	62.7	1.75
Yearly average	72.4	51.23

The average annual rainfall at Venice, based on the period of record, is 51.23 inches. The annual rainfall ranged from 74.15 inches in 1957 to 36.50 inches in 1961, and the monthly rainfall ranged from 13.85 inches in April 1957 to 0.10 inch in March 1956. The rains are usually the heaviest during the period June through October.

POPULATION

The population of Venice only increased from 507 in 1940 to 927 by 1950. Between 1950 and 1960, however, the population increased almost fivefold to 3,444, and the prospects are for a continued rapid increase.

WELL-FIELD

FACILITIES

The Venice well field in July 1962 consisted of 42 wells (fig. 3), excluding the wells at the water plant. Eighteen of these wells are dual—that is, one pump draws water from two wells. The single wells are equipped with centrifugal pumps; the dual wells are equipped with piston pumps. Well 5, however, is not equipped with a pump because the well reportedly will produce only a small amount of water. Well 10 is 6 inches in diameter; the rest are either 2 or 4 inches in diameter. Except for well 25, the wells range in depth from 33 to 144 feet. Well 25 was drilled to a depth of 185 feet but was later plugged back to 140 feet. Eleven of the wells are open to the first artesian aquifer, four are open to the second artesian aquifer, and 27 are open to both the first and second artesian aquifers.

Four wells are at the water plant (fig. 3). Water plant well 4 was not found and may have been destroyed. The other three wells range in depth from 304 to 458 feet and are used for emergency supplies. Well 706-226-5, just east of the Venice water plant, is privately owned. Data on these wells are given in table 2.

PUMPAGE

The monthly pumpage from the Venice well field as metered at the water plant and the monthly rainfall at Venice are shown graphically in fig. 2. The graph shows that between 1952 and 1955 the pumpage averaged between 5 and 6 million gallons per month. The pumpage rose sharply from an average of 7 million gallons per month in 1958 to more than 13 million gallons per month in 1961. The greatest pumpage for any month during the period January 1952 to June 1962 was 17.4 million in March 1962. The pumpage is usually the greatest in the winter, a period when the rainfall ordinarily is the least.

GROUND WATER

HYDROLOGIC UNITS

Ground water at the Venice well field occurs in a water-table (non-artesian or unconfined) aquifer and at least three artesian (confined) aquifers—the first artesian aquifer, the second artesian aquifer, and the Floridan aquifer. Cross sections A-A′, B-B′, and C-C′ in figure 3 show the character and distribution of the material composing the water-table and the first and second artesian aquifers. A generalized section and a generalized electrical resistivity log of the expected material at the site of the proposed waterway is shown in figure 4. The section shows the hydrologic units into which the material has been divided. The straight-line part of the resistivity log indicates the part of the material that is generally cased off in wells.

The water-table aquifer extends from the surface of the ground to about 18 feet below sea level. It consists of interbedded sandy limestones, sands, and shells. The aquifer may contain beds that are under artesian conditions, but the data are not adequate to delineate these beds. None of the wells for which records are available tap this aquifer except test wells 1, 2, and 3 (fig. 3). The aquifer, however, will probably produce adequate water for domestic purposes.

Below the water-table aquifer are beds about 20 feet in thickness that have a relatively low vertical permeability. These beds confine water in the first artesian aquifer. The material in the upper part of these beds is similar to the material in the water-table aquifer but contains more clay and has a lower permeability. The lower part is a sandy, argillaceous dolomite, which is soft to hard and similar to the material in the first artesian aquifer. The horizontal permeability of these beds in places may be high enough so that they will produce small amounts of water.

The first artesian aquifer lies below the upper confining beds, is about 15 feet thick, and is composed of sandy dolomite or dolomitic limestone that contains hard and soft layers. The aquifer seems to be moderately permeable, but the permeability seems to be lower in the west line of wells than in the easternmost wells of the south line.

Eleven wells in the Venice well field tap only this aquifer, and 27 tap the first artesian aquifer and the second artesian aquifer.

A second confining bed, about 15 feet thick, separates the first artesian aquifer from the second artesian aquifer. The bed occurs over a wide area and consists of very fine sandy clay or silt of low permeability. This bed has been found in wells at Sarasota, some 20 miles north of Venice, and in wells just south of Venice.

The second artesian aquifer consists of hard to soft, dense to porous dolomite and extends from about 70 to 130 feet below sea level. Water in the aquifer is confined under artesian pressure.

TABLE 2. Record of Wells at the Venice Well Field.

(Logs available: D, Drillers; E, electric; R, gamma ray)

Venice well field number	U.S. Geological Survey well number	Florida Geological Survey well number	Date completed	Depth of well (feet)	Casing		Logs available	Elevation of land surface above mean sea level (feet)	Water level		Yield	Remarks
					Depth (feet)	Diameter (inches)			Below land surface (feet)	Date of measurement	Gallons per minute	
1	705-226-18	—	—	66	41	4	E	—	—	—	—	
1N	705-226-19	W-4479	11-29-57	92	39	4	E,R	—	—	—	60	
2	705-226-20	—	—	67	46	4	E	13.0	5.3	7-12-62	—	
2N	705-226-21	W-4478	12- 5-57	100	39	4	E,R	13.1	5.5	7-12-62	60	
3S	705-226-22	—	—	47	31	2	E	12.4	4.3	7-12-62	—	
3N	705-226-23	—	—	103	31	2	E	12.2	4.1	7-12-62	—	
4S	706-226-24	—	1-16-56	125	32	2	—	—	—	—	—	
4N	706-226-25	—	—	110	32	2	E	12.2	3.8	7-12-62	—	
5S	705-226-26	—	—	35	32	2	E	—	—	—	40	
5	705-226-34	—	—	114	32	4	—	—	—	—	—	
5N	705-226-27	—	—	59	31	2	E	12.6	4.2	7-12-62	—	
6	705-226-28	—	—	112	33	4	E,R	11.4	3.9	7-12-62	—	
7S	705-226-29	—	1-17-56	105	30	4	E	—	—	—	30	
7N	705-226-30	—	—	105	29	2	D,E	10.9	2.3	7-12-62	—	
9N	705-226-1	—	—	105	30	2	—	8.8	.4	7-12-62	—	

TABLE 2 (Continued)

9S	705-226-2	———	———	110	29	4	—	8.3	.3	7-15-62	—	
10	705-226-3	———	———	113	32	6	E,R	12.0	3.7	7-12-62	—	
11N	705-226-4	———	———	104	31	2	D,E	11.6	3.1	7-12-62	—	
11S	705-226-5	———	1-18-56	134	34	4	E,R	—	—	———	30	
12N	705-226-6	———	———	96	28	2	E	11.9	3.7	7-12-62	—	
12S	705-226-7	———	———	57	29	2	E	12.2	4.3	7-12-62	—	
13N	705-226-8	———	———	108	33	2	E	12.0	3.5	7-12-62	—	
13S	705-226-9	———	———	33	30	2	E	11.9	3.5	7-12-62	—	
14N	705-226-10	———	———	109	32	2	E	12.0	3.4	7-12-62	—	
14S	705-226-11	———	1-20-56	124	32	4	D,E,R	12.0	3.5	7-12-62	40	
15	705-226-12	———	7-30-57	98	34	4	E,R	—	—	———	60	
15E	705-226-16	W-4476	10-31-57	105	40	4	D,E,R	12.8	5.0	7-12-62	25	
16	705-226-13	W-4328	8- -57	111	45	4	D,E,R	11.8	3.2	7-12-62	60	
17	705-226-14	W-4475	11-24-57	114	48	4	D,E,R	11.6	4.2	7-12-62	46	
18	705-226-15	W-4477	11-29-57	140	46	4	E,R	11.0	1.8	7-12-62	37	
21	705-226-17	W-5244	12- 9-59	144	84	4	D,E,R	12.9	3.2	7-12-62	50	
22	705-225-1	W-5246	11- 8-59	125	52	4	D,E,R	13.4	3.7	7-12-62	60	
23	705-225-2	W-5247	11-14-59	120	104	4	D,E,R	13.2	4.6	7-12-62	42	
24	705-225-3	W-5248	11-22-59	120	52.5	4	D	13.8	4.5	7-12-62	60	
25	705-225-4	———	———	185	120	4	D,E,R	14.4	2.0	7-12-62	—	Well plugged back to 140 ft
26	705-225-5	W-5245	11-17-59	118	83	4	D,E,R	14.2	3.5	7-12-62	60	
27	705-225-6	W-5249	12- 2-59	118	54	4	D,E,R	14.5	4.8	6-14-62	64	
28	705-225-7	———	6-25-59	60	40	4	—	—	—	———	45	
29	705-225-8	W-5250	12-15-59	65	42	4	D	—	—	———	58	
30	705-225-9	W-5251	12-21-59	110	42	4	D	—	—	———	50	

TABLE 2 (Continued)

Venice well field number	U.S. Geological Survey well number	Florida Geological Survey well number	Date completed	Depth of well (feet)	Casing: Depth (feet)	Casing: Diameter (inches)	Logs available	Elevation of land surface above mean sea level (feet)	Water level: Below land surface (feet)	Water level: Date of measurement	Yield: Gallons per minute	Remarks
31	705-225-10	W-5243	12-22-59	59	42	4	D	14.0	5.5	7-19-62	60	
32	705-225-11	—	12-24-59	59	42	4	D,E,R	13.9	6.8	7-12-62	60	
Plant well 1	706-226-1	—	—	304	146	6	E,R	—	—	—	—	Emergency supply well
Plant well 2	706-226-2	—	—	403*	78	6	—	—	—	—	—	*Well bridged at 124 ft; emergency supply well.
Plant well 3	706-226-3	—	—	458	80	8	—	—	—	—	—	Emergency supply well
Plant well 4	706-226-4	—	—	—	—	—	—	—	—	—	—	Well destroyed?
	706-226-5	—	—	414	140	6	E,R	10.4	+12.9	7-13-62	—	Owner, Albert Blackburn water level above land surface
Test well 1	705-226-31	—	1962	20	20	1½	—	11.10	3.47	7-12-62	—	Test well
Test well 2	705-226-32	—	1962	20	20	1½	—	11.13	3.43	7-12-62	—	Do
Test well 3	705-226-33	—	1962	20	20	1½	—	—	—	—	—	Do

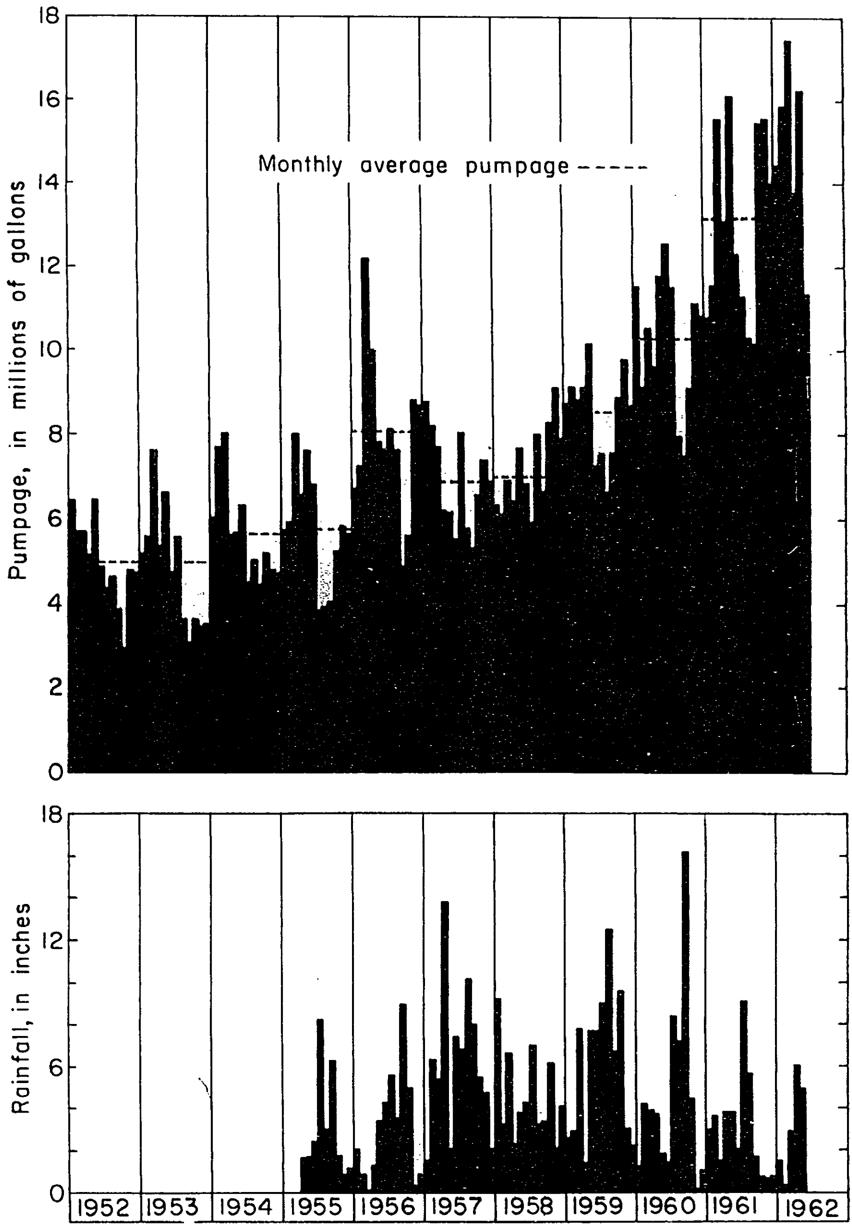


Figure 2. Monthly pumpage from Venice well field and monthly rainfall at Venice, 1952-62.

Four wells in the Venice well field (21, 23, 25, and 26) tap only this aquifer.

The second artesian aquifer is separated from the underlying Floridan aquifer by a thick section of sandy limestone and dolomite, clayey sands, and clay. This section was estimated from a log of well 706-226-4 (fig. 2) to lie from about 130 to 270 feet below sea level. The section, as a unit, has a low vertical permeability but may contain beds whose horizontal permeability is relatively high. Beds of low permeability in this section confine water in the Floriday aquifer under pressure.

The Floridan aquifer consists of a large thickness of alternate layers of hard and soft limestone. These layers of limestone, so far as is known, act essentially as a hydrologic unit. The water in the Floridan aquifer at Venice is highly mineralized.

RECHARGE AND DISCHARGE

Ground water moves downgradient, from a high piezometric level to a low piezometric level. By mapping the piezometric surface in an aquifer the lateral direction of ground-water movement can be determined. By comparing the piezometric surfaces of aquifers above and below each other, the direction of interaquifer flow can be determined.

A statewide map of the piezometric surface of the Floridan aquifer shows that the water in the Floridan aquifer at Venice comes from the northeast outside of Sarasota County. No maps, however, are available for the piezometric surfaces of the overlying aquifers. A part of the recharge for the first and second artesian aquifers, however, probably comes from the area a few miles east of the Venice well field where the land surface is relatively high. The water-table aquifer, of course, is recharged locally by rainfall. The rate of recharge to the water-table aquifer is probably high because almost all the rainfall percolates downward or is evaporated rather than running off over the surface of the ground.

The water levels in most of the wells in the Venice well field were measured on July 12, 1962, 14 hours after pumping from the well field had ceased. The average elevation of the water level in test wells 1 and 2, which tap the water-table aquifer, was 7.6 feet above sea level. The average elevation of the water level in six wells (2, 5N, 5S, 12S, 13S, and 32), which tap the first artesian aquifer, was 8.1 feet; and the average elevation in three wells (21, 23, and 26), which tap only the second artesian aquifer, was 9.6

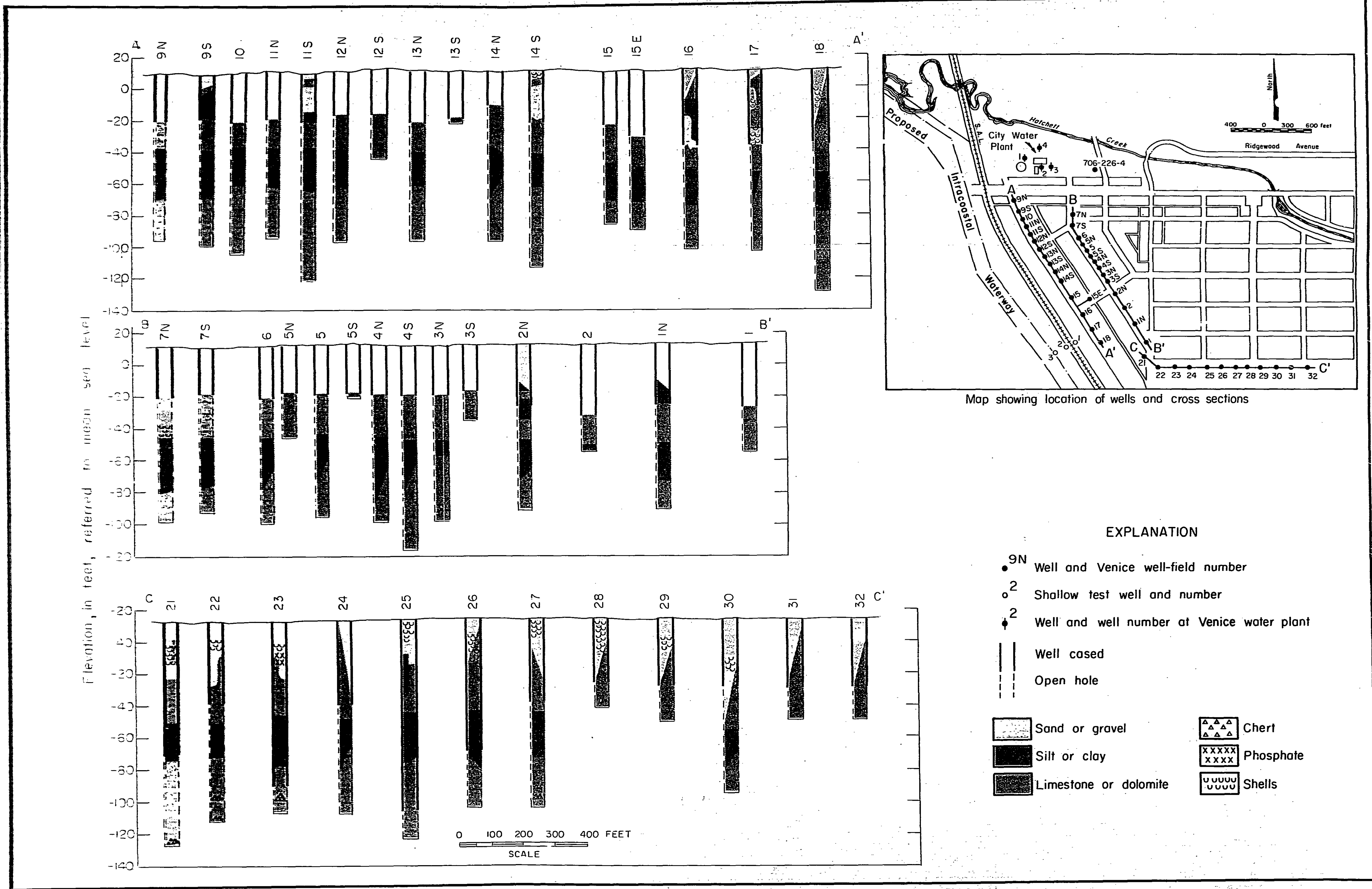


Figure 3. Geologic cross sections through the west, east, and south lines of wells of the Venice well field and map showing location of wells.

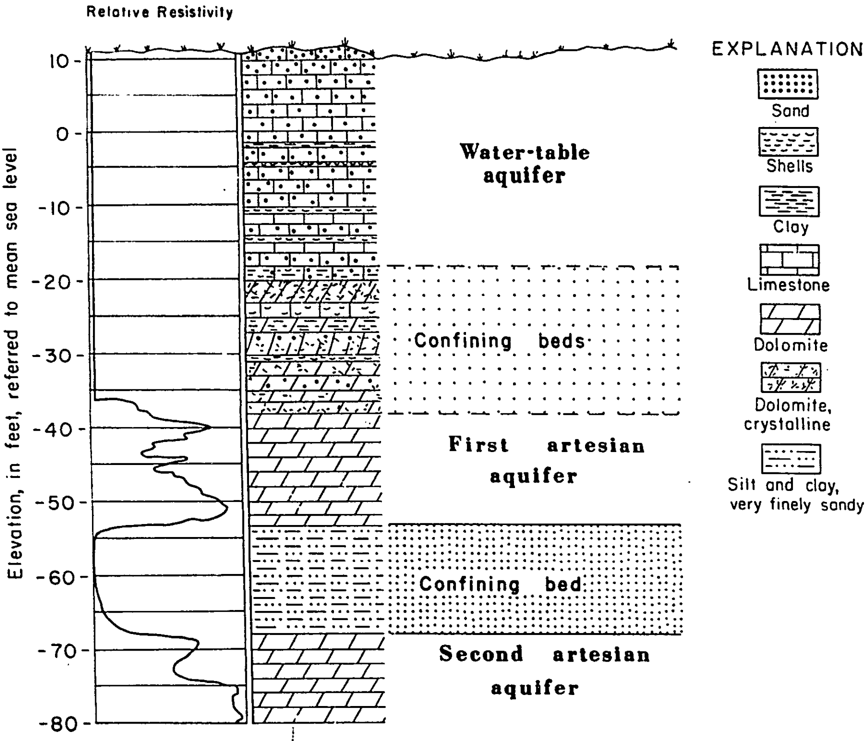


Figure 4. Generalized geologic section and electrical resistivity log near Venice well field at site of proposed waterway showing hydrologic units.

feet. The pressure in well 706-226-5, which taps the Floridan aquifer, was measured on July 13, 1962 to be 23.8 feet above sea level. Thus, it was found that, on July 12, 1962, the deeper the aquifer, the higher the piezometric surface.

These water levels indicate that on July 12, 1962, after the well field had been idle for about 14 hours, water in general was moving, however slowly, up from the Floridan aquifer into the second artesian aquifer, from the second artesian aquifer into the first artesian aquifer, and from the first artesian aquifer into the water-table aquifer.

When water is pumped from the first and second artesian aquifers, the piezometric surfaces of these aquifers are lowered. This lowering is great enough near the pumping wells to change the direction of flow between the water-table and first artesian aquifer. Water is then induced into the first and second artesian aquifers by leaking downward from the water-table aquifer, supplementing the upward leakage of water from the Floridan aquifer.

Where wells are open to more than one aquifer, water moves up or down the well bore from the aquifer having the greatest pressure into the aquifer having the least pressure. Of the three wells at the water plant for which record of casing and depth are available, two (plant wells 2 and 3) are open to both the Floridan aquifer and the second artesian aquifer. Water from the Floridan aquifer, therefore, moves up the well bores of these two wells into the second artesian aquifer. Moreover, water from the second artesian aquifer moves into the first artesian aquifer through the 27 wells that are open to both the first and second artesian aquifers when these wells are not being pumped.

HYDRAULIC PROPERTIES

Three pumping tests were run to determine the hydraulic properties of the first and second artesian aquifers. The tests were made by pumping one well at a constant rate and observing the change of water level in one or more nearby observation wells.

While these tests were being made, water was supplied to the city from the wells farthest from those being tested. The wells that were supplying the city were pumped at a constant rate until the water levels in the wells to be used in the test had stabilized or until the change in the water levels was so slow that it could be extrapolated through the period of the test. Because pumping from wells outside the field could not be controlled, the tests were begun after about 6 p.m. and were continued until about 7 a.m. the following morning—a period when the withdrawals from private wells were at a minimum.

The pumping tests were conducted to determine three aquifer constants—the coefficient of transmissibility (T), the coefficient of storage (S), and the coefficient of leakage (P′/m′). The coefficient of transmissibility is a measure of the ease with which an aquifer transmits water and is defined as the quantity of water, in gallons per day, that will move through a vertical section of the aquifer 1 foot wide under a unit hydraulic gradient. The coefficient of storage is a measure of the capacity of the aquifer to store or release water and is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head. The coefficient of leakage is a measure of the ability of the confining bed to leak water. It is defined as the flow, in gallons per day, that will cross a square foot of the interface between the aquifer and the confining bed under a unit head difference.

The pumping tests were analyzed by using a family of type curves developed by Cooper (1963). The type curves are based on a formula developed by Hantush and Jacob (1955) for the drawdown around a pumped well in an artesian aquifer whose confining bed leaks water to the aquifer at a rate proportional to the drawdown.

The first test was made by pumping well 9S and observing the drawdown in wells 9N and 10. Wells 9S, 9N, and 10 tap both the first and second artesian aquifer. The drawdowns were plotted against the time since the pumping started divided by the distance of the observation well from the pumping well. The plots are shown in figure 5. From the drawdown observed in well 9N the coefficient of transmissibility was computed to be 5,600 gpd per ft (gallons per day per foot); the coefficient of storage, 8.7 x 10^{-5}; and the coefficient of leakage, 1.3 x 10^{-3} gpd per ft^3. From the drawdown observed in well 10, the coefficient of transmissibility was computed to be 6,100 gpd per ft; the coefficient of storage, 1.1 x 10^{-4}; and the coefficient of leakage, 1.4 x 10^{-3} gpd per ft^3.

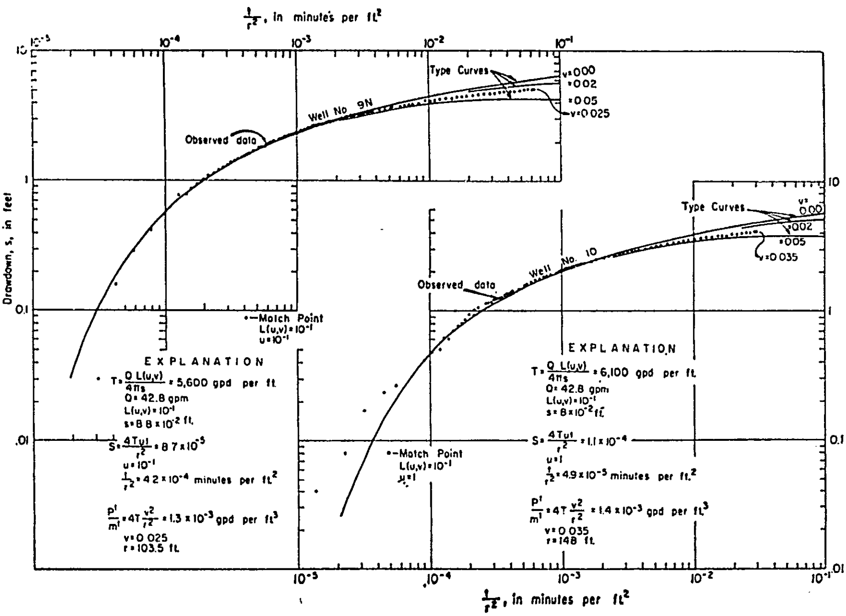


Figure 5. Logarithmic plots of the drawdown in well 9N and in well 10 versus t/r^2.

The second test was made by pumping well 31 and observing the drawdown and recovery in well 32. Both wells are open to the first artesian aquifer. From the drawdowns observed in well 32 (fig. 6), the coefficient of transmissibility was computed to be 8,500 gpd per ft; the coefficient of storage, 1.3 x 10^{-4}; and the coefficient of leakage, 7 x 10^{-3} gpd per ft^3.

The third test consisted of pumping well 21 and observing the drawdown and recovery in well 23. Both wells are open to the second artesian aquifer. The test, however, may not be reliable because of the proximity of wells tapping both aquifers.

The permeability of the first and second artesian aquifers is probably quite variable. The coefficient of transmissibility of the first and second artesian aquifers in the vicinity of well 9S was much less than the coefficient of transmissibility of the first artesian aquifer at well 31. Also well 5, though open to both aquifers, reportedly will produce so little water that it is not being used, presumably because the material it penetrates is of low permeability.

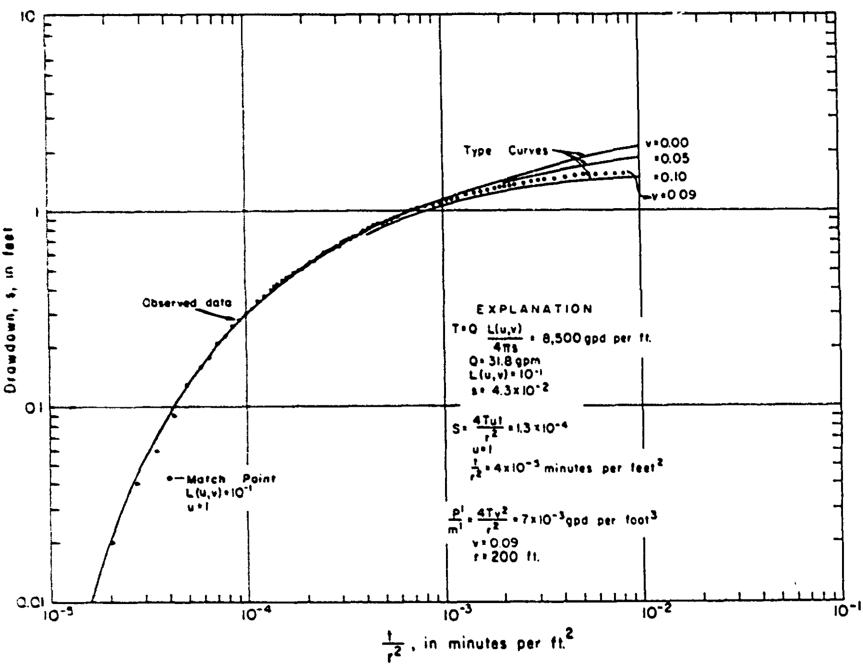


Figure 6. Logarithmic plot of the drawdown in well 32 versus t/r^2.

The coefficient of leakage at well 9S is much less than the coefficient at well 31. The coefficients, however, are not comparable. The coefficient at well 9S is determined by the leakage through the confining beds above the first artesian aquifer and by leakage through the confining beds below the second artesian aquifer. The coefficient at well 31 is determined by the leakage through the confining beds just above and below the first artesian aquifer.

CHEMICAL QUALITY OF WATER

Ground water contains various substances dissolved from the air, the soil, and the material of which the aquifer is composed. The concentration of the various substances increases with, among other things, the length of time water is in contact with these materials. Water samples were collected from most of the wells in the Venice well field in July 1962. On most of the samples, alkalinity, sulfate, chlorides, hardness, pH, and specific conductance were determined (table 3).

Samples were taken from six wells that tapped only the first artesian aquifer and from four wells that tapped only the second artesian aquifer. The six samples from the first artesian aquifer had an average sulfate concentration of 29 ppm, an average chloride concentration of 49 ppm, a carbonate hardness of 307 ppm, and a noncarbonate hardness of 31 ppm. The four samples from the second artesian aquifer had an average sulfate concentration of 420 ppm, an average chloride concentration of 102 ppm, a carbonate hardness of 688 ppm, and a noncarbonate hardness of 500 ppm.

The analyses show that the water in the first and second artesian aquifers is typical of that in many limestone aquifers in Florida. The water in the Floridan aquifer at Venice is highly mineralized, rendering it undesirable for a public supply. The water in the second artesian aquifer at the Venice well field, though less mineralized than that in the Floridan aquifer, is more mineralized than that in the first artesian aquifer.

The analyses, however, probably do not show the character of the water that was originally in the first and second artesian aquifers. For example, the highest concentration of sulfate, 1,140 ppm, was in the sample taken from well 706-226-4, which taps the Floridan aquifer. The sample having the next highest concentration of sulfate, 1,060 ppm, was a composite sample taken from wells 9N and 9S that tap both the first and second artesian aquifers. The high concentration of sulfate in this sample is

TABLE 8. Chemical Analyses of Water from the Venice Well Field

Analyses in parts per million except pH and specific conductance. Analyses, U. S. Geological Survey.
Aquifer sampled: W, water-table; f, first artesian; S, second artesian; F, Floridan

Venice well field number	U.S. Geological Survey well no.	Date of collection	Depth of well (feet)	Depth of casing (feet)	Aquifer sampled	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity: Carbonate (CO_3)	Alkalinity: Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color	Remarks
1	705-226-18	7-12-62	66	41	f	77	—	—	—	—	—	—	187	880	49	48	—	—	—	—	360	48	794	7.7	—	
2	705-226-20	7-12-62	67	46	f	77	—	—	—	—	—	—	144	292	112	85	—	—	—	—	374	184	800	7.8	—	
2N	705-226-21	7-12-62	100	38	f,S	77	—	—	—	—	—	—	141	286	94	38	—	—	—	—	324	90	728	7.8	—	
8S	705-226-22		47	31																						
8N	705-226-23	7-12-62	109	31	f,S	78	—	—	—	—	—	—	162	328	80	60	—	—	—	—	364	95	860	7.6	—	1
4S	706-226-24		125	32																						
4N	706-226 25	7 12-62	110	32	f,S	77	—	—	—	—	—	—	140	284	180	75	—	—	—	—	444	212	986	7.7	—	1
6	705-226-28	7-12-62	112	38	f,S	78	—	—	—	—	—	—	132	268	252	98	—	—	—	—	525	305	1,150	7.5	—	
7S	705-226-29		105	30																						
7N	705-226-30	7-12-62	105	29	f,S	79	—	—	—	—	—	—	100	204	630	205	—	—	—	—	940	773	1,990	7.2	—	1
9N	705-226-1		105	30																						
9S	705-226-2	7-12-62	110	30	f,S	77	—	—	—	—	—	—	91	184	1,060	170	—	—	—	—	1,330	1,180	2,370	7.7	—	1
10	705-226-3	9- 7-62	113	32	f,S	77	—	—	—	—	—	—	117	238	488	115	—	—	—	—	770	575	1,510	8.2	—	
11N	705-226-4	7-12-62	104	31																						
11S	705-226-5	7-12-62	184	34	f,S	77	—	—	—	—	—	—	118	240	446	115	—	—	—	—	730	534	1,470	7.7	—	1
12N	705-226-6		96	28																						
12S	705-226-7	7-12-62	57	29	f,S	78	—	—	—	—	—	—	126	256	230	100	—	—	—	—	510	300	1,120	7.5	—	1
18N	705-226-8		108	38																						
18S	705-226-9	7-12-62	33	30	f,S	76	—	—	—	—	—	—	132	268	350	130	—	—	—	—	690	470	1,400	7.7	—	1

14N	705-226-10		109	32																						
14S	705-226-11	7-12-62	124	32	f,S	78	—	—	—	—	—	—	129	262	330	130	—	—	—	—	650	436	1,350	7.5	—	1
15	705-226-12	7-12-62	98	34	f,S	78	—	—	—	—	—	—	158	320	220	85	—	—	—	—	525	263	1,120	7.8	—	
16	705-226-13	7-12-62	111	45	f,S	78	—	—	—	—	—	—	118	240	450	150	—	—	—	—	770	574	1,570	7.7	—	
17	705-226-14	7-12-62	114	48	f,S	76	—	—	—	—	—	—	114	232	390	130	—	—	—	—	710	520	1,440	7.6	—	
18	705-226-15	7-12-62	140	46	f,S	76	—	—	—	—	—	—	106	216	470	140	—	—	—	—	750	573	1,530	7.6	—	
21	705-226-17	7-12-62	144	84	S	77	—	—	—	—	—	—	113	230	260	92	—	—	—	—	530	342	1,120	7.8	—	
22	705-225-1	7-12-62	125	52	f,S	76	—	—	—	—	—	—	124	252	244	42	—	—	—	—	515	308	1,080	7.6	—	
23	705-225-2	7-12-62	120	104	S	77	—	—	—	—	—	—	136	276	252	72	—	—	—	—	540	314	1,100	8.0	—	
24	705-225-3	7-12-62	120	52	f,S	78	—	—	—	—	—	—	110	224	438	90	—	—	—	—	695	512	1,380	7.9	—	
25	705-225-4	7-12-62	185	120	S	78	—	—	—	—	—	—	96	194	650	150	—	—	—	—	930	771	1,810	7.6	—	2
26	705-225-5	7-12-62	118	83	S	77	—	—	—	—	—	—	106	216	520	95	—	—	—	—	750	573	1,450	7.6	—	
27	705-225-6	7-12-62	118	54	f,S	77	—	—	—	—	—	—	105	214	560	105	—	—	—	—	815	640	1,560	7.7	—	
28	705-225-7	7-12-62	60	40	f	75	—	—	—	—	—	—	173	352	3.2	43	—	—	—	—	292	8	669	7.8	—	
29	705-225-8	7-12-62	65	42	f	75	—	—	—	—	—	—	176	358	4.8	42	—	—	—	—	290	0	673	7.7	—	
30	705-225-9	7-12-62	110	42	f,S	77	—	—	—	—	—	—	100	204	600	105	—	—	—	—	875	108	1,660	7.9	—	
31	705-225-10	7-12-62	59	42	f	76	—	—	—	—	—	—	169	344	3.6	42	—	—	—	—	270	0	653	7.6	—	
32	705-225-11	7-12-62	59	42	f	75	—	—	—	—	—	—	157	318	.4	32	—	—	—	—	252	0	584	7.7	—	
Plant well 3	706-226-3	9- 7-62	458	80	F	76	24	0.10	358	135	223	7.4	92	186	1,020	500	0.6	0.2	0.01	2,610	1,450	1,300	3,210	7.4	20	
*	706-226-5	9- 6-62	414	140	F	78	.9	.00	296	143	102	6.4	7.9	16	1,140	265	1.8	.0	.02	2,290	1,330	1,310	2,450	6.5	25	
Test well 1	705-226-31	9- 7-62	20	20	W	76	11	.01	160	15	24	.8	161	326	131	53	.3	.1	.07	564	460	194	877	7.6	15	

*Well is privately owned.
1Composite sample.
2Well plugged back to 140.

probably the result of the intrusion of water from the Floridan aquifer through the water-plant wells into the second artesian aquifer. The next highest concentration of sulfate, 650 ppm, was in the sample taken from well 25. Well 25 was originally drilled to a depth of 185 feet but was later plugged back to 140 feet. The high concentration of sulfate in the sample from well 25 may result from water below 140 feet leaking upward past the plug. The sample having the lowest concentration of sulfate, 0.4 ppm, was taken from well 32, the easternmost well in the south line of wells. Well 32 taps only the first artesian aquifer.

SALT-WATER LEAKAGE FROM PROPOSED WATERWAY

The route of the proposed intracoastal waterway in the vicinity of the Venice well field is shown in figure 3. The proposed waterway parallels within a few hundred feet the west line of wells.

The waterway, when constructed, will be filled with salt water. The salt water, being heavier than fresh water, will displace the fresh water in the water-table aquifer and form a salt-water wedge whose base will rest on the upper confining beds. The salt water will leak downward into the first artesian aquifer when a downward hydraulic gradient exists across the upper confining beds. Such a gradient may be created by heavy pumping from the Venice well field.

Figure 7 shows how salt water leaking into the first artesian aquifer would contaminate the well field. If wells tapping the first artesian aquifer were pumped, the salt water in the first artesian aquifer would be drawn directly into the wells. On the other hand, if wells tapping only the second artesian aquifer were pumped, salt water in the first artesian aquifer would move downward through wells open to both aquifers into the second artesian aquifer. Or if the head in the first artesian aquifer is greater than the head in the second artesian aquifer, salt water would seep downward through the confining bed separating the two.

In order to determine the effect of constructing the waterway on the well field, estimates were made of the rate of salt-water leakage into the first artesian aquifer for various patterns and rates of pumpage. The amount of the seepage was estimated by applying Darcy's law. To make the estimate, it was necessary to know the area of the interface between the salt-water wedge and the confining beds above the first artesian aquifer, the coefficient of leakage of the upper confining beds, and the head differential between the salt-water wedge and the first artesian aquifer.

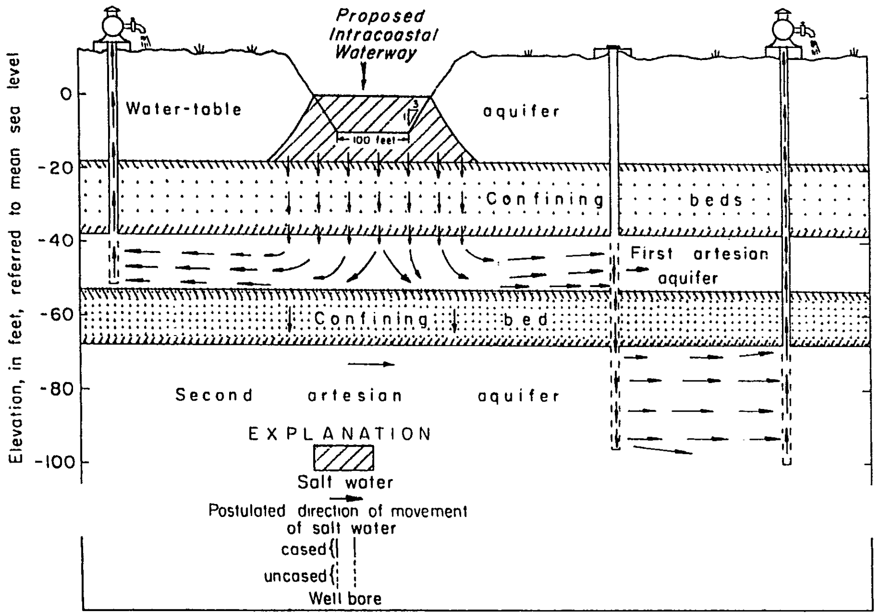


Figure 7. Generalized cross section near Venice well field at site of proposed waterway showing postulated direction of salt-water movement.

SALT-WATER WEDGE

The area of the interface between the salt-water wedge and the upper confining beds can be determined easily from the width of the base of the salt-water wedge. This width was estimated from the relationship between salt water and fresh water and from the theoretical position of the water table near the proposed waterway.

The relationship between salt water and fresh water under static conditions may be expressed as follows:

$$h = \frac{t}{g - 1}$$

where h equals the depth of fresh water, in feet below sea level; t equals the height of the water table, in feet above sea level; g equals the specific gravity of sea water, and 1 is the specific gravity of fresh water. The relationship is generally referred to as the Ghyben-Herzberg principle, after the names of the two men who first described it.

The specific gravity of ground water is, for practical purposes, 1.000, and the specific gravity of sea water is ordinarily about 1.025. If the specific gravity of sea water is 1.025, the above equation shows that $h = 40\ t$. In other words, for every foot of fresh water above sea level, there is 40 feet of fresh water below sea level.

This relationship is modified somewhat by the conditions at the Venice well field. The bottom of the water-table aquifer is about 18 feet below sea level. Assuming the stage of the waterway remains at sea level, the above relation shows that the salt-water fresh-water interface will be at the bottom of the aquifer below a point where the water table is 0.45 foot above sea level. Where the water table is below 0.45 foot above sea level, the depth to the interface may be determined by $h = 40\ t$; and where the water table is higher than 0.45 foot above sea level, the aquifer will be filled with fresh water. Thus, the distance from the edge of the waterway to the point where elevation of the water table is 0.45 foot determines the width of the base of the salt-water wedge.

The theoretical position that the water table would take if the waterway were constructed may be determined mathematically. It can be shown (Jacob, 1950, p. 378) that the following formula, based on the assumptions of Dupuit, describes the steady-state profile of the water table between two completely penetrating streams:

$$h^2 - h_0^2 = 2\ W/P\ (ax - x^2/2)$$

where h is the height of the water table above the base of the aquifer, h_0 is the height of the stream stage above the base of the aquifer, W is the rate of accretion (rainfall penetration) to the water table, P is the permeability of the material composing the aquifer, a is the distance from the stream to the ground-water divide, and x is the distance from the edge of the stream to any point h on the water table.

The distance from the waterway to the point where the water table is 0.45 foot above sea level can be estimated by use of this formula. The bottom of the water-table aquifer is about 18 feet below sea level so that $h_0 = 18$ feet; W at the waterway is estimated to average about 1 foot per year after taking into account leakage from the water-table aquifer. The permeability P of the material composing the water-table aquifer is estimated to be about 250 gpd per ft^2. And if the proposed waterway simulates one stream, and Hatchett Creek simulates the other, the distance to the ground-water divide is about 1,500 feet, assuming that the divide is midway between the two simulated streams. Based on these estimates, the water table is computed to rise to above 0.45 foot above sea level at a little less than 70 feet from the waterway. The toe of the salt-water wedge, therefore, is estimated to extend to about 70 feet from the edge of the waterway. If the toe of the salt-water wedge extends 70 feet from the edge of the waterway on both sides of the waterway, the width of the base of the salt-water wedge will be 300 feet ($70 + 70 + 160 = 300$), the sea-level width of the waterway being 160 feet.

COEFFICIENT OF LEAKAGE

Although the coefficient of leakage of the confining beds that separate the salt-water wedge, which will exist if the waterway is constructed, from the first artesian aquifer is not known, coefficients were determined at well 9S and at well 31. The coefficient as determined from the test at well 9S was 1.3×10^{-3} gpd per ft^3. Well 9S is nearer than well 31 to the proposed waterway, and the coefficient determined at this well is probably more representative of the actual coefficient of the upper confining beds at the waterway than is the coefficient at well 31. It should be remembered, however, that the pumping tests were conducted in the well field and not along the route of the waterway where the leakage would occur.

In the estimates of the amount of salt-water leakage that follow, the coefficients of leakage as determined from the pumping tests are assumed to represent the coefficient of leakage of the confining beds between the salt-water wedge and the first artesian aquifer. This is equivalent to assuming that all the leakage into the first artesian aquifer is through the upper confining beds. Such a premise, of course, assumes that the upper confining beds are more permeable than they are.

HEAD DIFFERENTIAL ACROSS CONFINING BEDS

In order to determine the head differential that will exist across the confining beds when the waterway is constructed, the head at the base of the water-table aquifer and the pumping level of the first artesian aquifer beneath the waterway must be determined.

HEAD AT BASE OF SALT-WATER WEDGE

The head at the base of the salt-water wedge was determined from the relationship between salt water and fresh water. The bottom of the water-table aquifer is about 18 feet below sea level (fig. 4). The specific gravity of sea water is about 1.025 and the specific gravity of fresh water is about 1.00. A column of sea water, therefore, 18 feet high has the same weight as a column of fresh water 18.45 feet high (18 x 1.025). Thus, the head at the base of the salt-water wedge is equivalent to that of a column of fresh water extending 0.45 foot above sea level.

PUMPING LEVEL OF PIEZOMETRIC SURFACE

The drawdown due to the pumping of water from the Venice well field was computed by the use of the coefficients of transmissibility and of leakage that were determined from the pumping tests. Before computing the drawdowns, however, the nonpumping or the design level of the piezometric surface must be determined. These drawdowns will be subtracted from the design level of the piezometric surface in order to determine the pumping level.

Design piezometric surface: The nonpumping piezometric surface, of course, fluctuates so that there is no fixed level from which the drawdowns should be subtracted. For the purposes of this analysis, the level of the piezometric surface during a period when the piezometric surface is low will be used. This level, referred to in this report as the design piezometric surface, is the average level of the nonpumping piezometric surface during a period of a few days or weeks when the surface is at its lowest.

If a record of the fluctuations of the piezometric surface were available over a sufficiently long period, the design piezometric surface could be established from the record. Unfortunately, only one set of measurements of the surface is available. The measurements were made on July 12, 1962 after the well field had been idle about 14 hours. The average elevation of the water level in two wells tapping the water-table aquifer was 7.6 feet above sea level; the average elevation in six wells tapping the first artesian aquifer was 8.1 feet above sea level; and the average elevation in three wells tapping the second artesian aquifer was 9.6 feet above sea level. The nonpumping piezometric surfaces of both the first and second artesian aquifers at the Venice well field doubtless lie above the water table most, if not all the time.

Other investigators (Jacob, 1943) have shown that in humid areas where the water levels are not affected by pumping, the water table in general fluctuates with the accumulated departures from average rainfall. A graph of the accumulated departures from average rainfall at Venice is shown in figure 8. The graph shows that at Venice the accumulated departures from average rainfall in July 1962 were about average for the period 1955-62. Accordingly, an elevation of 7.6 feet above sea level for the water table is probably about average.

The water table probably fluctuates 6 or 7 feet over a period of several years. The water table under nonpumping conditions, therefore, probably drops to as low as 4 or 5 feet above sea level and rises to as high as 10 or 12 feet above sea level. The piezometric surface of the first artesian aquifer under non-pumping conditions, being higher than the water table, probably will not drop below about 5 feet above sea level except for periods of a few days or weeks. The elevation of the design piezometric surface is, therefore, considered to be 5 feet above sea level.

Computing the drawdown: The drawdown in the vicinity of a pumping well after an infinite period of pumping may be computed from the following formula developed by Hantush and Jacob (1955):

$$s_m = (Q/2T)\ K_0\ (r/B)$$

where Q is the discharge of the well; T is the coefficient of transmissibility; K_0 is the modified Bessel function of the second kind and of zero order; r is the distance from the center of the well to any point in the field; and $B = (Tm'/P')^{1/2}$ where P'/m' is the coefficient of leakage. The drawdown at any point near a group of pumping wells is equal to the sum of the drawdowns of the individual wells at that point.

The formula assumes that the water table will not be lowered by the leakage from the water-table aquifer into the first artesian aquifer. However, the leakage will result in some lowering of the water table, especially near the pumping wells. This lowering will result in reduced leakage to the first artesian aquifer, and consequently the drawdown will be greater than that computed from the formula.

For the purpose of computing the drawdown in the vicinity of the waterway, the supply wells are assumed to draw water from both the first and the second artesian aquifers. The coefficient of transmissibility (T) was assigned a value of 5,500 gpd per ft, and the coefficient of leakage (P'/m') was assigned a value of 1.3×10^{-3}

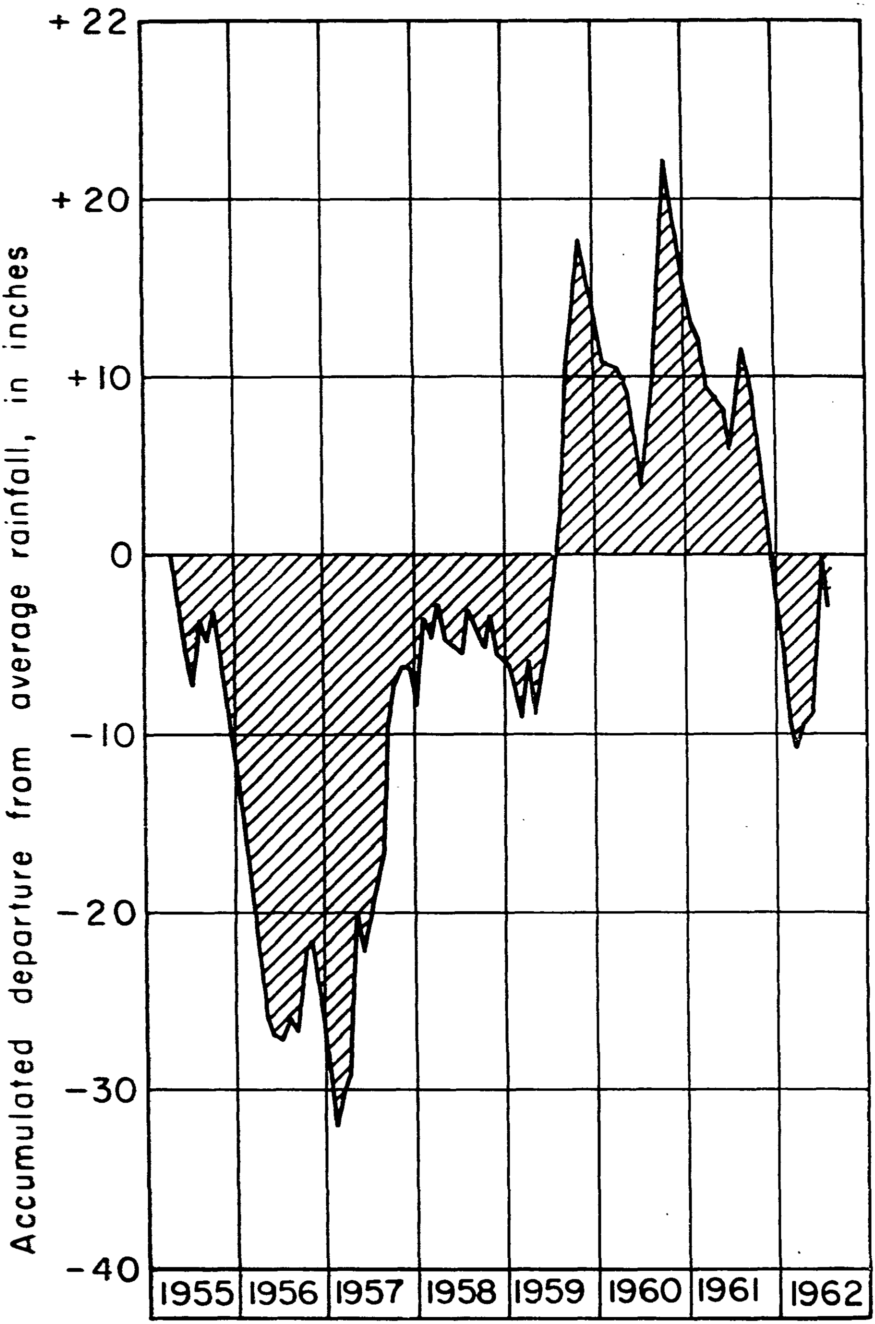
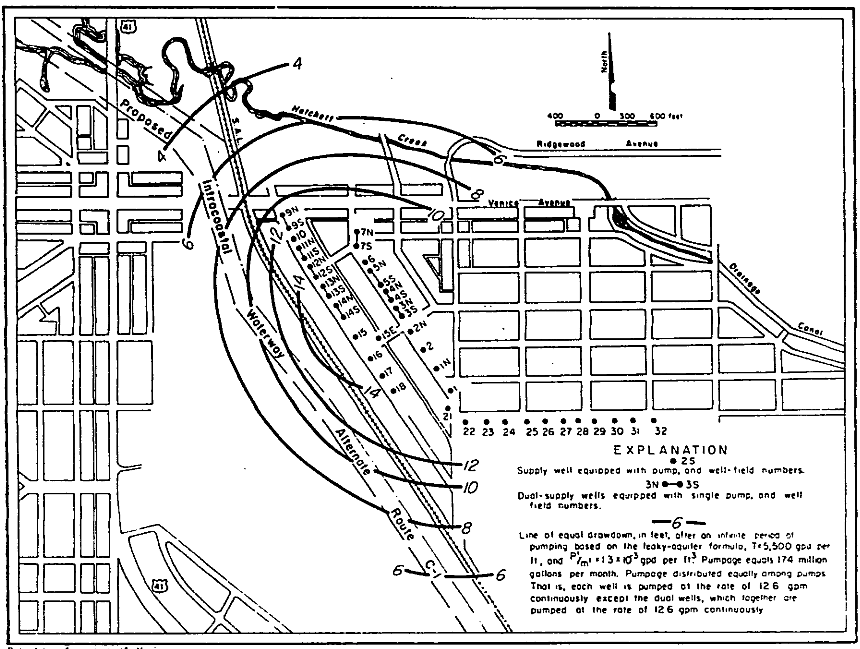


Figure 8. Accumulated departures from average rainfall at Venice, 1955-62.

gpd per ft³. Although the pumping tests indicate that the coefficients might be quite variable, the values assigned to these coefficients are probably low. If the coefficients had been assigned greater values, a smaller drawdown beneath the waterway would have been computed.

The drawdown for two patterns of pumping was computed. The pumpage in the first pattern was divided equally among the pumps on the west, east, and south lines of wells. The pumpage in the second pattern was divided equally among the pumps on the east and south lines of wells. Figure 9 shows the drawdowns resulting from the first pattern of pumping. It was assumed that the west, east, and south lines of wells had been pumped for an infinite period at the rate of 17.4 million gallons per month or 12.6 gpm (gallons per minute) per pump. This rate equals the greatest monthly pumping rate on record (fig. 3). The maximum drawdown beneath the centerline of the waterway for these conditions was computed to be slightly more than 12 feet.



Base taken from map of Venice by Maness and Brown (Surveyors) November 1955

Figure 9. Computed drawdown along proposed waterway due to pumping 17.4 million gallons per month from the west, east, and south lines of wells of the Venice well field.

Figures 10 and 11 show the computed drawdown after an infinite period of pumping for the second pattern of pumping. The drawdowns shown in figure 10 were computed on the assumption that no water was pumped from the west line of wells and that the pumping rate of 17.4 million gallons per month was divided equally among the pumps (19.2 gpm per pump) in the east and south lines of wells. The maximum computed drawdown beneath the centerline of the waterway for these conditions was slightly more than 10 feet.

The computed drawdowns shown in figure 11 were based on a pumping rate of 11.4 million gallons per month equally divided among the pumps in the east and south lines of wells. This pumping rate is the same per pump (12.6 gpm) as the pumping rate of 17.4 million gallons per month divided equally among all the pumps in the well field. The maximum drawdown beneath the centerline of the waterway for these conditions was computed to be slightly less than 7 feet.

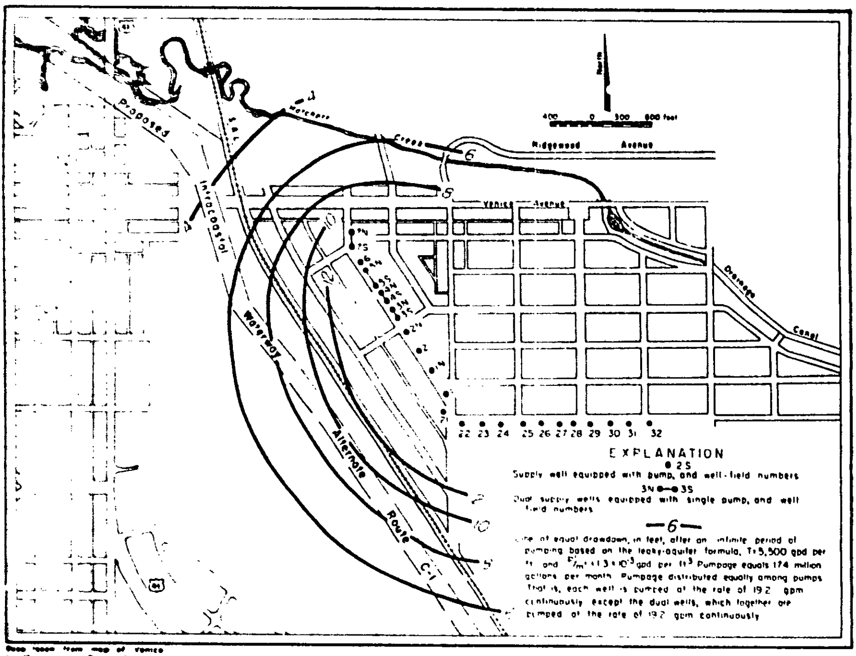
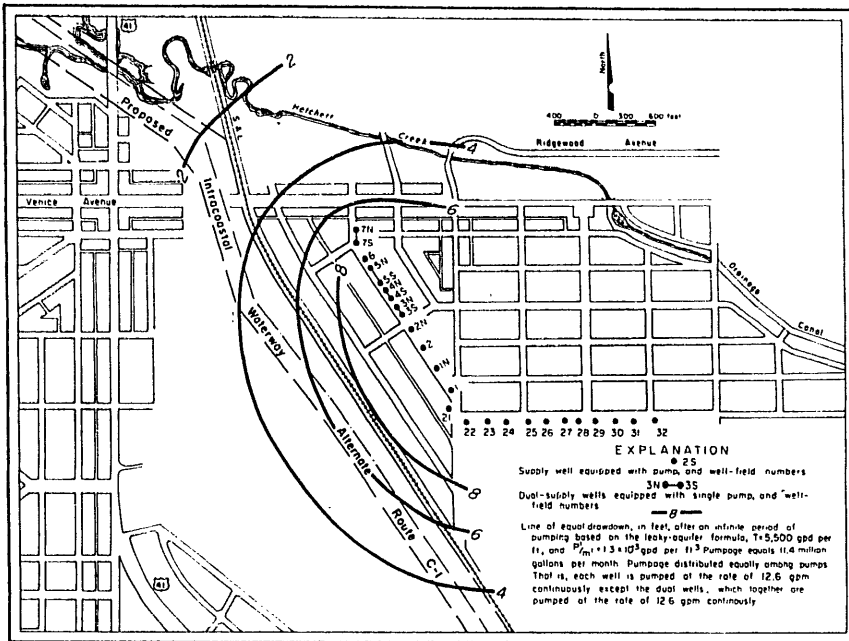


Figure 10. Computed drawdown along proposed waterway due to pumping 17.4 million gallons per month from the east and south lines of wells of the Venice well field.



Base taken from map of Venice by Maness and Brown (Surveyors) November 1955

Figure 11. Computed drawdown along proposed waterway due to pumping 11.4 million gallons per month from the east and south lines of wells of the Venice well field.

The drawdown for other pumpage rates for these patterns of pumping may be determined easily from figures 9 and 10 because the drawdown is proportional to the pumping rate.

The head differential across the confining beds is equal to the difference between the head at the base of the salt-water wedge and the pumping level of the piezometric surface of the first artesian aquifer. The head at the base of the salt-water wedge was shown to be equivalent to that of a column of ground water extending 0.45 foot above sea level. The pumping level of the piezometric surface after an infinite period of pumping may be estimated by subtracting the computed drawdown (figs. 9, 10, 11) from the design piezometric surface of 5 feet above sea level.

RATE OF SALT-WATER LEAKAGE

The rate of salt-water leakage from the waterway into the first artesian aquifer may be computed from Darcy's law:

$$Q = (P'/m') (h') A$$

where Q is the rate of salt-water leakage, P′/m′ is the coefficient of leakage of the confining beds that separate the salt-water wedge from the first artesian aquifer, h′ is the head differential across the confining beds, and A is the area of the interface between the salt-water wedge and the confining beds or the surficial area of the confining beds through which the salt water will leak.

Estimates were made of the rate of salt-water leakage and the resulting increase in the average chloride content of the pumped water. The increase will be greater than that estimated in some wells and less in others, depending on the location of the wells and the rate and pattern of pumping. Water from wells near the center of pumping and near the waterway will have the greatest increase in chlorides, and water from wells farthest from the center of pumping and the waterway will have the least increase in chlorides.

One set of estimates was based on a coefficient of leakage of 1.3 x 10^{-3} gpd per ft^3, and one set was based on a coefficient of leakage of 7 x 10^{-3} gpd per ft^3.

Based on a coefficient of leakage of 1.3 x 10^{-3} gpd per ft^3, the rate of leakage of the salt water into the first artesian aquifer was computed to be about 10,000 gpd or about 300,000 gallons per month for a pumping rate of 17.4 million gallons per month drawn from the west, east, and south lines of wells. This is the rate and the pattern of pumping that was used to compute the drawdowns shown in figure 9. Assuming that the salt water contains 20,000 ppm chloride, about average for sea water, the chloride content of the pumped water would be increased by about:

$$\frac{300{,}000 \times 20{,}000}{17{,}400{,}000} = 350 \text{ ppm}$$

If it is assumed that the west line of wells is not pumped and that the pumping rate is 17.4 million gallons per month, the chloride content of the water would have increased on the average only 240 ppm. This is the rate and pattern of pumping that was used in computing the drawdowns shown in figure 10. But, if the amount of water drawn from each pump is reduced so that the pumping rate is only 11.4 million gallons per month, the chloride content of the water would increase on the average 80 ppm. This rate and pattern pumping was used in computed the drawdowns shown in figure 11.

In order to calculate the increase in the chloride content of the water based on a coefficient of leakage of 7 x 10^{-3} gpd per ft^3, it is only necessary to multiply the estimates based on a coefficient of leakage of 1.3×10^{-3} gpd per ft^3 by the ratio $\frac{7 \times 10^{-3}}{1.3 \times 10^{-3}}$ or by 5.4. For example, for a coefficient of leakage of 7×10^{-3} gpd per ft^3 and a pumping rate of 17.4 million gallons per month drawn from the west, east, and south lines of wells, the increase in chlorides would be computed to be: 350 x 5.4 or about 1,800 ppm.

A question of interest is at what rate could the well field be pumped without causing any salt-water leakage from the waterway. This rate can be estimated easily if it is remembered that the drawdown is proportional to the rate of pumping. If equal amounts of water were taken from each of the pumps in the west, east, and south lines of wells, such as was assumed in computing the drawdowns shown in figure 9, the well field could be pumped at the rate of about 6 million gallons per month without causing any salt-water leakage. If equal amounts of water are drawn from each of the pumps on the east and south lines of wells, as was assumed in computing the drawdowns shown in figure 10, the well field could be pumped at the rate of about 7 million gallons of water per month without any salt-water leakage.

Although these estimates of the rate of salt-water leakage are the best that can be made with the available data, the estimates are intended to be used only as a guide or in indication of the effect that constructing the intracoastal waterway along route C-1 would have on the Venice well field. The results are conditional and should be treated as such.

The estimates do not include any increase in chlorides that might be caused by: (1) The downward leakage of water from Hatchett Creek. (The drawdowns shown in figures 9 and 10 are great enough to cause water in Hatchett Creek, which at times has a high chloride content, to leak downward); (2) pumping from private wells; or (3) any disturbance of or cutting into the upper confining beds.

SUMMARY

1. Ground water at the Venice well field occurs in a water-table aquifer and at least three artesian aquifers: the first artesian aquifer, the second artesian aquifer, and the Floridan aquifer. The water-table aquifer extends from the surface of the ground to about 30 feet below the surface. The first artesian aquifer lies from about 50 to 65 feet below the surface, and the second artesian aquifer lies from about 80 to 130 feet below the surface. The top of the Floridan aquifer is about 280 feet below the surface.

These aquifers are separated by material having a low vertical permeability.

2. The water supply for Venice, other than that for emergencies, is withdrawn from 42 wells that tap either the first or the second artesian aquifer or both. The water from the first artesian aquifer is generally of a better quality than that from the second artesian aquifer.

Water from the Floridan aquifer is highly mineralized but is used during emergencies.

3. At least two of the wells at the Venice water plant are open to both the second artesian aquifer and the Floridan aquifer. Water from the Floridan aquifer moves up these wells into the second artesian aquifer and contributes in part to a poorer quality of water in the second artesian aquifer.

4. A coefficient of transmissibility of 5,600 gpd per ft, a coefficient of storage of 8.7×10^{-5}, and a coefficient of leakage of 1.3×10^{-3} gpd per ft^3 were calculated from a pumping test on well 9S. The wells used in the test were open to both the first and second artesian aquifers. From a test on well 31, the coefficient of transmissibility was calculated to be 8,500 gpd per ft; the coefficient of storage, 1.3×10^{-4}; and the coefficient of leakage, 7×10^{-3} gpd per ft^3. The wells used in the test were open to the first artesian aquifer.

5. Should the proposed waterway be constructed, the salt-water will form a wedge in the water-table aquifer beneath the waterway. If the Venice well field is pumped intensively, salt water will seep from the waterway into the first artesian aquifer and then into the well field.

The estimates of the increase in the chloride content of the pumped water under certain conditions range from 80 to 1,800 ppm.

CONCLUSIONS

1. Wells at the Venice well field, which are cased only through the first artesian aquifer but which tap the Floridan aquifer, allow water of an inferior quality from the Floridan aquifer to contaminate the second artesian aquifer. This contamination can be prevented by extending the casing through the second artesian aquifer.

2. Grouting or otherwise treating the section of the waterway along the well field so as to make the formations less permeable

may be an effective method of reducing the amount of salt-water leakage from the waterway.

3. The effect of the construction of the waterway on ground water may be monitored by determining the chloride content of water in and measuring the water levels in wells near the waterway. An increase in the chloride content of water in the first artesian aquifer at the waterway will constitute a warning that salt-water is leaking downward. The danger of salt-water leakage will increase if the size of the salt-water wedge beneath the waterway increases. The extent of the salt-water wedge should be monitored carefully.

The amount of salt-water leakage may be controlled by reducing the rate of pumping from the field or by redistributing the pumping so that it is farther from the waterway.

4. A low-level dam near the mouth of the Hatchett Creek would act as a salt-water barrier to prevent salt water from moving up the creek. The pumping of wells located along Hatchett Creek upstream from this dam would induce fresh water from the creek into the aquifers.

REFERENCES

Cooper, H. H., Jr.

1963 Type curves for non-steady radial flow in an infinite leaky aquifer: U. S. Geol. Survey Water-Supply Paper 1545-C.

Hantush, M. S.

1955 (and Jacob, C. E.) Non-steady radial flow in an infinite leaky aquifer: Am. Geophys. Union Trans., v. 37, no. 6, p. 702-714.

Jacob, C. E. (also see Hantush, M.S.)

1943 Correlation of ground-water levels and precipitation on Long Island, New York: Am. Geophys. Union Trans., Pt. 1, Theory, p. 564-573.

1950 Flow of ground water in engineering hydraulics (H. Rouse, ed.): New York, N.Y., John Wiley and Sons, p. 321-386.

Stringfield, V. T.

1933a Ground-water resources of Sarasota County, Florida: Florida Geol. Survey 23d - 24th Ann. Rept., p. 121-194.

1933b Exploration of artesian wells in Sarasota County, Florida: Florida Geol. Survey 23d-24th Ann. Rept., p. 195-227.