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WATER SURVEY & RESEARCH PAPER NO. 9

15 MAY 1953

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STATE OF FLORIDA

State Board of Conservation

DIVISION OF WATER SURVEY & RESEARCH

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SALT WATER INTRUSION IN FLORIDA–1953

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DIVISION OF WATER SURVEY & RESEARCH
OFFICE OF THE CHIEF ENGINEER
ROOM 64 CALDWELL BUILDING
TALLAHASSEE, FLORIDA

15 May 1953

The State Board of Conservation
State of Florida
The Capitol
Tallahassee, Florida

Gentlemen:

I have the privilege to transmit herewith as Water Survey and Research Paper Number 9, a report entitled: "Salt Water Intrusion in Florida, 1953." This report contains the results of a comprehensive survey involving the encroachment of salt water into the ground water supplies of areas adjacent to the coast line of Florida.

Surveys of local areas concerned about the intrusion of salt water have been made previously but the results obtained were necessarily limited in scope.

The growth of municipalities, the expanding industrial development, and the more extensive use of water for irrigation in recent years have caused acute salt water intrusion in certain localities.

In order to provide a yardstick for measuring future encroachment it was deemed advisable to conduct a state-wide survey. Consequently, the services of Doctor A. P. Black, Ph.D., Head Professor, Department of Chemistry, University of Florida were enlisted; he, with his colleagues in that Department, Doctor Eugene Brown, Ph.D., and Mr. J. M. Pearce, M.S., determined upon the methods of making the survey, gathered the available information from many cooperators and sources, summarized and arranged the information so gathered and submitted the results of their labors to this office for editing and publication.

The work contributed by Doctor Black and his associates in the preparation of this report has been outstanding and worthy of commendation by your Board. The information contained herein will prove of considerable value in the future development of this State.

Respectfully submitted,

A. G. Matthews
Chief Engineer

AGM:oh

Preface

A state-wide survey of salt water intrusion in Florida has been undertaken for the Division of Water Survey and Research of the State Board of Conservation, Tallahassee, under the general direction of Colonel A. G. Matthews, Chief Engineer of this Division. Laboratory and field work was performed by Eugene Brown and J. M. Pearce, Research Assistants, under the direction of Dr. A. P. Black, Head of the Department of Chemistry, University of Florida.

This report includes a brief detailed discussion of certain selected areas, and contains a summary of the findings. A composite record of analyses supplemented by much additional data obtained from several cooperators and numerous other sources was published as Water Survey and Research Paper No. 6, "Chemical Character of Florida's Waters – 1951."

Preliminary work of organization was done during December 1947 and January 1948. Actual analyses were continuously made during the period February 1948 to December 1948, inclusive, and in critical areas periodic checks have been made up to the date of publication of this paper.

Arrangements were made, by letter and personal visits, for cooperators from representative private and municipal water supplies along the coast of Florida, both the Atlantic Ocean and the Gulf of Mexico, to mail samples of water to Gainesville for analysis by the Water Research Project of the University of Florida. A system was evolved whereby mailable cartons, each containing an 8-ounce bottle, were forwarded in sufficient number for return shipment of a sample from each well of the cooperator. Reports of these analyses were furnished each of the cooperators during the period of the survey.

In addition, the District Engineer, Corps of Engineers, U. S. Army, at Jacksonville supervised the collection of samples during each month from over 60 wells, (flowing or being pumped in Central Florida). The District Engineer also transmitted a monthly record of water level readings in all test wells in Central Florida. The District Engineer for the Northern District of Florida, Ground Water Division, U.S.G.S. at Tallahassee submitted some water samples from each of 110 U.S.G.S. wells in North and West Florida for analysis.

The District Engineer for the Southern District of Florida, Ground Water Division, U.S.G.S. at Miami transmitted records of the chloride content of many wells under his supervision in South Florida. Arrangements were made with the Director of Laboratories of the Florida State Board of Health whereby a sample of water from each well, as received in the respective laboratories at Jacksonville, Tallahassee, Orlando, Tampa, Miami and St. Petersburg during a period of one month, was analyzed for alkalinity and chloride content by local personnel.

As an aid in determining what areas are affected by salt water intrusion, 6796 samples from 2914 wells were examined for chloride content. These records are too voluminous for inclusion in this report and are kept on file for future reference. Additional chemical analyses of ground water may be found in publications referred to by Bibliography numbers 3,4,12,14,17,20,22,29,32,39,40,41,42,43,44 and 67.

For detailed discussions of the geology and hydrology of Florida, readers are referred to the Bibliography numbers 18,31,32,35 and 45. Stratigraphic studies of wells may be found in publications referred to by Bibliography numbers 18,28, 29,33,34,35,46,47,50,51,53,54 and 55.

Acknowledgments

The Director and his assistants gratefully acknowledge the full cooperation of Colonel A. G. Matthews, Chief Engineer, Division of Water Survey and Research, who initiated, sponsored and provided the funds to make this study possible.

Dr. Herman Gunter, Director of the Florida Geological Survey and his Associate Geologist, Dr. R. O. Vernon, were especially helpful in furnishing much useful advice and literature. To Col. Willis E. Teale, former U.S. District Engineer at Jacksonville, his Executive Officer, Mr. J. R. Peyton, his Maintenance Engineer at Camp Roosevelt, Mr. H. F. Sharp, we are indebted for cooperation in authorizing the assistance of Mr. A. D. Brown and Mr. A. W. Brown in collecting many samples at Mayport and throughout Central Florida.

The assistance and cooperation of members of the U. S. Geological Survey is especially acknowledged. Mr. H. H. Cooper, Jr., District Engineer, Ground Water Division at Tallahassee, provided maps and advice, and his assistant, Mr. Carl Essig collected many samples throughout Northern Florida. Mr. Gerald G. Parker, former U. S. District Engineer, U.S.G.S. Ground Water Division, Miami, was most generous by advice during conference, by permitting the use of data compiled by his office and by the use of his extensive publications. Mr. Nevin D. Hoy, U. S. District Engineer, U.S.G.S., Miami, furnished maps, diagrams, and kindly reviewed the manuscript concerning the Atlantic Coast of South Florida.

To the Florida State Board of Health and especially to Dr. A. V. Hardy, Director of Laboratories, is due our appreciation in arranging for the analysis of water samples.

Mr. T. W. Young, Associate Horticulturist, Agricultural Experiment Station, Lake Alfred, furnished much valuable data regarding wells along the Florida East Coast.

The Water Research Project is especially grateful to Black Laboratories, Inc., Gainesville, not only in renting space during a critical period while the Chemistry Building at the University of Florida was in process of construction, but also in making available their library and other facilities, and in addition, furnishing many valuable records from their files.

The Water Research Project gratefully acknowledges the aid of the following by furnishing data and/or analyzing samples of water:

Mr. H. L. Berkstresser, Panama City, Superintendent of Water & Sewers

Mr. W. D. Collins, Panama City, Chemist

Mr. S. K. Keller, Clearwater, Pinellas County Water System

Mr. John S. Long, Tampa, Superintendent

Mr. A. B. Michaels, Deerfield Groves, Merritt Island

Mr. E. F. Sisson, Pensacola, Newport Industries

The cooperation of the persons or parties listed below in collecting and shipping samples is gratefully acknowledged:

Boca Raton – Mr. J. C. Mitchell, Mayor; Mr. W. R. Prendergast, Water Superintendent
Boynton – Mr. John Raulerson, Jr., Water Superintendent
Branford – Mr. F. J. Dorsett, Water Superintendent
Brooksville (Weekiwachee Springs) – Mr. Newton A. Perry, P. O., Box 82
Clearwater – Mr. F. C. Middleton, City Manager
Cocoa – Mr. Claude H. Dyal, City Clerk
Crackertown – Mr. M. M. McCall
Crystal River – Mr. Ray Thompson, Mayor
Dania – Mr. Luther Sparkman, City Manager
Daytona Beach – Manager, Riviera Hotel
Deerfield – Mr. R. R. Richardson, Water Superintendent
Delray Beach – Mr. Harry Purdom, Gulf Stream Golf Course
Dunedin – Colonel C. E. O'Connor, City Manager
Eau Gallie – Mr. Charles M. Coleman, Water Superintendent
Fort Myers – Mr. Lamar Bomar, Water Superintendent
Hobe Sound – Mr. J. A. King, Water Superintendent
Hollywood – Mr. Robert F. Armstrong, Water Superintendent
Homosassa – Mr. Elmo Reed, Homosassa River Corporation
Homosassa Springs – Mr. Oscar T. Johnson, Homosassa Springs Hotel
Inglis – Florida Power Corporation
Jacksonville Beach – Mr. Walter Bartholomew and Mr. H. J. MacCotter, past and present City Managers
Jupiter – Mr. Prentice Yervy and Mr. Charles U. Gardner, Officer in Charge, Jupiter Light Station
Lake Worth – Mr. J. W. Brock, Water Superintendent
Lantana – Mr. Harry Rogers, Water Superintendent
Largo – Mr. D. H. Morris, Water Superintendent
Mayo – Mr. D. C. Geiger, City Clerk
Mayport – Mr. A. H. Brown, U. S. Engineer's Office, Jacksonville
Melbourne – Mr. R. B. Meserve and Mr. G. P. McPherson, past and present City Managers
New Port Richey – Mr. Fred K. Marchman, Chairman, City Council
Naples – Mr. Burless Stallons and Mr. W. F. Savidge, past and present Water Superintendents
New Smyrna Beach – Mr. Hardy C. Croom, Water Superintendent
Panama City – International Paper Company, Mr. B. F. Leto, Chief Chemist
Perry – Mr. R. E. Stokes, Jr., Water Superintendent
Pinellas Park – Mr. Harry N. Taylor, Director of Works
Pompano – Mr. W. E. Smith, Water Superintendent
Riviera Beach – Mr. Rex Kanoth, Fire Chief
Sarasota – Mr. E. T. Carlson, Water Superintendent
Sebastian – Mr. R. B. Letchworth, P. O. Box 52
Stuart – Mr. L. B. Eurit, City Manager; Mr. Fred J. Walton, Water Superintendent
Stuart, Stuart Ice Plant – Mr. R. J. West, President
Tampa Coca-Cola Bottling Company – Mr. F. J. Kelsey
Tampa Florida Brewery – Mr. Karl Schweiberger
Walgreen Drug Company, Tampa – Mr. Lounsberry
Citizens' Bank Building, Tampa – Mr. George Pendley, Chief Engineer

Sears Roebuck & Company, Tampa — Mr. C. B. Yent, Operating Superintendent
Florida Ice Company, Tampa — 3400 Nebraska
City Laundry and Cleaners, Tampa — E. Osborne & 19th Street
Seminole Ice Company, Tampa — Louisiana Avenue & Tampa Northern Railroad
Tarpon Springs — Mr. Joe McCreary, and Mr. W. T. McGurn, past and present City Managers
Titusville — Mr. E. I. Kreps, Water Superintendent
Venice — Mr. W. B. Surls, Water Superintendent
Vero Beach — Mr. W. B. Crosley, Chief Engineer, City Power Plant
Wabasso, Deerfield Groves — Mr. A. B. Michael
Wabasso — Mr. George Lier, Texaco Service Station, P. O. Box 223
West Palm Beach, Seminole Golf Club — Mr. T. C. Watson
Yankeetown — Mr. Tom Knotts

It is evident that many persons have contributed their time and effort in all possible ways toward the completion of this project. The many authors listed in the Bibliography have, through their writings, provided valuable reference material from which much of this paper was drawn. To all of these and to many others too numerous to mention here, we gratefully acknowledge and express our appreciation.

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CHAPTER 1

The Extent of Salt Water Intrusion

A. Definition and Statement of Problem

The problem of salt water intrusion is not peculiar to the State of Florida, but is one which may be found in many coastal areas where large volumes of water must be withdrawn from permeable formations in contact with sea water. The general relations between fresh water and salt water along sea coasts were first determined through the work of European investigators,[27] whose conclusions have since been applied in many coastal areas throughout the world. Although the possibility of salt water intrusion has always existed in the coastal areas of Florida, it has become of utmost importance in certain of these areas only within the past 25 years. This increase in both degree and extent of salt water intrusion has been due directly to the growth of the state during this period. Greatly expanded industrial development, rapid growth of municipalities, and more extensive irrigation practices have all contributed toward an ever-increasing demand upon our fresh-water reserves.

These activities along our coastal areas have resulted in acute salt water intrusion in some localities (see Table 3 and Figure 1), and have increased the probability of salt water intrusion in others. In many areas it has been necessary to abandon salted wells and develop new supplies (see Table 1 below).

TABLE 1

SALT WATER INTRUSION INTO MUNICIPAL WATER SUPPLIES

Date	Location	Problem	Remedy
1924	Tampa	Salt infiltration in wells	New plant on Hillsborough River
1925	Miami	Salt infiltration in first well field one and one-half miles from Biscayne Bay	New well field
1930	St. Petersburg	Salt infiltration in wells	New plant and wells at Cosme NW Hillsborough County
1930	Tarpon Springs	Salting of Lake Tarpon well	New wells (see below)
1937	Daytona Beach	Salting of two wells (No. 1 & No. 10)	Wells plugged
1939	Miami	Salt ten miles up Miami Canal and past Miami well field six and one-half miles from Biscayne Bay	Tidal gate control in canal
1941	Miami (Coconut Grove)	Salt infiltration in wells	Abandoned plant, wells, and infiltration gallery
1940	Fort Myers	Salt infiltration in wells	New well field
1942	Port Orange	Salt infiltration in wells	New wells
1943	Vero Beach	Salt in two wells 660' deep	Five shallow wells 60' deep Five additional wells, 1952
1945	Fort Lauderdale	Salt infiltration from canal that threatened municipal well field	Additional wells
1948	Daytona	Salt infiltration in two municipal well fields	New well field
1948	New Port Richey	Salt infiltration in well	New well and decreased pumpage from old well
1948	Tarpon Springs	Salt infiltration in wells	New wells
1948	Stuart	Salt infiltration in wells	Two ball park wells (1950)
1949	Pinellas Park	Salt infiltration in wells	Supply abandoned for tie-in to St. Petersburg supply
1949	Pinellas County Water System	Salt infiltration in two wells near Walsingham	Emergency use only
1952	Clearwater	Salt infiltration in wells	Six wells abandoned; new wells

As the danger of salt water intrusion in Florida became evident, special investigations jointly sponsored by the Geological Survey, United States Department of the Interior, and the Florida State Geological Survey were begun in several local areas about 1930.[1 to 11] The most exhaustive investigation ever undertaken anywhere in the United States was begun in southeastern Florida, because of the appearance of salt water from the sea in the Miami well field during 1939. This latter investigation includes intensive studies of the conditions for salt water encroachment in the Miami areas.[12 to 22,62,63]

No statewide survey has previously been made to establish the widespread danger of salt water intrusion. It is the purpose of this report to summarize information from many sources in regard to salt water intrusion in Florida and provide a basis for measuring future encroachment.

B. Quantitative Evaluation of the Extent of Salt Water Intrusion

While the composition of sea water varies slightly due to dilution at the mouths of surface streams and submarine springs, an average composition of sea water by Dittmar is accepted as a criterion.[4]

TABLE 2

AVERAGE COMPOSITION OF SEA WATER

Constituent	Parts Per Million
Calcium	419
Magnesium	1304
Sodium	10707
Potassium	387
Bicarbonate	150
Sulphate	2693
Chloride	19352
Total dissolved solids	35012

Various investigators[4,23,24,50] have devoted considerable study to criteria for detecting intrusion of sea water into fresh water. Some of these criteria are:

(1) magnesium/calcium ratio equals three.
(2) chloride/sulphate ratio equals seven.
(3) increase in chloride content.
(4) resistivity.

The ratios (1) and (2) are invalid because of several exchange processes. Changes in the composition of simple well water—sea water mixtures are not comparable to modification of sea water in the ground or through marine and estuarine sediments because of:[23]

(1) cation or base exchange.
(2) anion change or sulphate reduction.
(3) solution of gypsum or anhydrite, and subsequent precipitation of calcium carbonate at high pH values.
(4) precipitation from normal sea water saturated with calcium carbonate after sulphate reduction, especially if bicarbonate is converted to carbonate by high pH conditions.

$$3\ Na_2SO_4 + C_6H_{12}O_6 \xrightarrow{\text{Anaerobic bacteria}} 3\ H_2S + NaHCO_3$$

TABLE NO. 3

HARDNESS AND CHLORIDE CONTENT OF THE LARGER PUBLIC WATER SUPPLIES IN FLORIDA

Location	Population[a]	Source of Supply	Treatment Employed[b]	Untreated Hardness	Untreated Chloride
Apalachicola	3,197	Wells	None	400	98
Apopka	2,248	Wells	None	140	12
Arcadia	4,770	River	Coagulation	48	34
Auburndale	3,769	Wells	None	94	10
Avon Park	4,369	Wells	None	75	5
Bartow	8,675	Wells	Lime softening	242	9
Belle Glade	6,889	Lake	Softening & Coagulation	130	87
Blountstown	2,110	Wells	None	146	28
Bonifay	2,254	Wells	None	136	7
Bradenton	13,609	Lake	Coagulation	103	8
Boynton Beach	2,534	Wells	None	94	21
Carrabelle	2,357(c)	Wells	None	194	15
Chattahoochee	8,466	Wells	None	118	5
Chipley	2,940	Wells	None	104	3
Clearwater	15,535	Wells	None	180	16–287
Clermont	2,143	Wells	None	110	14
Clewiston	2,485	Lake	Coagulation	82	36
Cocoa	3,538	Lake	Coagulation	75	152
Crestview	4,873	Wells	None	108	2
Dade City	3,792	Wells	None	120	7
Dania	4,531	Wells	None	278	32
Daytona Beach	29,254	Wells	Lime-soda softening	345	65–215
Deerfield Beach	2,113	Wells	None	140	13
De Funiak Springs	3,039	Wells	None	70	4
Deland	8,536	Wells	pH correction	138	12
Delray Beach	6,264	Wells	None	181	26
Dunedin	3,162	Wells	None	165	26–81
Eustis	4,011	Wells	None	84	8
Fernandina	4,388	Wells	None	350	33
Ft. Lauderdale	36,000	Wells	Lime softening	239	21
Ft. Meade	2,801	Wells	None	175	13
Ft. Myers	13,145	Wells	Lime-soda softening	304	38
Ft. Pierce	13,418	Wells	Softening	300	55
Ft. Pierce		Surface	Coagulation	60	55
Frostproof	2,238	Wells	None	153	16
Gainesville	26,577	Wells	Lime-soda softening, fluoridation	224	10
Green Cove Springs	3,283	Wells	None	145	9
Haines City	5,620	Wells	None	146	16
High Springs	2,074	Wells	Lime softening	203	8
Holly Hill	3,186	Wells	Lime-soda softening	320	65
Hollywood	14,135	Wells	Zeolite softening	268	48
Homestead	4,554	Wells	None	184	11
Jacksonville	198,880	Wells	None	274	20
Jacksonville Beach	6,242	Wells	Zeolite softening	321	15
Jasper	2,325	Wells	None	348	10
Key West	21,724	Wells	Lime softening	191	13
Lakeland	30,846	Wells	None	209	11
Lake Wales	6,802	Wells	None	136	8
Lake Worth	11,714	Wells	Lime softening	190	23
Leesburg	7,365	Wells	None	142	14
Live Oak	4,048	Wells	Lime softening[d]	250	10
Madison	3,150	Wells	None	144	5
Marianna	5,830	Wells	None	123	27
Melbourne	4,188	Wells	Lime softening	348	69
Miami	247,262	Wells	Lime softening	247	48
Milton	2,028	Wells	None	4.0	4
Monticello	2,263	Wells	None	146	6
Mulberry	2,016	Wells	None	149	10
Mt. Dora	3,039	Wells	Fluoridation	116	8
New Smyrna Beach	5,749	Wells	Zeolite softening	339	66
North Miami	10,721	Wells	Lime softening	241	20
Ocala	11,588	Wells	Lime-soda softening	303	18
Orlando	51,826	Wells	Coagulation	50	20
Ormond Beach	3,340	Wells	Lime-soda softening	342	187
Pahokee	4,476	Lakes	Coagulation	127	40
Palatka	9,172	Spring	Coagulation	24	10
Palmetto	4,099	Wells	None	916	50
Panama City	25,743				
Millville Wells		Wells	Lime softening	114	12
St. Andrews Wells		Wells	None	209	15–101
Pensacola	43,263	Wells	pH correction	12	9
Perry	2,787	Wells	Iron removal	242	6
Pinellas County Water System	15,000	Impounded reservoir	Coagulation	17	16–50
Plant City	9,208	Wells	None	184	15
Pompano	5,708	Wells	None	140	22
Port St. Joe	2,747	Wells	None	136	15
Quincy	6,586	Creek	Coagulation	14	15
Raiford State Prison	2,100	Wells	None	146	12
Riviera Beach	4,027	Wells	None	142	29
St. Augustine	13,418	Wells	Softening and coagulation	312	47
St. Cloud	2,088	Wells	None	162	10
St. Petersburg	95,612	Wells	Lime softening	181	10
Sanford	11,742	Wells	Fluoridation	142	54
Sarasota	18,705	Wells	Zeolite softening	1100	157
Sebring	4,092	Wells	None	70	5
Starke	2,901	Wells	None	166	13
Stuart	2,892	Wells	Iron removal	338	39–147
Tallahassee	27,158	Wells	None	142	4
Tampa	124,073	River	Coagulation and/or softening	144	14
Tampa Purity Springs	14,000	Springs	None	120	15
Tarpon Springs	4,309	Wells	None	233	63–178
Titusville	2,590	Wells	None	170	23
Vero Beach	4,750	Wells	Lime-soda softening	282	35
Wauchula	2,846	Wells	None	280	10
West Palm Beach	43,052	Lake	Coagulation	77	34
Wildwood	2,013	Wells	None	200	12
Winter Garden	3,501	Wells	None	112	10
Winter Haven	8,263	Wells	None	115	10
Winter Park	8,219	Wells	None	137	12

(a) 1950 Census Figures, compiled by the Florida State Chamber of Commerce.
(b) Other than aeration and/or chlorination.
(c) 1945 Census
(d) Plant not operating.

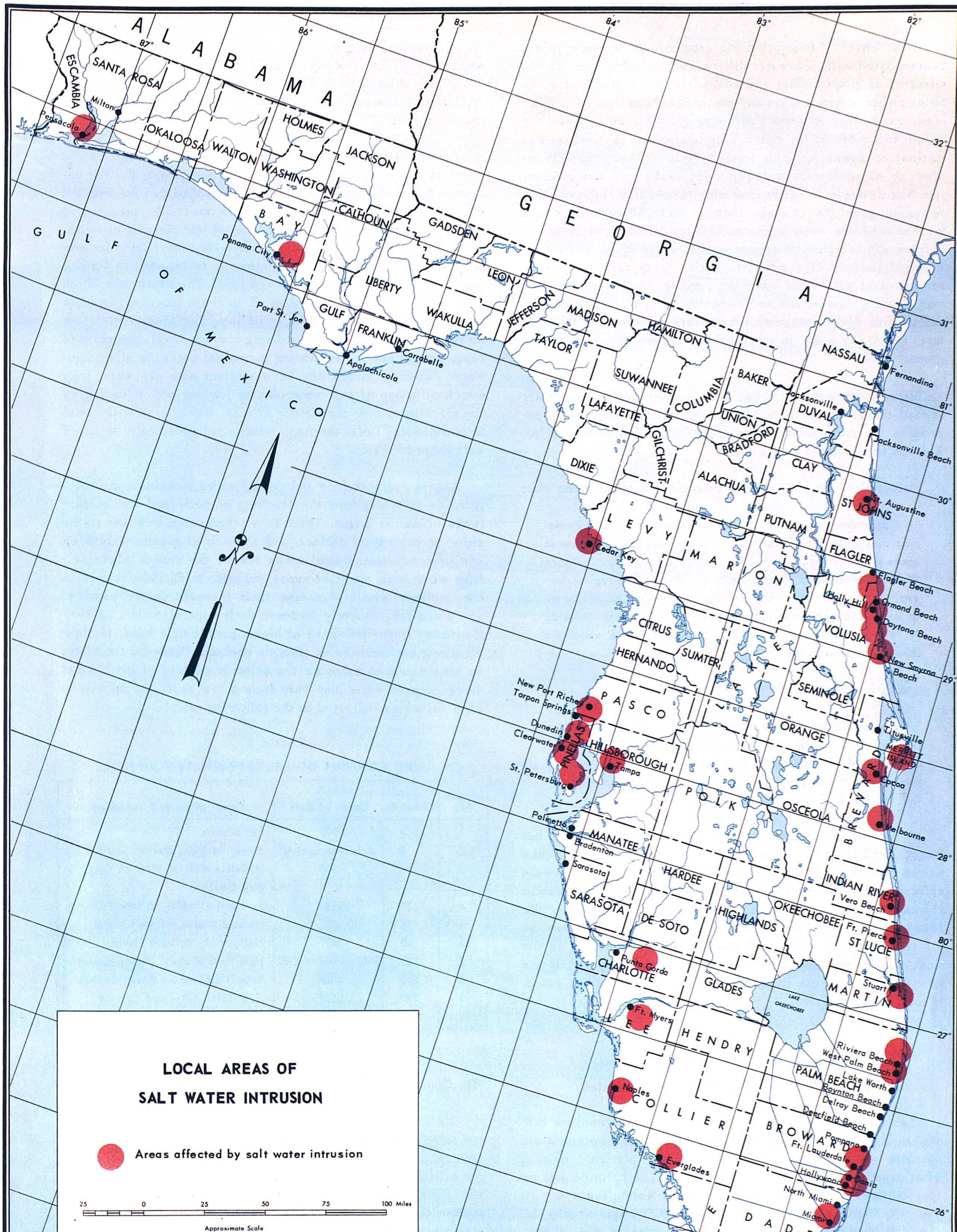

LOCAL AREAS OF
SALT WATER INTRUSION
Areas affected by salt water intrusion
Approximate Scale
Division of Water Survey and Research
1 MAY 1953
ALABAMA
GEORGIA
GULF OF MEXICO

FIGURE 1

S. K. Love[24] found that the composition of ground water contaminated with sea water differed considerably from simple mixtures of ground water and sea water in the Miami area, by being richer in calcium ion and poorer in magnesium and sodium ions, a condition different from those indicated by Revelle.[23] Within two miles of the coast, clay (uncommon in Tamiami formation) or organic colloids from the ground saturated with respect to magnesium ion and sodium ion, exchanged with calcium ion. Magnesium and sodium ions were removed by flushing. New intrusion gave the reverse, that is during drought landward movement of sea water appeared to bring about an exchange of calcium ion adsorbed on clay or organic colloids for magnesium and sodium ions of sea water. During rainy periods seaward movement of salt water gave the reverse. No anion exchange was found as the actual and computed values of chloride ion, sulfate ion, and bicarbonate ion in fresh water—sea water mixtures were the same in comparable samples of contaminated ground water.

Matson and Sanford[25] had noted earlier that in some salty ground waters of southern Florida the calcium ion was in excess of the magnesium ion, whereas in sea water magnesium ion was in excess of calcium ion.

Stringfield[4] in 1933 made the significant observation that:

"It is noteworthy that all the wells in the Florida Peninsula that yield water relatively high in chloride content are in areas near the coast except for limited areas as for instance Sanford and vicinity (See Bulletin 11, Florida Geological Survey, p. 25, 1933) and a few deep wells drilled in search of oil or water, and that the artesian head in the area of high chloride is less than the head in the areas farther inland where the chloride content is low."

Stringfield continues:

"Tests should be made periodically of the chloride content of the water from certain wells, and at the same time observations should be made on the head in these wells to detect any possible future increase in chloride with further lowering of the head."

A number of investigators have used other criteria. but Roger Revelle[23] of Scripps Institute of Oceanography has shown that of all the major ions occurring in sea water only chloride ion is unaffected by exchange processes. Increase in chloride ion is, therefore, the most reliable indicator of the first stages of salt water intrusion into ground water. Since, of all criteria which have been studied, the chloride ion is the most reliable and may be determined simply and rapidly, it has been selected for use in this research to determine the extent of salt water intrusion.

C. Distinction Between Connate Salt Waters, Residual Salt Waters and Salt Water Intrusion

The chief distinction between connate and residual salt waters is primarily time of deposition and saline concentration. Connate water is the concentrated saline solution remaining after deposition took place in early seas. The chloride content may be several times the salinity of sea water. For example, the 1930 Sholtz well at Cedar Keys had 69,550 ppm of chloride, the 1940 Hilliard well had 60,200 ppm of chloride at 4500 feet, and the 1939 Cory well had 24,700 ppm of chloride at 9772 feet.

Residual salt waters may be considered to be those waters containing the residuals left within younger formations in drowned valleys by the more recent seas. Since these younger formations have been partly flushed by ground water, the salinity of residual salt waters is less than that of connate salt waters. Examples of residual salt waters are Little Salt Springs (1430 ppm chloride) and Warm Salt Springs (9350 ppm chloride) of Sarasota County, and Salt Springs (2800 ppm chloride) of Marion County.

For the purposes of this study, salt water intrusion is defined as a present-day encroachment of sea water into the unconfined ground water along coastal areas, and/or into confined aquifers in contact with sea water in which the piezometric head has been lowered below sea level by the pumping of wells. Unconfined ground water has a water table that roughly follows the local topography in coastal areas or is exposed in surface basins of low head above mean sea level. The depth from which salt water was originally flushed in these aquifers depends upon the permeability, compressibility, and elasticity of the strata, the hydraulic gradient during low sea level, and elapsed time. Unconfined ground waters in coastal areas, or along tidewater canals or rivers may be in contact with sea water from which diffusion of salt water due to loading and unloading by the tides cannot be prevented. At other times large withdrawal from wells may lower the fresh water head sufficiently to speed salt water intrusion.

Almost every surface and ground water contains some chloride ion resulting from the leaching of soils and sedimentary rocks of marine origin. There is a progressive increase in the chloride content of surface and unconfined ground waters as one proceeds from inland areas toward the coasts where salt from windblown spray becomes evident. In Florida, waters in the confined aquifers receive their recharge in the highland areas and progressively increase their mineralization, as they flow away from such areas of higher piezometric head, to show a consequent increase in chloride content. There is, therefore, no single normal value for the chloride content of fresh water since potable water may vary from a few parts per million to such values as indicated in the following table:

TABLE 4

CHLORIDE CONTENT OF SELECTED WATER SUPPLIES

Sample No.	ppm Chloride	Depth of Well	Description and Location
1	7	200'	Pensacola
2	8	Artesian spring	Silver Springs, Marion County
3	12	80'	Millville Well at Panama City, Bay County
4	15	1015'	Jacksonville No. 11, Duval County
5	38	80–90'	Hialeah Wells, City of Miami
6	80	247'	Holly Hill, Volusia County
7	160	200' cased to 120'	New Port Richey, Pasco County
8	280	480'	Sebastian, Indian River County
9	590	650'	Eau Gallie, Brevard County
10	640	Artesian spring	Silver Glen Spring, Marion County

D. Chart Showing Principal Constituents of Selected Waters

The chemical characteristics of waters may be graphically compared by converting the analysis of the principal constituents in parts per million (milligrams per liter) to equivalents per million (milligram equivalents or milli-equivalents per liter) and plotting the metallic (cation) constituents on the upper column of a bar graph while the non-metallic (anion) constituents are plotted on the lower column. Figure 2 shows the sodium content (yellow) and chloride content (green) of selected waters in comparison with the other principal constituents. Sulphur Springs and Quincy No. 2 represent residual salt water from old saline deposits. Tarpon Springs No. 3 and Daytona-Seabreeze plant represent sea water intrusion into an unconfined aquifer.

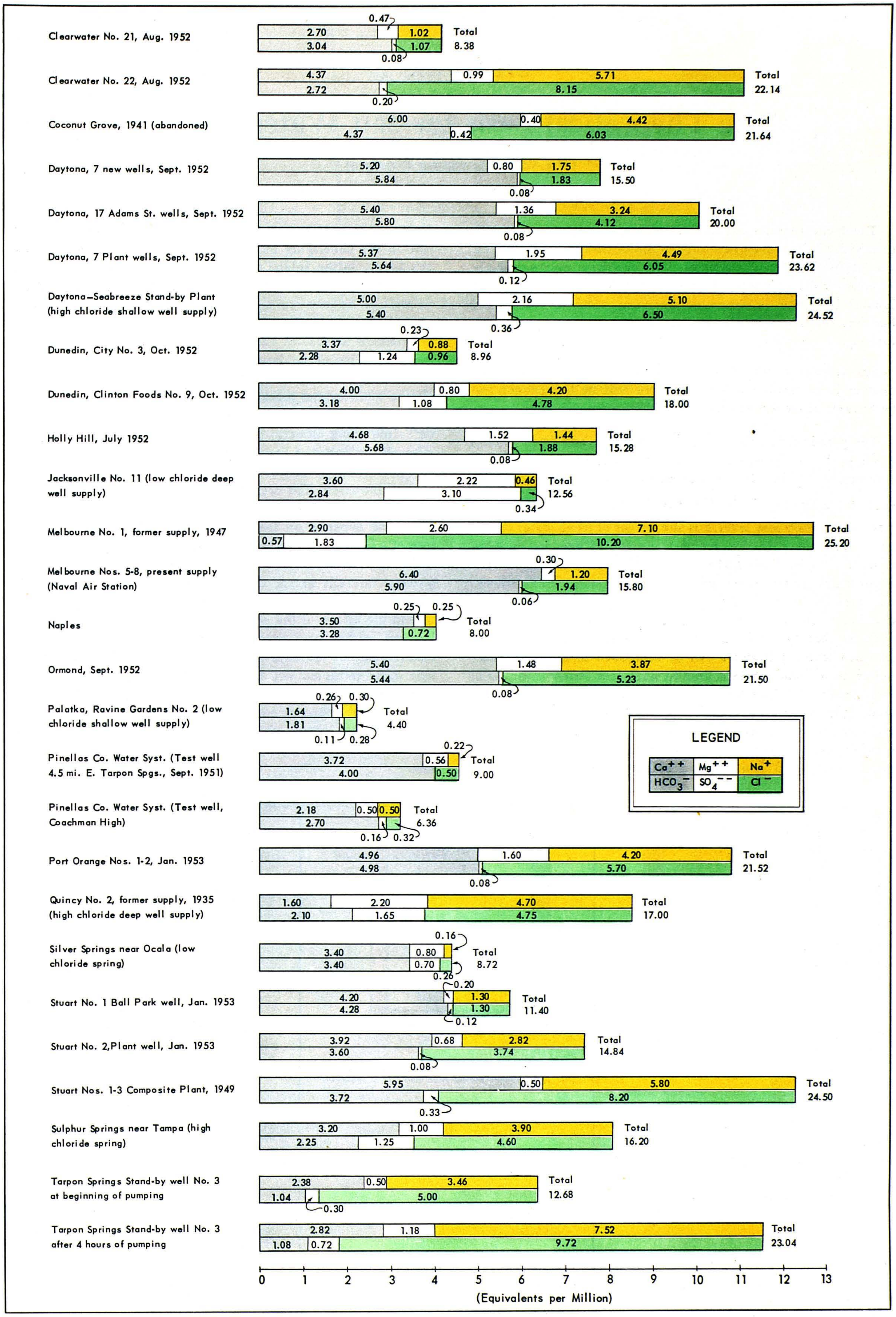


FIGURE 2. Principle Constituents of Selected Waters

CHAPTER 2

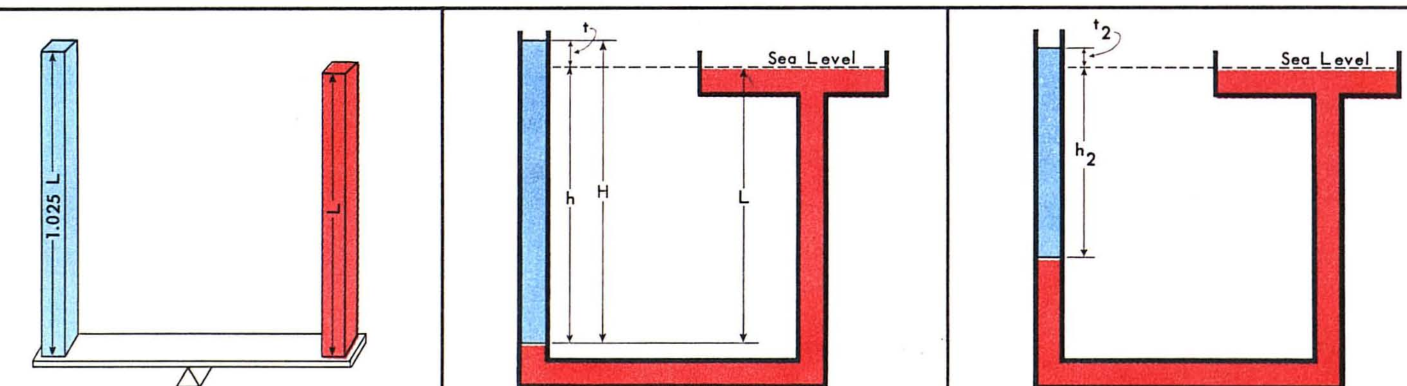
The Theoretical Basis for Salt Water Intrusion

(The Ghyben–Herzberg Principle)

The basic requirement for the infiltration of salt water into fresh water is that they be either in direct contact or separated by a relatively permeable aquifer. This condition exists throughout much of the perimeter of Florida as the ground water of the Coastal Lowlands is separated from sea water by formations that are, for the most part, porous and permit the passage of water quite readily.

Sea water is heavier than fresh water and when the two come together in permeable formations there will be a tendency for the heavier sea water to displace the lighter fresh water.

The piezometric relationship between salt and fresh water, known as the Ghyben-Herzberg Principle, has been summarized by Brown.[27] This principle may be expressed mathematically: $H = h + t = hg$ or $h = \frac{t}{g-1}$ (See Fig. 3) where h is the depth of fresh water below sea level, t is the height of fresh water above sea level, and g is the specific gravity of sea water. The value of g varies from 1.024 to 1.026,[4] being greater in the deeper parts of the ocean and less near coastal areas where sea water is diluted by fresh water discharged from rivers and off-shore springs. As applied in actual practice, the equation indicates that for each foot of fresh water which lies above mean sea level, salt water will be depressed in the permeable aquifer to a depth of 38.4 feet to 41.7 feet below mean sea level. Taking 1.025 as the value commonly found along coastal areas, it is easily seen that for each foot of fresh water head, salt water is depressed 40 feet below mean sea level. It may be safely assumed that in a coastal area where the fresh water head is maintained at a minimum height, for example of 4 feet above sea level, the maximum height to which salt water will rise in the underlying formations will be 160 feet below mean sea level. In the inland portions of the peninsula, salt water occurs only at great depths, due to the high piezometric surface, as well as to intervening impervious layers. In coastal areas, where the piezometric surface is low, salt water may be found at moderate depths. In such cases, sea water may invade fresh water supplies either laterally or vertically, if the fresh water head is sufficiently lowered. If an impervious formation seals off the aquifer from the saline water below, only lateral intrusion may then occur, either from the ocean itself or by seepage of saline water directly into the aquifer from tidal canals or streams. In some of the coastal areas, of course, the piezometric surface is sufficiently high to effectively prevent either type of intrusion. The draft from a well creates a "cone of depression," or lowering of the piezometric head. The extent of this cone depends on the permeability of the aquifer and the rate at which the water is withdrawn from the well. If the draft is heavy, the cone may vertically deepen to a source of salt water or laterally extend to salt water. A well that may be safely pumped at a given rate today may not be pumped at the same rate in the future, if the overall fresh water head of the area is lowered, either from excessive withdrawal elsewhere, or excessive surface drainage into the ocean. In some coastal areas, salt water intrusion may be controlled by construction of control works in the canals[28,60,63]; in others, the only solution may be abandonment of the well field and location of another farther inland, where the fresh water head can be maintained at a sufficiently high level to prevent salt water intrusion.



The basic principle is that of balanced weights.

1 cubic foot of sea water weighs 64.06 lbs.

1 cubic foot of fresh water weighs 62.5 lbs.

Thus salt water is $\frac{64.06}{62.5}$ or 1.025 times as heavy as fresh water and a column of salt water L feet in height will balance a column of fresh water (1.025) L feet in height.

A. BASIC PRINCIPLE

Connect the salt and fresh water columns shown in A by a connecting tube and add a reservoir to the top of the salt water column. The result is shown above. Then as explained in A,

$$H = 1.025\ L$$

$$\text{or } h + t = 1.025\ L = 1.025\ h$$

$$h = \frac{t}{(1.025 - 1)} = \frac{t}{.025}$$

When $t = 1$, $h = 40$.

Hence for every foot of fresh water above sea level there are 40 feet of fresh water below sea level.

B. BASIC PRINCIPLE APPLIED TO FRESH WATER HEAD

Lower the surface of the fresh water column shown in B and the result is shown above. The fresh water head is now t_2 and by equation shown in B,

$$h_2 = \frac{t_2}{.025}$$

As a result of lowering the fresh water surface, the salt water has risen in the left tube an amount equal to $(h - h_2)$.

$$\text{But } (h - h_2) = \frac{t}{.025} - \frac{t_2}{.025} = \frac{t - t_2}{.025}$$

So when $(t - t_2) = 1$, $(h - h_2) = 40$

Hence for every foot of drawdown of a fresh water table the salt water beneath the fresh water will rise 40 feet.

C. BASIC PRINCIPLE APPLIED TO DRAW-DOWN

FIGURE 3. Explanation of the Ghyben–Herzberg Principle

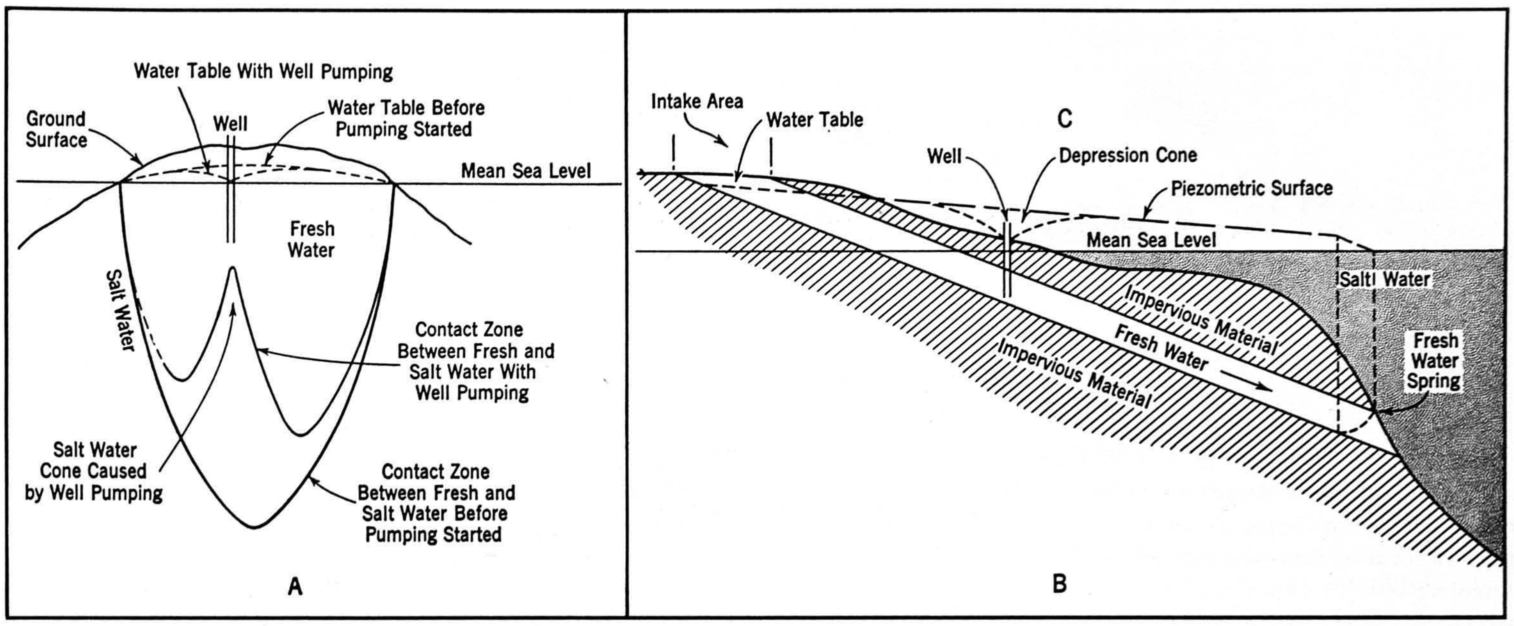


FIGURE 3A. General Relation between fresh and salt water. **A** is a cross section of a small island or peninsula of permeable sand showing general relationship between fresh and salt water. **B** shows relation between fresh and salt water under artesian conditions. *(From Journal AWWA, October, 1951, "Geological and Hydrologic Factors Affecting Perennial Yield of Aquifers" by V. T. Stringfield and H. H. Cooper.)*

CHAPTER 3

Geology and Hydrology of Florida

A. Topography

Any discussion of ground water problems in Florida requires at least some knowledge of the topography of the state and of the water-bearing formations or aquifers, as well as of the geological formations in which they occur, and through which the underground water flows.[29,30,31,32,62,63]

The Floridan Plateau is usually defined as the projection of the continent of North America that separates the deep water of the Atlantic Ocean from the deep water of the Gulf of Mexico. As thus defined, it includes not only the state of Florida, but an equally great or greater area that lies submerged, largely on the western side, beneath water less than 300 feet in depth. It is approximately 500 miles long and varies in width from 250 to 400 miles. It consists of a core of deeply buried metamorphic rocks overlaid by sedimentary rocks, chiefly limestones, several thousand feet in thickness. During the millions of years of its existence, the Floridan Plateau has been alternately dry land or covered by shallow seas. The later inundations have left behind well-defined marine terraces.

The part of the Plateau that lies above sea level – which we know as the State of Florida – may be divided into five topographic regions: the Coastal Lowlands, the Central Highlands, the Tallahassee Hills, the Marianna Lowlands, and the Western Highlands. The general outline of these regions may be seen from Figure 4. The topography of Florida is described in reports by Matson and Sanford,[25] Cooke,[30,31] Stringfield[8] and others.

Although the altitude ranges from sea level to only 345 feet above sea level, the topography is quite varied. The Coastal Lowlands border the coast from the Georgia line at the St. Mary's River to the Alabama line at the Perdido River. They extend inland for varying distances as can be seen in Figure 4, being relatively narrow in the northern portion of the peninsula, and comprising the southern one-third of the peninsula. The inner edge of the lowlands lies at about the 100-foot contour line. The Coastal Lowlands originally consisted of plains representing marine terraces which were the bottoms of the sea during previous high-water levels.

The Western Highlands, which lie between the Perdido and Apalachicola Rivers, extend inland from the Coastal Lowlands to the Alabama line. This region includes the valleys of the Escambia, the Blackwater, the Yellow, and other rivers. The northern part is hilly, approaching a probable maximum of 345 feet above sea level. The southern part ranges from 100 to 200 feet above sea level, and is deeply trenched by narrow, steep-walled valleys that cut down nearly to sea level. The areas below 270 feet include remnants of marine terraces. Drainage is good throughout the area, due to the presence of many rivers and streams.

The Central Highlands extend from a 60-mile stretch along the Georgia line, between the northern Withlacoochee and St. Mary's River, south-southeastward to the vicinity of Glades County, a distance of some 250 miles. Although the Central Highlands follow the crest of the Floridan Plateau, they lie somewhat closer to the Gulf than to the Atlantic Coast. Much of the northern part of the Highlands is a nearly level plain[30] ranging about 150 feet above sea level. The area between

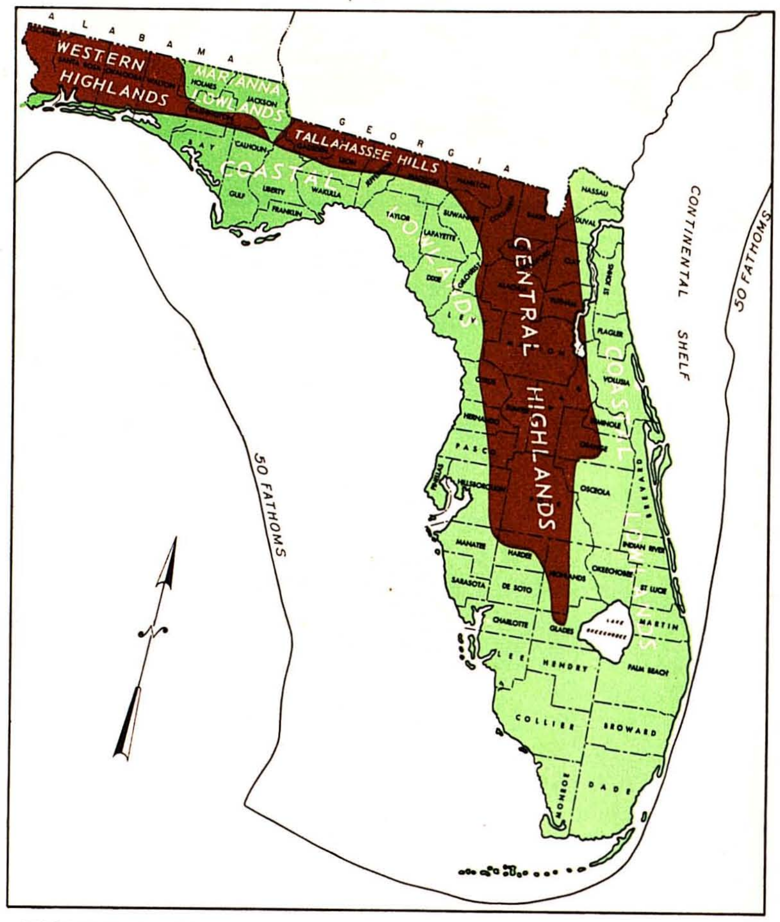


FIGURE 4. Topographic regions of Florida. *(From Florida Geological Survey Bulletin No. 17.)*

Alachua and Pasco Counties is alternately hills and hollows, interspersed with broad low plains from former marine terraces, and ranges in altitude from 200 feet to less than 40 feet above sea level. The only surface stream is the southern Withlacoochee River and its tributaries.

To the east of this region and extending beyond it to the southern tip of the Highlands is what is known as the Lake region. Much of the upland area contains numerous sink holes or other depressions and lakes that range in diameter from a few feet to several miles. The sink holes formed by the removal of underlying soluble limestone by ground water are typical in such areas as Alachua, Marion, and Citrus Counties. Lakes occupying depressions, some of which are probably old sink holes, are numerous in Lake and Polk Counties, being within the area referred to above as the Lake region. Topography of this nature bears an important relationship to ground water, as it was formed chiefly by the action of ground water on the soluble underlying limestone, and because surface water enters the formation through the sinks and lakes, thus recharging the water-bearing rocks, even though they are not present at the surface. Limestone, especially pure limestone, is soluble in surface water containing carbon dioxide, and where such rocks lie close enough to the surface to be reached by such water, we find sink holes, caves, or lakes. In such a region, much of the drainage flows underground. Within the area termed the Central Highlands are found the Piezometric Highs which supply water to the coastal areas under artesian pressure. Where the limestone is deeper and overlain by impervious beds, the sur-

plus rainwater runs over the surface of the land and cuts valleys to the sea. Both of these types of topography are to be found in Florida.

B. Name, Age, and Description of Aquifers and Aquaclude

Figure 5 represents a structural map of Florida based on the top of Ocala limestone as penetrated in wells (FSGS Bulletin 31). Table 5 lists the geologic formations of the tertiary and quaternary systems while Figure 6 shows where these formations occur at or near the surface of the ground.

Geologic time is recorded by Era, Period, Epoch, and Age as succeedingly smaller increments of time.[21] The shortest epoch is over one million years. Other epochs are much longer to a maximum of seventy-five million years. Almost all of the sedimentary deposits penetrated by water wells in Florida belong to the Cenozoic era covering approximately the last sixty million years. All epochs of the Tertiary and Quaternary periods that constitute the Cenozoic era are represented in these sedimentary deposits.

The Eocene limestones, Oligocene limestones, and the Tampa limestone of Miocene epoch constitute the principal artesian aquifer of South Florida and West Florida. The Oligocene is missing in much of the northern half of Peninsular Florida, so the Eocene limestones and Tampa limestone of the Miocene constitute the principal artesian aquifer of this region. They all deliver copious amounts of water to wells. The water is potable and of low mineral content near recharge areas, but progressively increases in salinity and alkalinity as the distance of the discharge area from the recharge area increases or contamination by pollution increases. The water may become quite saline and non-potable at great distance from the recharge area by dissolving saline residues.

According to Figure 5, the Ocala limestone (upper Eocene) has been eroded from the surface of a large part of Brevard, Citrus, Levy, Orange, and Volusia Counties of Central Florida. The main aquifers of this region are the older Eocene formations. The Eocene limestones are so widespread that they are considered the structural basis of Florida. The Eocene limestones are at or above mean sea level in a dome inclosing the valleys of the Suwannee, Santa Fe, Wacasassa, and Southern Withlacoochee Rivers. The upper surface of these formations dips from the central Eocene dome toward the west, northeast, south and southeast to approximately 500 feet below mean sea level at St. Marks, Jacksonville, Sebastian, and St. Petersburg. The slope is much more gentle to the east, the formation being less than 200 feet below mean sea level at Cocoa and St. Augustine, and less than 100 feet below mean sea level along the Atlantic Coast from Titusville to Flagler Beach. The slope then plunges to 1000 feet below mean sea level at West Palm Beach, Fort Myers, and in Gulf and Franklin Counties of West Florida. The dip continues south until these formations are over 1200 feet below sea level in extreme South Florida. This great depth is also reached in the vicinity of Apalachicola by a second Eocene formation which outcrops in Jackson County.[34]

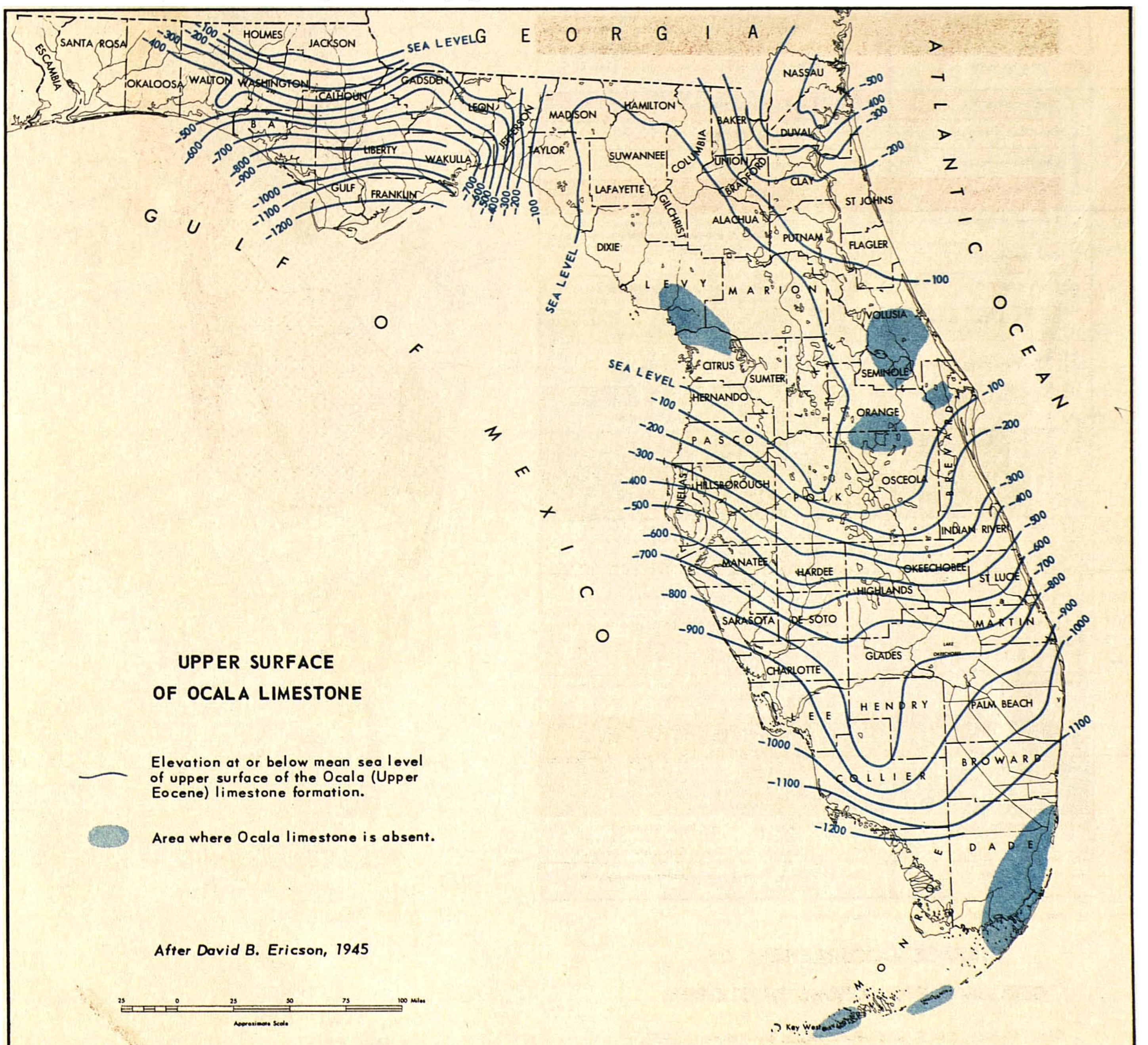
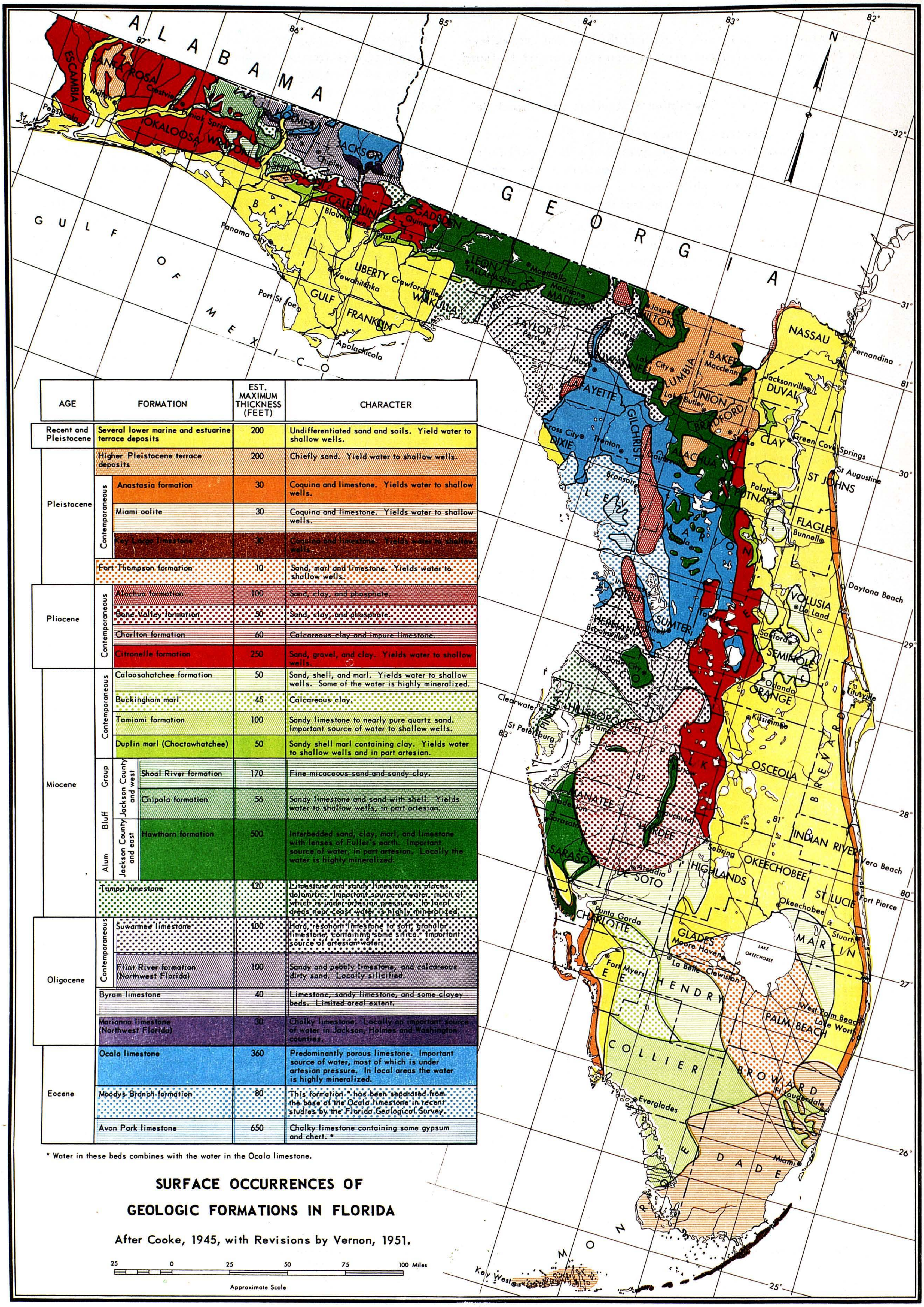


FIGURE 5. Structural map of Florida showing the upper surface of the Ocala (Upper Eocene) limestone formation as penetrated by wells. *(From Fla. Geological Survey Bulletin 31)*



AGE		FORMATION	EST. MAXIMUM THICKNESS (FEET)	CHARACTER
Recent and Pleistocene		Several lower marine and estuarine terrace deposits	200	Undifferentiated sand and soils. Yield water to shallow wells.
Pleistocene		Higher Pleistocene terrace deposits	200	Chiefly sand. Yield water to shallow wells.
	Contemporaneous	Anastasia formation	30	Coquina and limestone. Yields water to shallow wells.
	Contemporaneous	Miami oolite	30	Coquina and limestone. Yields water to shallow wells.
	Contemporaneous	Key Largo limestone	30	Coquina and limestone. Yields water to shallow wells.
		Fort Thompson formation	10	Sand, marl and limestone. Yields water to shallow wells.
Pliocene	Contemporaneous	Alachua formation	100	Sand, clay, and phosphate.
	Contemporaneous	Bone Valley formation	50	Sand, clay, and phosphate.
	Contemporaneous	Charlton formation	60	Calcareous clay and impure limestone.
	Contemporaneous	Citronelle formation	250	Sand, gravel, and clay. Yields water to shallow wells.
Miocene	Contemporaneous	Caloosahatchee formation	50	Sand, shell, and marl. Yields water to shallow wells. Some of the water is highly mineralized.
	Contemporaneous	Buckingham marl	45	Calcareous clay.
	Contemporaneous	Tamiami formation	100	Sandy limestone to nearly pure quartz sand. Important source of water to shallow wells.
	Contemporaneous	Duplin marl (Choctawhatchee)	50	Sandy shell marl containing clay. Yields water to shallow wells and in part artesian.
	Alum Bluff Group, Jackson County and west	Shoal River formation	170	Fine micaceous sand and sandy clay.
	Alum Bluff Group, Jackson County and west	Chipola formation	56	Sandy limestone and sand with shell. Yields water to shallow wells, in part artesian.
	Alum Bluff Group, Jackson County and east	Hawthorn formation	500	Interbedded sand, clay, marl, and limestone with lenses of Fuller's earth. Important source of water, in part artesian. Locally the water is highly mineralized.
		Tampa limestone	120	Limestone and sandy limestone, in places, dolomitic. Important source of water, much of which is under artesian pressure. In local areas near coast water is highly mineralized.
Oligocene	Contemporaneous	Suwannee limestone	100	Hard, resonant limestone to soft, granular limestone, containing some silica. Important source of artesian water.
	Contemporaneous	Flint River formation (Northwest Florida)	100	Sandy and pebbly limestone, and calcareous dirty sand. Locally silicified.
		Byram limestone	40	Limestone, sandy limestone, and some clayey beds. Limited areal extent.
		Marianna limestone (Northwest Florida)	30	Chalky limestone. Locally an important source of water in Jackson, Holmes and Washington counties.
Eocene		Ocala limestone	360	Predominantly porous limestone. Important source of water, most of which is under artesian pressure. In local areas the water is highly mineralized.
		Moodys Branch formation	80	This formation * has been separated from the base of the Ocala limestone in recent studies by the Florida Geological Survey.
		Avon Park limestone	650	Chalky limestone containing some gypsum and chert. *

* Water in these beds combines with the water in the Ocala limestone.

SURFACE OCCURRENCES OF GEOLOGIC FORMATIONS IN FLORIDA

After Cooke, 1945, with Revisions by Vernon, 1951.

FIGURE 6

TABLE NO. 5

GEOLOGIC FORMATIONS OF THE TERTIARY AND QUATERNARY SYSTEMS IN FLORIDA

After Cooke, 1945, with additions by Vernon, 1951.

AGE			FORMATION	EST. MAXIMUM THICKNESS (FEET)	CHARACTER
Recent and Pleistocene			Several lower marine and estuarine terrace deposits	200	Undifferentiated sand and soils. Yield water to shallow wells.
Pleistocene			Higher Pleistocene terrace deposits	200	Chiefly sand. Yield water to shallow wells.
Pleistocene			Anastasia formation; Miami oolite; Key Largo limestone	30	Coquina and limestone. Yield water to shallow wells.
Pleistocene			Fort Thompson formation	10	Sand, marl, and limestone. Yields water to shallow wells.
Pliocene	Contemporaneous		Alachua formation	100	Sand, clay, and phosphate.
Pliocene	Contemporaneous		Bone Valley formation	50	Sand, clay, and phosphate.
Pliocene	Contemporaneous		Charlton formation	60	Calcareous clay and impure limestone.
Pliocene	Contemporaneous		Citronelle formation	250	Sand, gravel, and clay. Yields water to shallow wells.
Miocene	Contemporaneous		Caloosahatchee formation	50	Sand, shell, and marl. Yields water to shallow wells. Some of the water is highly mineralized.
Miocene	Contemporaneous		Buckingham marl	45	Calcareous clay.
Miocene	Contemporaneous		Tamiami formation	100	Sandy limestone to nearly pure quartz sand. Important source of water to shallow wells.
Miocene	Contemporaneous		Duplin marl (Choctawhatchee)	50	Sandy shell marl containing clay. Yields water to shallow wells and in part artesian.
Miocene	Alum Bluff Group	Jackson County & west	Shoal River Formation	170	Fine micaceous sand and sandy clay.
Miocene	Alum Bluff Group	Jackson County & west	Chipola formation	56	Sandy limestone and sand with shell. Yields water to shallow wells and in part artesian.
Miocene	Alum Bluff Group	Jackson County & east	Hawthorn formation	500	Interbedded sand, clay, marl, and limestone with lenses of Fuller's earth. Important source of water, in part artesian. Locally the water is highly mineralized.
Miocene			Tampa limestone	120	Limestone and sandy limestone, in places dolomitic. Important source of water, much of which is under pressure. In local areas near coast water is highly mineralized.
Oligocene	Contemporaneous		Suwannee limestone	100	Hard, resonant limestone to soft, granular limestone, containing some silica. Important source of artesian water.
Oligocene	Contemporaneous		Flint River formation (Northwest Florida)	100	Sandy and pebbly limestone, and calcareous dirty sand. Locally silicified.
Oligocene			Byram limestone	40	Limestone, sandy limestone, and some clayey beds. Limited areal extent.
Oligocene			Marianna limestone (Northwest Florida)	30	Chalky limestone. Locally an important source of water in Jackson, Holmes and Washington counties.
Eocene			Ocala limestone	360	Predominantly porous limestone. Important source of water, most of which is under artesian pressure. In local areas the water is highly mineralized.
Eocene			Moody's Branch formation *	80	Predominantly porous limestone. Important source of water, most of which is under artesian pressure. In local areas the water is highly mineralized.
Eocene			Avon Park limestone**	650	Chalky limestone containing some gypsum and chert.
Eocene			Tallahassee limestone**	650	Crystalline limestone, argillaceous limestone.
Eocene			Lake City limestone**	500	Chalky limestone locally containing gypsum and chert
Eocene	Contemporaneous		Oldsmar limestone	1,200	Predominantly limestone but contains some gypsum and chert.
Eocene	Contemporaneous		Salt Mountain limestone (Northwest Florida)	200	Soft, chalky limestone
Paleocene	Contemporaneous		Cedar Keys limestone	570	Hard limestone.
Paleocene	Contemporaneous		Porters Creek formation (Northwest Florida)	Several hundred	Brittle, gray to black clay.

*The Moody's Branch formation has been separated from the base of the Ocala limestone in recent studies by the Florida Geological Survey.

**Water in these beds combines with the water in the Ocala limestone.

The Oligocene limestones lie unconformably on the Eocene limestones in the surface exposures in Taylor, Suwannee, and Hamilton Counties with a dip toward the west, while surface exposures in Hernando, Pasco, and Polk Counties dip to the south and southeast. The upper surface of the Oligocene occurs at 75 feet below mean sea level at New Port Richey as the Suwannee limestone.

The Tampa limestone (Miocene) overlays the Suwannee limestone (Oligocene) in South Florida and the Flint River formation in West Florida. Tampa limestone directly overlays Eocene limestones in Central Florida where Oligocene deposits are missing. The Hawthorn formation of the Miocene occurs above sea level in the Tallahassee Hills and Central Highlands, then dips below sea level along the coast of West Florida and along the slopes of the Ocala dome to become chiefly an aquaclude that acts as a seal above the principal artesian aquifer at varying depths. According to Stubbs,[9] the Hawthorn lies directly on the Eocene in Seminole County where water from the Ocala limestones and Hawthorn formation is hard, and sometimes highly mineralized in the east and northeastern part of Seminole County. The result is a variation in the depth necessary for a well to penetrate the principal artesian aquifer. In areas where the principal artesian aquifer is deeply buried, and the Hawthorn formation is nearer the surface, the latter may deliver less copious amounts of potable artesian water to wells, as for instance in some Sarasota County wells.[4]

Parker[18] indicates that the highly saline waters of Little Salt Spring (1450 ppm chloride) and Warm Salt Spring (9300 ppm chloride) in Sarasota County are artesian waters of the Hawthorn formation that filter through unflushed Pleistocene sea deposits to dissolve highly saline residues and become highly mineralized. The magnesium content of Warm Salt Springs exceeds the calcium content as happens in sea water. The high calcium content and high total hardness of such waters of South Florida may be due to base exchange[24] or possible solution of limestones in sea water.

There are few Pliocene formations and correlation is difficult in the Citronelle formation, so geologists have mapped the Ocala, Suwannee, and Tampa limestones in the Gulf elbow as the younger formations are missing.[31] The State of Florida shows little structural deformation since the Pliocene epoch that ended one to two million years ago.[18] A crustal warping during the late Pliocene epoch raised the Citronelle (Pliocene deltaic land formation) to 300 feet above mean sea level in north and central Florida and accounts for the broad embayment of the Gulf elbow between Apalachicola and Clearwater. The Bone Valley formation (estuarine and marine), Caloosahatchee Marl (marine), Buckingham Marl (marine), and the Tamiami formation (marine) are deposits of Pliocene seas. These seas submerged all of South Florida as far north as Tampa, extended 50 miles inland to the western edge of the St. John's River Valley, parallel to the Atlantic Coast of Florida, and further embayed the Gulf Coast of Florida.

No consideration of the physiography can ignore the Pleistocene terrace deposits that overlie most of the older formations in Florida. The Pleistocene lies unconformable on the Pliocene, which is unconformable on the Miocene. The Pleistocene has reworked some of the Pliocene deposits. Repeated oscillations of the sea during the Pleistocene epoch deposited marine terraces[18,35] during the interglacial Aftonian, Yarmouth, Sangamon and Iowan substage of the Wisconsin ages of high sea levels. Fresh water by solution and erosion partly flushed these porous deposits or sediments during the glacial stages of the Nebraskan, Kansan, Illinois and Wisconsin ages of low sea levels, but left residues in undisturbed impervious sediments. As a result, three terraces were deposited above the Coastal Lowlands; at approximately 270 feet (msl) as the Brandywine formation during Aftonian age, at 215 feet (msl) as the Coharie formation during Yarmouth age, and at 170 feet (msl) as the Sunderland formation during Yarmouth age. Three terraces were deposited during the Sangamon interglacial age, namely Wicomico formation at 100 feet (msl), Penholloway formation at 70 feet (msl), and the Talbot formation (see Figure 11) at 42 feet (msl). The Pamlico formation (see Figure 10) was deposited during the interglacial Peorian substage of the late Wisconsin age at 25 feet above mean sea level,[35] and a bench at Silver Bluff[20] was formed at 5 feet above mean sea level during a halt as the Pamlico sea receded. The Key Largo limestone, Miami oolite, Anastasia formation, and Fort Thompson formation were deposited during the Pleistocene epoch.[18] The lowering of the sea at the close of this epoch did not flush all the saline residue from the relatively impervious Caloosahatchee Marl and the Fort Thompson formation. Vorhis[28] and Parker[22] have recorded that the Caloosahatchee yields potable water for small domestic supplies in the Fort Lauderdale area. Unconfined ground waters in the Anastasia, Miami oolite and Tamiami formation along the lower Atlantic Coast are potable. These latter porous formations have evidently been flushed of their marine residues of former seas except for occasional salt lenses.

The Tamiami formation has one of the highest permeabilities ever observed by the Geological Survey, United States Department of the Interior.[22]

The only deposits of the Recent epoch are the fresh water marl (Lake Flirt marl), organic soils (peat) and beach dunes.

It is noted that the saline waters of the Lake George area, for example Salt Springs near Lake Kerr in Marion County, Ponce de Leon Springs in Volusia County, and the artesian wells of Seminole County, flow through deposits that were covered by the Pamlico sea and probably have not been flushed of Pleistocene marine residues during the Recent epoch.

C. Piezometric Surface of Water in the Upper Eocene Formations

If observations are made of the height to which water will rise in cased wells penetrating the Eocene limestones and lines are drawn on a map where these values are the same, there is obtained a piezometric map showing with considerable accuracy the topography of the water surface throughout the formations. Such a map is shown in Figure 7. From the map it is seen that within a small area in Polk County between Lakeland and Haines City, water will rise in cased wells penetrating the Upper Eocene to a height of 120 feet above sea level. This is called the "Southern Piezometric High." The high column of ground water present in this area forces ground water to move laterally away in all directions. Since water beneath the ground always flows from an area of high piezometric head to an area of low head, it is evident that areas containing piezometric highs are areas in which water is recharged into the formation, and areas containing piezometric lows are areas of discharge. Thus, surface water recharged into the Upper Eocene in the southern high in Polk County may be recovered under considerable artesian head along the lower East Coast of Florida as far south as Miami, and also along the West Coast from Tampa to Fort Myers. Another large high, the so-called "Northern Piezometric High," extends in a broad band from just north of Palatka in Putnam County through Bradford and Baker Counties, and into Georgia. Smaller sub-highs are located near DeLand in Volusia County, near Dade City in Pasco County, near Dunellon in Marion County, and just south of Madison in Madison and Taylor Counties. The map likewise shows that water recharged into the northern high in Bradford and Baker Counties may be recovered under high artesian pressure from the municipal wells supplying Jacksonville.

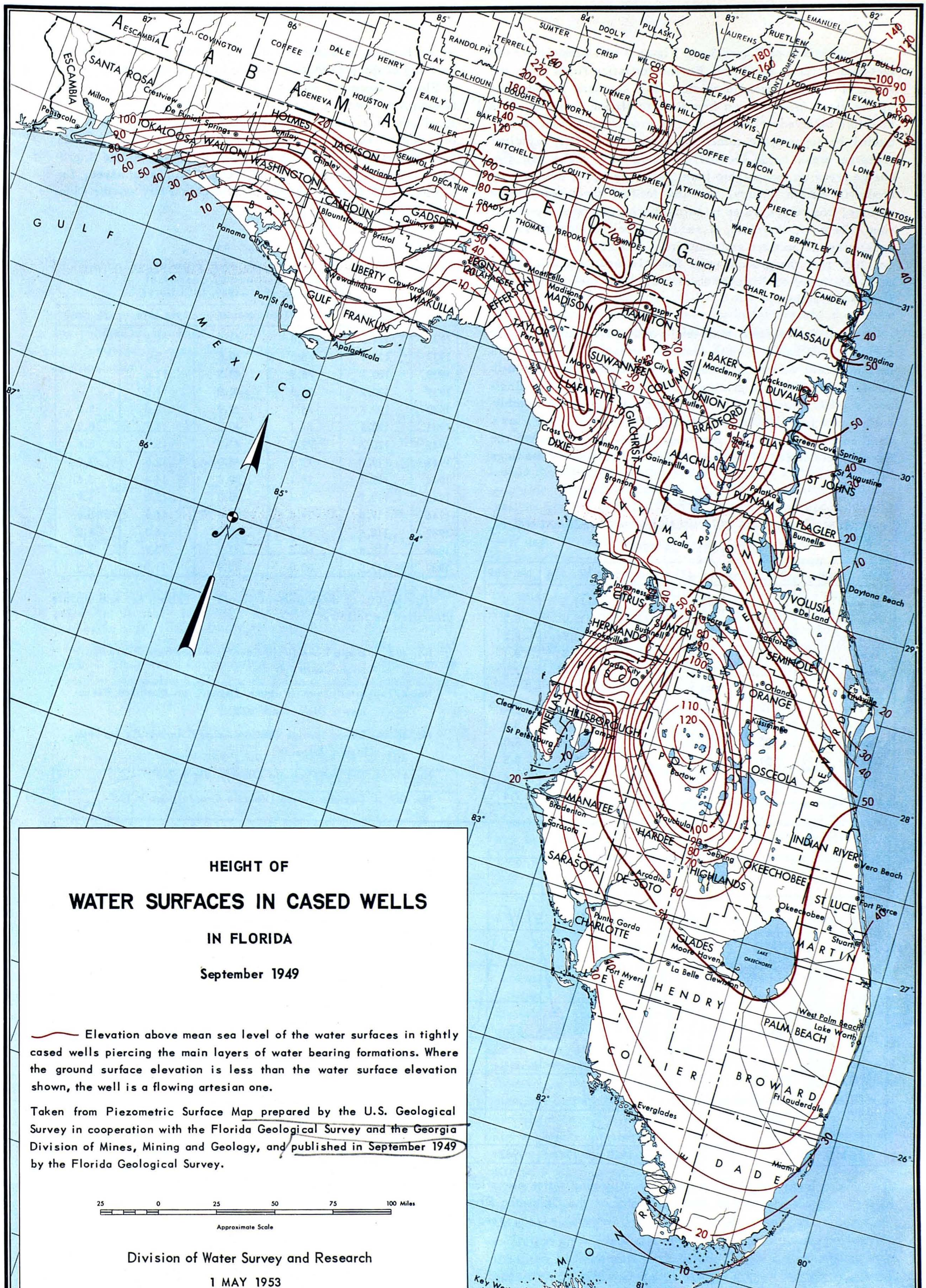

HEIGHT OF
WATER SURFACES IN CASED WELLS
IN FLORIDA
September 1949
Elevation above mean sea level of the water surfaces in tightly cased wells piercing the main layers of water bearing formations. Where the ground surface elevation is less than the water surface elevation shown, the well is a flowing artesian one.
Taken from Piezometric Surface Map prepared by the U.S. Geological Survey in cooperation with the Florida Geological Survey and the Georgia Division of Mines, Mining and Geology, and published in September 1949 by the Florida Geological Survey.
25 0 25 50 75 100 Miles
Approximate Scale
Division of Water Survey and Research
1 MAY 1953
ALABAMA
GEORGIA
GULF OF MEXICO
LAKE OKEECHOBEE

FIGURE 7

A comparison of Figure 5 and Figure 7 will demonstrate the fact that water in the Upper Eocene formation flows down the slope of the formation in western and southern Florida, but up the slope in the region from Polk to Marion Counties. It is therefore believed[32] that in Florida ground water flow is controlled by topographic rather than structural relief, principal recharge areas being located on topographic highs and discharge areas on topographic lows. Since the Upper Eocene outcrops in Marion County, we find located there many large springs, from which water is being discharged from the formation. There is, therefore, a saddle or belt of low pressures separating the northern and southern piezometric highs. We may conclude that the ground water from the southern half of the peninsula receives little or no recharge from the northern portion of the state.

It must be realized that this piezometric surface is not constant, but has a normal seasonal variation, as well as a normal annual variation. Both types of variation are shown in tabular form. The data given were furnished by the U. S. Engineer's office, Jacksonville.[36] Table 6A shows the monthly variation of five piezometric surfaces for 1948. Table 6B shows their annual variation for the years 1936–1949 inclusive, the water levels listed being the average of the monthly readings for each year. It is evident that there has been no extensive lowering of the piezometric surface in the large recharge areas of Florida. Recovery after the summer rains is indicated in all cases. Any lowering of the water table has been in areas of local recharge immediately dependent on rainfall, or where over-development has taken place. The effect of dry periods such as 1943–1944–1945 is shown by the chart, Figure 8, prepared by the District Engineer, U.S.G.S., Tallahassee, for U.S.E.D. 392 (Marion 5) well at Sharpe's Ferry on the Oklawaha River.

TABLE 6A

MONTHLY READINGS (FT., MSL) OF FIVE PIEZOMETRIC SURFACES FOR 1948*

Month (1948)	No. 404	No. 471	No. 46	No. 414	No. 489
January	–	80.6	41.1	11.5	5.5
February	119.2	80.6	41.2	15.0	8.2
March	119.1	81.6	41.3	13.9	8.2
April	116.1	81.4	41.3	10.3	8.1
May	118.0	80.6	41.0	7.6	7.3
June	117.1	80.1	40.5	13.3	–
July	117.0	80.3	40.3	12.5	7.5
August	120.0	81.2	40.4	13.7	8.3
September	120.2	81.2	41.6	12.9	8.0
October	121.1	81.6	41.6	13.1	8.5
November	118.1	81.2	41.5	14.5	7.4
December	118.2	79.1	41.3	14.0	7.1

TABLE 6B

YEARLY AVERAGES (FT., MSL) OF FIVE PIEZOMETRIC SURFACES, 1936–1949, INCLUSIVE*

Year	No. 404	No. 471	No. 46	No. 414	No. 489
1936	121.5	76.6	41.3	11.6	–
1937	121.0	76.0	40.8	12.0	–
1938	120.7	76.5	40.5	11.8	–
1939	120.2	76.8	40.2	11.5	–
1940	120.7	76.0	39.9	12.4	8.2
1941	120.2	77.1	40.2	13.7	8.2
1942	120.7	79.0	41.3	15.1	8.6
1943	119.7	77.1	40.0	12.8	7.9
1944	119.1	78.1	39.8	14.4	5.6
1945	119.1	79.4	40.3	15.2	5.9
1946	119.4	79.4	41.1	14.8	5.8
1947	118.6	78.9	40.7	14.0	6.0
1948	118.5	80.8	41.1	12.7	7.6
1949	117.5	80.0	40.9	11.2	7.5

* The points of measurement listed in Tables 6A and 6B are identified as follows:

No. 404 – Eagle Lake (Polk County) on Southern Piezometric High, depth 600'

No. 471 – Interlachen (Putnam County) on Northern Piezometric High, depth 303'

No. 46 – Silver Springs (Marion County) in saddle between highs. Artesian

No. 414 – DeLand (Volusia County), depth 293'

No. 489 – Daytona Beach (Volusia County), depth 185'

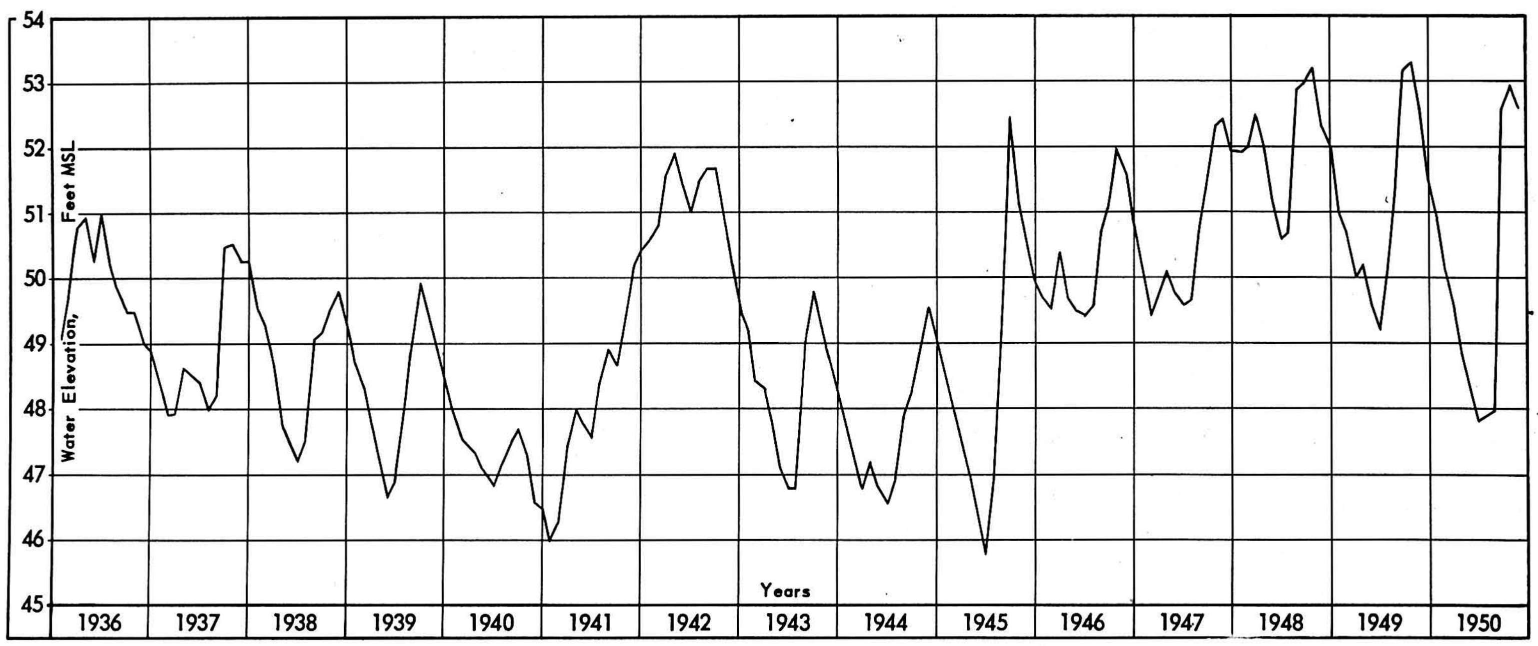


FIGURE 8. Variation of ground water elevation (ft., msl) in Corps of Engineers Well No. 392 located at Sharpe's Ferry on the Oklawaha River. *(From H. H. Cooper, Jr., District Engineer, U. S. Geological Survey, Tallahassee, Florida.)*

CHAPTER 4

Factors Responsible for Salt Water Intrusion

A. Increased Demands by Municipalities

An increased demand for water by municipalities follows any population increase. Population increases in Florida may be illustrated by the following table: (from the 1950 Census of Population).[37]

TABLE 7

POPULATION OF THREE LARGEST FLORIDA CITIES

	1930	1940	1950
Miami	110,637	172,172	249,276
Jacksonville	129,549	173,065	204,517
Tampa	101,161	108,391	124,681
State Total	1,468,211	1,897,414	2,771,305

The above table does not adequately reflect the rapid increase in population of the larger metropolitan districts since World War II. 1950 population figures taken from the Florida Handbook are: Dade County (Miami) 495,084; Duval County (Jacksonville) 304,029; and Hillsborough County (Tampa) 249,894. That water consumption increases with population is shown by comparing Table 7 with Table 8 listed below.

TABLE 8

AVERAGE DAILY CONSUMPTION IN MILLION GALLONS PER DAY OF THREE LARGEST FLORIDA CITIES

	Miami	Jacksonville	Tampa
1930	9.4	10.9	-
1940	22.5	14.1	7.4
1945	33.9	21.9	14.5
1948	45.2	25.8	14.9
1951	48.8	28.6	18.0

The rapid increase in the urban population of Florida during the last quarter century has brought with it increased water consumption from municipal supplies and instigated a search for new sources of supply in many instances. Tampa, for example, had to seek surface supplies during the third decade of this century from the Hillsborough River because of salt water intrusion. Miami has had to control salt water intrusion in the Miami Canal for the past ten years. The original Miami wells, one and one-half miles inland, were ruined by salt intrusion in 1925, and the new wells, six and one-half miles inland, were threatened by a ten mile encroachment of salt water up the Miami Canal in 1939.[13,22,63] About 1930 St. Petersburg had to abandon local wells because of salt water intrusion and seek an inland supply thirty-seven miles distant in northwest Hillsborough County.[5] These areas are discussed more fully later in this report.

B. Increased Demands by Agriculture

Modern irrigation has increased the volume of water consumed by agriculture. Many orange groves are irrigated by portable pumps and light-weight aluminum distribution systems. Thousands of flowing artesian wells are used for irrigation in the lower level areas, and have markedly lowered the piezometric head, particularly in Manatee, Sarasota, and Seminole Counties.[4] Wells that formerly flowed with high head, now flow under low heads and in some cases must be pumped.

C. Increased Demands by Industry

The consumption of water by industry already greatly exceeds the total consumption of all of Florida's 353 public water supplies. Hydraulic mining is estimated to require 75 million gallons per day in Polk County.[65] Eight paper and pulp mills in Florida are estimated to use 150 million gallons of water per day,[66] with two additional plants under construction estimated to require an additional 75 million gallons per day. To this total of 300 mgd for two industries, a large consumption of water for other industrial uses must be added, particularly for the washing of fruits and vegetables, and for refrigeration. The widespread installation of air conditioning equipment has made significant demands on some municipal or private supplies. The total demand is not presently heavy but may be heavy in the future.

D. Excessive Drainage

Excessive drainage depletes recharge. High water levels in the Everglades and under the Atlantic Coastal Ridge were materially lowered by the digging of the Everglades Drainage Canals during the first quarter of the current century. The result has been excessive drainage and a lower water table that no longer holds in check the salt water from the ocean.

E. Lack of Protective Works Against Tidewater in Bayous, Canals, and Rivers

Particularly in South Florida[22] between Miami and Fort Lauderdale numerous canals and old discharge channels cut the Atlantic Coastal Ridge. Salt water passing into these canals under tidal head or wind pressure makes direct contact with fresh water and is the cause of intrusion of salt water into the adjacent aquifers whenever the drawdown by wells causes a lowering of the water table in the vicinity of the canals. A team consisting of the United States government, the State of Florida and the Central and Southern Florida Flood Control District has a project designed to prevent the majority of the damages due to recurring floods and drought.[67] The plan, shown on Figure 9 provides an interrelated and comprehensive system of water control which will directly benefit 2,300,000 acres. In varying degrees this plan will also benefit cross-state navigation, recreation, municipal and agricultural water supplies, municipal and agricultural development, agricultural production, wildlife and fresh water fish, public health and sanitation, conservation of soils and water, and the control of both salt water encroachment and over-drainage.

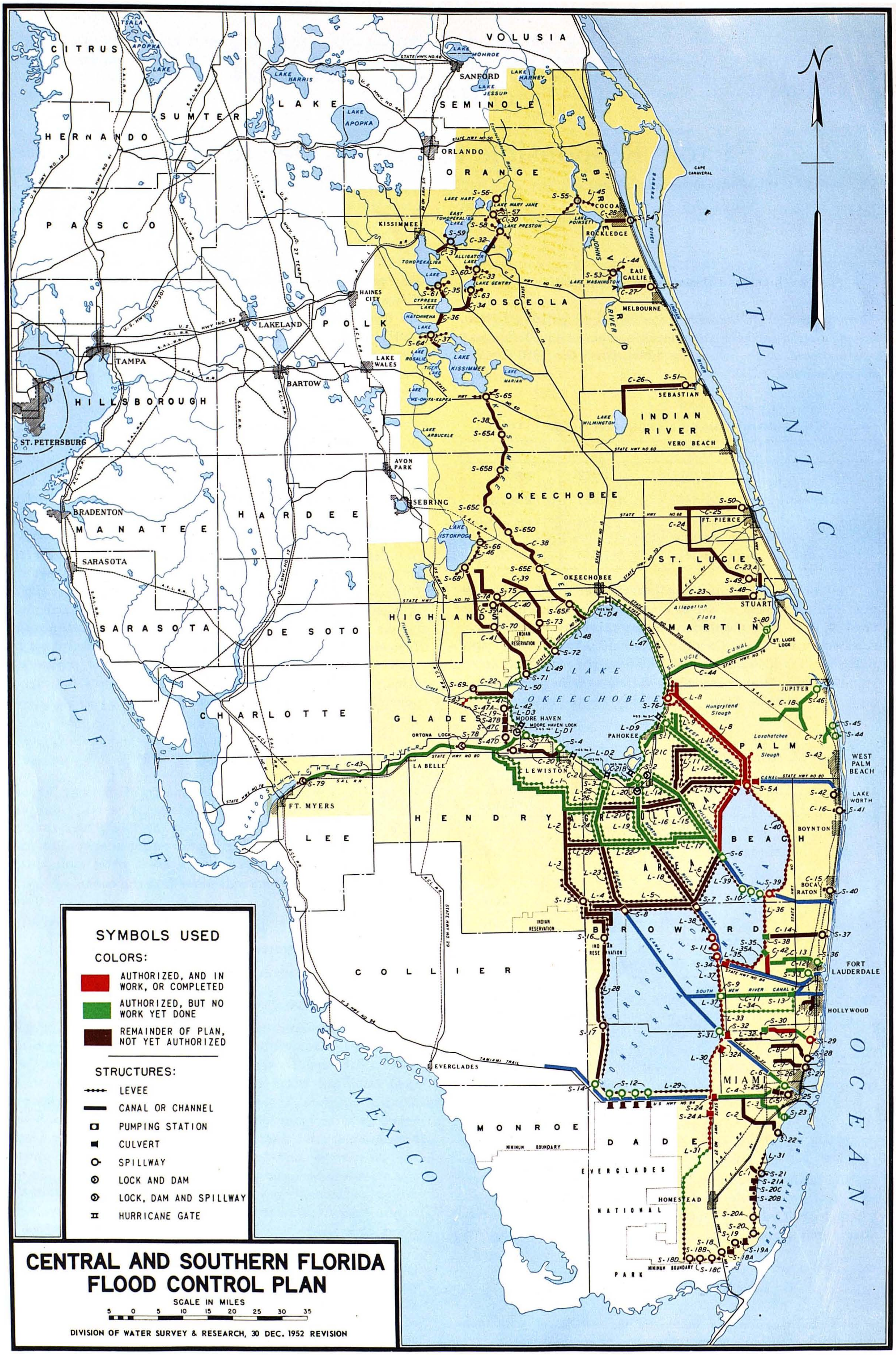

CENTRAL AND SOUTHERN FLORIDA FLOOD CONTROL PLAN
SCALE IN MILES
5 0 5 10 15 20 25 30 35
DIVISION OF WATER SURVEY & RESEARCH, 30 DEC. 1952 REVISION
SYMBOLS USED
COLORS:
AUTHORIZED, AND IN WORK, OR COMPLETED
AUTHORIZED, BUT NO WORK YET DONE
REMAINDER OF PLAN, NOT YET AUTHORIZED
STRUCTURES:
LEVEE
CANAL OR CHANNEL
PUMPING STATION
CULVERT
SPILLWAY
LOCK AND DAM
LOCK, DAM AND SPILLWAY
HURRICANE GATE
ATLANTIC OCEAN
GULF OF MEXICO
LAKE OKEECHOBEE
VOLUSIA
CITRUS
LAKE
SEMINOLE
SUMTER
HERNANDO
ORANGE
PASCO
OSCEOLA
POLK
BREVARD
HILLSBOROUGH
INDIAN RIVER
OKEECHOBEE
HARDEE
MANATEE
ST. LUCIE
SARASOTA
DE SOTO
HIGHLANDS
MARTIN
CHARLOTTE
GLADES
PALM BEACH
HENDRY
LEE
BROWARD
COLLIER
MONROE
DADE
ORLANDO
SANFORD
KISSIMMEE
TAMPA
ST. PETERSBURG
LAKELAND
BARTOW
SEBRING
BRADENTON
SARASOTA
FT. MYERS
LA BELLE
MOORE HAVEN
PAHOKEE
FT. PIERCE
STUART
VERO BEACH
MELBOURNE
COCOA
WEST PALM BEACH
FORT LAUDERDALE
HOLLYWOOD
MIAMI
HOMESTEAD
EVERGLADES
EVERGLADES NATIONAL PARK

FIGURE 9

In basic terms, structures are provided so as to insure:[68]

(a) The rapid removal of flood waters.
(b) The storage of sufficient portions of the surplus waters.
(c) The prevention of over-drainage.
(d) The prevention of the infiltration of salt water.
(e) The protection of developed areas.

Control spillways will act as salt water barriers, where drainage channels enter salt water. The plan also provides levees back of the coast to prevent wind driven seas from inundating the rich agricultural areas along the coast in South Dade County.

F. Improper Location of Wells

It is very important in locating wells, in an area subject to salt water intrusion, that they be located as far as economically feasible from the source of possible salt water intrusion, and also that they be properly spaced with respect to each other. This fact was not realized in the early development of Florida, so many municipal water supplies derived from wells were located too near salt water. As examples, the original well fields of both Miami and Tampa as well as those of several smaller cities and towns have been abandoned. Studies have made engineers aware that wells should be spaced in proportion to the circle of influence in order to avoid interference and excessive drawdown. The proper spacing of wells is dependent upon the permeability of the formation and the amount of water to be withdrawn. These two variables will determine the diameter of the circle of influence and this should always be determined by using test holes before final spacing in the well field is decided upon.

G. Highly Variable Annual Rainfall With Insufficient Surface Storage During Droughts

The most important single problem having to do with water conservation and control in Florida lies in the fact that the high average rainfall of over 50 inches is highly seasonal. Approximately 60 per cent of it falls during the period 1 June to 30 September, thus leaving only 40 per cent during the other eight months that are relatively dry. This results in successive periods of floods and droughts. This seasonal variation in rainfall is reflected in variations in the piezometric surface shown in Table 6A. An inspection of monthly water levels in a large number of wells which have been observed by the Jacksonville District Office of the U. S. Engineers (1935–1949) shows a regular and recurring variation of 2–3 feet in the piezometric surface or head. These conditions are intensified when a period of two or three dry years are successive. Huge surface storage of water is required if an adequate head is to be maintained in the unconfined aquifers sufficient to avoid the danger of salt water intrusion in coastal areas during such droughts. A summary of press reports during May, 1952, indicates that the demands for water for watering lawns, etc. during an extended period of drought exceeded the supply to such an extent that voluntary or compulsory rationing of water was resorted to in many localities.

H. Uncapped Wells and Leakage

Uncapped artesian wells, in many cases flowing to waste, represent a serious loss of ground water and must inevitably result in lowered ground water levels. Many old artesian wells have broken or corroded casings that permit highly saline water from salt residuals to contaminate the fresh water in overlying strata. Few of the wells were completely cased, as it was customary to case to "hard rock" and then extend the drilling until a desirable flow was obtained.

The water level in an overlying formation, or in unconfined groundwater, in many localities may be higher or lower than that of an underlying confined or artesian aquifer, so of necessity a well should be cased and provided with a suitable valve.

CHAPTER 5

Typical Examples of Salt Water Intrusion

For purposes of discussion the counties west of the Suwannee River are designated as West Florida and those east and south of this river are designated as Peninsular Florida.

A. Salt Water Intrusion Along the Gulf Coast of West Florida

The Ocala limestone is wide-spread in Florida and lies unconformably below younger beds including the Oligocene if present. The Oligocene appears in almost all sub-surface strata of West Florida except in Taylor and Jackson Counties as a chalky marl related to the Vicksburg group, consisting of Marianna limestone and Byram limestone.[34] The Oligocene outcrops from the Gulf Coast in Jefferson and Taylor Counties northeast to the Georgia line, and also outcrops in Jackson County and west through Holmes and Washington Counties into Alabama. The Flint River equivalent of the Suwannee limestone (Oligocene) has been widely identified in West Florida in contrast to the widespread distribution of the Suwannee limestone in Northcentral Florida and the southern part of Peninsular Florida. Limestone formations older than the Upper Eocene are not of general interest in a study of the hydrology of Florida, as their aquifers are highly mineralized and at too great a depth for economical drilling. Younger beds of Tampa limestone (Miocene), Hawthorn formation (Miocene), Citronelle formation (Pliocene), and Pleistocene terrace formations are found in the aquifers of West Florida.

The ten foot piezometric contour (Fig. 7) closely parallels the coast in Dixie, Taylor, Jefferson, Wakulla, Franklin, Gulf and Bay Counties. An area of low surface with flowing artesian wells extends a few miles inland along the entire Gulf Coast of West Florida and up the valleys of the larger rivers such as the Apalachicola, Choctawhatchee, Escambia and Perdido Rivers for 20 to 30 miles.[42]

Most of the water supplies of West Florida are soft and very low in total dissolved solids. These waters are believed to come from younger sediments. The sediments in the unconfined aquifer are more predominantly clastic, sorted gravels, sands, and clays of the alluvial or deltaic type covered by Pleistocene sands, rather than the predominantly limestone formations of Peninsular Florida. Shallow wells are principally used in Escambia and Santa Rosa Counties for municipal supplies, but deep wells are predominant for this purpose in all other counties of West Florida.[48]

Salt water intrusion is local in the sparsely settled coastal areas of West Florida. Analyses of water from artesian springs and wells in this area show that the normal chloride content of these waters is less than 25 ppm except for well-known mineral springs. It is believed that a chloride content of 196 ppm in the Wakulla County USGS Well No. 15, St. Marks' city well, 175 feet deep cased to 40 feet, indicates salt water intrusion in the unconfined aquifer.

In Walton County, USGS Well No. 13, O. H. Saltsman, at Point Washington, drilled 450 feet deep, contained 450 ppm chloride in April 1948 and 250 ppm chloride in October 1948. USGS Well No. 14, Grammar School at Point Washington, drilled 400 feet deep, contained 410 ppm chloride in April 1948 and 206 ppm in October 1948. These wells are located on Choctawhatchee Bay and salt water intrusion is indicated.

No evidence of serious salt water intrusion is shown in the data for Santa Rosa, Okaloosa, Gulf, Franklin, Jefferson, Taylor, and Dixie Counties on the Gulf Coast or for the counties of West Florida that do not border the Gulf of Mexico.

The effect of huge withdrawals by large industries, Armed Services installations, and the larger municipalities when located near the coast may be illustrated by examples in Escambia and Bay Counties.

ESCAMBIA COUNTY

According to Cooke,[31] "a layer of Pleistocene sand and gravel covers much of Escambia County. The underlying Citronelle formation (Pliocene) is exposed in bluffs along the rivers and bays as far south as Pensacola." An interesting situation is that of Newport Industries, whose wells are located within one mile of Bayou Chico at Pensacola. Their wells No. 2, 3, and 4 were abandoned before 1943 due to screen failures and increase in salt content. Well No. 5, 2400 feet from Bayou Chico and Well No. 6, 2500 feet from Bayou Chico, were reduced in output in 1947 from 2000 gallons per minute to approximately 1000 gallons per minute because of increasing chloride content in these wells. Well No. 7, 2500 feet from Bayou Chico, had increased from 8 ppm chloride in 1940 to 235 ppm in 1948 and is on a stand-by basis. In contrast, Well No. 8, 4800 feet from Bayou Chico and Well No. 9, 4000 feet from Bayou Chico, have thus far maintained an almost constant chloride content of 8 and 18 ppm chloride with withdrawals of 2000 gallons per minute each.

It is known that the U. S. Navy abandoned wells across Bayou Chico from Newport Industries because of high chloride content. According to the City Manager of Pensacola, salt water encroachment in this area is rather slow and gradual. It usually requires from 15 to 20 months after the first rise in chloride content before a well has salted to such an extent that it is unusable. The Pensacola supply, which is derived from five shallow wells, contained 12 to 16 parts per million chloride in April 1948. According to records furnished by the District Engineer, Ground Water Division, U. S. Geological Survey, Tallahassee, Florida: the water level in Escambia Well No. 45, about 0.5 mile south of Cantonment, which averaged 44.40 feet msl in 1948, was 15 to 20 feet lower than in 1941. The water level in Escambia Well No. 46, about 0.4 mile east of Ensley, which averaged 69.83 msl in 1948 has risen from 6 to 11 feet since 1941. The water level in Escambia Well No. 60 (foot of H Street, Pensacola) averaged 2.04' above msl in 1948 and has recorded no really noticeable difference between 1941 and 1948. The danger of salt water intrusion at the latter point of low piezometric head is obvious.

A 1951 water resource study, by Ralph C. Heath and William E. Clark, "Potential Yield of Ground Water on the Fairpoint Peninsula (Santa Rosa County), Florida"[65] shows an upper (unconfined) aquifer to a depth of 60 to 85 feet below land surface, composed of sands of Pleistocene and Recent age, with water containing less than 39 ppm total dissolved solids. The upper aquifer is separated from a lower aquifer by 10 to 20 feet of clay that acts as an aquaclude. The lower aquifer, beginning at 80 to 110 feet below land surface and extending to 120 or 160 feet, is composed of argillaceous clay, probably of Pliocene age. While generally fresh throughout the peninsula, water in the lower aquifer is salty near the shore to indicate that it is in contact with the sea.

Pumping tests indicate that the upper aquifer will probably yield 100,000 gallons of water per day without danger of salt-water encroachment. The lower aquifer is believed to be suitable only for domestic supplies when the withdrawal from individual wells is usually small.

BAY COUNTY

According to Cooke,[31] "The Peninsula south of St. Andrews Bay was under water during Pamlico time (Figure 10). The shore of the Gulf followed the north shore of St. Andrews Bay from St. Andrews to Millville but lay 2 or 3 miles inland east of Millville. All parts of Bay County are probably underlain by the Citronelle formation or its off-shore equivalent, but most of the county is covered by Pleistocene terrace deposits."

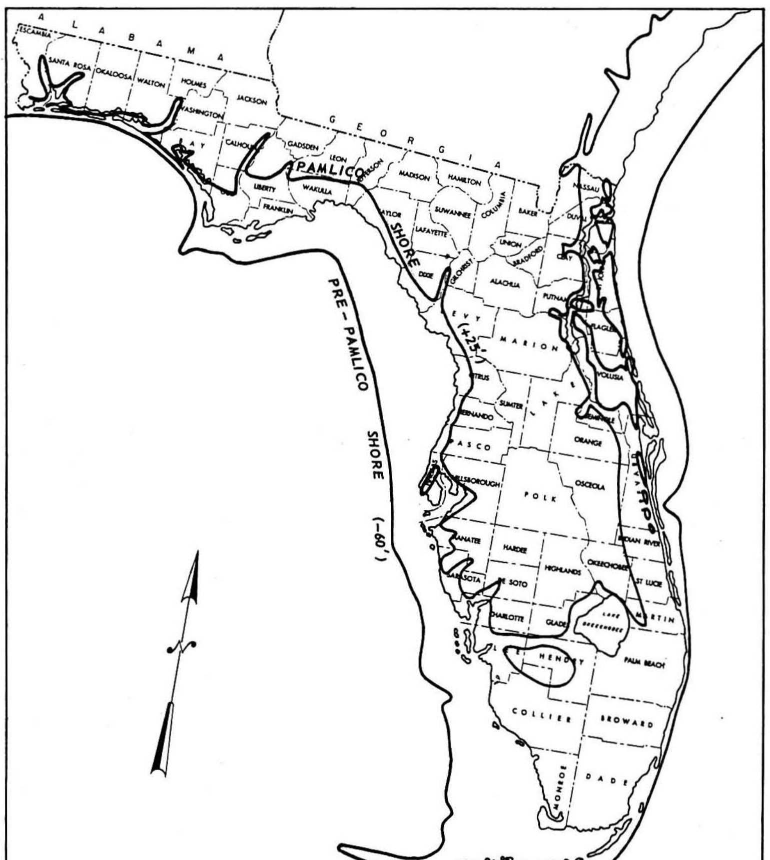


FIGURE 10. Pamlico and pre-Pamlico Shore Lines in Florida.
(From Florida Geological Survey Bulletin No. 17).

The 98 to 148 foot cased Millville wells for Panama City do not show evidence of salt water intrusion as the chloride content in all wells was less than 21 ppm during 1948 and these wells have been practically constant in chloride content since 1936. According to records of the District Engineer mentioned above the water level in Bay 7 Well at St. Andrews averaged 18.85' above msl in 1947 and was about two feet higher in 1948. The 650 foot St. Andrews wells of Panama City, cased to 150', do not penetrate the principal artesian aquifer whose surface is 900 or more feet below sea level and whose piezometric head is less than 10 feet. Their chloride content of less than 100 ppm may be due to salt residuals of the Pamlico Sea (+25' msl) or to salt water intrusion. There is danger of salt intrusion if the head in the unconfined ground water table or surface basin is lowered less than 640/40 = 16 feet above mean sea level.

The Southern Kraft Division of International Paper Company at Panama City, Millville area, abandoned their wells No. 3 and No. 7, located on a narrow peninsula between St. Andrews Bay and Watson Bayou, because of salt water intrusion. They developed a new well field farther inland. Wells No. 1 and No. 2 adjacent to Bayou Martin, an arm of St. Andrews Bay, have shown increasing chloride content, while Well No. 5, adjacent to Watson Bayou showed a chloride content of 390 ppm in September 1948. Although their new well field is farther inland than the Panama City Millville wells, they show increasing chloride content in a few cases that may be due to salt residuals of the Pamlico Sea that covered this area.

B. Salt Water Intrusion Along the Gulf Coast of Peninsular Florida

The upper Eocene limestones have been eroded and washed away from an area that includes most of Levy County and the northern half of Citrus County. This area extends to the Gulf Coast from the Wacasassa River south to Crystal Bay (Fig. 5). A middle Eocene formation, the Avon Park, outcrops at Sulphur Springs on the Wekiva River three miles southwest of Gulf Hammock,[49] and represents the oldest limestones that occur in surface exposures in Florida (Figure 6).

In 1950 the Cedar Key municipal supply, consisting of five wells, had a composite analysis showing 675 ppm chloride as evidence of salt water intrusion. In 1947 the 160 foot well of the Florida Power Corporation at Inglis had 429 ppm total dissolved solids, 17 ppm chloride, and 288 ppm total hardness. The latter evidently is drawing water from older sediments at about the ten foot piezometric contour. In contrast the valley of the southern Withlacoochee River is a discharge area with its accompanying piezometric saddle from which huge springs of low mineralization flow. For example Rainbow Springs on the 30 foot piezometric contour has an annual mean flow of 452 m.g.d.,[32] 81 ppm total dissolved solids, 3.5 ppm chloride and 69 ppm total hardness. This spring evidently is overflow from an aquifer with a nearby recharge area, as mineralization would progressively increase as the distance from the recharge area increases. The potential uses of such a large volume of water of constant temperature and low mineralization by industry are evident.

The upper Eocene limestones occur at sea level between Crystal River and the Chassahowitzka River along the Gulf Coast of Citrus County. They then dip from sea level at the northern border of Hernando County to 200' below sea level in the vicinity of Hudson in Pasco County. The Suwannee (Oligocene) is the surface exposure for Hernando County and all except the southwest quarter of Pasco County. The Crystal River municipal supply, from a well 150' deep, has 125 ppm total dissolved solids, 3 ppm chloride and 98 ppm total hardness. This mineralization is the same as at Inverness and both are probably outflows from a nearby recharge area in the Tsala Apopka Lake region. Homosassa Springs with a mean free flow of 120 m.g.d.[32] is highly mineralized with 1200 ppm total dissolved solids from residuals or by tidal effects. Chassahowitzka Springs with a mean free flow of 53 m.g.d.,[32] has 261 ppm total dissolved solids, 53 ppm chloride and 176 ppm total hardness. The abundance of water in the aquifers of this region is further evident from the mean flow of 102 m.g.d. at Weekiwachee Springs, 12 miles southwest of Brooksville and 10 miles from the Gulf on the 50 foot contour with 161 ppm total dissolved solids and 8ppm chloride. This spring has a carbonate hardness

of 144 ppm to class it as a moderately hard water whose origin is probably in the Tampa Piezometric High south of Brooksville.

The Gulf coastal area of Citrus and Hernando Counties is a north-to-south strip of only a few miles width. The steep gradients toward the Gulf from the Central Highlands that border this region on the east indicate a discharge area in which the drainage is by means of "runs" or rivers from springs to the Gulf, carrying the overflow of aquifers at several piezometric levels. There are no large withdrawals of water by cities or industries, so there is no evidence of salt intrusion.

PASCO COUNTY

The surface of the Upper Eocene limestones dips from 200 feet below sea level at Hudson in Pasco County to 300 feet below mean sea level at Tarpon Springs in Pinellas County. Tampa limestone (Miocene) becomes a surface exposure in the southwest quarter of Pasco County. According to records from the office of the Florida State Geologist, a well (+42' msl) drilled at New Port Richey during January 1949 shows Pliocene to Recent 0 to –65 feet, Tampa (Miocene) –65 to –75 feet, and Suwannee limestone (Oligocene) –75 to –200 feet. Absence of Hawthorn (Miocene) means absence of any impermeable layer to prevent vertical intrusion. In a deep well drilled at Oldsmar in 1942, Florida Geological Survey W–8, the Eocene was penetrated at a depth of –320'. The well was completed to a total depth of 3255' and on August 10, 1942 the water had a chloride content of 2100 ppm. Variations in the chloride content of the old city well at New Port Richey were noted early in 1948 and brought to the attention of the Chairman of the City Council at New Port Richey, with the result that drawdown tests have since been used to supplement frequent analyses of chloride content. The static level on June 3, 1948 fell from 4.98' at start to 2.40' msl while pumping 490 g.p.m. and the chloride was raised from 180 to 610 ppm. The piezometric level was lowered sufficiently during periods of high pumping to approach mean sea level which was below salt water levels in the nearby river and the Gulf of Mexico during periods of high tide. It was necessary to throttle the deep well pump discharge to limit the drawdown and prevent further salting until a new well could be drilled in an area of higher elevation, +42' msl, and higher piezometric head, +5' msl. The 1949 well was drilled to a depth of 200 feet with 150' of casing. It yields 250 g.p.m. with a drawdown of 2 feet and maintains a static head of +3' (msl) while pumping. On June 11, 1949 the chloride content was 79 ppm. Various private wells in the New Port Richey area show evidence of widespread salt water intrusion.

PINELLAS COUNTY

Pinellas County is the only county in the State of Florida in which problems of and remedies for salt water intrusion are not self-contained. The base of the Pinellas Peninsula has long been known as an outflow area from which highly mineralized waters are discharged. Numerous wells in the area east of Palm Harbor and north of Safety Harbor and Oldsmar have been affected by salt water intrusion. Wall Springs on the Gulf Coast and Espiritu Santo Springs at Safety Harbor on Old Tampa Bay are well known mineral spas. It is believed that these springs represent leakage through highly mineralized sediments that have not been flushed of their mineral contents because of low piezometric head due to absence of the Hawthorn clays that act as an aquaclude. A study of Figure 10 reveals that a seaway existed from Oldsmar by way of Lake Tarpon to New Port Richey during the +25' msl Pamlico Sea. This sea drowned aquifers that remain salty to the present day. A study of well logs in the Cosme Odessa well field reveals an estimated 35 feet of Hawthorn at approximately mean sea level, while the absence of the Hawthorn is noted in the logs of wells at New Port Richey and Oldsmar, to indicate erosion of the Hawthorn.

Salt water intrusion may result in either of two ways. In the absence of an impermeable aquifer, it may penetrate a formation either laterally or vertically. If, however, an impermeable formation or aquaclude is present below the surface, such formation will serve to check the vertical rise of salt water and intrusion can take place laterally only above such an aquaclude. All geological evidence indicates that conditions for both lateral and vertical intrusion of salt water exist throughout the entire extent of Pinellas County and that the Ghyben and Herzberg equation relationships may be properly applied throughout the entire county. This results from the fact that the formations are known to be permeable, that salt water is present on both sides of the narrow peninsula which is Pinellas County, and that the maximum fresh water head of 16 feet is sufficient to depress salt water to a maximum depth of 640 feet below sea level.

The Eocene limestones in Pinellas County are not considered as the principal artesian aquifer. Because of contact with the sea through porous formations they are characterized by high mineralization with its resulting high hardness, and in addition have high hydrogen sulfide content. The principal aquifer for Tarpon Springs and New Port Richey is the Suwannee (Oligocene) limestone with less than 8 ppm silica and less than 15 ppm magnesium ion content. The younger Tampa (Miocene) limestone underlies all Pinellas County and occurs as surface exposures in certain parts of Pinellas County. In much of the area the Tampa limestone is overlain by unconsolidated Pleistocene surficial deposits. The Tampa limestone forms with the widespread underlying Suwannee limestone a continuous aquifer. Outcrops of Tampa limestone occur near Palm Harbor on the Coast, so a permeable formation is in direct contact with sea water in the Pinellas Peninsula as the formation dips to the south.

Saint Petersburg

The former supply of the City of St. Petersburg was from local artesian wells. The steadily increasing withdrawal of fresh water from the formations permitted the entrance of salt water to such an extent that serious damage has been done throughout the area. Due to the lack of surface storage the past and present supply depends on wells. In 1929 the present Cosme Odessa well field was located 37 miles away in NW Hillsborough County, in order to get away from salt water intrusion. The city completed the construction of the well field and a modern filtration plant. The raw water from the well field has 173 ppm total dissolved solids, 142 ppm total hardness and 8 ppm chloride content.

Tarpon Springs

Tarpon Springs has a unique history insofar as its water supply is concerned. About 1930 a complete coagulation and filtration plant was constructed to take water from Lake Butler, now Lake Tarpon, but before the plant was placed in operation, it was found that the chloride content of this particular lake was excessive and the water could not be used. Therefore, this plant was abandoned. In 1948 Tarpon Springs had two wells on Groose Avenue, whose composite varied from 190 ppm chloride to 470 ppm, with an average of 300 ppm chloride. According to records of the District Engineer, Ground Water Division, U.S.G.S., Tallahassee, the head was +3.23' msl in 1947 and 2.99' msl in 1948. This represents definite and serious salt water intrusion in an area of low piezometric head. By November 1952 Tarpon Springs had abandoned the Groose Avenue No. 1 well because of excessive chloride content. The chloride content of Groose Avenue No. 2 well was 117 ppm. Lake Tarpon No. 3 well was on a stand-by basis except for use during 5 to 6 days per month, after which use it becomes salty. Number 4 Golf Course well varies in chloride content. Wells No. 5 and No. 6 were aban-

doned. Well No. 7 on East Tarpon Avenue was drilled in May 1951 to a depth of 97 feet with 48 feet of casing. The water contained 199 ppm total dissolved solids, 101 ppm chloride and 88 ppm total hardness during October 1952. In summary, salt water intrusion has been and is an immediate problem for Tarpon Springs.

Dunedin

Higher terraces up to the Penholloway Terrace (65 to 70 feet msl) have maintained an "island"(with higher piezometric head east of the Clearwater and Dunedin areas)that runs from Seminole almost to Tarpon Springs. In order to visualize the situation, the reader is again referred to Figure 10 which shows the Seminole-Clearwater-Palm Harbor area as an island in the 25 foot Pamlico Sea. This condition also existed during the earlier 42 foot Talbot Sea (Figure 11). East of Clearwater, these higher

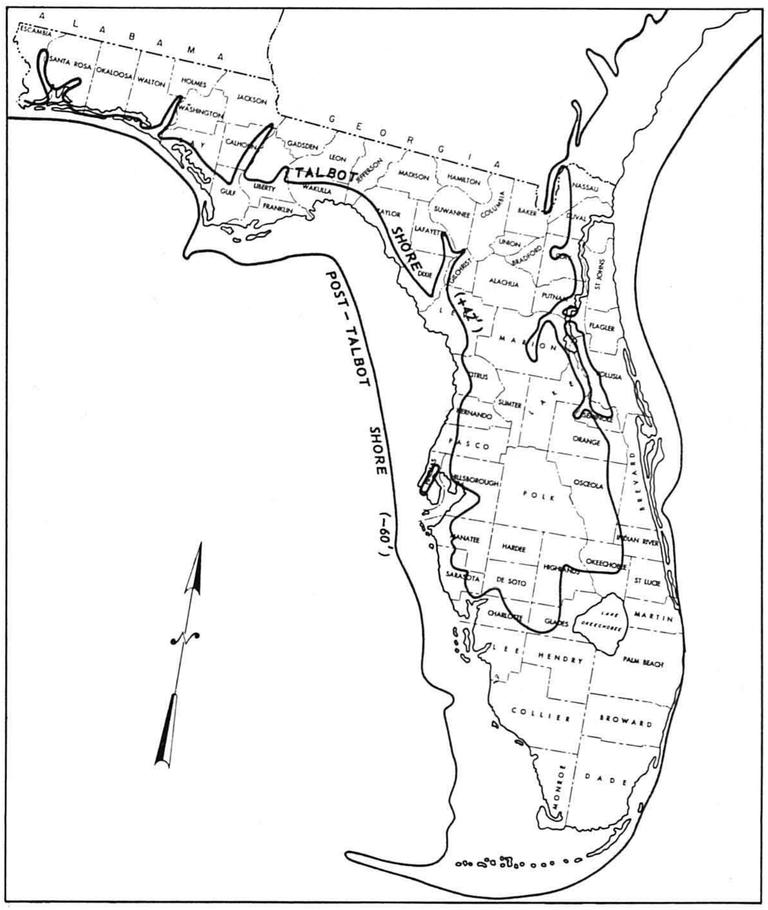


FIGURE 11. Talbot and post-Talbot Shore Lines in Florida.
(From Florida Geological Survey Bulletin No. 17).

terraces constitute an aquifer with a piezometric head up to 16 feet that has become known as the Coachman High. In this area as elsewhere throughout the county this aquifer may be considered as fresh water that is floating on more highly mineralized water. Because of comparatively shallow wells, low rate of pumping, and head, the chloride content during 1948 of Dunedin's 147 foot Broadway No. 1 well was 50 ppm, and Dunedin's 149 foot Highland Avenue No. 2 well was 28 ppm. During October 1952 the No. 1 well had increased to 81 ppm chloride but the chloride content of No. 2 well showed no change. The No. 3 well, depth 153 feet, was drilled during 1949 through a weathered hard layer to porous limestone, and its chloride content in October 1952 was 34 ppm. The neighboring eight wells of Florida Division, Clinton Foods Incorporated, operate at much higher pumping rates and vary from 200 to 400 feet in depth. In October 1952 the 200 foot wells had 170 to 458 ppm chloride, while a 300 foot well had 636 ppm chloride and a 400 foot well had 735 ppm chloride. All of these wells respond to tidal variations as does nearby Curlew Creek and all show immediate decrease in chloride content after heavy rainfalls to indicate that the increased weight of water in the nearby fresh water aquifer changes the gradient sufficiently to push the more saline water to greater depths.

That chloride concentrations have been no problem in this particular city is due to two reasons: the demand has not exceeded available well yield which would cause a rise in chloride concentrations, and they are fortunate enough to be on a ridge section on a piezometric contour where water stands higher above sea level than in most sections of the county. However, it can be stated with certainty that when demands increase, the City of Dunedin will have to look outside its present well supply for an adequate supply of potable water.

Clearwater

The City of Clearwater derives its supply from 15 wells penetrating the underlying Tampa limestone to depths ranging from 195 to 296 feet. As the city has grown and demands upon the system have increased, the salt content has risen steadily to a point where during the dry spring season the chloride content is well above the maximum concentration allowable by the U. S. Public Health Service and the Florida State Board of Health.

For a period of several months during 1948 the water research project analyzed water samples from several of the Clearwater wells for chloride content. This work was repeated in August 1952. Table 9 shows the chloride values for 1948 and for the same wells four years later.

These results clearly indicate that while the effect has been more pronounced in the case of some wells than others, there is probably not a single well in the present well field which is not showing to a greater or less extent the characteristic variations in chloride content due to salt water intrusion. By August 1952 Clearwater had abandoned well Nos. 6, 9, 10, 14, 15, and 20. The early abandonment of well Nos. 8, 19, and 22 is indicated. The chloride content of many Clearwater wells decreased due to decreased pumping with the advent of summer rains or due to rapid recovery by local recharge. However, several wells adjacent to Clearwater Bay were saline beyond recovery and of necessity were abandoned. Of greater interest, well No. 14, located far inland on the municipal Golf Course, reached a value of 1068 ppm chloride. Equally disturbing is the fact that a sample of water from the U.S.G.S. observation well located between the 10 foot and 12 foot contours in the recharge area between Coachman and Safety Harbor, showed a chloride content of 531 ppm. This fact, together with the high chloride content of municipal well No. 14 on the Golf Course conclusively establishes the presence of salt water under the recharge area of the Coachman High. Hydrographs from test wells maintained by the United States Geological Survey clearly reflect the variations due to the seasonal nature of the annual rainfall, and also graphically the tidal effects on the fresh water table. Because of these facts, it is felt that it must be assumed that salt water lies beneath the entire Pinellas Peninsula at depths dictated by the Ghyben-Herzberg equation. The need for a supplementary source of water for Clearwater is immediate.

TABLE 9

CHLORIDE CONTENT OF EIGHT CLEARWATER WELLS

Well	1948 Maximum	June 1952	August 1952
No. 7	---	223	101
No. 8	160	343	226
No. 13	120	75	---
No. 18	---	97	55
No. 19	55	90	174
No. 21	24	42	38
No. 22	50	204	289
No. 23	20	34	27

Pinellas Park

During 1948, it was found that the No. 2 Pinellas Park well had a chloride content of 492 ppm and that No. 1 well had a chloride content of 563 ppm. These wells have since been abandoned and the city of Pinellas Park now secures its entire municipal supply from the St. Petersburg Water System.

Pinellas County Water System

Because of the inability of the Gulf Beaches to produce fresh water in any appreciable quantity, the Board of County Commissioners in 1937 instituted the formation of the Pinellas County Water System to supply the towns along the coast from Belleair Beach to Pass-a-Grille. That well water was not available within any appreciable distance is evidenced by the fact that the original water system used surface water as a raw water supply. The original reservoir was formed by constructing a dam across McKay Creek and had a capacity of 20 million gallons. At a later date the spillway height was increased to increase the capacity of the reservoir to 40 million gallons after which an additional dam was placed on McKay Creek providing an additional 150 million gallons. The McKay Creek source was further developed to a capacity of 300 million gallons, making the total reservoir capacity 450 million gallons in 1952. However, in 1946, with the addition of new treatment plant facilities, two 300 foot wells were drilled to augment the surface supply. When these first wells were put into service in mid 1946, the chloride content ranged from 90 to 120 parts per million but the concentration has risen well above 300 parts per million at the present time. With the advent of the 1949 Spring Season, the use of these two supplementary wells adjacent to the surface reservoirs was begun on 27 March for one week with a consequent increase in chloride content.

TABLE 10

CHLORIDE CONTENT OF TWO WELLS OF PINELLAS COUNTY WATER SYSTEM

	3 June 1946	27 March 1949	2 April 1949
North Well	90	246	300
South Well	118	198	645

The wells have since been on a stand-by basis, and when used have immediately shown increasing chloride content. These wells reflect definite salt water intrusion far inland near Walsingham in Pinellas County. Salt water intrusion is widespread in Pinellas County in the area south of Largo and particularly along the Gulf Beaches. It is, therefore, necessary to provide fresh water as a first necessity in support of a beach development whereby millions are being invested in apartments and homes for year round visitors. Currently, the Pinellas County Water System is expanding in an attempt to keep the beaches adequately supplied with water, and is investigating supplies inside of Pinellas County as future sources of water. The long range plan contemplates the development of a well field east of Lake Tarpon in an extreme north-east area of Pinellas County. The contemplated transmission line parallels the Lake Fern Road to U. S. Highway 19 in Tarpon Springs. Thence, south along newly located U. S. Highway 19 to Belle Haven. Thence, south via Coachman and County Road 27 to County Road 54 east of Largo. Thence, west to Largo and south via County Road 15 to a connection with the Indian Rocks plant east of Walsingham. The plans are to furnish towns and others, if desired, with an adequate supply of water of better quality than locally available. The November 1951 twelve-inch test well 4.5 miles east of U. S. 19 on Lake Fern Road was drilled to 380 feet and cased from +25' msl to −148' msl. After pumping for 28 hours at the rate of 650 g.p.m. the water had 220 ppm total dissolved solids, 214 ppm total hardness and 12 ppm chloride. Plans are in progress to develop an interim supply in the Coachman High. According to a report by the Florida State Geologist, a test well No. 1 drilled in this area to a depth of 313 feet and cased for 75 feet was completed on December 12, 1952. The well was drilled at an elevation +80' msl. The piezometric head was +12.4' msl and when pumped at 415 g.p.m. had a drawdown of 3.5 feet. The water had 173 ppm total dissolved solids, 135 ppm total hardness and 12 ppm chloride. It is therefore of better quality than the 1951 test well water, but is in limited supply. There is no evidence of salt water intrusion and further exploration to determine the actual position of underlying salt water will be of interest. The F.G.S. report shows geologic formations by depths as follows:

0' to 35' Pleistocene
35' to 45' Area Zone
45' to 70' Hawthorn (Miocene)
70' to 250' Tampa (Miocene)
250' to 313' Suwannee (Oligocene)

From the preceding statements, it is obvious that the problem of salt water intrusion into water-bearing aquifers of a large portion of Pinellas County is acute. In many areas the chloride content has increased to a concentration where the water is no longer potable. The increase in chlorides in many municipal supplies is rapidly approaching a danger point, and since the maximum undeveloped perennial yield has been recently reported to be 8 mgd, a new source of water, ample in quantity and superior in quality, must be provided in order to assure a sufficient supply for the growth of the county. In 1947 the U.S.G.S. in cooperation with the F.G.S. began a careful and detailed study of the geology and hydrology of the county to determine the extent of salt water intrusion. Within the next few months a general report on ground water resources of Pinellas County is expected.

HILLSBOROUGH COUNTY

The various aquifers in the Tampa area have been penetrated by numerous wells and are fairly well known. An inspection of the logs of wells drilled in Hillsborough County indicates that the Hawthorn formation is at or very near sea level throughout most of the Tampa area and varies in thickness from less than 25 feet in some areas to 90 feet in others. According to Florida Geological Survey Report No. W–1604, a well drilled in October 1947 for the Tampa Electric Company on Hooker's Point shows geologic formations by depths as follows:

0' to 23' Hawthorn limestone (Miocene)
23' to 380' Suwannee limestone (Oligocene)
380' to 510' Ocala limestone (Upper Eocene)
510' to 542' "Lower Ocala" limestone (Upper Eocene)
542' to 592' Peronella dalli bed (Upper Eocene)
592' to 720' Avon Park limestone (Middle Eocene)

Below the Hawthorn is also found Tampa limestone overlaying the Suwannee limestone which overlays the Ocala limestone. It is probable that wells less than 400 feet deep derive their water in this area largely from the Tampa limestone and Suwannee limestone, whereas wells drilled to greater depth and cased to 400 feet derive their water from the Eocene. These formations may be described as porous and permeable limestones and give large yields to wells penetrating them. As the city and its environs have grown and as industrial expansion has taken place, the increased demands for water have brought about salt water intrusion.

From the map representing the piezometric surface in Florida, (Fig. 7) it is evident that water can flow south downslope from the 80 foot Tampa High to the South of Brooksville,

or west from the 120 foot Southern High in Polk County. There is a "saddle" or low pressure belt along the Valley of the Hillsborough River as this valley has springs with a large outflow. A ten foot piezometric contour originally protected the Tampa area by static pressure that prevented salt water from entering the formations and caused many wells to have artesian flow. The original supply of the City of Tampa consisted of about 25 wells drilled to depths of approximately 200 feet within a mile radius of the City Hall. These wells were drilled between 1901 and 1910 and were artesian with sufficient head to flow into surface reservoirs. Increased draft lowered the piezometric head and increased the chloride content so that it was necessary to seek a surface supply in 1924.

Many wells in downtown Tampa are used as a source of cooling water for air conditioning or refrigeration systems. The Tampa Cold Storage Company and the Atlantic Ice Company abandoned such wells because the increased salinity rendered the water excessively corrosive. One analysis of water in such a well used for air conditioning by Sears Roebuck & Company showed 820 ppm chloride and water from a similar well used for air conditioning by Southern Brewing Company contained 1740 ppm chloride in June 1948. All wells in downtown Tampa, of which records are available, yield waters containing relatively high chloride concentrations and many wells of high salinity and accompanying high corrosiveness have been abandoned. An inspection of Table 11 indicates that the chloride content becomes progressively less and less in wells on the higher terraces and under higher piezometric head as the distance from tidal water in the bays and river increases. For the Tampa area, the statement can be made that Hooker's Point area and most of downtown Tampa is salted to such an extent that well water

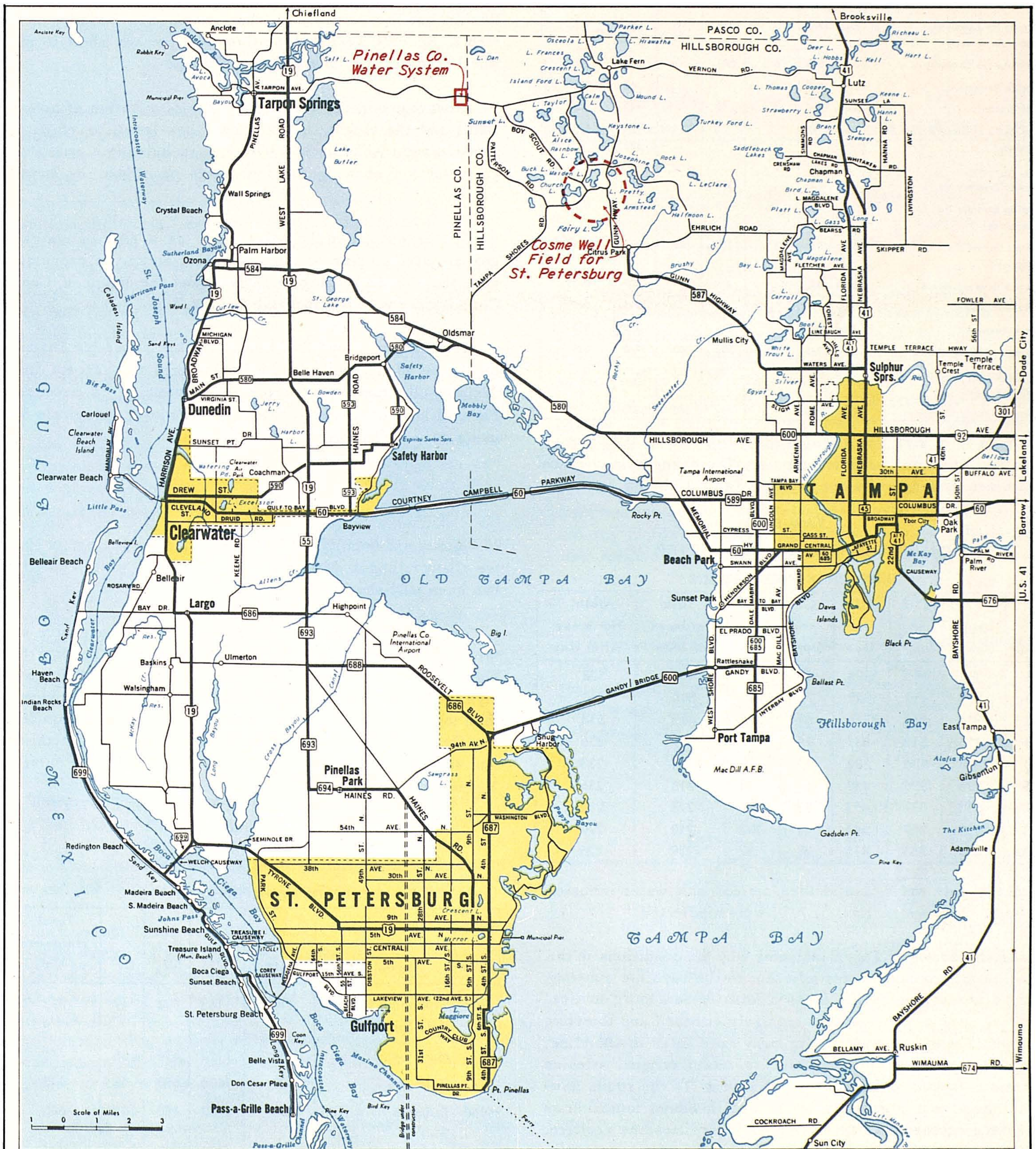


FIGURE 12. St. Petersburg, Tampa and vicinity showing McKay Creek reservoirs, Cosme Well Field, Pinellas County Water System wells and other pertinent information.

is not potable. In contrast wells on the higher terraces have low chloride content as indicated in the next table.

TABLE 11

CHLORIDE CONTENT OF WELLS IN THE TAMPA AREA

Well	Date of Analysis	Diam. (inches)	Depth (feet)	Cased (feet)	Cl ppm	Dist. in Mi. From Tidal Waters
Composite sample of 9 wells for Tampa Municipal Supply	Feb. 1908				253	
Composite sample of all wells and Magbee Springs constituting the Tampa Municipal Supply	Sept. 1922				584	
City Laundry, Osborne & 19th	Aug. 1948	6	308		16	2.5
City Well, Buffalo & 15th St., Stand-by	Aug. 1948				18-39	2.25
Drew Field No. 5, Stand-by	Aug. 1948	5	508		22	2
Purity Springs, Composite	June 1948				40	4.5
Florida Ice Company, 3400 Neb. Avenue	Aug. 1948	8	350		46	1.75
Seminole Ice Company	Aug. 1948	6	281		76	2.25
Florida Brewery No. 3	July 1948				148	0.25
Wolf Brothers	Aug. 1948	4	70		149	0.5
City Wells at Bway & 23rd St., Stand-by	Aug. 1948				180 180 250	0.6
Florida Brewery No. 1	July 1948	3	500			
Florida Brewery No. 2 Composite	July 1948	2½	500		203	0.25
Tampa Coca-Cola Bottling Company	July 1948	6	180	180	268	0.5
Florida Brewery No. 4	July 1948		325		280	0.25
Walgreen Drug	July 1948		51		328	0.5
Sears Roebuck	Aug. 1948				820	0.5
Southern Brewing Company	June 1948	6	300	180	1740	0.5
Tampa Electric Company, Hooker's Point	Oct. 1947		720	117	15500	0
Tampa Electric Company	Oct. 1947		704	140	15500	0

A group of nine wells drilled at Drew Field in 1942 became highly saline after a few months use. The changes in chemical character of these wells are listed in Table 12 below.

TABLE 12

CHANGES IN CHEMICAL CHARACTER OF NINE DREW FIELD WELLS

No.	Depth (feet)	TDS at Start	TDS After Use	Cl at Start	Cl After Use	Total Hardness at Start	Total Hardness After Use
1	334	395	1698	76	690	448	528
2	214	411	1829	72	762	598	551
3	208	371	1718	51	696	403	514
4	436	513	647	96	149	389	306
5	508	286	301	22	30	231	233
6	208	336	450	44	84	218	256
7	511	307	453	23	28	223	232
8	513	359	544	44	102	210	290
9	478	356	415	30	32	239	226

Of these nine wells, six showed serious salt water intrusion and only three wells, Nos. 5, 7, 9, were unaffected.

An inspection of Fig. 6 indicates why the conditions in the Pinellas-Hillsborough areas adjacent to the bays are substantially different from similar areas of Manatee-Sarasota Counties. Not only is the former area extensively embayed and therefore in contact with salt water along many more miles of shoreline, but more important an aquaclude to retain original artesian pressures is thin, discontinuous, or absent. To the south, however, the almost completely impervious Hawthorn formation as a surface exposure overlays the underlying limestone aquifers. As a result, as has been shown above, salt water intrusion is widespread in the exposed permeable formations of Pinellas-Hillsborough Counties, whereas salt water intrusion is not taking place through the Hawthorn formation in the counties to the south where artesian pressures, while somewhat lower near the coast, are still sufficient to guard against salt water intrusion.

Preliminary results of an investigation by the Florida Geological Survey of the ground water resources in the Ruskin area are in press for publication as an Information Circular: "The Artesian Water of the Ruskin Area of Hillsborough County, Florida," by Harry N. Peek, U.S. Geological Survey. A published summary of the findings contains the following statements with respect to this area:

"There are three small areas in the vicinity of Ruskin, about 18 miles south of Tampa, in which wells yield water with a relatively high salt content. One of these is at Adamsville, about nine miles north-northeast of Ruskin, and two are between Ruskin and Adamsville, as shown on a map included in the report. Records available at this time are too short to show whether these salty areas are expanding.

Other maps in the report show the distribution of artesian wells and the height, in feet above sea level, to which the artesian water will rise in wells. Also included is a generalized cross-section showing the formations penetrated by artesian wells.

The investigation is being made as a part of statewide ground-water studies of the Geological Survey in cooperation with the Florida Geological Survey and the Board of County Commissioners of Hillsborough County."

According to Lloyd Dickman of Ruskin Vegetable Distributors, most of the wells in the Ruskin area flow except during January, February and March when pumping is necessary. Farmers know they are to watch the drawdown and refrain from using deep well pumps.

MANATEE COUNTY

Matson and Sanford[25] have described the geology of Manatee County, and a description of the ground water conditions has been published by Stringfield.[5]

The Hawthorn formation occurs as a surface exposure near the coast and extends to depths of four to five hundred feet before it overlays about 150' of Tampa limestone, which overlays the Eocene limestones. Other surficial deposits are younger than the Hawthorn formation. The principal artesian aquifer is the Ocala limestone with waters that are highly mineralized and very hard, as shown in Table 13 taken from Water Survey & Research Paper No. 6.

TABLE 13

CHEMICAL CHARACTER OF DEEP WELLS IN MANATEE COUNTY

Year	Well	Depth	TDS	SO_4	Cl	Total Hardness as $CaCO_3$
1908	Bradenton former Well Supply	410	1163	594	49	773
1923	Manatee	650	1173	616	38	745
1947	Palmetto	620	1600	650	50	916
1950	Rubonia Irrigation Well	800	1100	480	181	643
1950	Tellevast Irrigation Well	823	910	463	81	567

The great depth of the Hawthorn seal and excessively high mineralization of these artesian waters indicates remote recharge of the underlying strata. Water from the Hawthorn will vary in quality depending upon local residuals. Water from surficial material is limited in quantity and usually soft, unless contaminated by sea water near the coast. Over one thousand irrigation wells with heads up to 30 feet above mean sea level have been drilled in the western areas of the county where land surfaces are low. Bradenton, the county seat and largest city, abandoned well water as a source of municipal supply about 1940, and developed a surface supply from Lake Ward.

In 1932 connate water having more than twice the salinity of sea water was found in H. C. Ditmas' 398 foot well on Anna Maria Key.(5)

SARASOTA COUNTY

Stringfield(4) has made exhaustive studies of ground water in Sarasota County. Limited amounts of soft water may be obtained from shallow wells ending in surficial deposits and sometimes in the upper part of the Hawthorn Formation. Water from the lower part of the Hawthorn Formation, the Tampa limestone, and the Ocala limestone is similar in chemical quality to that in Manatee County. Near the coast in areas of low head, highly saline waters with high chloride content are found in the Hawthorn Formation and the Tampa limestone. Salt Spring and Little Salt Spring in Sarasota County(18) are sink-hole lakes that yield highly saline waters.

The City of Sarasota uses highly mineralized waters from wells as a source of municipal supply. Zeolite softening is provided, due to the excessive hardness. Sulfates and fluorides are also excessive. Plans are in progress looking toward the development of a surface supply from the Manatee River and the new plant has been so designed as to treat this water when it is available.

In 1948 the chloride content of seven 135 foot wells in series at Venice was 76 to 90 ppm. The chloride content of No. 1 and No. 4 plant deep wells was 236 ppm. A 1947 analysis of the Warfield Avenue shallow well had 312 ppm bicarbonate, 251 ppm sulfate, 94 ppm chloride and 1159 total hardness.

CHARLOTTE, LEE AND COLLIER COUNTIES

The area of Florida south of Sarasota, DeSoto, and Highlands Counties, has been exhaustively studied by Parker.(18) Generally it may be said that the entire area has artesian water of high mineral content due to its great distance from the recharge area and due to solution of highly mineralized residuals.

Buckingham marl, Caloosahatchee Formation, and the Tamiami Formation outcrop in this area. Older limestone and calcareous deposits are found at great depths free from the clastic sediments characteristic of West Florida. The Fort Thompson Formation, Key Largo limestone, Anastasia Formation, Miami oolite, as well as Pleistocene terrace formations occur in South Florida. The Lake Flirt Marl and organic peat deposits of Recent Age also occur.

All of the area south of the Caloosahatchee River except the Devil's Garden was submerged by the 25 foot Pamlico Sea, and the latter area was submerged during the 42 foot Talbot Sea, both of Pleistocene epoch. (Figures 10 and 11).

TABLE 14

CHEMICAL CHARACTER OF RAW MUNICIPAL WATER SUPPLIES IN CHARLOTTE, LEE AND COLLIER COUNTIES

Year	Water Supply	Depth	HCO_3	SO_4	Cl	Total Hardness
1944	Punta Gorda Alligator Creek	----	256	42	175	334
1946	Punta Gorda Alligator Creek	----	244	31	102	257
1923	Fort Myers Former Artesian	495	----	331	822	742
1937	Fort Myers 1–13 Former Wells	37	254	80	202	369
1942	Fort Myers 1–20 Former Wells	37	257	26	74	274
1948	Fort Myers 21–36 New Wells	26	370	10	38	304
1953	Fort Myers 21–36 New Wells	26	361	65	50	384
1942	Naples 1–10	75	205	0	97	200
1950	Naples 1–17	75	200	0	26	184
1952	Naples 1–22	75	220	8	21	180
1926	Everglades No. 1	432	294	80	133	236
1935	Everglades No. 2	462	294	118	696	549

Punta Gorda and Fort Myers

The same general conditions prevail at both Punta Gorda in Charlotte County and at Fort Myers in Lee County. Because of excessive hardness and mineralization both cities have abandoned use of deep-seated artesian wells. Punta Gorda has developed a surface supply from Alligator Creek. Appropriate chemical treatment is provided. At Fort Myers on the other hand, no surface supply is available within the present economic radius, and about 1935 the city constructed a new well field of 10 shallow wells and a modern softening plant. In 1940 a second shallow well field was developed adjacent to the first field. As water demand increased, most of the wells in the first field showed evidence of salt water intrusion and the second well field was ruined by trade wastes. After extensive investigation the city in 1947 developed and now uses a third shallow well field located three miles east of the water plant.

Shallow wells in Lee County near the coast are saline.

A situation similar to that found in the Gulf beaches in Pinellas County is also found at Fort Myers Beach. A very limited quantity of reasonably fresh water can be obtained from shallow well points, the fresh water floating on the underlying salt water. All deep-seated supplies are highly mineralized.

Naples

In the early days of Naples the quality of the water available was unsatisfactory, since it contained iron and in excess of 500 ppm of hardness. Through excessive pumping the water became salty. In late 1944, the city acquired through purchase a 1925 franchise from the Naples Improvement Corporation. In 1945, a softening plant was completed with a capacity of 250 g.p.m. supplied from 10 three inch shallow wells. In 1949, two additional wells were completed. In 1950, five additional four inch wells were completed. In 1951, the softening plant was enlarged to a capacity of 750 g.p.m. and five new wells added for a total of 22 wells with 75 feet average depth. The wells are skimming a Ghyben and Herzberg lens. A test well adjoining well No. 6 was deliberately drilled in January 1952 to −112 feet to locate salt water with 550 ppm chloride content.

Naples is an outstanding example of what can be accomplished by careful planning. As demands have increased, the

city, by adding wells properly spaced and pumped under controlled conditions, has been able to constantly assure itself of an ample supply of water of excellent quality, and should be able to do so for many years to come. The city has an ordinance regulating the drilling of wells within the city limits.

In a 24-hour pumping test conducted in August 1952, the rate of pumping was increased from 460 g.p.m. to 730 g.p.m. with practically no effect on water quality. In spite of that fact, however, it is planned to add new wells as water demand increases.

The deep wells at Everglades City are highly saline as indicated in Table 14.

C. Salt Water Intrusion Along the East Coast of Peninsular Florida

DADE COUNTY

The U. S. Geological Survey, in cooperation with Dade County and the cities of Miami, Miami Beach, and Coral Gables, began an exhaustive investigation of the ground water resources of Southeastern Florida in the fall of 1939. Their investigation of salt water intrusion is one of the most comprehensive to be found in this country, and is still continuing today. When the Water Research Project at the University of Florida began its study of salt water intrusion in the State of Florida in December 1947, it was not thought necessary to repeat the excellent work done by the U. S. Geological Survey in the Miami area, but rather to concentrate its work elsewhere and seek the cooperation of the U. S. Geological Survey in the preparation of this report. The personnel in the Miami office of the U. S. Geological Survey have cooperated with this Project to the fullest extent, releasing to us for our files their analyses and other pertinent data.

The discussion presented here is largely based upon publications cited in the Bibliography.(13,19,63)

Miami is on the Atlantic Coastal Ridge, an irregular, low, sand-mantled limestone strip some six miles wide lying between the marshy Everglades to the west and Biscayne Bay to the east. The latter is a shallow body of water separating the Atlantic Coastal Ridge from the off-shore bar on which Miami Beach is situated. In several places drainage canals have been cut through the Ridge to drain off water from the Everglades and Lake Okeechobee to the Atlantic Ocean.

Water Bearing Formations

Ground water in Southeastern Florida occurs in two principal ways: (1) as artesian water, confined under pressure in deeply buried formations and, (2) as unconfined water, in the shallower formations.

The artesian water occurs in the Eocene and associated younger limestones which supply ground water to wells throughout much of Florida. These limestones are generally considered as a hydrologic unit to which the name 'Florida Aquifer' has been applied (Parker, 1946).

Wells drilled through the confining formations will release this water and it will flow at the surface throughout Southeastern Florida. However, the artesian water in this part of the State is so highly mineralized as to be unfit for human consumption or for most industrial purposes.

The unconfined ground water occurs in a huge underground reservoir composed of the porous formations that lie above the confining layers capping the artesian aquifer. It is this unconfined ground water that is the source of most well water supplies in this area, and the highly permeable rocks that contain it have been referred to by Parker as the Biscayne aquifer.(63)

This aquifer is composed of beds of limestone, calcareous sandstone, and quartz sand, ranging in age from upper Miocene through Pleistocene. Along the coast this highly productive water-bearing formation generally extends to depths of about 120 feet, in certain areas to about 200 feet, and thins out to the west. Beneath the Biscayne aquifer lie beds of clay, marl, silt, sand, and shells which are relatively impermeable and act as confining beds for the artesian water in the underlying Floridan aquifer. In the Miami area this aquaclude is about 600 feet thick and includes not only the Hawthorn formation but also the greater portion of the Tamiami formation. (See Figure 13.) A more complete description of the geology of this area may be found in reports by Cooke,(31) Parker and Cooke,(18) and Parker.(63)

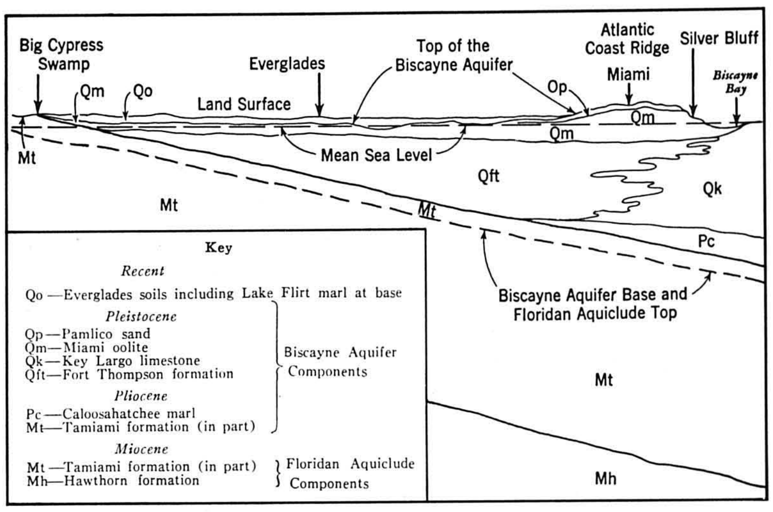


FIGURE 13. Cross Section of Miami Area showing geologic formations and Biscayne aquifer. Drawing not to scale. *(After Gerald G. Parker, U.S.G.S., Washington, D. C., and taken from p. 821, Jour. AWWA, Oct. 1951.)*

Water table maps for Southeastern Florida show that the ground water moves in an easterly or southeasterly direction, (See Figure 7), from the Everglades toward the sea, under a very low gradient. The drainage canals in the area influence the direction of this movement, with the consequence that a large volume of ground water reaches the sea by way of the canals.

Although some ground water moves into the area through slow southeastward percolation from the west, a much larger portion is derived through rainfall directly upon the area. Studies recently concluded(63) indicate that of the 60 inches of annual rainfall in Southeastern Florida some 63 percent, or 38 inches reaches the water table, whereas the remaining 37 percent, or 22 inches is lost by evapo-transpiration or surface runoff.

Studies of the permeability of the aquifer show it to be among the most permeable ever tested by the U. S. Geological Survey.(18)

Quality of the Ground Water

The quality of the ground water in the aquifer is fairly uniform. The concentration of total dissolved solids ranges from about 225 to 275 ppm, and the total hardness averages 250 ppm expressed as calcium carbonate. The color varies and the more

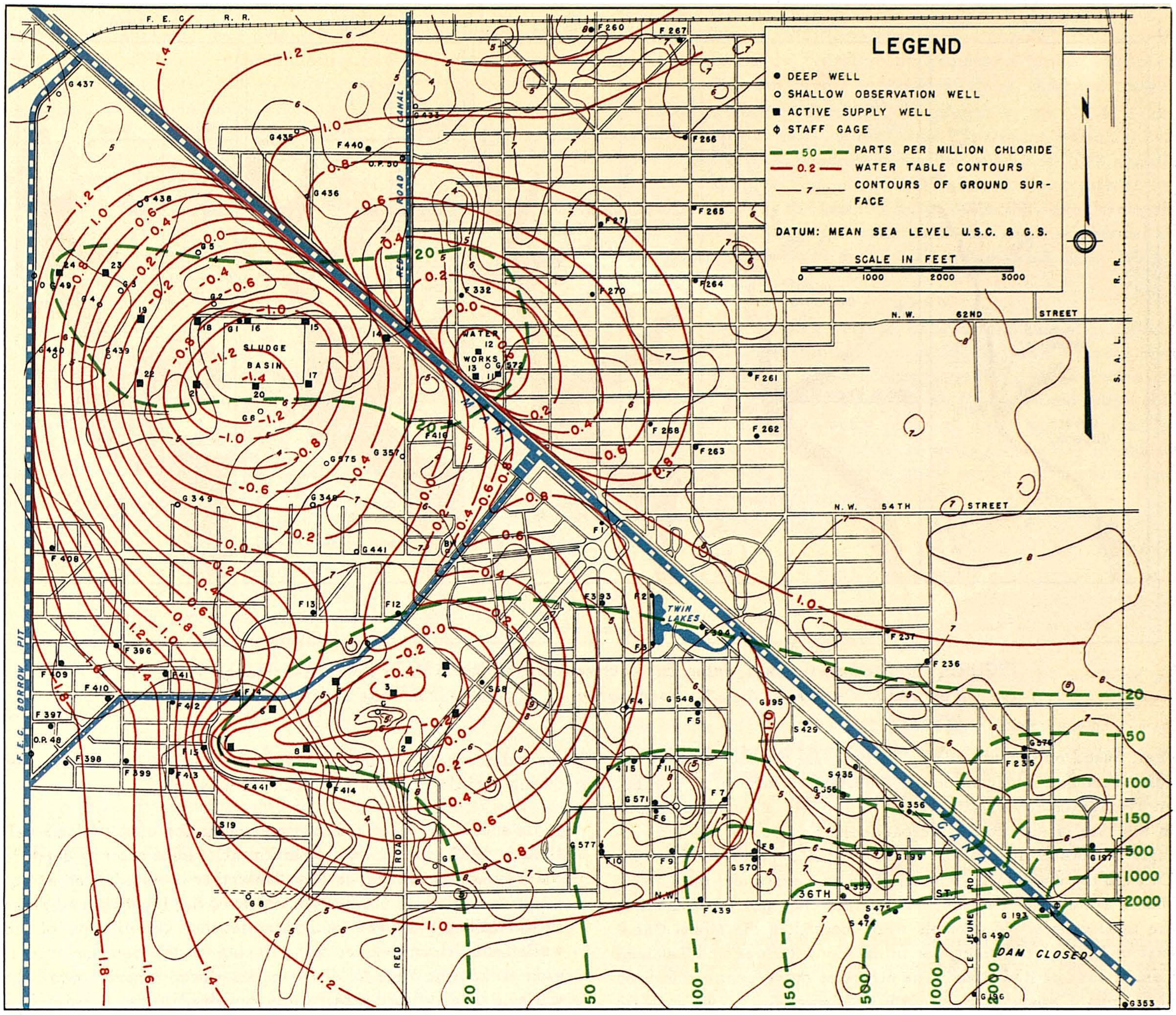


FIGURE 14. **Isochlor Map of Miami Well Field Area showing chloride concentrations on June 16, 1952. Water table contours and ground elevations are also shown. Information shown is subject to revision.** *(From District Engineer, Ground Water Division, U.S.G.S., Miami, Florida.)*

highly colored water is derived from peat, muck and other organic materials. The normal concentration of chloride is about 25 parts per million, although the water from the wells comprising the new southwest well field of the City of Miami has chloride content of less than 20 ppm. Changes in the quality of canal water are reflected in water from adjacent wells and the reverse is also true. Along the portions of those canals discharging into Biscayne Bay the quality of the surrounding ground water changes with the advances and retreats of the salt water from the ocean via these tidal canals.

Salt Water Encroachment in the Aquifer

Along the coast near Miami in an area as much as two miles wide in places, and farther inland adjacent to some canals, the ground water in the aquifer has been contaminated by salt water encroachment. High chloride concentration in wells near the bay shows that salt water from the ocean is the source of the contamination. It is apparent that contamination of the aquifer has occurred by lateral intrusion along Biscayne Bay and from the canals at times when low rates of flow in the canals allowed sea water to move upstream for several miles.

An indication of the extent to which ground water in the Miami area has been contaminated by salt water may be obtained by a comparison of past and present records of analyses. An isochlor map, Figure 14, shows the chloride concentration in the Miami Springs well field area in June 1952, as well as the height of the water table for the same period. It is interesting to note that although the cone of depression around the well field extended below sea level, the chloride values were normal. These maps are prepared and issued regularly by the Miami office of the U. S. Geological Survey as part of the cooperative program still being conducted in this area.

An historical sketch of salt water intrusion in the Miami area is shown in Figure 15, wherein a series of maps indicate the progress of the salt contamination.

The maps for 1904 and 1918 are based largely on estimated and known conditions, but the remainder are based on samples from wells generally more than 60 feet deep. These maps clearly show the trend of salt water advancing inland and displacing fresh water. They show that salt water has not yet reached the Miami well field by direct infiltration from the Bay at depth in the aquifer, and likewise show why it was necessary in 1941 to abandon the ground water supply at the Coconut Grove water plant. Elsewhere along the coast the distance the salt water has penetrated may be more or less than in this area, depending on the degree to which nearby drainage canals have lowered the water table. In the Silver Bluff area this salt wedge moved inland slowly with a calculated average advance of 235 feet per

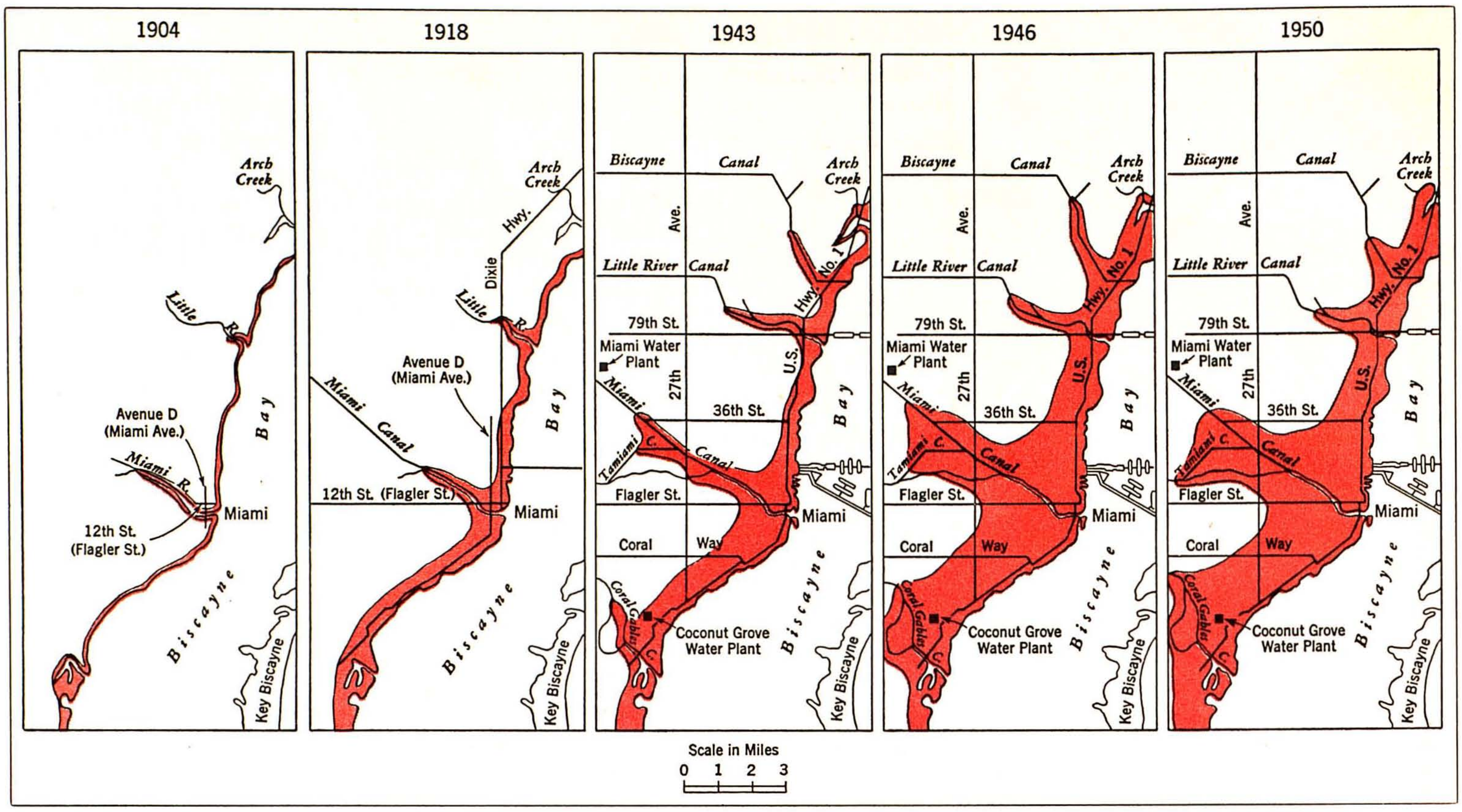


FIGURE 15. Progressive Salt Water Encroachment in the Miami Area from 1904 through 1950.
(After Gerald G. Parker, U.S.G.S., Washington, D. C., and taken from p. 828, Jour.,AWWA, Oct. 1951.)

year, based on records ending in 1942. By October of 1944 the salt water had advanced some 2000 feet farther in 27 months, an average of about 890 feet per year. This great acceleration in the rate of salt water encroachment was due to the exceedingly low-water levels during an extended period of drought. Through the cooperative efforts of Dade County and the City of Miami, removable controls were at this time placed in most of the tidal canals. No controls were located in the Miami Canal east of N. W. 36th Street, nor in the Coral Gables and Tamiami Canals east of Red Road. The effect of these controls may be seen from a study of Figure 15. A comparison of the map for 1946 with that for 1950 clearly shows that in the Biscayne, Little River, and Miami Canals actual seaward retreat of the inland end of the salt water tongue has occurred. The controls in these canals have prevented farther inland intrusion of sea water during dry seasons. These maps also show continued inland advance of salt water along the Tamiami and Coral Gables Canals, brought about by the lack of controls east of Red Road.

It may also be noted that in the areas between the canals containing controls, no farther inland migration of the salt wedge from Biscayne Bay has occurred since 1946. These controls have, therefore, accomplished a dual purpose. In the first place, they have prevented the inland flow of sea water along the bottoms of the canals during dry periods when the flow of canals was insufficient to hold back the sea water. In the second place, the water table in areas between the canals has been raised somewhat, with the effect of halting lateral intrusion of sea water from Biscayne Bay into the permeable eastward face of the aquifer.

It is evident that salt-water intrusion in the Miami area conforms with the Ghyben-Herzberg principle, which consequently provides a basis for proper future development of the Biscayne aquifer. Since the latter is floored by an impervious formation at an average depth of 100 feet, vertical intrusion is precluded and lateral intrusion may be prevented by an average water table of 2.5 feet above average bay level. Hence the only safe supply for perpetual use must be located west of the 2.5 foot contour line of the water table. It is, however, possible for salt water to move inland by way of the canals and contaminate the adjacent areas should adequate controls be inoperative during periods of low stage in the canals.

It should be noted that the contamination of the Miami well field in 1939 was not due to movement of salt water at depth in the aquifer from Biscayne Bay, but rather to an advance of sea water up the Miami Canal as a result of the low flow and stage in the canal. When the salt water reached the vicinity of the well field, it came under the influence of the cone of depression around the well field and hence moved inward toward the wells. Fortunately, the salt water remained in the canal only a short time so that the amount of salt reaching the wells did not permanently damage them. Since the encroachment, the salt water that reached the well field has largely been removed through pumping and by dilution with fresh water. A re-occurrence of the encroachment may be prevented by adequate study, planning and control in future ground water developments and drainage programs.

BROWARD COUNTY

In the course of the investigation of the water resources of Southeastern Florida, begun in 1939 by the U. S. Geological Survey, a considerable amount of data was obtained in Broward County. This knowledge was greatly augmented by a detailed study, begun in 1946, of the geology and ground water resources of the Fort Lauderdale area. The results of this investigation, which was conducted by R. C. Vorhis of the U. S. Geological Survey, were published in 1948 by the Florida Geological Survey.[28] The material presented in this section is based upon this report.

Salt water intrusion in the Fort Lauderdale area may occur in any one of the four following ways: (1) from the ocean, (2) from ocean-water tongues extending up canals, (3) from canals into which saline Everglades ground water has seeped, (4) from the saline connate or residual water underlying the area at a depth of 150 to 300 feet or more.

In the Fort Lauderdale area intrusion from the ocean directly into the aquifer is thought to occur only within a mile or so of

the shore. The factors which have made this type of encroachment less rapid and less extensive in this area than in Dade County are: (1) lower transmissibility of the aquifer, (2) layers or beds of sediments that are relatively impermeable, (3) less pumpage, (4) a higher water table.

The most serious threat of well-field contamination from ocean water lies in the lateral movement of salt water from the North New River Canal. Although the municipal well field has never been actually contaminated by salt water, a well at the Dania plant of the Florida Power and Light Company has shown a chloride content of 2700 ppm. This well is approximately 300 feet from the South New River Canal.

Everglades water seeping into the aquifer from the North New River Canal does not render the water unfit for drinking, as the chloride content decreases when diluted with fresh water in the aquifer.

The average annual water table of approximately 4 feet above sea level is adequate to depress sea water to a depth of 160 feet below sea level beneath the well field. As long as draw-downs are controlled and water is not withdrawn from this depth or below, intrusion can only occur laterally. The salt-water tongues extending up the North New River Canal can be checked in only two ways: (1) by providing sufficient flow in the canal to keep ocean water held back and (2) by construction of dams or control works as far downstream as possible to prevent ocean water from advancing into critical areas.

PALM BEACH COUNTY TO BREVARD COUNTY

Throughout this area there is little or no danger of vertical salt water intrusion into the shallow aquifers, since the underlying clay beds (the Hawthorn formation) are impervious, and hold the saline water in the upper Eocene formation under considerable pressure. If wells are drilled too deep this saline water will be obtained. The water-bearing formations used for production of municipal ground water supplies are chiefly the Anastasia and the underlying Caloosahatchee Marl in the Titusville-Cocoa-Melbourne coastal fringe; and the Tamiami in the Lake Worth-Fort Lauderdale region.

Lateral intrusion may occur in these aquifers from the ocean or from tidal canals and rivers as a result of low ground water levels.

It should be understood that the relatively high piezometric surface throughout this area, (See Figure 7), has no bearing upon the possibility of lateral movement of ocean water into these shallow aquifers, as this piezometric surface is a measure of the pressure in the upper Eocene formation – a formation that is excluded from contact with the shallow aquifers by the thick impervious layers of the Hawthorn formation. Therefore, lateral intrusion may be prevented only by the presence of a sufficiently high water table in the unconfined aquifer to exclude sea water from the areas where cones of depression are created by pumpage.

As an example, one of the six fairly shallow wells comprising the Fort Pierce well field became salted in 1939–40; this condition abated as withdrawals were decreased. The city of Fort Pierce is fortunate in that it has available for use both surface and ground water sources and separate plants for the chemical treatment of each supply. This makes it possible to employ a planned program of withdrawal of well water and consequently avoid salt water intrusion.

The high chloride content of artesian water from the upper Eocene formations is illustrated by data furnished by Mr. A. B. Michaels of Deerfield Groves on Merritt Island. The 24 wells used for irrigation showed from 1940 to 1947 a chloride content of about 750 ppm; this figure checks very closely with the analyses made during the course of the project. A further example of the mineralization of the artesian water in this area may be found in information furnished the project by Mr. T. W. Young, Associate Horticulturist of the Citrus Experiment Station at Lake Alfred. The Citrus Experiment Station has since 1938 annually analyzed samples from some 150 index wells scattered from Stuart to Oak Hill, the samples being collected during the spring months when the wells generally suffer the greatest withdrawals. The chloride content of these wells ranged from about 200 ppm to around 10,000 ppm.

Analyses of flowing wells at Wabasso and Sebastian indicate an almost constant chloride content over a period of many years and do not exhibit any tendency toward salt water intrusion. Other wells in the area, especially on Merritt Island, show chloride contents that apparently vary with depth and with location. The high chloride content of these wells may be due to penetration of salt "lenses," penetration of pockets of connate saline water, or solution of marine residuals.

VOLUSIA COUNTY

Geology

Volusia County is the most critical area for possible salt water intrusion on the East Coast of Florida. The county is an area of low relief under which the Eocene dome rises to a height of 100 feet below present sea level at the county's northern and southern borders (Figure 5). This dome at minus 100 feet (msl) extends West from the coast beyond the St. Johns River Valley before buried Eocene limestones approach sea level. The county has been largely eroded of Ocala limestone, so older Eocene limestones are in contact with the sea at relatively shallow depths.

According to Stubbs[9] the Hawthorn has been almost entirely removed by erosion at the southern and western borders of the county along the St. Johns River Valley and the Caloosahatchee marl lies unconformably on the Eocene limestones.

The surficial exposures in Volusia County are lower marine and/or estuarine terrace deposits, except for the Anastasia formation on narrow barrier islands of the Pamlico Sea along the western shores of the Halifax River and Mosquito Lagoon, and also except for the Caloosahatchee formation on a larger island of the same sea composing an area of higher relief surrounding DeLand (Figure 6).

According to Cooke:[31] "The Caloosahatchee marl probably underlies the entire county though surface exposures are confined to the southwestern part. The Caloosahatchee ends at a depth of 113 feet in a well at Barberville and enters the formation in city well No. 1 at Daytona Beach at 35 feet."

Hydrology

The plus 25 feet (msl) Pamlico Sea, (Figure 10), covered the Valley of the St. Johns River at the western border of the county. Another Pamlico seaway existed as a continuous passage in the Valley of Tomoka Creek and the Valleys of Haw Creek, the latter being northwest of the former and extending beyond the county's borders.

The St. Johns River Valley along the county's western and southern borders is a discharge area or a leakage zone in which the piezometric contours of the Southern High fall to less than plus 20 feet msl, (Figure 7). Areas of artesian flow containing waters of high mineralization have been located by Stubbs[9] in

the Lake Harney, Lake Jessup and Lake Monroe vicinities of neighboring Seminole County.

The widespread extent of highly mineralized waters in the principal artesian aquifer underlying the county is indicated by the examples listed below:

(1) In 1946, Blue Springs of Volusia County, 2.5 miles West of Orange City, with a mean free flow of 104 M.G.D., had water with a chloride content of 775 ppm, which indicates the presence of saline residues remaining from earlier geologic invasions of the sea.[32]

(2) Ponce de Leon Springs, 8.5 miles northeast of DeLand, with a mean free flow of 19 M.G.D., had waters with chloride contents of 622 ppm in 1923 and 231 ppm in 1946.[32] These large differences are probably due to seasonal dilution of the leakage zone saline spring by local recharge.

(3) In 1948, U.S.E.D. well No. 425, 7.5 miles northeast of Barberville, 143 feet deep, 30 foot head, had water with a chloride content of 200 ppm according to analysis by this Water Research Project.

(4) To the north in neighboring Flagler County at Bunnell, U.S.E.D. well No. 449, 180 feet deep, had 17.5' (msl) head in 1948. In 1924 the Bunnell city well, 123 feet deep, had water with a chloride content of 735 ppm and other high mineralization. The latter was abandoned prior to 1934, after well No. 2, 86 feet deep, was drilled. In 1949 water from the No. 2 well had a chloride content of 27 ppm (W. S. & R. Paper No. 6) to indicate an unconfined aquifer or skimming of the artesian aquifer.

(5) In 1949 the New Smyrna Beach artesian U.S.E.D. well No. 485, (U.S.G.S. Volusia 24), 144 feet deep, 12 feet (msl) head, had water with a chloride content of 760 ppm according to analysis by this Water Research Project.

(6) In 1948 the Daytona Beach artesian U.S.E.D. well No. 489, (U.S.G.S. Volusia 27), 185 feet deep, 7.0–8.2 feet (msl) head, had water with a chloride content of 154 ppm according to records of this Water Research Project.

The piezometric head of 10 feet (msl) between New Smyrna Beach and Ormond, (Figure 7), has no bearing on the possibility of lateral intrusion into unconfined aquifers along the coast. Again, lateral intrusion into unconfined aquifers may be prevented only the by presence of a sufficiently high water table.

The situation throughout that portion of Volusia County adjacent to the Halifax River and Mosquito Lagoon is made more critical because there are rivers, drainage canals and lagoons that permit the entrance of tidal salt water to substantial distances inland. For example, the U. S. Highway No. 1 bridge crossing the Tomoka River is approximately three miles above the latter's point of confluence with the Halifax River. Water samples collected from the bridge on 6 March 1953 showed a chloride content of 2980 ppm near the surface and 4110 ppm near the bottom. The maximum distance of salt water penetration up the Tomoka River has not been determined. A drainage canal which passes within 2000 feet of most of the Daytona Beach wells discharges into the Halifax River at Holly Hill on the north and near Port Orange on the south. The Holly Hill wells are likewise located within 500 feet of this drainage canal.

Daytona Beach

Daytona Beach has of necessity depended upon well water supplies from an area of low relief in which no adequate surface supply is available. Rapid growth of population in the city has necessitated frequent development of additional well water supplies in an area of critical salt water intrusion. The added burden of increased demands during the winter and spring months of low rainfall has periodically overtaxed the water supply. Fully considered long-range plans for adequate water supplies have quickly become obsolete in the face of unusual demands. Nevertheless, controlled pumping under close observation presents an example of what can be done under duress.

A. Plant Wells. In 1909, wells numbered one to six were drilled and in 1910 the mainland softening plant was constructed. Well Nos. 7 and 8 were drilled in 1927. These wells, 162–252 feet in depth, and 2600 feet west of the Halifax River have been used almost continuously to the present date and are now called the plant wells. In 1930, a composite water sample had a chloride content of 132 ppm. In 1949, under normal pumping rate of 50 G.P.M. per well, the chloride content was unchanged.

B. Seabreeze Wells. In 1923, the Seabreeze plant was constructed with three wells. In 1928, four more wells were added. These seven wells are 160–250 feet in depth. This plant is on the narrow peninsula, or beach side, within 50–100 feet of the Halifax River and 2700 feet west of the Atlantic Ocean. The provision of this treated supply was made necessary by the rapid development of the beach area, as at that time there was no water main crossing the River. In 1930, a composite sample of water from this plant had a chloride content of 160 ppm. The chloride contents of individual wells are recorded in tabular form for 1937 and 1949.

TABLE 15

CHLORIDE CONTENT OF WATER FROM SEABREEZE WELLS, DAYTONA BEACH

Well No.	1930	1937	1949	1952
1	160	120	165	286
2		122	117	
3		120	82	
4		124	199	
5		124	341	
6		124	807	
7		112	1114	

By 1949, serious salt water intrusion had developed in four of the wells. In 1952, with controlled pumping and supplementary supply from the mainland plant, the composite water had a chloride content of 286 ppm. Early abandonment of this well field must be contemplated.

C. Adams Street Wells. In 1936, the present mainland softening plant, designed for four M.G.D., was constructed and ten additional wells, Nos. 1 to 10, were drilled 6900 feet west of the Halifax River. These wells are now known as Adams Street wells. The average daily water consumption based on yearly totals gradually increased from 1.25 M.G.D. in 1938 to 2.5 M.G.D. in 1943. With the construction of the Adams Street wells, use of the plant wells was discontinued.

Within a few weeks after the new well field was placed in operation, the presence of salt water intrusion was apparent and careful tests showed that it had taken place only in wells 1 and 10, which had been drilled approximately 50 feet deeper than the other wells. Thus, the great importance of well depth in Volusia County became clearly apparent. Well No. 1, 250 feet in depth, and which had showed the most evidence of salt water intrusion with chloride content of 1585 ppm, was filled completely and abandoned in 1937. Well No. 10 was plugged to 185 feet from a depth of 254 feet and was used as an observation well until 1950, when an automatic well recorder was installed and it is now known as Volusia 27. Piezometric heads in this well are recorded in Tables 6A and 6B as U.S.E.D. 489. It is believed that maximum and minimum values in the following table reflect recovery after high rainfall.

TABLE 16

RECORD OF RAINFALL AND GROUND WATER ELEVATIONS

FOR US.E.D. WELL NO. 489 = U.S.G.S. VOLUSIA NO. 27

Year	Maximum G W Elevation (Ft. msl)	Minimum G W Elevation (Ft. msl)	Annual Rainfall (inches)
1941	9.2	6.5	62.0
1942	9.4	7.0	37.3
1943	9.1	5.4	56.4
1944	8.1	5.1	51.5
1945	8.5	4.2	47.0
1946	6.4	5.1	58.8
1947	7.2	4.6	66.6
1948	8.5	5.5	53.7
1949	8.3	6.6	43.3

In addition to this observation well, a second observation well, located in the waterfront park on the west bank of the Halifax River, had an automatic well recorder installed in 1950 and was designated U.S.G.S. Volusia 25.

In 1943, a second battery of ten wells, Nos. 11 to 20, (F.G.S. wells W–750 to W–759), were drilled in the Adams Street field at an elevation of approximately seven feet mean sea level. According to the driller's logs:

(1) the top soil and coquina average five feet in depth;

(2) then Blue clay and marl alternating with some sand was encountered to approximately 80 feet in depth where the first limited quantity of water usually flowed to indicate penetration of the aquaclude and artesian pressure;

(3) then alternating hard and soft rock were encountered to approximately 150 feet depth;

(4) and finally the wells were completed after sufficient flow was obtained at 165–220 feet depth.

Records of the chloride content of water from wells in the Adams Street field are listed in table form below.

TABLE 17

CHLORIDE CONTENT OF WATER FROM ADAMS STREET WELLS, DAYTONA BEACH

Well No.	Depth (feet)	Cased (feet)	Ground Elev. (ft. msl)	Chloride Content in ppm 1936	1937	1943	1945	1948	1952 1953
1	250	95	12	185	1585		↑	↑	↑
2	----	----	----	102	104				
3	197	118	9	113	142				
4	----	----	----	117	144				
5	166	100	12	119	142				
6	203	118	11	102	128				
7	201	79	11	99	130				
8	201	82	12.5	90	86				
9	217	100	13	99	88				
10	254	112	9	172	172				
							138	128	160
11	215	83				138-198			
12	200	84				80			
13	192	85				67			
14	191	91				119			
15	220	101				103			
16	167	81	7			140			
17	172	85				158			
18	168	87				134			
19	165	81				140			
20	165	81				142	↓	↓	↓

In 1949 an experiment was conducted to determine the effect of increased pumping rate on the chloride content of water from the plant wells. The following table shows the results of this test.

TABLE 18

PUMPING RATE AND CHLORIDE CONTENT OF COMPOSITE SAMPLES FROM PLANT WELLS, DAYTONA BEACH

March 1949 Day	G.P.M.	Chloride (ppm)
21st	350	127
22nd	1225	209
24th	875	211
25th	350	143
27th	700	203
28th	700	197
29th	350	158
31st	350	136

This interesting and important experiment clearly revealed a fact already becoming apparent, that the wells recover quickly after overpumping, a fact which, while favorable, has as yet received no satisfactory explanation.

Average daily water consumption continued to increase until it reached 2.75 M.G.D. in 1947 and 3.25 M.G.D. in 1948.

D. Canal Wells. In 1949, after the experiment listed above and after a study of rainfall records and hydrographs, seven wells were drilled along the canal west of the Adams Street field, with similar specifications as to depth and construction. Records of the chloride content of waters from these wells are recorded below.

TABLE 19

CHLORIDE CONTENT OF WATERS FROM CANAL WELLS, DAYTONA BEACH

Well No.	1950	Mar. 1952	July 1952	Sept. 1952	Jan. 1953	Mar. 1953
21	97					
22						
23	61					
24	77	58	62	65	63	63
25	55					
26	50					
27	44					

In the case of this well field, protection against overpumping was provided by the installation of turbine type pumps of only 100 G.P.M. capacity at the designed head.

During each of the past five years, both average daily consumption and maximum peaks have steadily increased until maximum daily demands have now reached 9 M.G.D. Tests made at frequent intervals during each year have shown a consistent picture. With the beginning of the dry winter season, values for chloride in all well fields except the Canal wells begin to increase and the increase continues until the beginning of the rainy season, usually in June or July. With the advent of heavy summer rains and lowered demands, chloride contents rapidly drop back to normal levels, and the water may show the presence of organic color indicating local recharge.

In June, 1952, the piezometric head in Volusia 27 well, located near the center of Adams Street field, reached a low level while other wells were being pumped at 3.85 feet (msl).

E. Protective Legislation. In 1940, a municipal ordinance was enacted regulating the drilling of wells within the city limits. While this gives some protection, the need for the organization of a water conservation district for the protection and conservation of ground water supplies in adjacent areas is clearly indicated.

Ormond

The water supply picture at Ormond parallels in general that of Daytona Beach. The city is supplied by four wells of the same average depth, 190–200 feet deep, and the water is closely similar to that of Daytona Beach in chemical quality. Table 20 below indicates that the average value for chloride content has increased from 146 ppm in 1923 to approximately 200 ppm at the present time. This increase in chloride content is roughly proportional to the increase in water demand.

TABLE 20

CHLORIDE CONTENT OF WATER FROM ORMOND WELLS

Well	1923	1936	1938	1948	1950	July 1952	Sep. 1952	Jan. 1953
Composite of 3 Wells	146	176	174	182	186	200	186	196

Holly Hill

Holly Hill is located between Ormond and Daytona Beach. It is supplied by three wells, 213–227 feet deep, located closely adjacent to the drainage canal and less than 1000 feet from the Halifax River, which is tidal and whose water is essentially sea water. Even though the wells are somewhat deeper than is normal for the area, and even though they are located closer to sea water than any other wells in the area, inspection of Table 21 below indicates that they have shown no evidence of salt water intrusion. This is probably due to the fact that the pumpage from the Holly Hill wells has been consistently lower than from the Ormond wells.

TABLE 21

CHLORIDE CONTENT OF WATER FROM HOLLY HILL WELLS

Well	1948	1950	July 1952	Jan. 1953
Composite of 3 wells	71	67	67	68

Port Orange

The City of Port Orange is located approximately ten miles southeast of Daytona Beach. Its original supply was derived from a well approximately 150 feet deep. As water use has decreased, the chloride content of the water has shown a steady increase. The values shown in the table below are typical.

TABLE 22

CHLORIDE CONTENT OF WATER FROM ABANDONED PORT ORANGE WELL

Well	1946	1949	1950	1952
Old Well (1941)	420	750	425	447

In 1952, the City constructed a new well field and water softening plant located southeast of the City approximately one and a quarter miles west of the Halifax River. These wells vary in depth from 146–160 feet. Use of the new well field was begun early in 1952, although the plant was not completed and placed in operation until late fall of that year. Although the wells have been in operation only about one year, the chloride content of the water has already reached alarmingly high values. The chloride content of a composite sample collected in October, 1952 with two wells in operation showed 185 ppm chloride and a second composite sample collected in March, 1953 with three wells in operation showed 240 ppm chloride. These results indicate that while the situation has been somewhat improved by resorting to the new well field, the problem has not been solved.

New Smyrna Beach

New Smyrna Beach was supplied originally by two well fields, one of which is located approximately three miles west of the Halifax River which supplies the City proper, and a second on the beach to supply the rapidly growing beach area. Although the beach wells were quite shallow, increased pumpage resulted in substantial salt water intrusion and the water became unsatisfactory for use. In 1952, a line was constructed across the River and from that date the beach has been supplied from the mainland plant. The mainland well field consists of eight wells varying in depth from 78–180 feet, of which only a few are now used. Records of the past ten years indicate no salt water intrusion, since composite samples had a chloride content of 60 ppm in 1944, 66 ppm in 1948, and 66 ppm in March, 1953.

There are indications that the area lying west of New Smyrna Beach may be the most favorable in the county for the development of substantial quantities of water of low chloride content. Water from a well located at Samsula, 122 feet deep, and approximately five miles west of New Smyrna Beach and designated as U.S.E.D. observation well No. 446, had water with a chloride content of 18 ppm in 1948, according to the records of this Water Research Project. That water of high salinity is present at depth under New Smyrna Beach is attested to by the fact that a brine well having a chloride content of 16,400 ppm is employed by the city for regenerating the resinous exchange employed in the new municipal water softening plant. Such records as are available on this well indicate that it was drilled to a depth of 1005 feet with only 130 feet of casing. The piezometric head is in excess of ten feet, since the elevation of the plant site on which it is located is 10 feet (msl) and water flows over the top of the casing.

Summary

For reasons which have been indicated previously, and from the data which have been given, it is evident that the problem of increasing salinity in many of the municipal water supplies of Volusia County is becoming increasingly serious. From the data which are available, it is not possible to state with assurance whether these increased salinities are due to lateral salt water intrusion, vertical salt water intrusion, or to a combination of the two. A great deal of research will be necessary before the answers to these questions will be clear. Plans are now in progress looking forward to setting up the comprehensive geological and hydrological investigations of the county.

FLAGLER AND ST. JOHNS COUNTIES

The surface exposures in Flagler County and St. Johns County are several lower marine and/or estuarine terrace deposits, except for the Anastasia formation of coquina and limestone near the east coast. The Anastasia formation generally lies alongside the beaches with their characteristic sand dune ridges. It lies parallel to the Atlantic Coast as a narrow tongue from its northernmost occurrence on Anastasia Island opposite St. Augustine to the southern part of Palm Beach County (Fig.6).

According to Cooke (1945), the Anastasia formation rarely extends inland more than three miles beyond the Intracoastal Waterway, presumably rests unconformably on the Caloosahatchee marl and is commonly overlain unconformably by the Pamlico Sand. Coquina has been quarried in both Flagler County and St.

Johns County for use as a building stone.[31]

Data based on driller's logs and ground water investigation by the U. S. Geological Survey in 1945 at St. Augustine show geologic formations by depths (msl) as follows:

+35' to +25' Recent and Talbot Terrace deposits
+25' to −10' Anastasia
−10' to −55' Caloosahatchee

The St. Augustine wells, 65 feet in depth below ground surface therefore penetrate the Caloosahatchee for approximately 20 feet, and the wells 90 feet in depth penetrate it for approximately 45 feet.

The piezometric head in the Floridan aquifer drops from 50 feet (msl) in the northeastern part of St. Johns County to 40 feet (msl) at St. Augustine (Figure 7). The drop in head continues until it is 20 feet (msl) in the Clark Artesian well of Flagler County, 5.5 miles south of Summerhaven near the beach. In 1948 that well, U.S.E.D. 475, had a chloride content of 1740 ppm according to records of this Water Research Project.

As the Eocene dome or arch rises from minus 300 feet (msl) at the northern border of St. Johns County to minus 100 feet (msl) at the southern border of Flagler County (Figure 5), there is a sharp drop in the head to indicate a discharge area, with an aquaclude that becomes less and less in thickness and evidently cannot maintain the higher pressures that are characteristic across the valley of the St. Johns River in Putnam and Clay Counties to the northwest (Figure 7).

Where the aquifer crops out below sea level a fresh water submarine spring such as that about three miles east of Crescent Beach may occur.[32,62]

It should be noted that the piezometric heads have no relation to the heads in unconfined aquifers and cannot prevent lateral intrusion into unconfined aquifers in contact with the sea if overdevelopment takes place.

TABLE 23

CHEMICAL CONSTITUENTS (PPM) OF WELL WATERS IN FLAGLER AND ST. JOHNS COUNTIES

Well	Date	Depth (feet)	TDS	Ca	Mg	NaK	HCO_3	SO_4	Cl	Total Hardness
Flagler County										
Marineland										
12 wells	1947	18	444	83	8.9	39	294	0	64	244
5 wells	1949	18	732	144	3.0	103	415	0	180	373
St. Johns County										
Hastings										
No. 1	1949	600	1650	214	84	199	115	740	250	879
No. 2	1949	500	1400	204	84	220	115	880	200	856
No. 3	1948	600	1625	164	107	190	115	620	240	849
Ponte Vedra Beach										
No. 1 Old Water Plant	1947	600	422	56	37	16	174	132	33	287
St. Augustine										
No. 2 (abandoned)	1923	520	1780	143	87	302	162	361	635	714
Standby (Nos. 1-5)	1927	325	929	114	39	145	189	309	151	444
Composite (Nos. 1-11)	1935	90	1203	121	62	162	166	319	305	559
Composite (Nos. 1-14)	1948	65-90	429	119	3.3	2.0	349	26	30	312
Typical No. 15	1951	65	480	148	0.75	20	440	5	36	373
Moultrie Creek	1951		207	24	4.3	32	93	5	50	76

While these counties had their eastern parts exposed as a large island of the 25 foot (msl) Pamlico Sea (Figure 10), they were completely submerged by the 42 foot (msl) Talbot Sea (Figure 11). The St. Johns River Valley along the western borders of these counties is also a discharge area from which waters of high mineralization flow. The upper, unconfined aquifers of this area are generally low in magnesium and sulfate content, while artesian waters from deep wells are highly mineralized as shown in Table 23.

St. Augustine

In 1897, the first municipal well was drilled at St. Augustine to a depth of 371 feet. In 1903 that well was deepened to 550 feet and a second well was drilled to a depth of 520 feet. The constant use of water from these artesians wells, increased by the growing demands for water, resulted in the salinity and hardness indicated by the 1923 analysis shown in Table 23.

In 1924 the demands for a better water supply caused five wells to be drilled to a depth of 325 feet in a new location, but the waters from these wells proved to be of similar characteristics as shown by the 1927 analysis in Table 23.

In 1926 eight gravel-wall wells were drilled to a depth of 90 feet, and located about 700 to 800 feet apart along Holmes Boulevard, one and one-quarter miles west of the city limits. The water proved to be very hard, high in organic color, and had the taste of considerable iron as well as organic tastes and odors. However, in 1927 the senior author of this paper with George W. Simons of Jacksonville worked out a method of treatment.

In 1937 a new plant was constructed with a capacity of two M.G.D. and three wells 90 feet in depth were added. Additional wells 65 feet in depth have been drilled until the total is now 15 wells. It now requires continuous operation of the plant at maximum designed capacity to meet the daily demands for water and currently the plant capacity is being increased from two to five M.G.D., with appropriate increases in distribution facilities. The policy is to add new wells to meet increased water demands rather than risk ruining the aquifer by overdraft; so five new wells are now being added. St. Augustine may consider the use of Moultrie Creek as a source of supply, but no decision can be made until further studies are made of requirements in storage capacity, the cost of construction of such a reservoir, and whether sufficient storage can be maintained for the dry months in an area where highly mineralized water is being discharged.

According to Stringfield and Cooper;[62] "Along the east coast, south of St. Augustine, salty water in which the limestone was deposited or sea-water that entered the aquifer prior to Recent time has not been completely flushed from the aquifer, and therefore, although there is discharge from the aquifer and the artesian head is sufficient to prevent encroachment of sea water at present, the artesian water may have a relatively high chloride content."

DUVAL AND NASSAU COUNTY AREA

Jacksonville is the largest city in the United States deriving its entire supply from the natural flow of artesian wells. Its 46 wells range in diameter from six to twelve inches and average 1200 feet in depth; they have an estimated daily capacity of 100,000,000 gallons, and supply a daily average of over 30,000,000 gallons.

The Jacksonville water department first pumped water in 1880 to less than 200 customers. The source of water was then a brick-walled, earthen bottom reservoir or infiltration gallery fed by ground water. Within two years the streams supplying the reservoir became salted, probably from ocean water advancing up Hogan's Creek during storm tides and periods of very low flow in the creek. It was then thought possible to take water from the creek directly, from behind a dam constructed farther upstream where tidal action would not affect the quality of the water. This was satisfactory until periods of extreme drought reduced the flow in the creek dangerously, at which time the deep-seated artesian water was chosen as the best possible source for municipal supply. In 1884 the first artesian wells were used. These wells were four and six inches in diameter and about 500 feet deep. These wells produced enough water to

discontinue use of the surface supply, and artesian water has been used since that time.

Artesian water in the Duval County area is obtained from the Upper and Middle Eocene formations under a very high head. Studies indicate that this formation is recharged in part from the Northern High, some 50 to 75 miles west of Jacksonville, and perhaps in part from an outcrop of the formation in Southern Georgia. The quality of the water, although hard, is quite good. Artesian water in this area averages about 15 to 20 ppm chloride and the total hardness is about 275 ppm. Samples from wells in the Mayport area were collected for the project through the co-operation of the District Engineer, Jacksonville District, Corps of Engineers, U. S. Army. These wells showed an almost constant chloride content of 20 ppm throughout the sampling period.

Since the aquifer supplying large water supplies in this area is the Upper and Middle Eocene, the piezometric surface (Figure 7) of the formation is an index of the possibility of salt water intrusion. The large withdrawal from the formation by the city of Jacksonville has created a cone of depression in the piezometric surface, with the apex of the cone in the Jacksonville well field. Comparison of piezometric maps of the area constructed by Pirnie[56] in 1927 and Cooper[57] in 1940 indicate a lowering of the piezometric head in the Jacksonville area by some 25 feet, whereas the piezometric surface in the surrounding area has remained about the same.

The withdrawal of some 35 million gallons per day at Fernandina has created a cone of depression whose apex is more than 20 feet below sea level and more than 80 feet below the original piezometric surface.

In the area of minimum piezometric surface – the center of the Jacksonville well field – sea water will be depressed to a depth of 1600 feet below sea level. Cooper[57] has noted that the possibility of vertical intrusion is remote in this area as the aquifer is probably sealed off from any salt water in underlying formations by thick layers of impervious materials. That highly saline water is present in formations underlying the Middle Eocene in northern Florida is clearly indicated by recent studies of analyses of water from deep wells in this area. In certain localities this impermeable layer is either lacking, or has been ruptured, with the consequence that water of relatively high salinity is found at moderate depths. Throughout the Duval County area, however, lateral intrusion is sufficiently prevented by the high pressure of the artesian water. That this protection extends to the ocean itself is amply illustrated by the analyses made on the Jacksonville Beach wells. The chloride content of these wells is no higher than any other wells in the area.

It may thus be seen that conditions in this area are exactly opposite to those existing in extreme southeastern Florida. In almost all areas south of Volusia County most potable supplies are derived from surface sources or aquifers overlying the Upper Eocene, as water from the Eocene formations is too hard and highly mineralized. Since water supplies in the area south of Volusia County are not drawn from the Upper Eocene, the piezometric surface of this formation is entirely unrelated to salt water intrusion and the dominant factor in preventing salt water intrusion in this area is the maintenance of a sufficiently high water table in the unconfined aquifers.

It may be concluded that salt water intrusion in the Duval County area is highly improbable as long as the piezometric surface of water in the Upper Eocene remains anywhere near its present height.

Summarizing Statement

Of all the ions present in sea water the chloride ion is the most reliable index of the extent of admixture of fresh water and sea water, since the chloride ion is not commonly subject to oxidation or reduction or to the exchange that occurs under varying conditions or to varying extent among the other ions.

There are large areas in Florida where waters of high chloride content exist in confined (artesian) and non-confined aquifers. Some of these waters are connate water that has remained as highly concentrated saline solutions in the formations deposited from early seas.

Some of these waters have picked up saline residuals from more recent seas. Finally, some of these waters have a high chloride content due to current intrusion of sea water into fresh water aquifers.

The location, constant chloride content, and piezometric head of the first two cases are such as to distinguish them from the third case wherein a lowered piezometric head has brought about salt water intrusion, characterized by increasing chloride content. To the well known examples of salt water intrusion at Fort Myers, Miami, Tampa and St. Petersburg may be added examples revealed by this survey at Pensacola, Tarpon Springs, New Port Richey, Pinellas Park, Stuart, Daytona Beach, Panama City and Clearwater.

It may be concluded that salt water intrusion in the areas mentioned has been the direct result of large withdrawals and excessive drainage in areas of low piezometric head. Salt water intrusion may be expected in other areas adjacent to sea water if similar conditions develop.

Increasing chloride content and a lowered piezometric head in fresh water aquifers are the best indications of approaching salt water intrusion.

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