

AD-A075 819

GEOLOGICAL SURVEY TALLAHASSEE FLA WATER RESOURCES DIV F/G 8/8  
AVAILABILITY AND QUALITY OF WATER FROM SHALLOW AQUIFERS IN DUVA--ETC(U)  
OCT 78 L V CAUSEY , G G PHELPS

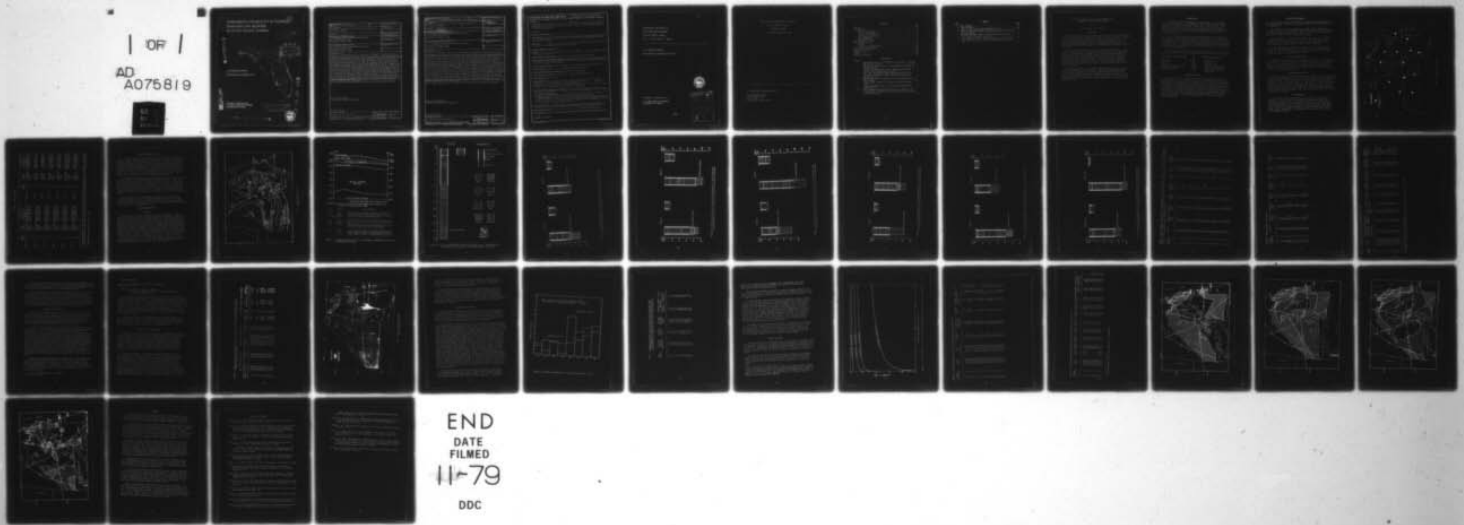
UNCLASSIFIED

USGS/WRD/WRI-79/078

NL

| OF |

AD  
A075819

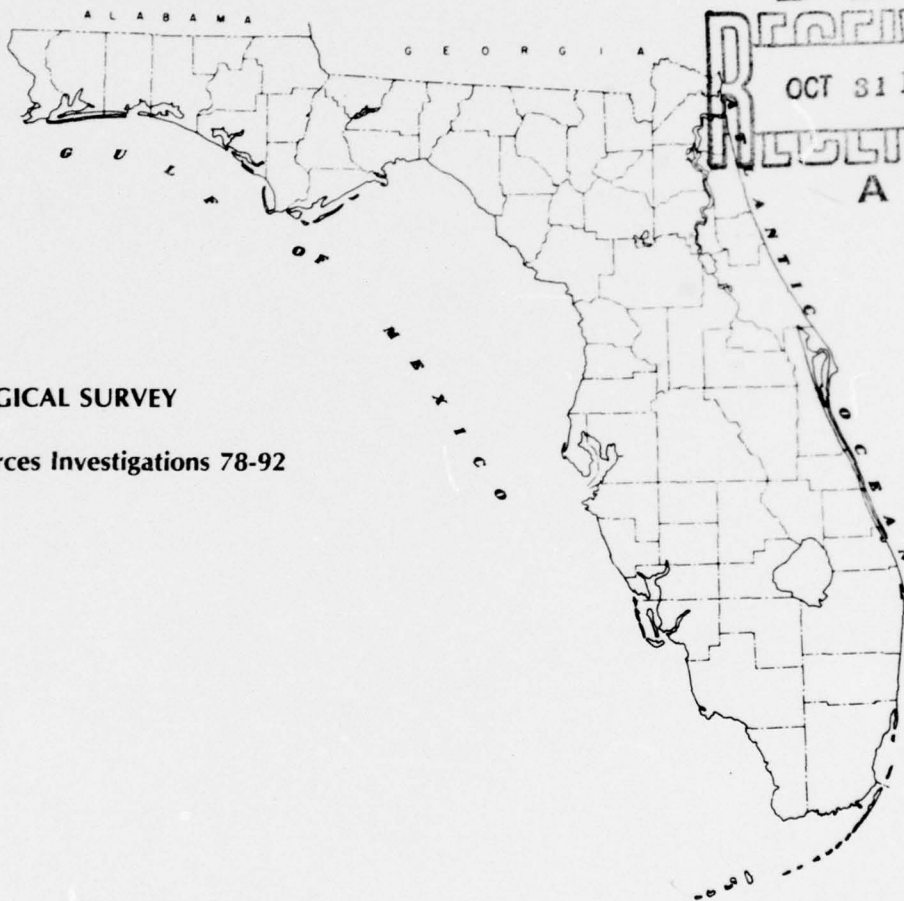


AVAILABILITY AND QUALITY OF WATER  
FROM SHALLOW AQUIFERS  
IN DUVAL COUNTY, FLORIDA

Ⓢ

LEVEL #

ADA 075819



DDC  
RECEIVED  
OCT 31 1979  
RECEIVED  
A

U.S. GEOLOGICAL SURVEY  
Water-Resources Investigations 78-92

DDC FILE COPY

Prepared in cooperation with  
U.S. ARMY CORPS OF ENGINEERS  
JACKSONVILLE, FLORIDA

DISTRIBUTION STATEMENT A  
Approved for public release  
Distribution Unlimited



70 10 30 023

70 10 30 023

<b>BIBLIOGRAPHIC DATA SHEET</b>	<b>1. Report No.</b> USGS/WRD/WRI-79/078	<b>2.</b>	<b>3. Recipient's Accession No.</b>
<b>4. Title and Subtitle</b> AVAILABILITY AND QUALITY OF WATER FROM SHALLOW AQUIFERS IN DUVAL COUNTY, FLORIDA		<b>5. Report Date</b> October 1978	
<b>7. Author(s)</b> Causey, L.V. and Phelps, G.G.		<b>8. Performing Organization Rept. No.</b> USGS WRI-78-92	
<b>9. Performing Organization Name and Address</b> U.S. Geological Survey, Water Resources Division 325 John Knox Road, F-240 Tallahassee, Florida 32303		<b>10. Project/Task/Work Unit No.</b>	
		<b>11. Contract/Grant No.</b>	
<b>12. Sponsoring Organization Name and Address</b> U.S. Geological Survey, Water Resources Division 325 John Knox Road, F-240 Tallahassee, Florida 32303		<b>13. Type of Report &amp; Period Covered</b>	
		<b>14.</b>	
<b>15. Supplementary Notes</b> Prepared in cooperation with the U.S. Army Corps of Engineers, Jacksonville District			
<b>16. Abstracts</b> The shallow-aquifer system in Duval County overlies the Floridan aquifer and is composed chiefly of sand, clay, sandy clay, and limestone. Thickness of the system ranges from about 300 to 600 feet. The upper 150 feet of deposits, consisting of the water-table and shallow-rock zones, are the most dependable and economical source of supplemental water supply. The principal shallow water-bearing zone is a limestone bed 40 to 100 feet below land surface. Aquifer tests conducted at 13 sites in Duval County show that yields from the shallow aquifer vary from place to place within the county owing chiefly to variations in lithology of the saturated rocks and sediments. The limestone of the shallow-rock zone will yield as much as 200 gallons per minute to wells; the maximum yield at most of the sites tested was between 30 and 100 gallons per minute. The water-table zone generally yields 10 gallons per minute or less but at one site, where a water-table well tapped a shell bed near land surface, the well yielded more than 40 gallons per minute. The quality of water in the shallow aquifer system in Duval County is generally acceptable for most domestic, commercial, and industrial uses.			
<b>17. Key Words and Document Analysis. 17a. Descriptors</b> *Water supply *Water quality *aquifers, ground water, water resources, hydrology			
<b>17b. Identifiers/Open-Ended Terms</b> Florida, Duval County, Jacksonville			
<b>17c. COSATI Field/Group</b>			
<b>18. Availability Statement</b> No restriction on distribution Prepared for NTIS by U.S. Geological Survey, WRD		<b>19. Security Class (This Report)</b> UNCLASSIFIED	<b>21. No. of Pages</b> 41
		<b>20. Security Class (This Page)</b> UNCLASSIFIED	<b>22. Price</b>

<b>BIBLIOGRAPHIC DATA SHEET</b>		1. Report No. USGS/WRD/WRI-79/078, USGS/WRI-78-92	2. <i>13-411</i>	3. Recipient's Accession No.
6	4. Title and Subtitle AVAILABILITY AND QUALITY OF WATER FROM SHALLOW AQUIFERS IN DUVAL COUNTY, FLORIDA,			5. Report Date October 1978
	7. Author(s) Causey, L.V. and Phelps, G.G. Phelps			6.
10	9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division 325 John Knox Road, F-240 Tallahassee, Florida 32303			8. Performing Organization Rept. No. USGS WRI-78-92 ✓
	12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division 325 John Knox Road, F-240 Tallahassee, Florida 32303			10. Project/Task/Work Unit No.
15. Supplementary Notes Prepared in cooperation with the U.S. Army Corps of Engineers, Jacksonville District			11. Contract/Grant No.	13. Type of Report & Period Covered
16. Abstract: The shallow-aquifer system in Duval County overlies the Floridan aquifer and is composed chiefly of sand, clay, sandy clay, and limestone. Thickness of the system ranges from about 300 to 600 feet. The upper 150 feet of deposits, consisting of the water-table and shallow-rock zones, are the most dependable and economical source of supplemental water supply. The principal shallow water-bearing zone is a limestone bed 40 to 100 feet below land surface. Aquifer tests conducted at 13 sites in Duval County show that yields from the shallow aquifer vary from place to place within the county owing chiefly to variations in lithology of the saturated rocks and sediments. The limestone of the shallow-rock zone will yield as much as 200 gallons per minute to wells; the maximum yield at most of the sites tested was between 30 and 100 gallons per minute. The water-table zone generally yields 10 gallons per minute or less but at one site, where a water-table well tapped a shell bed near land surface, the well yielded more than 40 gallons per minute. The quality of water in the shallow aquifer system in Duval County is generally acceptable for most domestic, commercial, and industrial uses.				
17. Key Words and Document Analysis. 17a. Descriptors *Water supply *Water quality *aquifers, ground water, water resources, hydrology				
17b. Identifiers/Open-Ended Terms Florida, Duval County, Jacksonville				
17c. COSATI Field Group				
18. Availability Statement No restriction on distribution			19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 41
Prepared for NTIS by U.S. Geological Survey, WRD			20. Security Class (This Page) UNCLASSIFIED	22. Price NT

409 325 907

**INSTRUCTIONS FOR COMPLETING FORM NTIS-35**

(Bibliographic Data Sheet based on COSATI

Guidelines to Format Standards for Scientific and Technical Reports Prepared by or for the Federal Government, PB-180 600).

1. **Report Number.** Each individually bound report shall carry a unique alphanumeric designation selected by the performing organization or provided by the sponsoring organization. Use uppercase letters and Arabic numerals only. Examples FASEB-NS-73-87 and FAA-RD-73-09.
2. Leave blank.
3. **Recipient's Accession Number.** Reserved for use by each report recipient.
4. **Title and Subtitle.** Title should indicate clearly and briefly the subject coverage of the report, subordinate subtitle to the main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific volume.
5. **Report Date.** Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected (e.g., date of issue, date of approval, date of preparation, date published).
6. **Performing Organization Code.** Leave blank.
7. **Author(s).** Give name(s) in conventional order (e.g., John R. Doe, or J. Robert Doe). List author's affiliation if it differs from the performing organization.
8. **Performing Organization Report Number.** Insert if performing organization wishes to assign this number.
9. **Performing Organization Name and Mailing Address.** Give name, street, city, state, and zip code. List no more than two levels of an organizational hierarchy. Display the name of the organization exactly as it should appear in Government indexes such as Government Reports Index (GRI).
10. **Project/Task/Work Unit Number.** Use the project, task and work unit numbers under which the report was prepared.
11. **Contract/Grant Number.** Insert contract or grant number under which report was prepared.
12. **Sponsoring Agency Name and Mailing Address.** Include zip code. Cite main sponsors.
13. **Type of Report and Period Covered.** State interim, final, etc., and, if applicable, inclusive dates.
14. **Sponsoring Agency Code.** Leave blank.
15. **Supplementary Notes.** Enter information not included elsewhere but useful, such as: Prepared in cooperation with . . . Translation of . . . Presented at conference of . . . To be published in . . . Supersedes . . . Supplements . . . Cite availability of related parts, volumes, phases, etc. with report number.
16. **Abstract.** Include a brief (200 words or less) factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.
17. **Key Words and Document Analysis.** (a). **Descriptors.** Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.  
(b). **Identifiers and Open-Ended Terms.** Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.  
(c). **COSATI Field Group.** Field and Group assignments are to be taken from the 1964 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the primary Field/Group assignment(s) will be the specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).
18. **Distribution Statement.** Denote public releasability, for example "Release unlimited", or limitation for reasons other than security. Cite any availability to the public, other than NTIS, with address, order number and price, if known.
- 19 & 20. **Security Classification.** Do not submit classified reports to the National Technical Information Service.
21. **Number of Pages.** Insert the total number of pages, including introductory pages, but excluding distribution list, if any.
22. **NTIS Price.** Leave blank.

AVAILABILITY AND QUALITY OF  
WATER FROM SHALLOW AQUIFERS  
IN DUVAL COUNTY, FLORIDA  
By L. V. Causey and G. G. Phelps

---

U.S. GEOLOGICAL SURVEY  
Water-Resources Investigations 78-92



Prepared in cooperation with  
U.S. ARMY CORPS OF ENGINEERS  
JACKSONVILLE, FLORIDA

1978

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DDC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	<input type="checkbox"/>
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or special
A	

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

---

For additional information write to:

U.S. Geological Survey  
325 John Knox Road  
Suite F-240  
Tallahassee, Florida 32303

## CONTENTS

	Page
Abstract. . . . .	1
Introduction. . . . .	2
Purpose and scope. . . . .	2
Area of investigation. . . . .	3
Previous investigations. . . . .	3
Well-numbering system. . . . .	3
Acknowledgments. . . . .	3
Shallow-aquifer system. . . . .	6
Shallow-aquifer tests . . . . .	6
Method . . . . .	6
Analyses of aquifer tests. . . . .	19
Water levels and recharge . . . . .	20
Availability of water . . . . .	23
Quality of water. . . . .	26
Summary . . . . .	34
Selected references . . . . .	35

## ILLUSTRATIONS

### Figure

1.	Map showing area of investigation and location of shallow aquifer test sites. . . . .	4
2.	Map showing the thickness of the sediments overlying the Floridan aquifer . . . . .	7
3.	Schematic geohydrologic section showing stratigraphic units of the shallow aquifer system . . . . .	8
4.	Well logs showing well design and geohydrology of the shallow-rock and water-table aquifers at the shallow aquifer test sites . . . . .	9
5.	Map showing areas of recharge to the Floridan aquifer in Duval County. . . . .	22
6.	Graph showing rainfall in Jacksonville January-August 1976. . . . .	24
7.	Distance-drawdown curves for selected shallow-aquifer characteristics . . . . .	27
8-11.	Maps showing generalized distribution of hardness, dissolved solids, chloride, and iron in water from the shallow-aquifer system. . . . .	30

TABLES

Table		Page
1.	Well numbers . . . . .	5
2.	Well records . . . . .	16
3.	Aquifer test data for the shallow-rock zone. . . . .	18
4.	Water levels in the water-table zone, shallow-rock zone and Floridan aquifer . . . . .	21
5.	Maximum potential yields of shallow-rock wells at sites 1-13, based on specific capacity . . . . .	25
6.	Field analyses of water from selected wells at sites 1-13. .	28
7.	Laboratory analyses of water from selected wells at sites 1-13 . . . . .	29

AVAILABILITY AND QUALITY OF WATER FROM SHALLOW  
AQUIFERS IN DUVAL COUNTY, FLORIDA

By

L. V. Causey and G. G. Phelps

ABSTRACT

The shallow-aquifer system in Duval County overlies the Floridan aquifer and is composed chiefly of sand, clay, sandy clay, and limestone. Thickness of the system ranges from about 300 to 600 feet. The upper 150 feet of deposits, consisting of the water-table and shallow-rock zones, are the most dependable and economical source of supplemental water supply. The principal shallow water-bearing zone is a limestone bed 40 to 100 feet below land surface.

Aquifer tests conducted at 13 sites in Duval County show that yields from the shallow aquifer vary from place to place within the county owing chiefly to variations in lithology of the saturated rocks and sediments. The limestone of the shallow-rock zone will yield as much as 200 gallons per minute to wells; the maximum yield at most of the sites tested was between 30 and 100 gallons per minute. The water-table zone generally yields 10 gallons per minute or less but at one site, where a water-table well tapped a shell bed near land surface, the well yielded more than 40 gallons per minute.

The quality of water in the shallow aquifer system in Duval County is generally acceptable for most domestic, commercial, and industrial uses. In some places, however, it has a high iron concentration and is hard. The iron concentration exceeds 0.3 milligrams per liter in water from the water-table or shallow-rock zones at 7 of the 13 aquifer test sites. The hardness of water from the aquifer ranges from about 60 to about 180 milligrams per liter.

## INTRODUCTION

Jacksonville, which includes most of Duval County, is the largest city in northern Florida. Rapid growth in parts of the city has created a need for information on sources of water for future supplies. At the present time (1977), practically all of the water used in Jacksonville comes from wells in the Floridan aquifer. Potential sources of additional freshwater in the area are surface streams and shallow aquifers above the Floridan aquifer.

As part of a Metropolitan Jacksonville Water Resources Investigation, the U.S. Army Corps of Engineers, Jacksonville District, is conducting an investigation to determine the feasibility of utilizing various sources of water in the area to supplement present supplies. The U.S. Geological Survey is assisting the U.S. Army Corps of Engineers in obtaining data to determine if using the shallow-aquifer system as a supplemental supply of fresh water in Jacksonville is feasible.

For those readers who prefer metric units rather than U.S. customary units, the conversion factors for terms used in this report are listed below:

<u>Multiply U.S. customary unit</u>	<u>By</u>	<u>To obtain metric unit</u>
inch (in)	25.40	millimeter (mm)
foot (ft)	0.305	meter (m)
mile (mi)	1.609	kilometer (km)
gallon per minute (gal/min)	0.0631	liter per second (L/s)
feet per day (ft/d)	.305	meters per day (m/day)
feet <sup>2</sup> /day (ft <sup>2</sup> /d)	.0929	meters squared per day (m <sup>2</sup> /day)

### Purpose and Scope

The purpose of this investigation is to obtain information about the shallow aquifer system, including the location of waterbearing zones, their water-yielding characteristics, the quality of water obtained, the hydraulic interrelation of zones within the shallow aquifers, and the variability of all these. The information will be used by the U.S. Army Corps of Engineers to evaluate the water-supply potential of the shallow aquifer system in Duval County. To obtain information at as many sites as possible, numerous small diameter test holes were drilled and cased. Casing diameters were 1 1/4 to 2 in. This report also outlines field procedures that can be used to evaluate the potential yield of shallow aquifers at sites not studied in this investigation.

### Area of Investigation

Duval County occupies about 840 mi<sup>2</sup> in northeastern Florida (fig. 1). Most of the county is within the corporate limits of the Consolidated City of Jacksonville.

The county has a humid, semitropical climate and an average annual rainfall of about 54 in. Rainfall is generally greatest from May to August when summer thunderstorms may yield several inches of rain in one part of the county and only a trace or none in other parts.

The topography in Duval County is mostly flat, but slopes gradually from sea level along the coast to about 190 ft above sea level in the southwest corner. Salt marshes cover much of the eastern part of the county and many freshwater swamps occupy the flat upland areas.

Surface drainage is primarily through the St. Johns and St. Marys Rivers, and their tributaries. The St. Johns River flows northeastward through the county and empties into the Atlantic Ocean. It is affected by tide throughout its length in Duval County.

### Previous Investigations

Fairchild (1972) describes the geology, extent, some of the hydrologic characteristics of the shallow aquifer system, and the general geography of Duval County. Derragon (1955), Leve (1961; 1966), and Leve and Goolsby (1969) cite general information on the shallow aquifer system and Cooke (1945), Vernon (1951), Puri and Vernon (1964), and Leve (1966) describe the formations that make up the system.

### Well-Numbering System

Two well numbering systems are used in this report. The U.S. Geological Survey identification number is based on latitude-longitude coordinates and a sequential number for the particular area proscribed by the final digit of seconds for those coordinates (table 1). Also used is a local well number prefixed by the letters, DS, indicating a shallow well in Duval County. Any available historic data may be obtained from computer files by using the U.S. Geological Survey identification number. Inquiries regarding availability of such data may be made to the U.S. Geological Survey District Office in Tallahassee, Florida.

### Acknowledgments

The authors express appreciation to Oscar Rawls, City Engineer, Department of Public Works, Jacksonville, for granting permission to construct test wells on City road rights-of-way; to J. A. Moss, District Maintenance Engineer, Florida Department of Transportation, Lake City, for granting permission to construct test wells along State road rights-of-way; and to D. F. Duggins, Manager of Plant Services, Duval County School Board, Jacksonville, for permission to construct wells on Duval County Schools property.



TABLE 1.--Well numbers

		U.S. Geological Survey		U.S. Geological Survey							
Well number	Local number	identification number	Well number	Local number	identification number						
Site 1	1	DS-244(b)	301647	0812741	01	Site 7	1	DS-240(b)	301758	0814631	03
	2	DS-245	301647	0812741	02		2	DS-241	301758	0814631	03
	3	DS-262	301647	0812741	03		3	(a)			
	4	(a)									
Site 2	1	DS-256(b)	302215	0812431	01	Site 8	1	DS-254	302003	0815412	01
	2	DS-257	302215	0812431	02		2	DS-255(b)	302003	0815412	02
	3	DS-263	302215	0812431	03		3	(a)			
	4	(a)									
Site 3	1	DS-248	302113	0813337	01	Site 9	1	DS-238(b)	301422	0815412	03
	2	DS-249(b)	302113	0813337	02		2	DS-239	301422	0815412	04
	3	DS-260	302113	0813337	03		3	(a)			
	4	(a)									
Site 4	1	DS-246(b)	301503	0813311	01	Site 10	1	DS-232(b)	302427	0814910	01
	2	DS-247	301503	0813311	02		2	DS-233	302427	0814910	02
	3	DS-261	301503	0813311	03		3	DS-272	302427	0814910	03
	4	(a)									
Site 5	1	DS-242	301111	0813334	01	Site 11	1	DS-250(b)	301806	0813850	05
	2	DS-243(b)	301111	0813334	02		2	DS-251	301806	0813850	06
	3	DS-269	301111	0813334	03		3	(a)			
	4	(a)									
Site 6	1	DS-252	301333	0814425	01	Site 12	1	DS-236(b)	302633	0813330	01
	2	DS-253(b)	301333	0814425	02		2	DS-237	302633	0813330	02
	3	DS-264	301333	0814425	03		3	DS-265	302633	0813330	03
	4	(a)									
Site 13	1	DS-234				1	DS-234				
	2	DS-235(b)				2	DS-235(b)				
	3	(a)				3	(a)				

<sup>a</sup> Indicates temporary water-table well constructed by driving plastic pipe into the ground. These wells were removed at the end of the investigation and so were not cataloged by the U. S. Geological Survey.

<sup>b</sup> Indicates pumped well in aquifer tests.

## SHALLOW-AQUIFER SYSTEM

The shallow-aquifer system overlies the Floridan aquifer and consists chiefly of sand, clay, sandy clay, and limestone. It ranges in thickness from about 300 ft in the south-central part of the county to about 600 ft in the northcentral part (figs. 2 and 3). The deposits between about 150 ft below land surface and the top of the Floridan aquifer are mostly clay and sandy clay interbedded with thin, discontinuous layers or local lenses of limestone and sand. Aquifers within that zone are not usually dependable sources of water. Because the shallower zone is generally more productive and less expensive to develop than the deeper zone, this study describes only the upper 150 ft of the shallow-aquifer system.

The sediments from land surface to a depth of about 25 to 50 ft comprise the water table zone. Below the surficial sands of the water table zone, beds of lower permeability occur in most parts of the county. These beds are underlain by the principal shallow water-bearing zone, a limestone bed 40 to 100 ft below land surface. This limestone is absent along the coast and locally in the south-central part of the county. In those areas the principal shallow water-bearing zone is a medium- to coarse-grained sand. The principal shallow water-bearing zone is known locally as the shallow-rock aquifer.

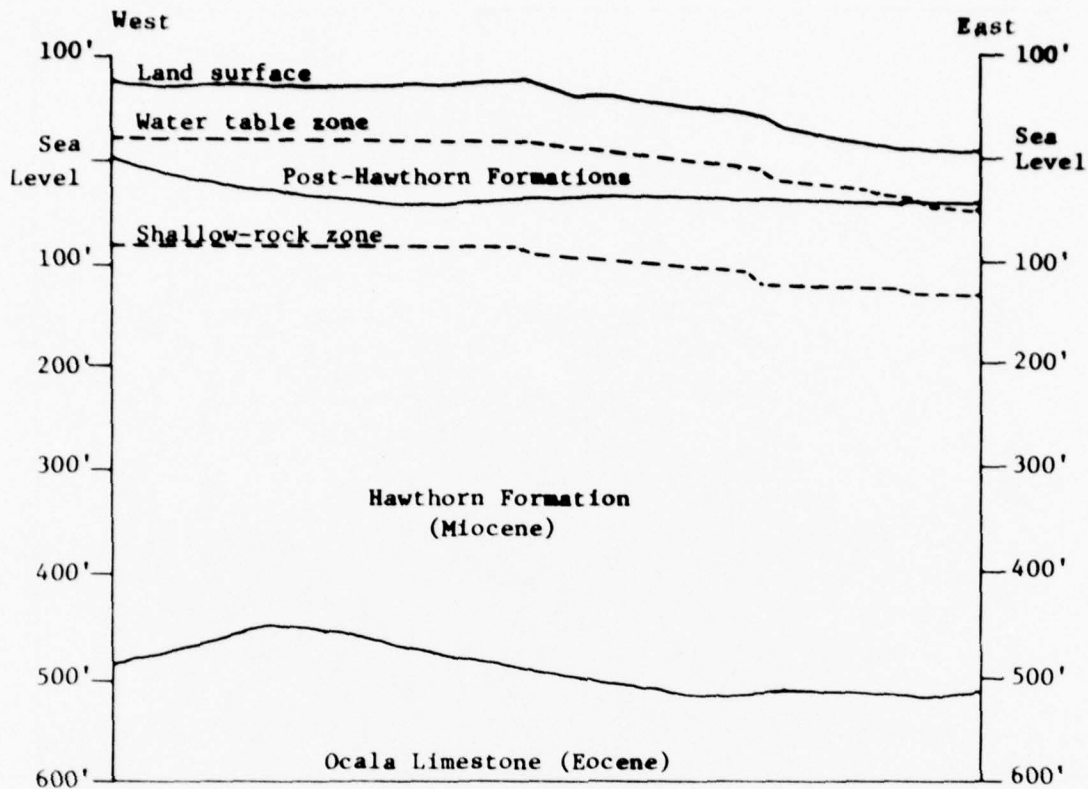
The permeability of the beds between the water table zone and the shallow-rock aquifer zone varies widely throughout the county. In some areas the shallow-rock aquifer is confined and is under artesian or leaky-artesian conditions, whereas in other areas the water table and shallow-rock zones function as a single hydrologic unit.

## SHALLOW-AQUIFER TESTS

### Method

Thirteen test sites were selected in Duval County (fig. 1, table 1) to better define the hydraulic characteristics of the shallow system. Two shallow-rock wells and one or two water-table wells were drilled at each site. Because little was known about the thickness of water-bearing zones, hydraulic characteristics, and yield of the shallow aquifer system, instrumentation and the tests were simplified so maximum areal coverage could be obtained with available funding. Well logs showing well design, water level on the date of drilling, lithology, and principal aquifer at each site are depicted in figure 4. The logs were prepared from driller's logs and examination of well cuttings. The completion depths of the shallow-rock wells range from 46 ft to 104.5 ft except at site 10 where they are 210 and 241 ft. Mud-filled cavities in the limestone at depths of 100 to 120 ft at site 10 made it necessary to drill the wells deeper to obtain clear water. The water table wells are 3.2 to 30 ft deep. Pertinent drilling and well-construction information for each site is listed in table 2.





Geohydrology modified from Fairchild, 1972.

Explanation--Dashed lines represent approximate lower limit of the respective shallow-aquifer zones.

Series	Formation	Lithologic Description
Holocene Pleistocene	Holocene and Pleistocene Deposits	Sand, tan to yellow, loose, medium to fine quartz, sometimes with shells and/or minor clay content--often has hardpan layer of iron oxide-cemented, rusty red to dark brown medium to fine sand in upper part of section--source of water to shallow sandpoint wells.
Pliocene or Miocene	Pliocene or Upper Miocene Deposits	Upper part--tan to buff, fine to coarse sand and gray to light gray sandy clay, clayey sand, and shell beds; clay often contains abundant mollusk shells. Lower part--limestone, tan to yellow, often highly sandy, porous, and cavernous--also few thin beds of brown crystalline, dolomitic, limestone--section is major source of water to shallow wells.
Miocene	Hawthorn Formation	Gray to blue-green and olive-green clay, sandy clay, and sandy limestone--usually phosphatic with abundant, well-rounded, polished, granules and pebbles of phosphate. Formation not usually considered a good source of water; some wells tap lenses of sand and limestone in the upper part.

Figure 3.--Schematic geohydrologic section showing stratigraphic units of the shallow-aquifer system.

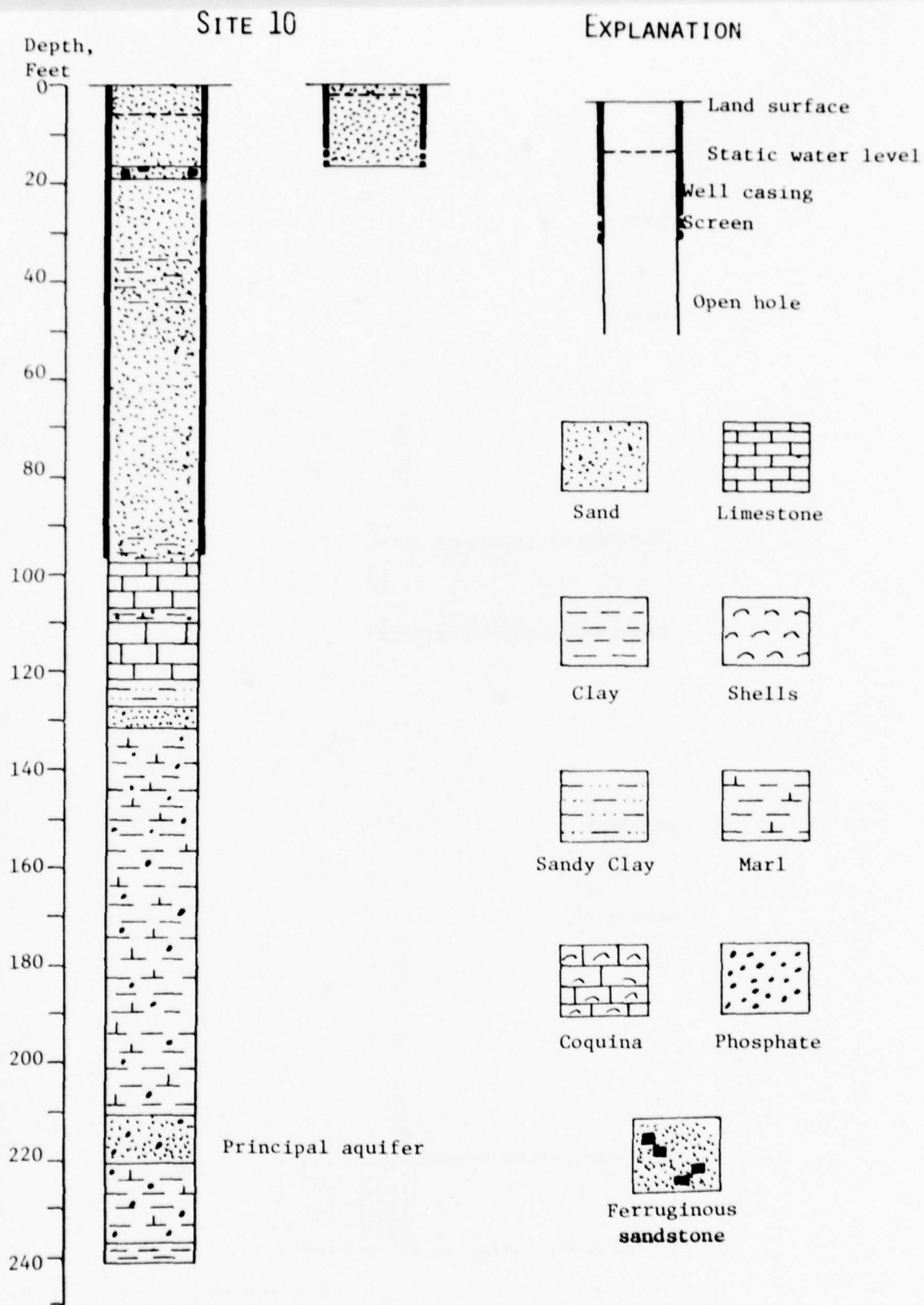


Figure 4.--Well logs showing well design and geohydrology of the shallow-rock and water-table aquifers at the shallow aquifer test sites.

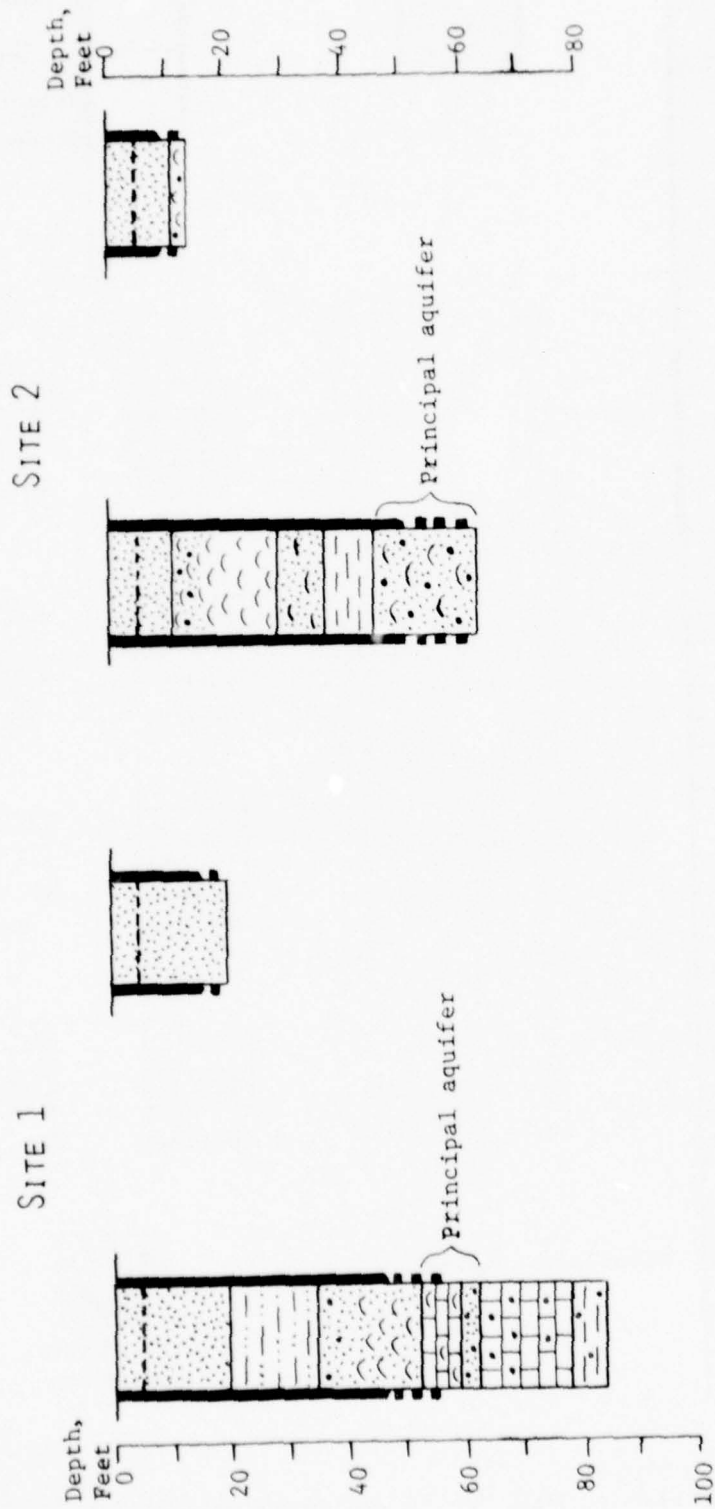


Figure 4.--Well logs showing well design and geohydrology of the shallow-rock and water-table aquifers at the shallow aquifer test sites.--Continued

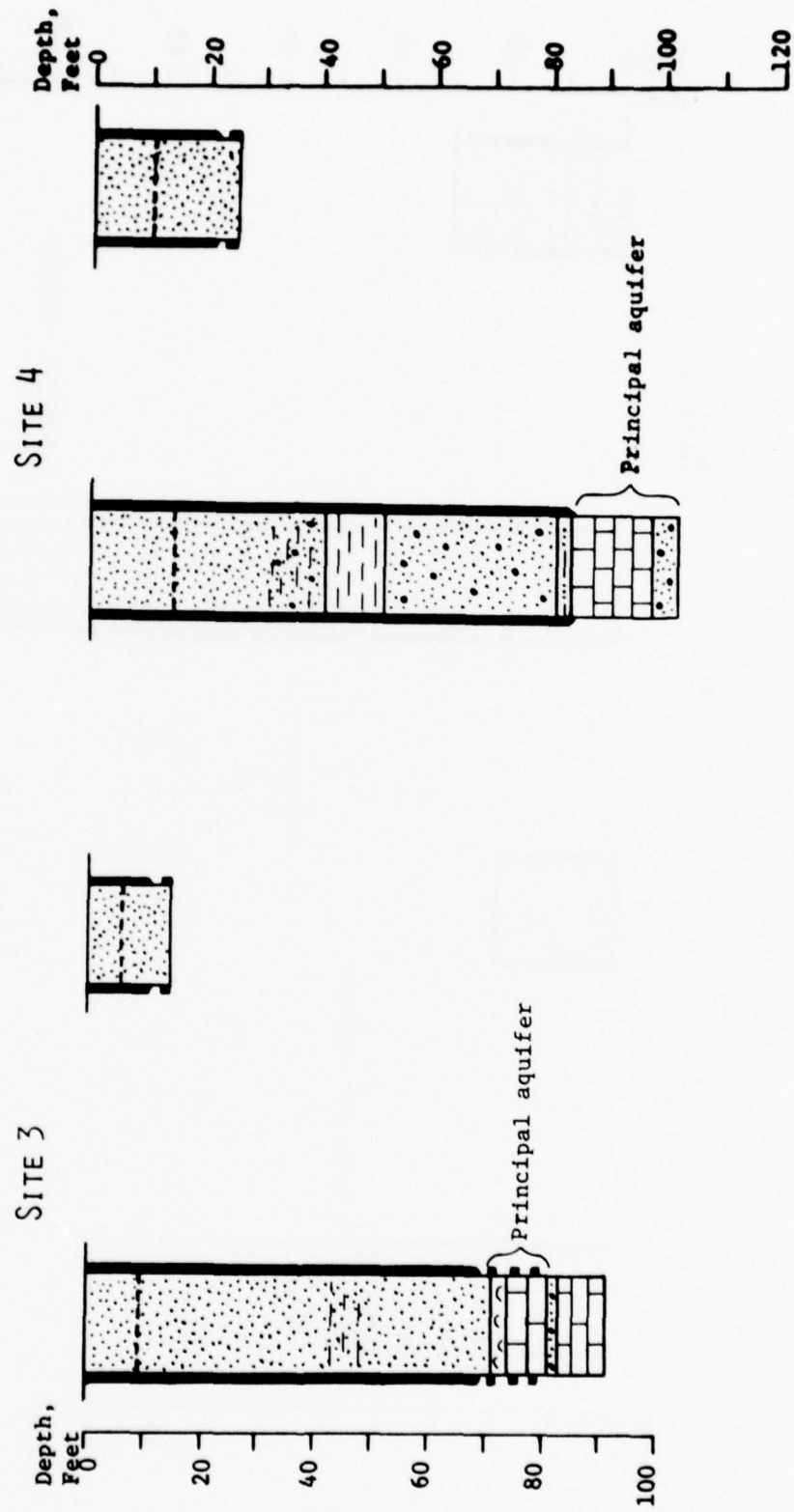


Figure 4.--Well logs showing well design and geohydrology of the shallow-rock and water-table aquifers at the shallow aquifer test sites.--Continued

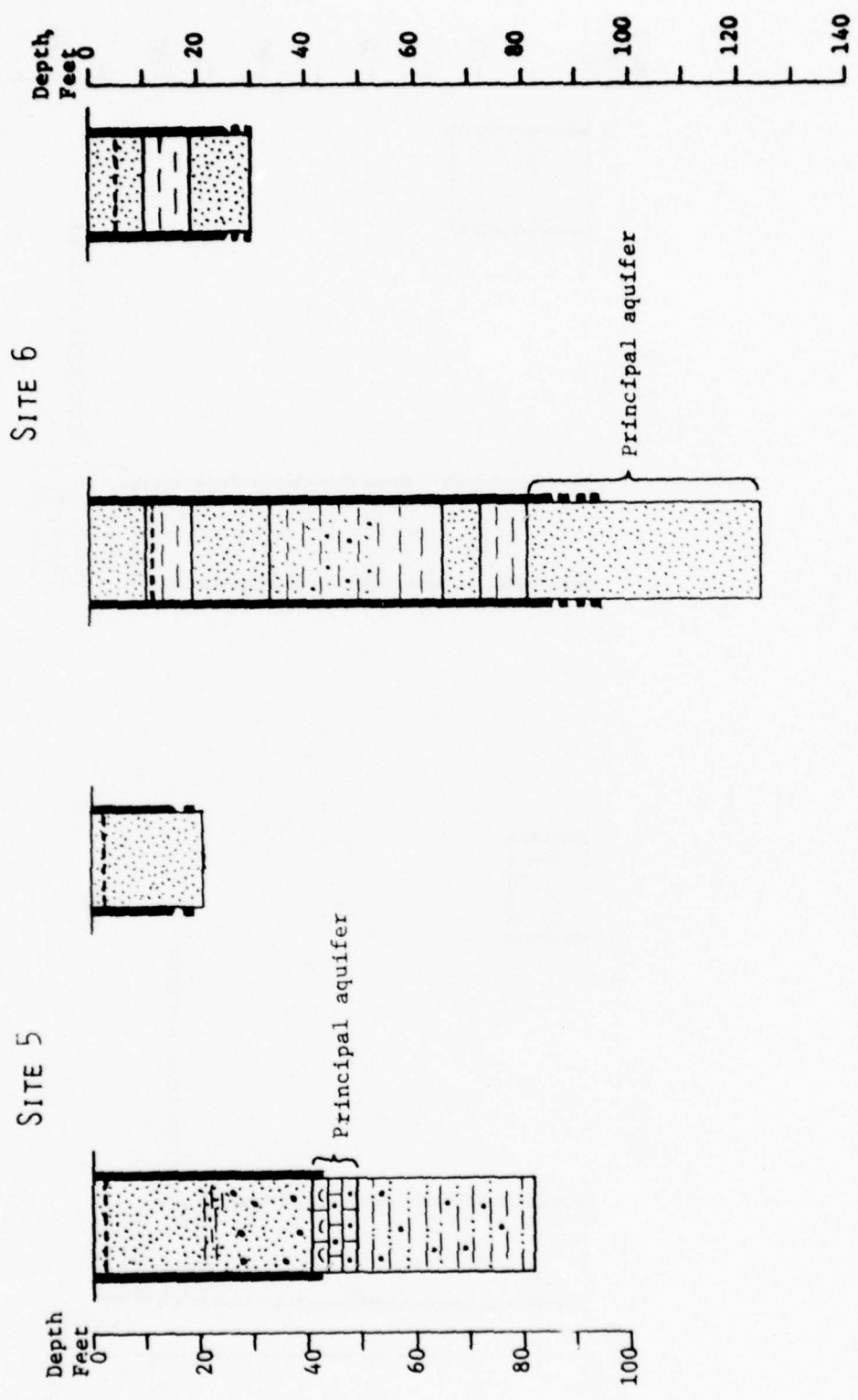


Figure 4.--Well logs showing well design and geology of the shallow-rock and water-table aquifers at the shallow aquifer test sites.--Continued

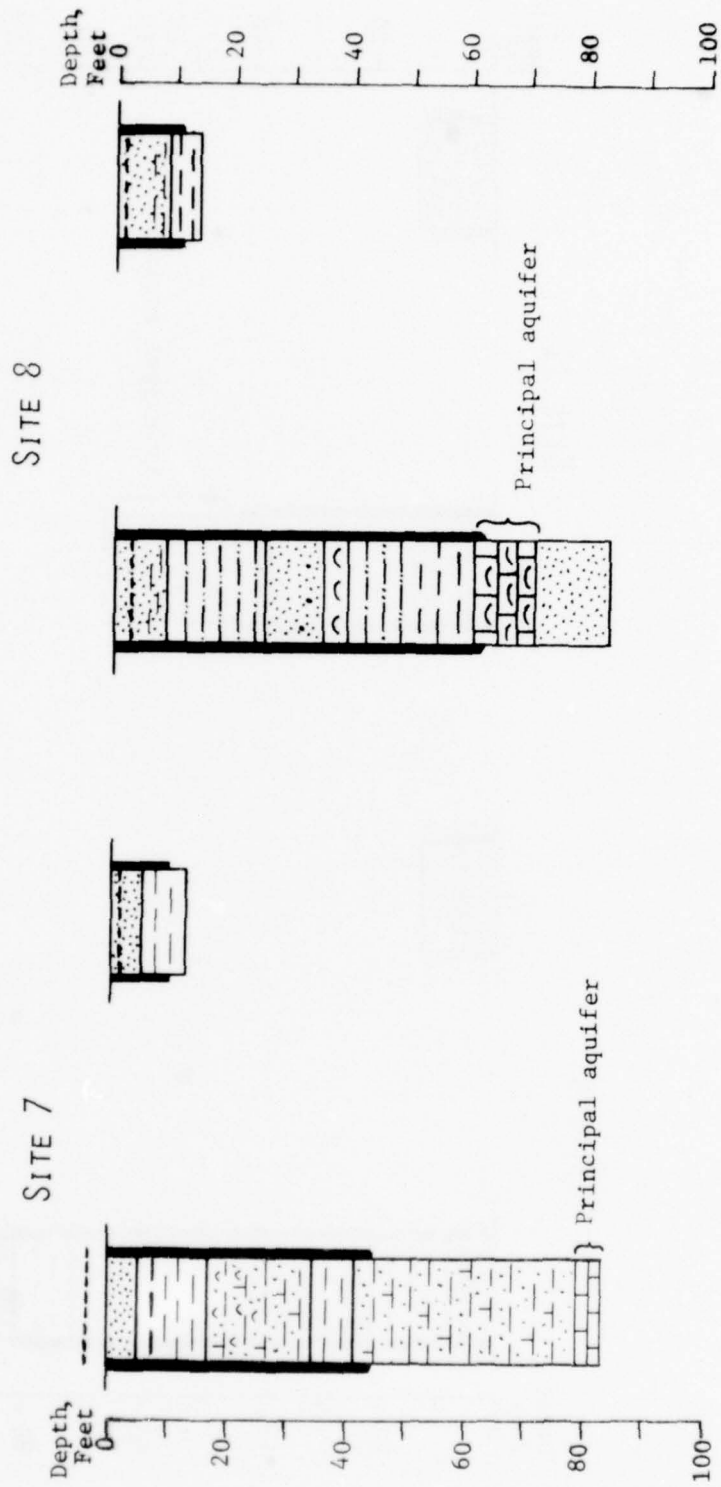


Figure 4.--Well logs showing well design and geohydrology of the shallow-rock and water-table aquifers at the shallow aquifer test sites.--Continued

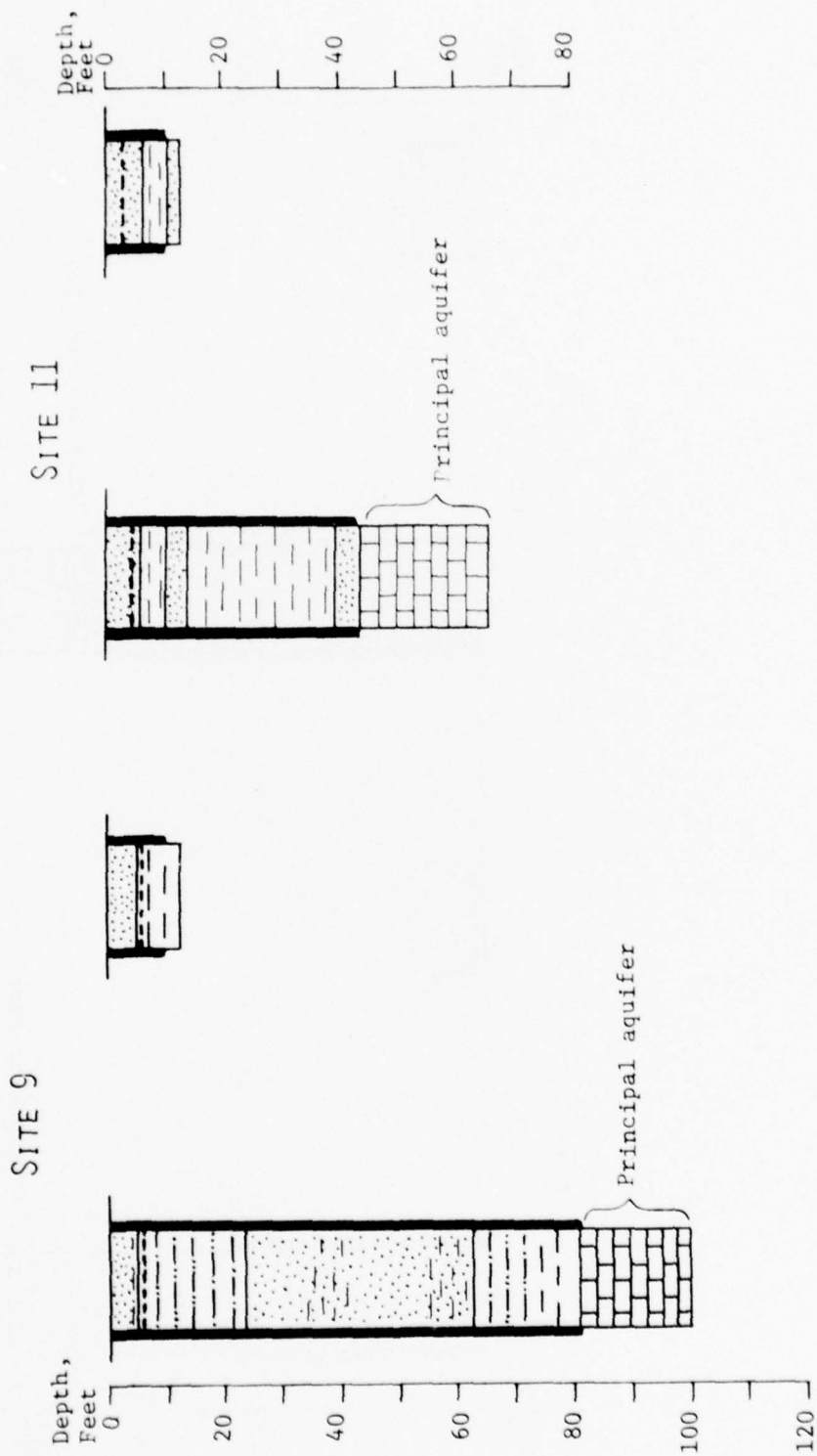


Figure 4.--Well logs showing well design and geohydrology of the shallow-rock and water-table aquifers at the shallow aquifer test sites.--Continued

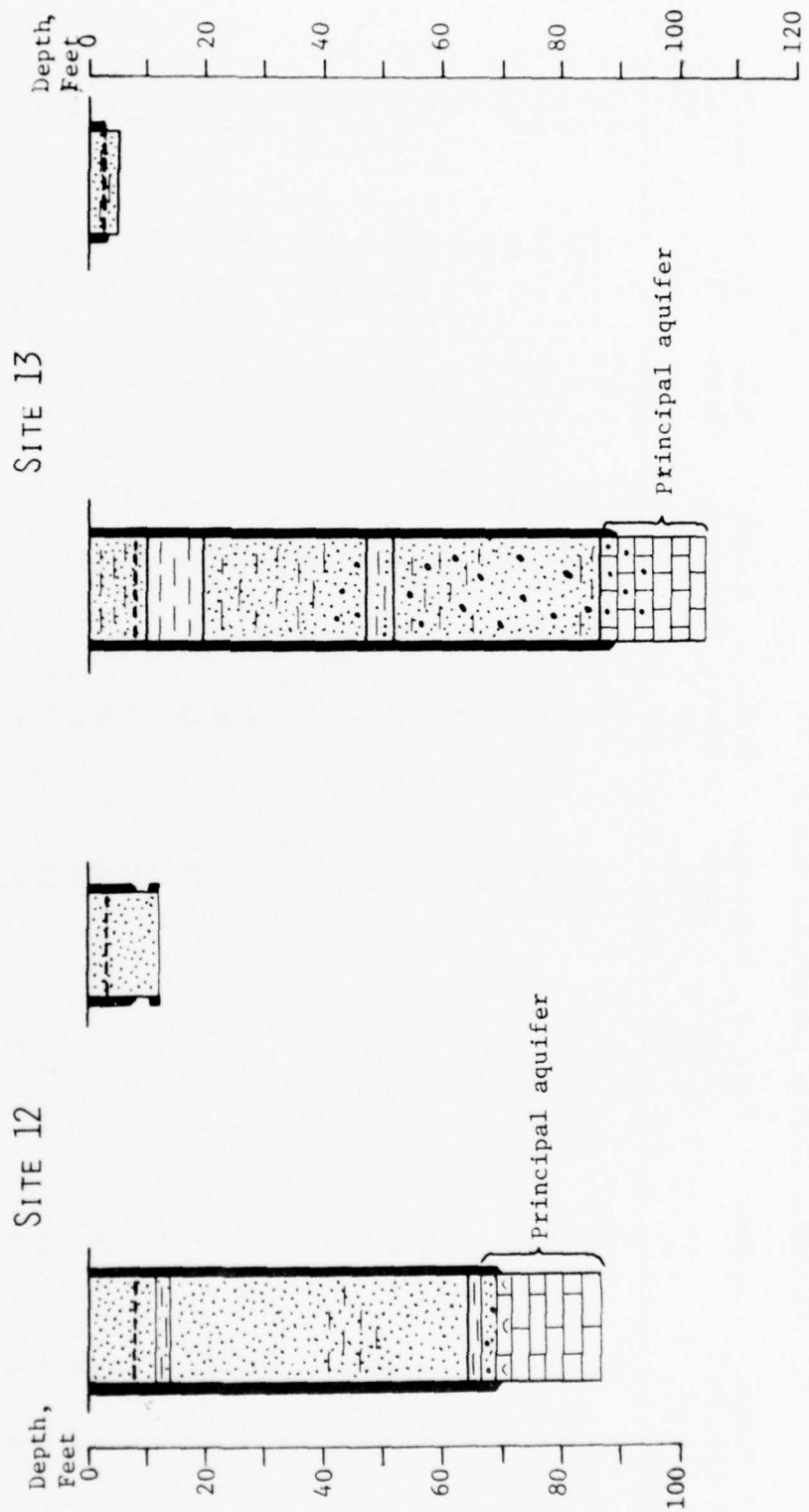


Figure 4.--Well logs showing well design and geology of the shallow-rock and water-table aquifers at the shallow aquifer test sites.--Continued

TABLE 2.--Well records. (Aquifer: WT, water-table; SR, shallow rock. Finish: S, screened; X, open-hole. Water level: +, above land surface; -, below land surface. Water level measured May 17, 1976. Altitude from U.S. Geological Survey topographic maps.)

Number Site Well	Aquifer	Drilled Depth (ft)	Completion Depth (ft)	Casing Depth (ft)	Casing Diameter (in)	Well Finish	Water Level (ft)	Altitude of site (ft)
1	SR	83.5	55	47	2	S	-5.44	22
1	SR	62.5	52	44	2	S	-5.38	22
1	WT	20	20	16	2	S	-3.94	22
1	WT	16	16	16	1 1/4	X	-3.80	22
2	SR	63.5	61	51	2	S	-4.70	9
2	SR	63	63	61	2	X	-4.38	9
2	WT	14	14	10	2	X	-5.35	9
2	WT	11	11	11	1 1/4	X	-5.30	9
3	SR	92.5	80	72	2	S	-9.13	45
3	SR	75	75	67	2	S	-9.13	45
3	WT	15	15	11	2	S	-6.53	45
3	WT	11.5	11.5	11.5	1 1/4	X	-6.55	45
4	SR	104.5	104.5	87	2	X	-15.56	50
4	SR	95	94	86	2	S	-14.99	50
4	WT	25	25	21	1 1/4	S	-10.54	50
4	WT	23	23	23	1 1/4	S	-10.60	50
5	SR	83	83	42.5	2	X	-2.87	15
5	SR	50	46	38	2	S	-2.92	15
5	WT	19	19	15.5	2	S	-2.89	15
5	WT	19	16.5	16.5	1 1/4	X	-2.85	15
6	SR	125.5	94	84	2	-X	-10.97	23
6	SR	94	94	86	2	S	-11.07	23
6	WT	30	30	26	2	S	-4.75	23
6	WT	27	27	27	1 1/4	X	-4.75	23
7	SR	83.5	83.5	45	2	X	+3.52	25
7	SR	60	60	42	2	X	+3.72	25
7	WT	10	10	10	1 1/4	X	-1.19	25
8	SR	83.5	83.5	63	2	X	-3.33	85
8	SR	83.5	83.5	63	2	X	-3.33	85
8	WT	15	10	10	1 1/4	X	-1.05	85

TABLE 2.--Well records (continued)

Number Site Well	Aquifer	Drilled Depth (ft)	Completion Depth (ft)	Casing Depth (ft)	Casing Diameter (in)	Well Finish	Water Level (ft)	Altitude of site (ft)
9	SR	101	101	82	2	X	-6.69	80
9	SR	94	94	82	2	X	-7.69	80
9	WT	10	10	10	1 1/4	X	-6.10	80
10	SR	210	210	188	1 1/4	X	-5.80	49
10	SR	241	231	97	2	X	-5.48	49
10	WT	16.8	16.8	13.3	2	S	-1.57	49
10	WT	16.5	16.5	16.5	1 1/4	X	-2.16	49
11	SR	66.5	66.5	44	2	X	-6.35	15
11	SR	55	55	44	2	X	-6.35	15
11	WT	10	10	10	1 1/4	X	-3.73	15
12	SR	88	88	71	2	X	-8.12	25
12	SR	76	76	71	2	X	-8.11	25
12	WT	12	12	8.5	2	S	-2.27	25
12	WT	10	10	10	1 1/4	X	-2.83	25
13	SR	104.5	104.5	89.5	2	X	-8.54	22
13	SR	95	95	88.5	2	X	-8.56	22
13	WT	3.2	3.2	3.2	2	X	0.00	22

1	6-30-76	53	11	-3.6	18	8.7	21.4	19	3.44	+0.20
2	7- 7-76	45	18	-4.7	4	1.7	20.3	20	6.28	no change
3	7- 6-76	73	11	-9.1	30	5.0	15.9	17	3.01	-0.05
4	6-28-76	86	22	-15.3	10	2.7	9.7	19	9.36	no change
5	6-29-76	41	8	-1.9	18	4.2	23.1	21	2.73	-0.96
6	7-28-76	83	43	-11.3	10	7.7	13.7	17	4.77	-0.06
7	8-10-76	80	5	+2.6	51	12.7	22.4	18	9.18	-0.47
8	7-26-76	63	17	-4.8	15	13.5	20.2	20	6.96	-0.10
9	8- 3-76	83	20	-6.0	48	10.8	19.0	20	6.80	no change
10	9- 9-76	210	10	-5.4	20	9.5	19.6	15	5.90	-0.06
11	7-13-76	45	22	-6.2	6	5.0	18.8	16	2.74	no change
12	7-14-76	67	21	-7.6	45	5.4	17.4	17	7.83	+0.20
13	7-19-76	88	18	-8.7	37	4.7	16.3	16	3.88	no change

1/ Above (+) or below (-) land surface.

2/ Pumping rate was maximum obtained with shallow-well pump (about 25 ft of lift).

30 30'

20'

10'

BR-18  
DOWD CO

AD  
WELLS

At each site, one shallow-rock well was pumped and the other wells were used as observation wells. The aquifer tests varied in length from 1.7 hours to 13.5 hours at pumping rates of 4 to 45 gal/min (gallons per minute). Data from the shallow-rock aquifer tests are summarized in table 3.

After the completion of the shallow rock-aquifer tests, one water-table well was pumped at each site. Except at site 2, the tests were of short duration because low yields indicated that the water table zone would not be a useful source of municipal or industrial supply. At site 2, the water-table well yielded a relatively large quantity of water and was pumped for a longer period. The water-table zone at site 2 is composed of a permeable shell bed which yielded more water than the shallow-rock zone. Except for well yields no data from the water-table tests are reported herein.

#### Analyses of Aquifer Tests

Because the shallow-rock aquifer zone in Duval County is relatively thin, heterogeneous, and discontinuous, the aquifer characteristics determined are approximate and are valid only for the site tested. They cannot be used to designate broad areas of high or low potential ground-water yield. For the same reason, the yields which might be observed after long-term (many days) pumping probably cannot be predicted accurately from the aquifer parameters determined in this investigation.

Several factors limit the accuracy with which the shallow-aquifer tests can be analyzed. First, pumping stress was limited by small well casings (2-in diameter) and by use of a suction pump (limited to about 25 ft of pumping lift). Also, the shallow-aquifer system in Duval County cannot be described accurately as either an unconfined or a leaky confined aquifer for the purpose of mathematical analysis. A comparison of depth-to-top of shallow-rock zone and water level of wells in table 3 shows that the water level at each site rises above the top of the principal water-bearing zone owing to confining pressure. However, the beds which overlie the shallow-rock zone are thin and discontinuous and do not form a uniform confining bed which is assumed to be present in a confined aquifer system. Finally, the response of the surficial aquifer system to pumping will differ from theoretical responses because the aquifer is not homogeneous and because the principal water-bearing zone is not continuous over a large area. For these reasons conventional analytical techniques did not yield consistent results.

A method of estimating transmissivity (the rate at which ground water is transmitted through a unit width of an aquifer under a unit hydraulic gradient) using the specific capacity of a well was described by Theis (1963) and Brown (1963). In this method a variable  $T'$  can be calculated and transmissivity estimated from a family of transmissivity curves plotted on a scale of  $T'$  versus specific capacity (Theis, 1963, fig. 99). For water table aquifers

$$T' = C (K - 264 \log_{10} 5S + 264 \log_{10} t)$$

(Theis, 1963, p. 333)

For artesian aquifers

$$T' = C (K - 264 \log_{10} (5S \times 10^3) + 264 \log_{10} t)$$

(Brown, 1963, p. 337)

where C = specific capacity, gal/min/ft

K = a factor depending on distance from the pumped well

t = length of the test, days.

Calculations of transmissivity were made for all sites using both the artesian and water-table formulas. Artesian conditions generally predominate (except at site 5, (table 3)) but it is assumed that the values calculated bracket the transmissivity of the aquifer. Values of T' were also calculated using the specific capacity of the observation wells as a cross check to help determine if losses due to turbulence were a factor in the calculations. At most sites both calculations of transmissivity were consistent. At site 4, however, turbulent flow probably occurred. Calculated transmissivity values ranged from about 250 ft<sup>2</sup>/day to a maximum of about 1300 ft<sup>2</sup>/day, assuming full artesian conditions.

In some areas, pumping the shallow-rock zone caused drawdowns in the water-table wells (table 3). This indicates that the beds between the water table and the shallow-rock zones are highly permeable, an important consideration if the water table zone is susceptible to pollution from, for example, septic tanks, storm runoff, or brackish water.

#### WATER LEVELS AND RECHARGE

Recharge to the shallow aquifer system occurs by downward percolation of precipitation, and, in some areas, by upward leakage from the underlying Floridan aquifer. The difference between the water levels in the water table and shallow-rock zones and in the Floridan aquifer indicates the direction of the vertical hydraulic gradient (table 4). An upward gradient would indicate upward leakage; and a downward gradient, downward leakage. The test sites with a downward hydraulic gradient between the shallow-rock zone and the Floridan aquifer coincide, in general, with areas of recharge to the Floridan aquifer as mapped by Causey (1975) (fig. 5).

Although the hydraulic relationship between the shallow-rock zone and the underlying Floridan aquifer was not investigated in this study, some hypotheses can be made. Short-term pumping of the shallow-aquifer system probably has a negligible effect on the potentiometric surface of the Floridan aquifer. However, in areas where the potentiometric surface of the Floridan aquifer is lower than that of the shallow-rock zone, pumping the shallow-rock zone could reduce recharge to the Floridan aquifer. Also, if water levels in the shallow-rock zone were lowered in areas where upward leakage from the Floridan aquifer occurs, the magnitude of the upward gradient would increase, perhaps resulting in increased upward leakage from the Floridan aquifer. Calculating the effect of such changes in leakage on the potentiometric surface of the Floridan aquifer is a complex

TABLE 4.--Water levels in the water-table zone, shallow-rock zone, and Floridan aquifer.  
(Datum is mean sea level)

Site number	May 1976 water levels		Summer 1976 water levels		Floridan aquifer water levels			
	Water-table zone	Shallow-rock zone	Water-table zone	Shallow-rock zone	Well number	Near site	May water level	August water level
1	18.06	16.56	20.09 (June)	18.40	D160	1,2	32.55	35.05
2	3.65	4.30	4.54 (July)	5.08				
3	38.47	35.87	39.02 (July)	35.86				
4	39.46	34.44	40.64 (July)	35.13	D291	4	44.5	47.0
5	12.11	12.08	13.19 (June)	13.10				
6	18.25	11.93	19.43 (July)	12.91	D115	6	27.75	28.35
7	23.81	28.52	22.51 (Aug)	27.58	D123	7	34.58	35.28
8	83.95	81.67	81.86 (July)	80.25	D254	8,9	51.8	51.9
9	73.90	73.31	74.82 (Aug)	73.97				
10	47.43	43.20	47.51 (Aug)	42.81	D425	11	35.2	36.0
11	11.27	8.65	11.76 (July)	8.82	D152	12	35.24	34.04
12	22.33	16.88	23.39 (July)	17.35	D262	12	33.72	36.32
13	22.00	13.44	19.53 (July)	13.31	D145	13		35.59

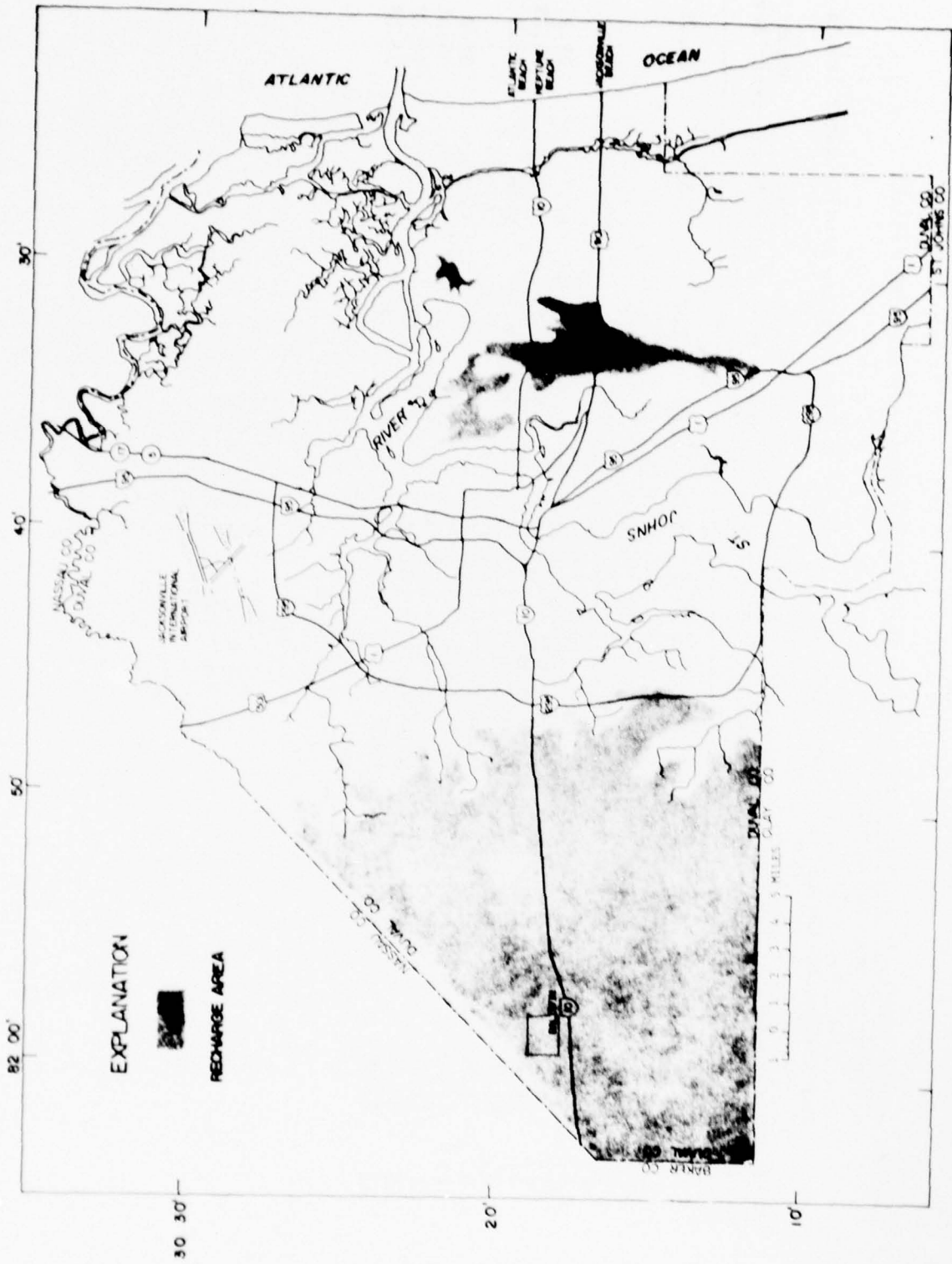


Figure 5.--Area of recharge to the Floridan aquifer in Duval County.

problem not within the scope of this study. However, if large quantities of water were pumped from the shallow aquifer system over a large area, and pumpage from the Floridan aquifer were not decreased, the potentiometric surface of the Floridan aquifer might decline.

Seasonal fluctuations in water levels in the two shallow zones and in the Floridan aquifer are also apparent in table 4. Rainfall in Jacksonville in 1976 (fig. 6) was less than average and more erratically distributed in time than usual. In general, however, water levels were lower at the end of the dry season (May) and rose with the onset of the summer wet season. Water levels rose at some sites and declined at others, depending upon their proximity to recharge areas, withdrawal areas, and the areal distribution of rainfall.

#### AVAILABILITY OF WATER

Yields from the shallow aquifers vary from place to place within the county owing chiefly to variations in lithology of the saturated sediments. The water-table zone, comprising sediments from land surface to a depth of about 25 to 50 ft, yields 10 gal/min or less to 2-in diameter wells in most parts of the county. At site 2 the water-table well taps a shell bed at a depth of about 10 ft below land surface and yields 40 gal/min.

The shallow-rock zone yields as much as 200 gal/min to individual wells; the maximum yield in most parts of the county is between 30 and 100 gal/min. Table 5 lists maximum potential yields from the shallow-rock zone. The yields are based on specific capacities obtained by pumping from 2-in diameter wells with a shallow-well pump which has a maximum intake lift of about 22 to 25 feet. The table lists both the maximum yields for artesian conditions and for water-table conditions at each site. Under artesian conditions, yield is directly proportional to drawdown as long as the potentiometric surface does not drop below the top of the aquifer. Yield was calculated based on the Thiem equilibrium formula (Ferris and others, 1962, p. 91) and the maximum available drawdown (drawdown from the static water level to the top of the principal water-bearing zone). Yield is not proportional to drawdown in a water-table aquifer because part of the aquifer is dewatered during pumping. Maximum available drawdown is the difference between the static water level in the well and the level at which the well would go dry. A graphic technique described by Johnson (1966, p. 107) which relates drawdown, yield, and specific capacity, was used to calculate the maximum potential yield for water-table conditions. As mentioned previously, the shallow-rock zone cannot be analyzed accurately as either an unconfined or confined aquifer. However the potential yields for artesian and water table conditions as shown in table 5 will bracket the potential yield at each site. The variation in yield from predictions for either water-table or artesian conditions is a function of the variation in vertical hydraulic conductivity of the overlying beds.

Yields could be increased by increasing the diameter of the wells. Increasing well diameter from 2 inch to 8 inch would increase the yield about 14 percent, according to Johnson (1966, p. 107). A more important factor would be decreased friction loss in the larger pipe. Anderson

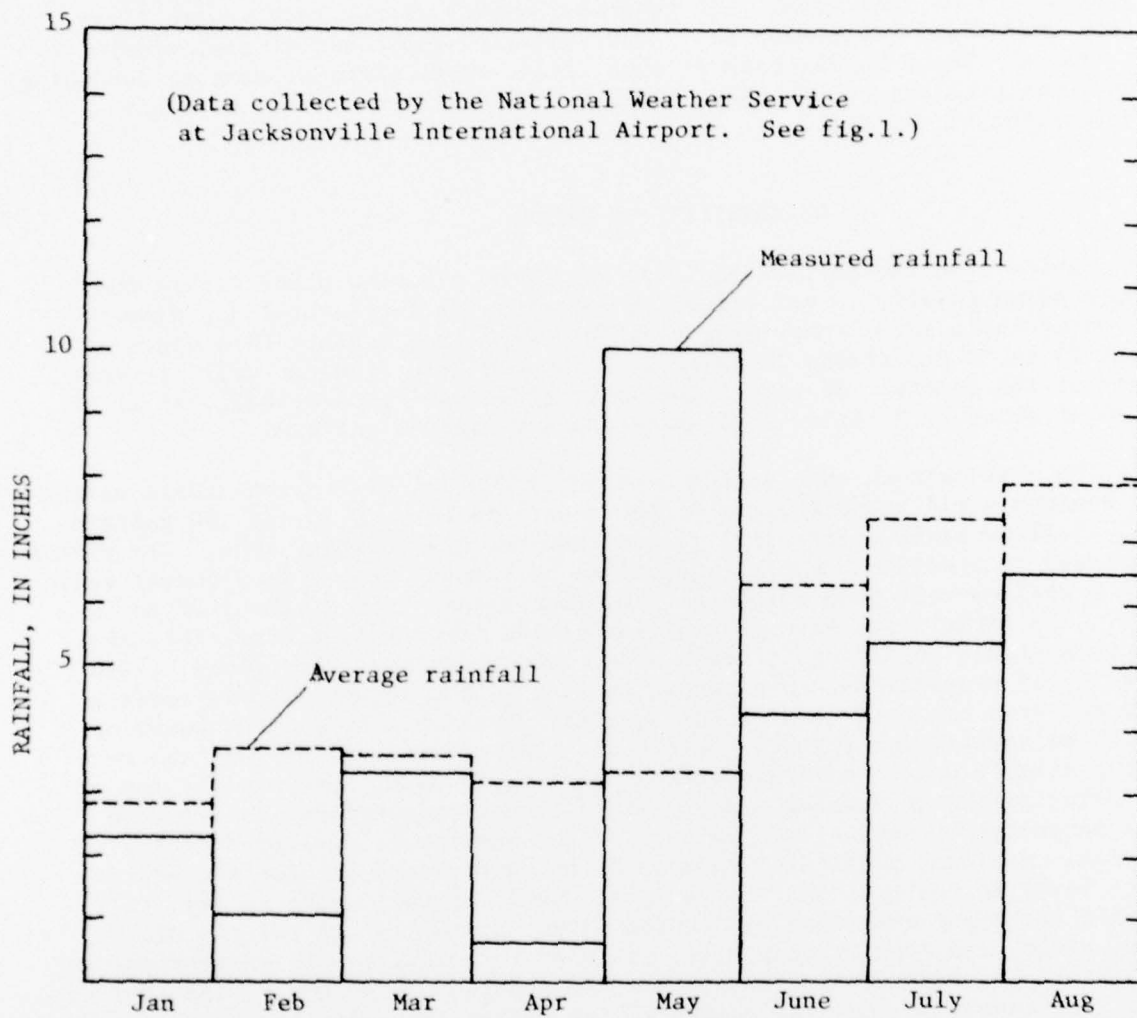


Figure 6.--Rainfall in Jacksonville January through August, 1976.

TABLE 5.--Maximum potential yields of shallow-rock wells at sites 1-13, based on specific capacity (yields determined for 2-in well and for pumping of less than 24 hours duration).

Site number	Specific capacity (gal/min)/ft	Duration of test (hrs)	Maximum available drawdown (ft)	Maximum potential yield (gal/min)	Artesian condition	Water-table condition
1	0.8	8.7	49.4	40		27
2	0.2	1.7	40.3	8		6
3	1.9	5.0	63.9	121		54
4	1.0	2.7	70.7	71		21
5	0.8	4.2	39.1	31		26
6	0.7	7.7	71.7	50		18
7	2.3	12.7	78.4	180		90
8	0.5	13.5	57.2	29		17
9	2.5	10.8	77.0	192		86
10	1.0	9.5	208.6	209		38
11	0.3	5.0	38.8	12		9
12	2.6	5.4	60.4	157		78
13	2.3	4.7	79.3	182		67

(1975, p.34) reports that for a pumping rate of 40 gal/min in a 2-inch pipe, friction head loss would be about 4 ft, while in a 8-inch pipe, friction loss would be effectively zero.

These potential maximum yield rates are based on pumping tests of less than 24 hours duration. As stated in the section on analyses of aquifer tests, the rates may be different from those obtained from tests of larger wells and of longer duration.

Some speculations about water levels after long-term pumping were made for the lower and upper range of calculated transmissivity. Using the Theis equation for nonsteady flow without vertical leakage, curves were plotted showing estimated drawdown after 30 days of pumping at rates of 10 and 50 gal/min (fig. 7). For these calculations an artesian value of storage coefficient of  $2 \times 10^{-4}$  was used. Although actual drawdown would be expected to be less because leakage undoubtedly occurs, by comparing the estimated drawdowns with the maximum available drawdowns from table 5, it can be seen that at some sites water levels would drop below the top of the aquifer and artesian conditions would no longer apply. The relationship between drawdown and distance is of interest because it gives information about how wells should be spaced to avoid interference.

The pumping rates obtained and low values of transmissivity determined for the 13 sites, together with the fact that the shallow-rock zone is thin and heterogeneous, show that the shallow-rock zone is not similar to the Floridan aquifer as a major source of freshwater. However, shallow-rock wells have been used successfully for many years for domestic supply and are an important supplemental source of water in Duval County.

#### QUALITY OF WATER

Information from this investigation and from a report by Fairchild (1972) indicate that the water in the shallow aquifers generally is acceptable for most domestic, commercial, and industrial uses although in some places in the county, iron concentration is high and the water is hard.<sup>1/</sup> Field analyses of water from the 13 sites are listed in table 6 and laboratory analyses in table 7.

The general distribution of water with given hardness, and dissolved solids, chloride, and iron concentration in water in the shallow aquifer system in Duval County is shown in figures 8, 9, 10, and 11. Local variations in quality may occur because of the heterogeneity of the aquifer system.

---

<sup>1/</sup>Water having an iron concentration in excess of 0.3 mg/L generally stains laundry and plumbing fixtures, and may have an undesirable taste. Hardness of water is classified by the U.S. Geological Survey (Durfor and Becker, 1964) as soft, up to 60 mg/L; moderately hard, 61 to 120 mg/L; hard, 121 to 180 mg/L; and very hard, over 180 mg/L.

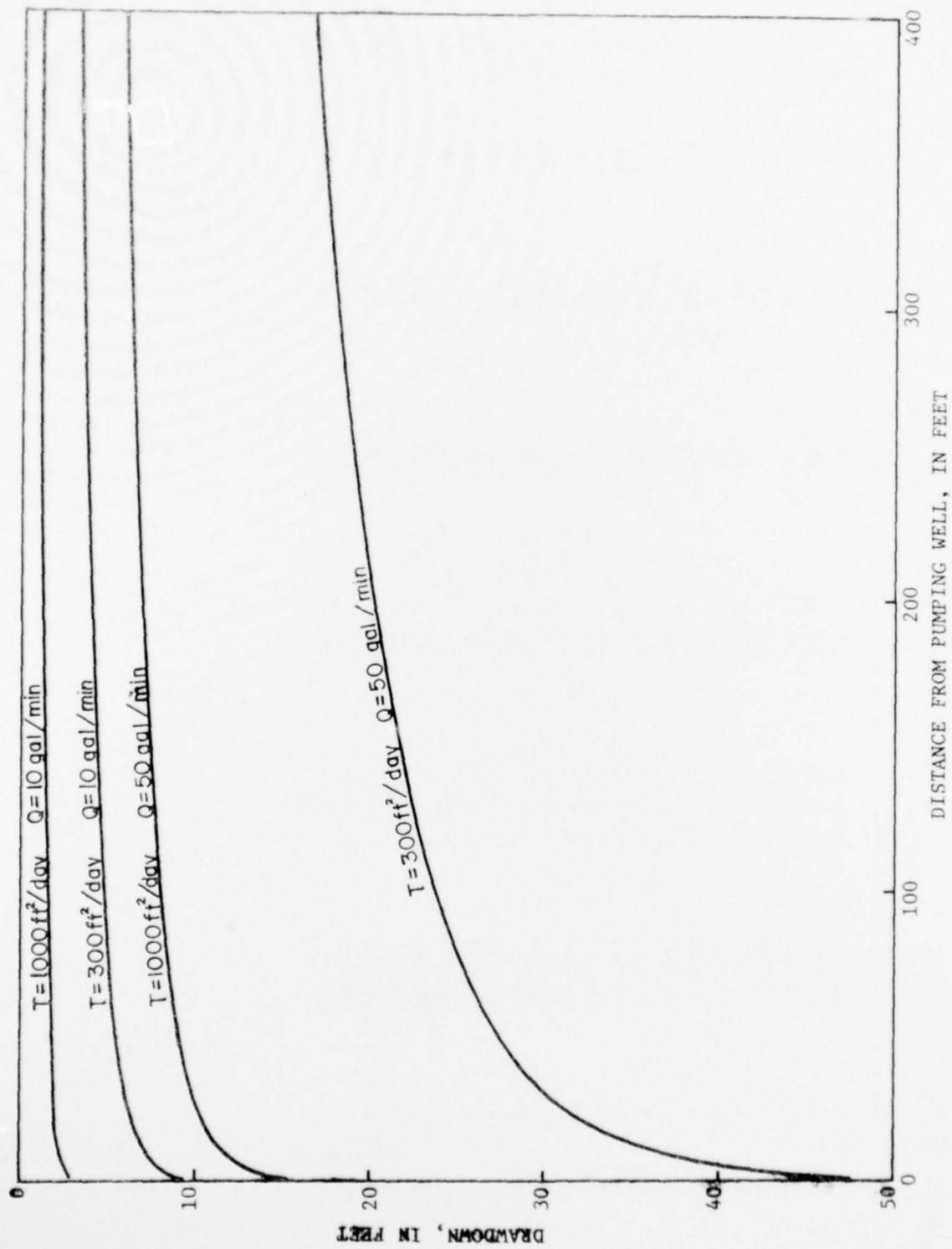


Figure 7.--Distance-drawdown curves for selected shallow-aquifer characteristics after pumping for 30 days.

TABLE 6.--Field analyses of water from selected wells at sites 1-13.

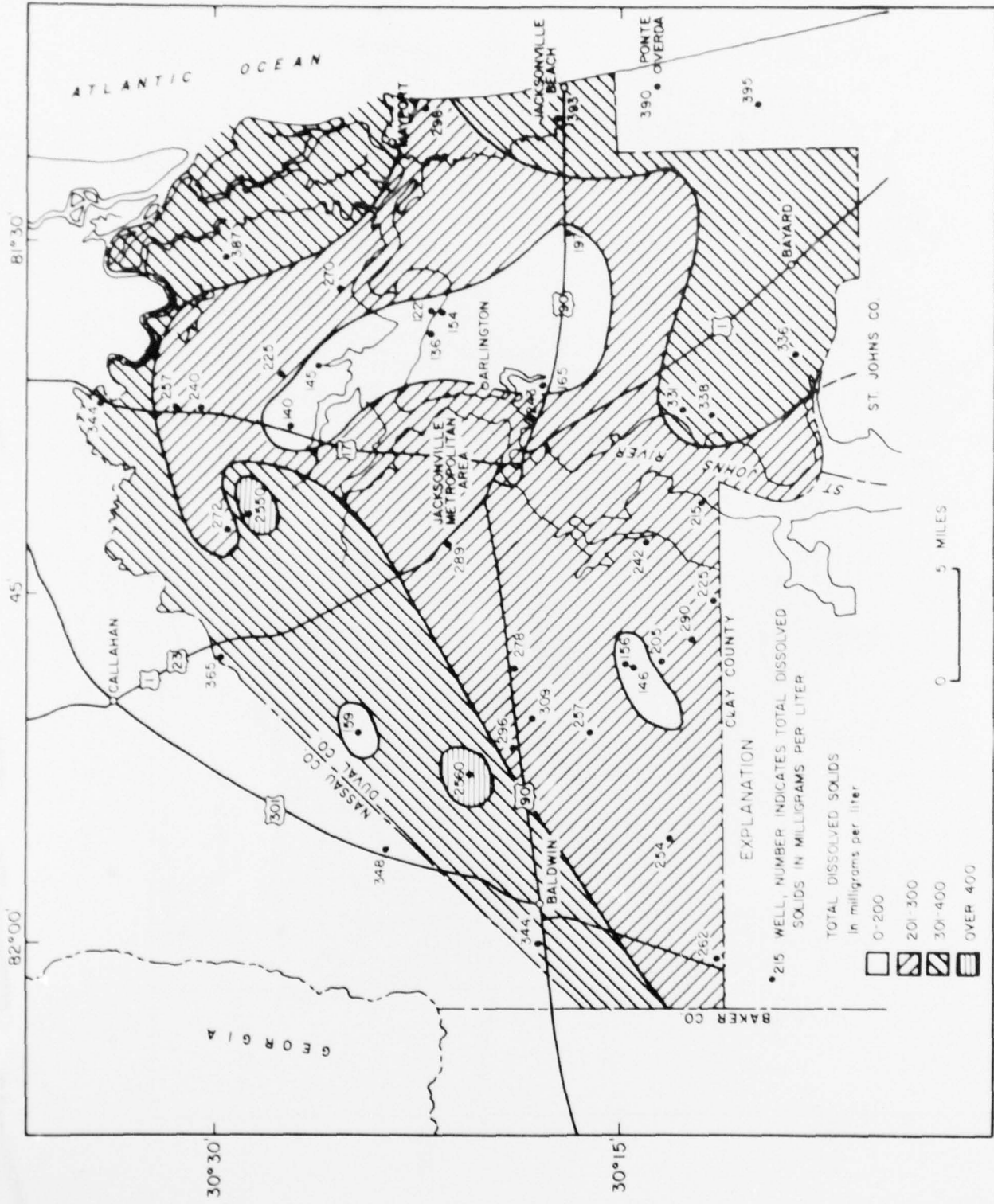
Number Site Well	Local number	Date of collection	Temperature (°C)	Specific Conductance (umhos)/cm	Chloride (mg/L)	Hardness as CaCO <sub>3</sub> (mg/L)	Iron (mg/L)	pH
1	1	6-30-76	21	595	22	312	1.5	6.8
1	3	10- 1-76	22.5	130	-	-	.75	5.5
2	1	7- 7-76	22.5	2,250	452	290	.09	7.3
2	3	7- 8-76	23	750	18	424	.34	6.8
3	2	7- 6-76	22.5	89	9	28	.25	6.1
3	3	10- 4-76	25	42	-	-	.17	4.9
4	1	6-25-76	24	190	10	84	.03	-
4	3	9-29-76	26	93	-	-	.02	-
5	2	6-29-76	22	460	12	244	.02	-
5	3	7-30-76	22.5	340	24	104	12.0	-
6	2	7-28-76	23	73	10	12	0.93	5.2
6	3	10- 1-76	22	115	-	-	3.3	4.8
7	2	8-10-76	21.5	540	8	308	0.0	7.2
8	2	7-27-76	21.5	525	15	252	1.0	6.9
9	1	8- 3-76	22	440	14	240	1.4	6.9
10	1	9- 9-76	22	345	6	184	.01	7.2
10	3	9-30-76	24	220	-	-	.07	6.2
11	1	7-13-76	23.5	460	18	236	-	-
11	2	9-30-76	23	525	-	-	8.8	6.8
12	1	7-14-76	22	310	12	160	.88	7.0
12	3	10- 4-76	25.5	115	-	-	.11	5.5
13	1	7-19-76	21.5	420	17	216	.06	7.4

TABLE 7.--Laboratory analyses of water from selected wells at sites 1-13.

Number Site Well	Local number	Iron (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Strontium (mg/L)	Hardness as CaCO <sub>3</sub> (mg/L)	Specific Conductance (umhos/cm)	pH
1	DS-244	1.5	110.0	3.9	16.0	0.9	2.1	26.0	0.60	290	620	-
2	DS-256	0.09	74.0	21.0	420.0	18.0	16.0	420.0	0.50	270	2300	-
4	DS-246	-	25.0	2.7	8.2	1.0	2.0	8.0	0.11	74	166	-
5	DS-243	-	91.0	3.6	10.0	1.3	3.8	13.0	0.05	240	502	-
7	DS-240	-	99.0	13.0	13.0	2.5	79.0	5.0	0.53	300	610	7.3
8	DS-255	-	88.0	5.4	16.0	2.5	2.0	16.0	0.52	240	490	7.6
9	DS-238	-	67.0	15.0	13.0	2.5	1.4	14.0	0.34	230	470	6.6
10	DS-232	-	37.0	12.0	6.3	1.1	5.5	4.2	0.16	140	295	7.3
11	DS-250	-	85.0	4.2	12.0	1.2	10.0	16.0	0.29	230	491	-
12	DS-236	0.88	21.0	9.7	8.8	1.1	1.5	15.0	0.07	92	225	6.9
13	DS-234	0.06	37.0	7.2	-	-	1.0	18.0	0.19	120	300	8.1

- Indicates sample was not analyzed for that parameter.





MODIFIED FROM FAIRCHILD, 1972

Figure 9.--Generalized distribution of dissolved solids in water from the shallow-aquifer system.



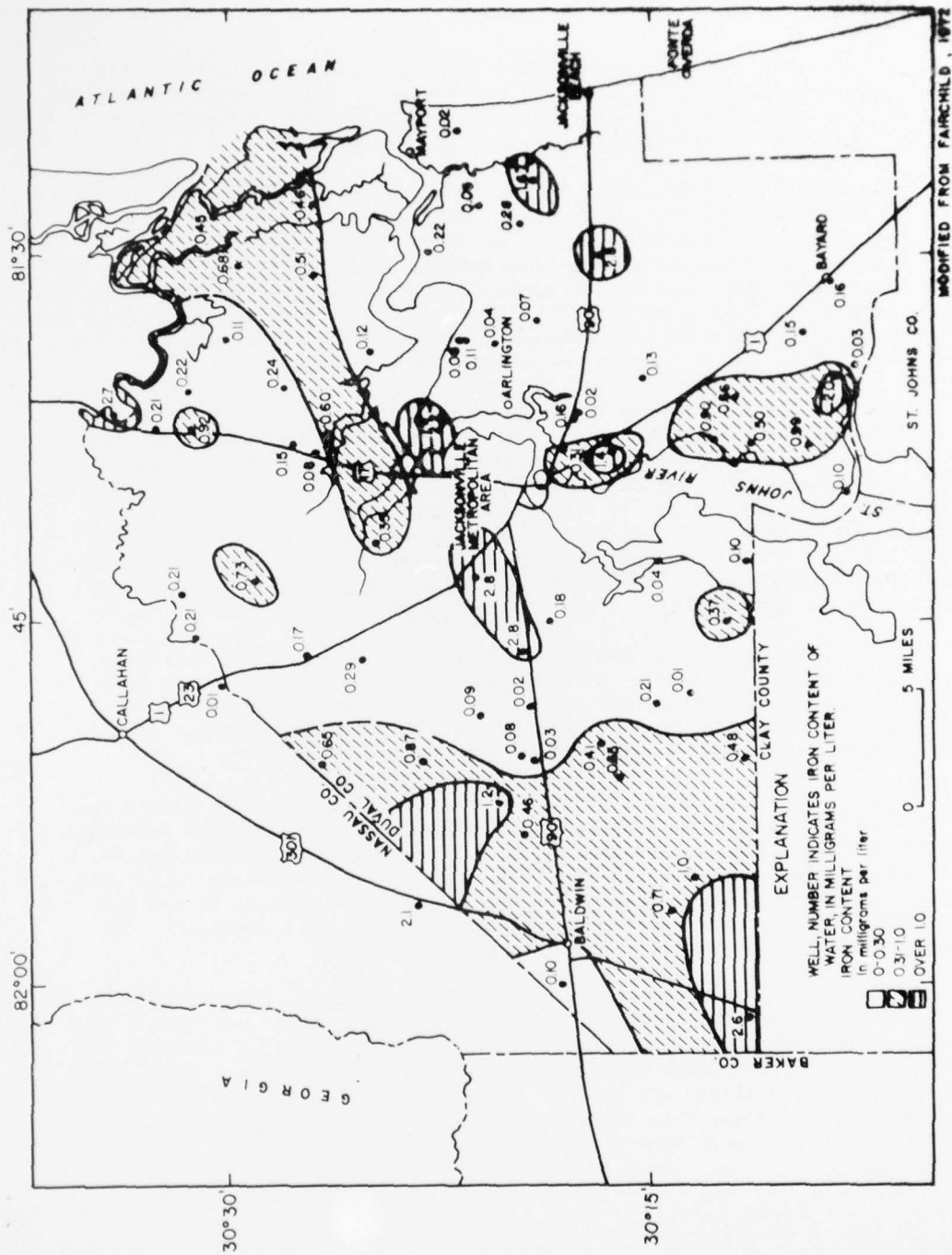


Figure 11.--Generalized distribution of iron in the water from the shallow-aquifer system.

## SUMMARY

Duval County, which occupies about 840 mi<sup>2</sup> in northeastern Florida, has a humid semitropical climate and an average annual rainfall of about 54 in. The area is mostly flat with salt marshes along the coastal part of the county and many freshwater swamps in the remainder of the county.

The shallow-aquifer system in Duval County overlies the Floridan aquifer, and is composed chiefly of sand, clay, sandy clay, and limestone. It ranges in thickness from about 300 to about 600 ft in Duval County. The upper 150 ft of deposits, which are the most dependable source of water, comprise the water-table and shallow-rock zones of the aquifer system. The water-table zone is composed mostly of sand from land surface to a depth of about 25 to 50 ft. The shallow-rock zone extends below the water-table zone to a depth of about 150 ft and is composed of sand, clay and limestone.

Aquifer tests were conducted at thirteen sites in Duval County. The shallow-rock zone tests ranged in length from about 2 hours to more than 13 hours. The water-table zone tests were of short duration because of low yields, except at site 2 where the water-table zone yield was high. Analyses of pumping tests are considered valid only for the sites tested because the lithology of the shallow aquifer system is heterogeneous and some beds are discontinuous. Testing of any prospective shallow-rock-zone well sites using the methods described in this report would be useful to determine the availability of water at those particular sites.

Transmissivity of the shallow-rock zone is several hundred ft<sup>2</sup>/day. The field pumping rates and low estimated values of transmissivity show that although the shallow-rock zone is not nearly as productive as the Floridan aquifer as a source of potable water, it is an important supplemental source of water supply in Duval County.

Yields from the shallow aquifers vary from place to place within the county owing chiefly to variations in lithology of the saturated sediments and rock. The principal shallow water-bearing zone, a limestone bed 40 to 100 ft below land surface, yields as much as 200 gal/min to wells; the average maximum yield at most of the sites tested is between 30 and 100 gal/min. Yields can be increased by increasing the well diameter. The water-table zone generally yields 10 gal/min or less.

Water in the shallow aquifer system in Duval County is generally of acceptable quality for most uses but in localized areas it may have a high iron concentration and be very hard. The iron concentration exceeded 0.3 mg/L in water from either the water-table zone or shallow-rock zone, or both, at 7 of the 13 aquifer test sites. The hardness of water from the shallow aquifer system ranges from soft (less than 60 mg/L) to very hard (more than 180 mg/L), but is very hard in most parts of the county.

#### SELECTED REFERENCES

- Anderson, K.E., 1975, *Water well handbook: Missouri Water Well and Pump Contractors Assn., Inc., Rolla, Mo.*, 281 p.
- Brown, R. H., 1963, Estimating the transmissibility of an artesian aquifer from the specific capacity of a well, in Bentall, Ray, compiler, *Methods of determining permeability, transmissibility, and drawdown: U.S. Geol. Survey Water-Supply Paper 1536-I*, p. 336-338.
- Callahan, J. T., 1964, The yield of sedimentary aquifers of the coastal plain southeast river basins: *U.S. Geol. Survey Water-Supply Paper 1669-W*, 56 p.
- Causey, L. V., 1974, Hydrologic map report, Southeastern Jacksonville, Florida: *U.S. Geol. Survey Open-file Rept.*, 12 maps.
- \_\_\_\_\_, 1975 Depth to water table, recharge areas, drainage basins, and relief of Duval County, Florida: *U.S. Geol. Survey Water Resources Inv. Rept. 52-75*, 4 maps.
- Causey, L. V., Stone, R. B., and Backer, M. I., 1975, Hydrologic maps of southwestern Jacksonville, Duval County, Florida: *U.S. Geological Survey Open-file Rept.*, 18 maps.
- Cooke, C. W., 1945, *Geology of Florida: Florida Geol. Survey Bull. 29*, 339p.
- Derragon, Eugene, 1955, Basic data of the 1955 study of ground water resources of Duval and Nassau Counties, Florida: *U.S. Geol. Survey Open-file rept.*
- Durfor, D.N., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962: *U.S. Geol. Survey Water-Supply Paper 1812*, 364 p.
- Fairchild, R. W., 1972, The shallow-aquifer system in Duval County, Florida: *Florida Division of Natural Resources, Bureau of Geology, Rept. of Inv. 59*, 50 p.
- Ferris, J. G. and others, 1962, Theory of aquifer tests: *U. S. Geol. Survey Water-Supply Paper 1536-E*, 174 p.
- Johnson, E.E., publisher, 1966, *Ground water and wells: Edward E. Johnson, Inc., Saint Paul, Minn.*, 440 p.
- Lang, S. M., 1961, Methods for determining the proper spacing of wells in artesian aquifers: *U. S. Geol. Survey Water-Supply Paper 1545-B*, 16 p.
- Leve, G. W., 1961, Preliminary investigation of the ground-water resources of northeast Florida: *Florida Geol. Survey Inf. Circ. 27*, 28 p.

- \_\_\_\_\_, 1966, Ground water in Duval and Nassau Counties, Florida: Florida Geol. Survey Rept. Inv. 43, 91 p.
- Leve, G. W., and Goolsby, D.A., 1969, Production and utilization of water in the metropolitan area of Jacksonville, Florida: Florida Geol. Survey Inf. Circ. 58, 37 p.
- Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geol. Survey Prof. Paper 708, 70 p., 9 pls.
- Puri, H. S., and Vernon, R. O., 1964, Summary of the geology of Florida and a guidebook to the classic exposures: Florida Geol. Survey Spec. Pub. No. 5, 312 p.
- Theis, C.V., 1963, Estimating the transmissibility of a water-table aquifer from the specific capacity of a well, in Bentall, Ray, compiler, Methods of determining permeability, transmissibility and drawdown: U.S. Geol. Survey Water-Supply Paper 1536-I, p. 332-336.
- Vernon, R. O., 1951, Geology of Citrus and Levy Counties, Florida: Florida Geol. Survey Bull. 33, 256 p.

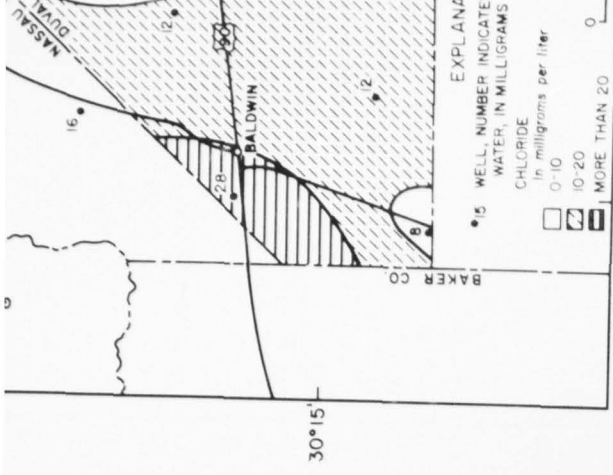


Figure 10.--Generalized di