SALINITY AND FLOW RELATIONS AND EFFECTS OF REDUCED FLOW IN THE CHASSAHOWITZKA RIVER AND HOMOSASSA RIVER ESTUARIES, SOUTHWEST FLORIDA

By Dann K. Yobbi and Lari A. Knochenmus

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CONVERSION FACTORS

The inch-pound units used in this report may be converted to metric (International System) units by the following factors:

Multiply inch-pound unit	*By*	*To obtain metric unit*
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02827	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

Additional Abbreviations

parts per thousand	=	ppt
Southwest Florida Water Management District	=	SWFWMD
microsiemens per centimeter	=	μS/cm
milligrams per liter	=	mg/L
degrees Celsius	=	°C

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ABSTRACT

The Chassahowitzka and Homosassa Rivers are spring-fed streams flowing into the Gulf of Mexico that may be affected by future development of ground water. Reduction of streamflow may result in upstream movement of saltwater in both streams; however, under certain reduced low-flow discharges, the estimated change in upstream extent of saltwater intrusion is on the order of several tenths of a mile and frequently within the range of predicted error.

Data on flow, tides, and salinity define the physical characteristics of the Chassahowitzka River and Homosassa River Estuaries. Waters along most of the estuaries were reasonably well mixed vertically for the streamflow and high-tide conditions observed during the study. Salinity of the rivers increases downstream and varies considerably at a given location. The location of low-concentration salinities appears to be less sensitive to changes in flow and tides and migrates over a smaller distance than high-concentration salinities.

Multiple linear-regression analysis was used to relate the vertically averaged 3- and 5-parts-per-thousand salinities in the Chassahowitzka River and the vertically averaged 2- and 5-parts-per-thousand salinities in the Homosassa River to flow of each river and high-tide stage of the gulf. For the positions of the 3- and 2-parts-per-thousand salinities, the square of the correlation coefficient for the predictive equations ranged from 0.77 to 0.85. For the positions of the 5-parts-per-thousand salinity, the square of the correlation coefficient for the predictive equations ranged from 0.73 to 0.88. Discharge proved to be the only significant parameter in the Chassahowitzka River equations, whereas discharge and tide stage were about equally significant in the Homosassa River equations.

A duration analysis for the Chassahowitzka River indicates that the daily maximum upstream extent of the vertically averaged 3- and 5-parts-per-thousand salinities for October 1984 through September 1985 was at or upstream of river miles 3.0 and 2.3, respectively, about 50 percent of the days. In the Homosassa River, the daily maximum upstream extent of the vertically averaged 2- and 5-parts-per-thousand salinities was at or upstream of river miles 5.0 and 3.6, respectively, about 50 percent of the days from October 1984 through September 1985.

Upstream movement of saltwater due to pumping 40 million gallons per day from a well field near the headwater springs of the Chassahowitzka River and the Homosassa River was estimated. In the Chassahowitzka River, pumping would cause a 15-percent reduction of average springflow (from 139 cubic feet per second to 118 cubic feet per second), possibly resulting in an upstream movement of the vertically averaged 3- and 5-parts-per-thousand salinities of about 0.3 mile. In the Homosassa River, pumping would cause a 13-percent reduction of average springflow (from 218 cubic feet per second to 190 cubic feet per second), possibly resulting in an upstream movement of both the vertically averaged 2- and 5-parts-per-thousand salinities of about 0.1 mile.

INTRODUCTION

Coastal southwest Florida is undergoing rapid urban development that has increased the demand for freshwater. As demands for freshwater increase in coastal areas, coastal streams and new regional well fields may be used to augment present supplies. There is concern that saltwater intrusion and changes in the salinity distribution in the river estuaries would occur as a result of withdrawals from either source.

The Chassahowitzka and Homosassa Rivers are coastal streams in Citrus and Hernando Counties (fig. 1) that discharge about 340 Mgal/d of brackish spring water to estuarine areas along the Gulf of Mexico. Fisheries and related estuarine resources in the area are substantial and are the foundation for important sport and commercial fishing industries. Pumpage and export of ground water from future regional well fields to urban centers could intercept water that is now being discharged to the rivers, thereby reducing streamflow and increasing estuarine salinity.

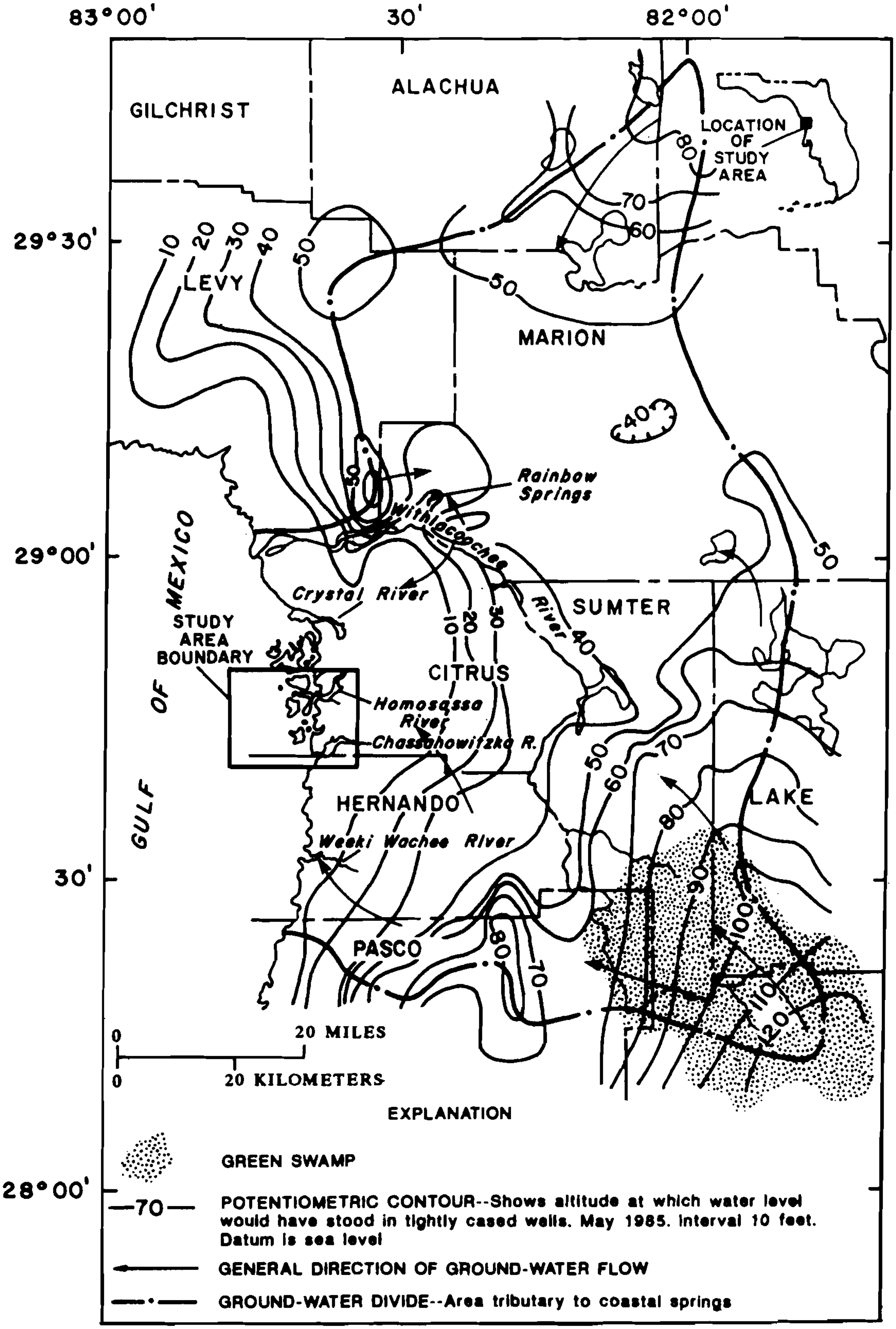


Figure 1.—Ground-water basin of the coastal springs-Withlacoochee River area including potentiometric surface of the Upper Floridan aquifer, May 1985. (Modified from Barr, 1985.)

Salinity is known to be strongly influenced by the quantity and variability of tributary streamflow as well as tidal fluctuations. There are presently insufficient data to determine relations among flow, tide stage, and salinity in the Chassahowitzka and Homosassa Rivers. Knowledge of such relations is needed to help manage freshwater resources and determine streamflow requirements to help maintain productive estuaries.

Salinity refers to the salt content of water, or more precisely, the concentration of dissolved solids in water. Forch and others (1902) defined it as "the total amount of solid material in grams contained in one kilogram of seawater when all the carbonate has been converted to oxide, the bromide and iodine replaced by chlorine, and all organic matter completely oxidized." Salinity is generally expressed as a concentration, in parts per thousand (ppt) of seawater.

In this report, a salinity of 3 ppt is used to establish the upstream extent of the zone of saltwater mixing in the Chassahowitzka River, and a salinity of 2 ppt is used to establish the upstream extent of the zone of saltwater mixing in the Homosassa River. These concentrations were selected because they are only slightly higher than the background salinity of the inflowing water of each river and each clearly indicates the presence of some saltwater from the gulf that was transported by tides.

Purpose and Scope

The purpose of this report is to evaluate the relation between flow and salinity in the Chassahowitzka River and Homosassa River Estuaries and to illustrate the effects of reduced flow by water-supply diversion on salinity intrusion in both estuaries. Data on salinity, flow, and high tides are used to describe the distribution and movement of saltwater.

Relations among flow, high-tide stage, and the maximum upstream extent of the vertically averaged 5- and 3-ppt salinities in the Chassahowitzka River and the vertically averaged 5- and 2-ppt salinities in the Homosassa River are evaluated by regression techniques. These relations are used to illustrate the effects of flow on the daily maximum upstream extent of the salinity locations in both rivers. Examples that show the effects of reduced spring flow by well-field pumpage on salinity locations in each river are presented.

Acknowledgments

This investigation was made by the U.S. Geological Survey in cooperation with the Southwest Florida Water Management District (SWFWMD). M.S. Flannery of SWFWMD contributed useful data and suggestions during the course of the study. The authors gratefully acknowledge the cooperation of local landowners who permitted construction of hydrologic instrument shelters on their property.

METHODS OF STUDY

Data Collection

Data collected as a part of this study consist of continuous tide stage and salinity (specific conductance) collected at gaging stations, periodic discharge measurements, and supplemental midchannel salinity measurements along the estuaries (figs. 2 and 3). Continuous recording stations were equipped with instruments that measured and recorded data at 15-minute intervals. Specific conductance was measured in microsiemens per centimeter and readings were compensated to a temperature of 25 °C. Specific conductance, in microsiemens per centimeter, was converted to salinity, in parts per thousand, on the basis of a U.S. Geological Survey computer program (R.L. Miller, U.S. Geological Survey, written commun., 1984) (table 1).

Tide-stage measurements were continuously collected at stations located 2.70 and 4.85 miles upstream of the mouth of the Chassahowitzka River (sites 21 and 29, fig. 2) and 0.20 and 5.40 miles upstream of the mouth of the Homosassa River (sites 41 and 55, fig. 3). Records at stations located near the mouths of each river (sites 21 and 41) were used for analysis in this report. For the Homosassa River, continuous stage at river mile 5.40 and a relation between area and stage provided a continuous record of cross-sectional area used in discharge calculations.

Two continuous-record specific-conductance stations were installed on the Chassahowitzka River. One instrument was installed 0.55 mile

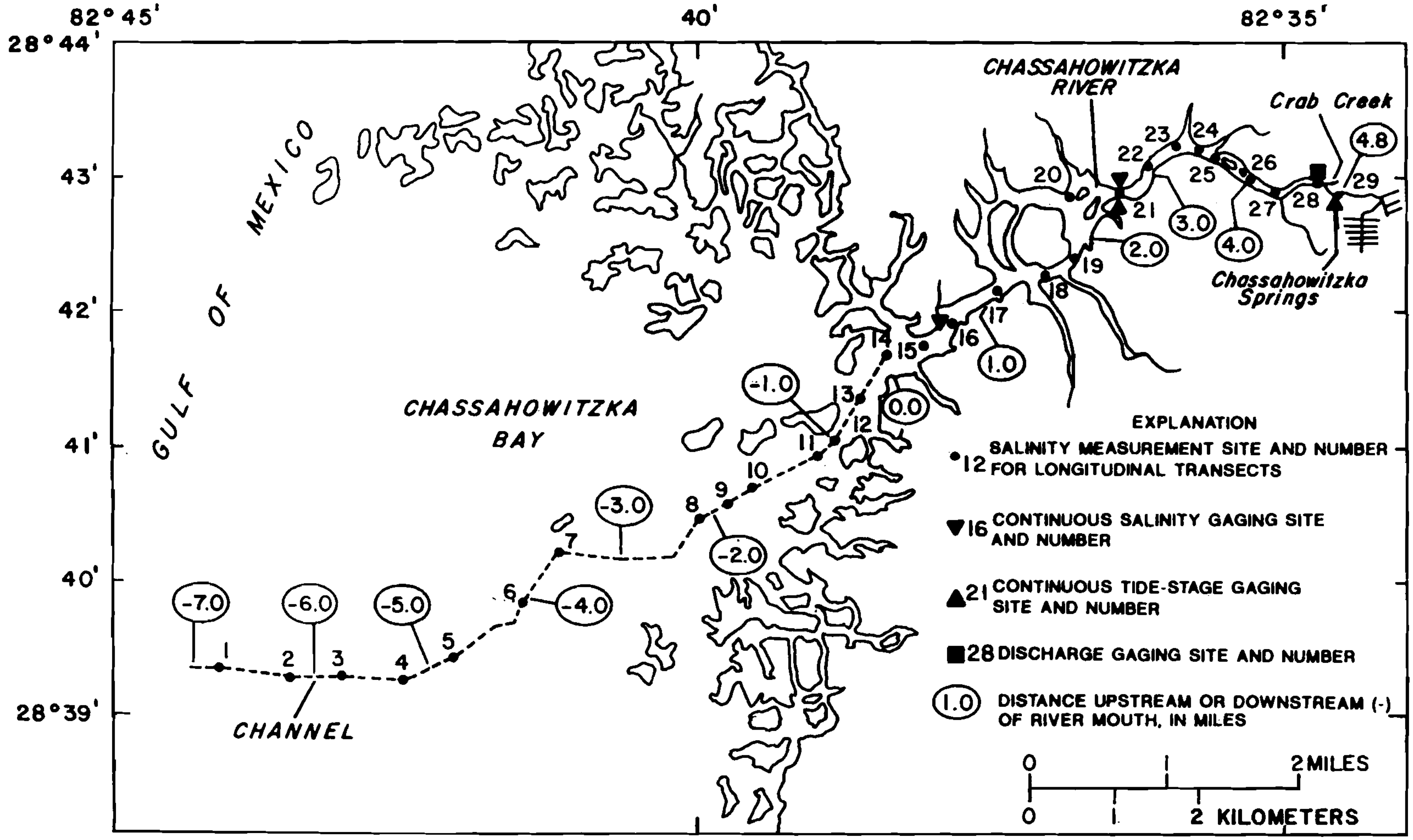


Figure 2. – Location of monitoring sites on the Chassahowitzka River and adjacent Gulf of Mexico.

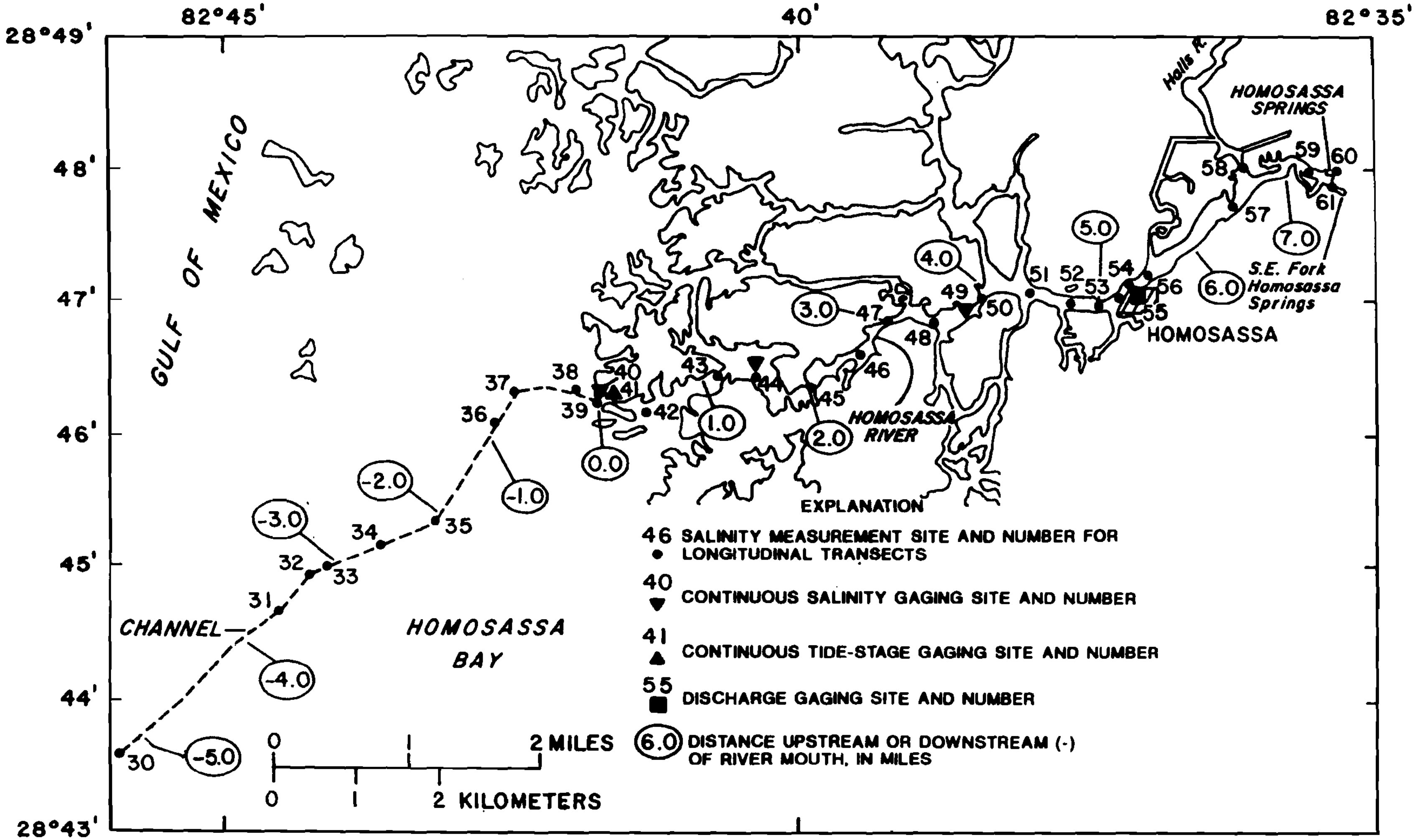


Figure 3. – Location of monitoring sites on the Homosassa River and adjacent Gulf of Mexico.

Table 1.—*Conversions from specific conductance to salinity*

[Compensated to a temperature of 25 degrees Celsius]

Specific conductance, in microsiemens per centimeter	Salinity, in parts per thousand
452	0.3
936	.5
1,940	1.0
3,785	2.0
4,675	2.5
5,500	3.0
8,945	5.0
13,040	7.5
17,000	10.0
20,870	12.5
24,660	15.0
28,370	17.5
29,200	18.0
32,040	20.0
35,640	22.5
39,200	25.0
42,710	27.5
46,180	30.0

upstream of the river mouth and operated from October 1984 to March 1986. The instrument was attached to a float with the probe about 3 feet below the water surface. The second instrument was installed 2.70 miles upstream of the river mouth (site 21, fig. 2) and was operated from October 1984 to March 1986. The instrument was attached to a dock with the probe about 1 foot above the river bottom. The recording interval of the probe at the lower site ranged from 0.3 to 40.3 ppt, and the recording interval of the probe at the upper site ranged from 0.1 to 8.7 ppt.

Salinity also was recorded continuously at three locations on the Homosassa River. One station was 0.15 mile upstream of the river mouth (site 40, fig. 3) and was operated from April 1984 to September 1985. The instrument was placed at the riverbank with the probe set at the river bottom. The second station was 1.51 miles upstream of the river mouth (site 44, fig. 3) and was operated from May 1985 to September 1985. The instrument was attached to a dock at the river bank with the probe about 1 foot above the river bottom. The third station was 3.72 miles upstream of the river mouth (site 49, fig. 3) and was operated from April 1984 to September 1985. The instrument was attached to a dock at the riverbank with the probe about 1 foot above the river bottom. The limits of conductivity measured by the probes at river miles 0.15 and 1.51 ranged from 0.3 to 40.3 ppt and at river mile 3.72 from 0.2 to 18.5 ppt.

Data necessary to gage discharge were collected at a site about 500 feet downstream of Chassahowitzka Springs (site 28, fig. 2) and at a site about 2 miles downstream of Homosassa Springs at the town of Homosassa (site 55, fig. 3). Four sets of continuous tidal discharge measurements were made on the Chassahowitzka River to develop streamflow ratings. An electromagnetic velocity meter was installed on the Homosassa River and two sets of continuous tidal discharge measurements were made to develop streamflow rating curves. Discharge records for Chassahowitzka River were produced from a relation between discharge and the altitude of groundwater levels. Discharge records for Homosassa River were produced through the use of stage records and discharge measurements.

Supplemental salinity data for periodic measurements were collected from a boat over a range of flows and high tides along longitudinal transects that extend from the Gulf of Mexico to the upstream extent of the zone of saltwater mixing in the two rivers (table 2). Sites were selected on the basis of distance from source, river geometry, and points of tributary inflows. All river distances used in this report are computed from the mouth, river mile 0.0, which was arbitrarily established at a line drawn across the river entrance. Salinity was measured using a portable multiparameter water-quality monitoring instrument. The equipment was calibrated in the laboratory prior to the start of each field trip.

Longitudinal salinity data were collected several times during a rising tide. The first run started close to low water and the last run ended near high water when maximum intrusion occurred. Readings were taken at 1- or 2-foot intervals from near water surface to the channel bottom. Salinity runs were made to coincide with extreme monthly tides predicted in the National Oceanic and Atmospheric Administration tide tables (U.S. Department of Commerce, 1985). Because higher high tides generally occur in summer, salinity runs were made at more frequent intervals during this time.

Table 2.—*Description of monitoring sites*

[S, salinity; TS, tide stage; Q, discharge]

Chassahowitzka River			Homosassa River		
Index number (fig. 2)	Distance relative to mouth (miles)	Properties measured	Index number (fig. 3)	Distance relative to mouth (miles)	Properties measured
1	-6.90	S	30	-5.50	S
2	-6.20	S	31	-3.60	S
3	-5.80	S	32	-2.60	S
4	-5.30	S	33	-2.30	S
5	-4.80	S	34	-2.10	S
6	-4.00	S	35	-1.50	S
7	-3.50	S	36	-.80	S
8	-2.20	S	37	-.55	S
9	-1.90	S	38	-.22	S
10	-1.60	S	39	.00	S
11	-1.00	S	40	.15	S
12	-.80	S	41	.20	TS
13	-.40	S	42	.55	S
14	.00	S	43	1.12	S
15	.31	S	44	1.51	S
16	.55	S	45	2.03	S
17	1.09	S	46	2.57	S
18	1.58	S	47	2.96	S
19	1.75	S	48	3.42	S
20	2.32	S	49	3.72	S
21	2.70	S,TS	50	3.87	S
22	3.07	S	51	4.30	S
23	3.35	S	52	4.66	S
24	3.52	S	53	4.92	S
25	3.70	S	54	5.17	S
26	4.03	S	55	5.40	S,TS,Q
27	4.28	S	56	5.60	S
28	4.76	S,Q	57	6.48	S
29	4.85	S	58	6.70	S
			59	7.35	S
			60	7.50	S
			61	7.55	S

Data Analysis

Data collected during the salinity runs were used to show the relation among high-tide stage, discharge, and salinity. The relation was developed using regression analysis, a statistical approach that determines a best-fit equation between one dependent variable and several independent variables. The location of the maximum upstream extent of the salinity was used as the dependent variable, and river discharge and high-tide stage were used as the independent variables. The salinity that represents the upstream extent of the zone of saltwater mixing (2.0 or 3.0 ppt) and the more saline 5-, 18-, and 25-ppt salinities were selected as reference indicators of salinity intrusion.

The upstream extent of the salinity lines were determined from longitudinal profiles drawn by linear interpolations between sampling points. The point of maximum intrusion was then determined by taking a vertically averaged reading of each salinity line, and regression equations were developed for the location of a point where the vertically averaged salinity equals that salinity at high tide. The following criteria were used to evaluate acceptable regression results:

1. R^2, the square of the correlation coefficient, was greater than 0.70, and
2. The regression coefficient of the independent variables falls within a 0.90 probability of not being equal to zero.

Satisfactory results that relate the maximum upstream extent of the vertically averaged 25- and 18-ppt salinities to flow of each river and high-tide stage of the gulf near the river entrances were not obtained. It appears that the analysis for these conditions was complicated by several factors, including: (1) variable gulf salinity caused by circulation within the gulf, precipitation on the gulf shelf, and littoral processes; (2) tidally affected discharge that makes accurate flow determinations difficult; and (3) low variability of flow and small responses to rainfall and runoff. Consequently, locations of the vertically averaged 25- and 18-ppt salinities were estimated by simple linear regression between the salinity location and the maximum salinity recorded at a reference station.

HYDROLOGIC SETTING

Surface drainage in the area is minimal, and most water movement is through ground-water flow in the Upper Floridan aquifer. Near the coast, springs and seeps discharge more than a billion gallons of water per day from the aquifer to rivers, swamps, and estuarine marshes that eventually flow to the Gulf of Mexico (Sinclair, 1978). No streams within the area, with the exception of the Withlacoochee River, extend more than a few miles inland.

Most freshwater occurs in solution cavities in the limestone and dolomite strata of the Upper Floridan aquifer, which is at or near land surface. Saltwater is present in the upper part of the aquifer near the coast and occurs at a depth of about 100 feet at a distance of 1 to 5 miles inland. Spring flow in most of the coastal area is affected by tidal fluctuations in the Gulf of Mexico, and selected springs may either discharge freshwater or saline water.

The ground-water basin of the coastal springs-Withlacoochee River area comprises about 3,400 mi^2, based on the potentiometric surface map of the Upper Floridan aquifer for May 1985 (Barr, 1985) (fig. 1). Water moves from areas of high potential to areas of low potential normal to the contour lines; generally, movement is from the interior toward the coastline. The pronounced inland curvature of the potentiometric contours in western Citrus County (fig. 1) is indicative of the ground water discharging from the Upper Floridan aquifer to springs in the Crystal, Homosassa, and Chassahowitzka Rivers. Spring flow generally increases during wet periods, but the increase in spring flow seemingly is not always proportional to the increase in rainfall due to storage in the system (Wetterhall, 1964). Rainfall averages 55 in/yr (Mann and Cherry, 1969) in the basin and is the source of water for the basin.

The principal surface drainage for the coastal areas is, from north to south, the Withlacoochee, Crystal, Homosassa, Chassahowitzka, and Weeki Wachee Rivers (fig. 4). With the exception of the Withlacoochee River, each of these four streams originates from a spring or group of springs, that is a first-order magnitude spring (average flow of at least 100 ft^3/s or 64.6 Mgal/d). Numerous other smaller springs and spring-fed streams dot the coastal fringe of the study area. The streams are generally shallow, and they alternately flood and drain marshes during tidal fluctuations. Names and discharge rates for 28 springs and spring groups that discharge to streams are given in table 3 and their locations are shown in figure 4.

Many springs along the coast discharge saline water. In general, the salinity decreases with distance from the coast because water levels in the Upper Floridan aquifer are higher and the saltwater interface in the aquifer is deeper. At times of high water levels in the aquifer, the saltwater interface is at its greatest depth, and discharge from the spring tends to be freshest. At times of low water levels, the depth to the saltwater interface is decreased. Under this condition, saltwater in the aquifer may mix with freshwater flowing toward the spring opening, causing increased salinity in the spring discharge.

Salinity in the spring-fed streams and marshes also is affected by movement of saline water from the gulf during tidal fluctuations. When tidal flow is upstream, saline water from the gulf moves inland; when tidal flow is downstream, saline water moves back toward the gulf. Because the source of most saline water in a tidal stream is the gulf, changes in tide stage will affect the quantity of saline water in the river. Maximum and minimum salinities in the streams occur just after maximum and minimum tide stages and at about the time of slack water (minimum velocity).

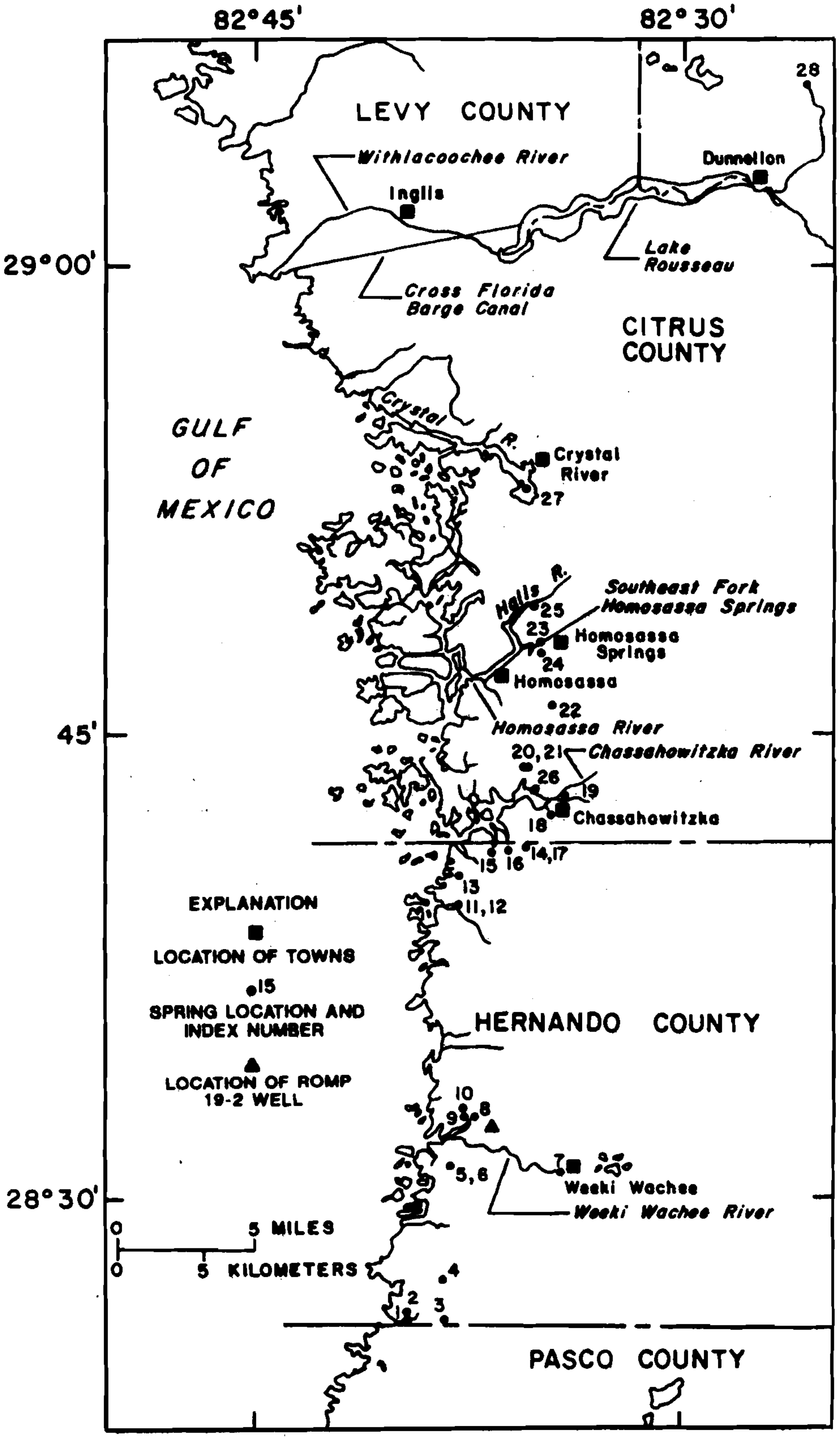


Figure 4.—Location of coastal springs and rivers.

Table 3. —*Hydrologic data for coastal springs*

[ft^3/s, cubic feet per second; mg/L, milligrams per liter; --, no data]

Spring No. (fig. 4)	Spring name	Period of record	Number of discharge measurements	Instantaneous discharge (ft^3/s) Average	Instantaneous discharge (ft^3/s) Range	Average chloride concentrations[1] (mg/L)
1	Unnamed spring No. 1	1964-65	6	8.7	5 – 11.0	391
2	Boat Spring	1962-64	2	3.8	1.5 – 6.0	17
3	Bobhill Springs	1961-72	6	3.3	2.0 – 4.4	5
4	Unnamed spring No. 2	1960	1	1	-- --	5
5	Unnamed spring No. 4	1962	1	10.0	-- --	1,600
6	Unnamed spring No. 5	1962	1	12.5	-- --	1,500
7	Weeki Wachee Springs	1917-74	364	176	101 – 275	5
8	Salt Spring	1961-75	11	30.6	24.7 – 38.9	912
9	Mud Spring	1961-75	6	52.0	0 – 128	8,000
10	Unnamed spring No. 6	1960	1	[2]5	-- --	2,700
11	Unnamed spring No. 7	1961	1	[2]50	-- --	--
12	839-238-7	1961	1	50.3	-- --	4,600
13	Unnamed spring No. 8	1961	1	[2]10	-- --	6,400
14	Unnamed spring No. 9	1961-64	3	28.8	20.9 – 35.4	136
15	Unnamed spring No. 10	1961	1	5	-- --	4,300
16	Unnamed spring No. 11	1961-64	2	15.6	5 – 26.2	3,800
17	Unnamed spring No. 12	1961-65	6	28.6	9.1 – 39.9	2,110
18	Baird Creek Springs	1964-65	5	31.1	11.1 – 53.1	2,350
19	Chassahowitzka Springs	1930-72	81	139	31.8 – 197	127
20	Ruth Spring	1961-72	6	8.8	8.0 – 11.8	460
21	Potter Spring	1961-65	6	6.5	0 – 22.0	460
22	Hidden River Springs	1964-65	5	26.5	7.0 – 65.6	1,300
23	Homosassa Springs	1931-74	90	106	80 – 165	812
24	Southeast Fork Homosassa Springs	1931-74	89	69.1	33 – 129	54
25	Halls River Springs	1964-66	12	162	95.7 – 291	1,020
26	Salt Creek Springs	1961	0	--	-- --	1,900
27	Crystal River Springs	1964-75	(3)	916	[4]-1,520 – 4,320	820
28	Rainbow Springs	1899-1974	(5)	763	487 – 1,230	3

[1]Average chloride concentration determined from individual measurements.
[2]Estimated.
[3]Daily discharge, tidally affected.
[4]Negative sign indicates upstream flow.
[5]Daily discharge.

The distribution of salinity in the tidally affected reaches of the study area varies longitudinally, horizontally, and vertically with time. The vertical and horizontal variations of salinity at a given location are dependent on the combined effects of freshwater flow and tidal conditions, both of which vary seasonally. Salinities are greater during periods of minimum freshwater flow and high tides and lesser during periods of maximum freshwater flow and low tides.

Tides in the study area are mixed semidiurnal; a higher high and lower high tide, as well as a higher low and lower low tide, each day are possible (fig. 5). The average diurnal tidal ranges are about 2.1 feet for the Chassahowitzka River near its mouth and about 2.0 feet for the Homosassa River near its mouth. Tides also vary seasonally, being higher on the average in summer and fall than in winter and spring. A summary of tide-stage data is given in table 4.

Because the most favorable conditions for maximum upstream movement of saltwater occur at high tide, duration curves for the higher high tides at Chassahowitzka and Homosassa Rivers were developed. The frequency of occurrence of higher high-tide stage is listed below and shown in figure 6. The extreme tides, in the less than 5-percent interval, reflect the influence of Hurricane Elena that passed offshore August 31 through September 1, 1985.

Percent of days equaled or exceeded, October 1984 through September 1985	Altitude of higher high-tide stage, in feet above sea level	
	Chassahowitzka River	Homosassa River
5	2.56	3.09
25	2.24	2.56
50	1.94	2.32
75	1.65	1.99
95	1.09	1.40

For comparison, high-tide stage data used in developing salinity regression equations ranged from 1.50 to 2.55 feet in the Chassahowitzka River equations and 1.37 to 3.26 feet in the Homosassa River equations.

DESCRIPTION OF ESTUARIES

The study area includes the tidal parts of the Chassahowitzka River and the Homosassa River Estuaries that have salinities up to 25 ppt. The Chassahowitzka River heads in southwestern Citrus County and flows westerly through about 5 miles of tidal marshes and lowlands to the Gulf of Mexico (fig. 1). Flow is derived chiefly from numerous springs, most of which are at the heads of tributaries in densely wooded areas. The area around the head springs and along the river is sparsely populated and remains in a nearly natural setting; it is used as a recreational area, mostly by local residents.

The channel of the Chassahowitzka River is 50 to 200 feet wide and about 3 feet deep at its headwaters and about 500 to 1,200 feet wide and about 5 to 15 feet deep near the gulf. Artificial waterways have been constructed tributary to the

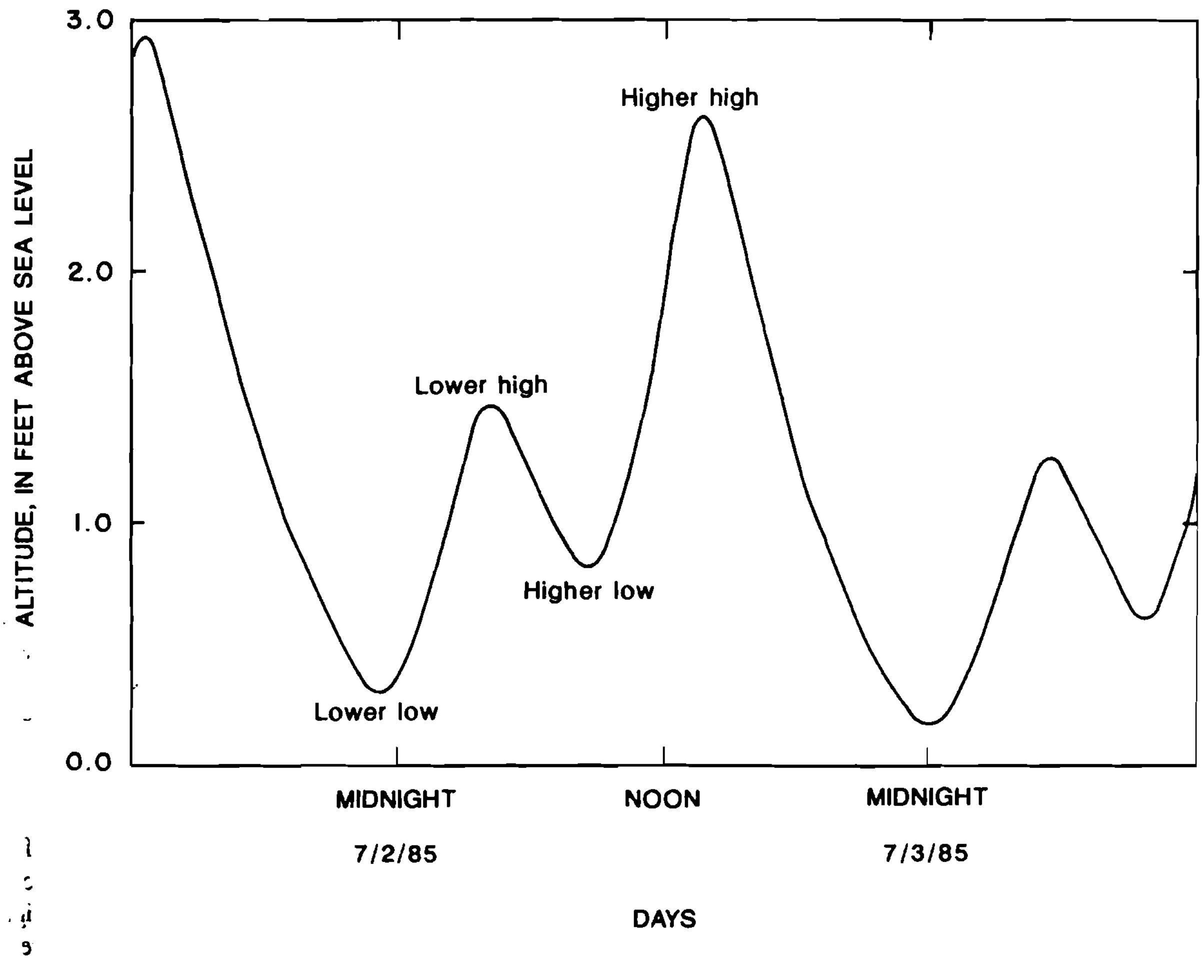


Figure 5.—Selected tidal hydrograph at the mouth of Homosassa River.

Table 4. —*Summary of monthly average tide-stage data for the Chassahowitzka and Homosassa Rivers*

[Stage data are in feet above or below sea level. —, no data]

Tide	Period of record	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Chassahowitzka River, river mile 2.70													
Higher high	1984-85	—	1.66	1.87	1.86	1.68	1.67	1.64	1.97	—	2.14	2.39	—
Lower low	1984-85	—	-.31	-.39	-.44	-.55	-.56	.45	-.12	—	-.03	.19	—
Chassahowitzka River, river mile 4.85													
Higher high	1966-78	1.91	1.88	1.84	1.76	1.81	1.92	1.99	2.05	2.06	1.99	1.99	2.05
Lower low	1966-78	1.29	1.26	1.21	1.20	1.29	1.41	1.49	1.52	1.54	1.41	1.37	1.39
Homosassa River, river mile 0.20													
Higher high	1984-85	2.27	1.94	2.18	2.09	1.94	1.90	1.88	2.33	2.47	2.48	2.73	2.36
Lower low	1984-85	.55	.26	.24	.14	-.02	.03	.09	.31	.32	.34	.49	.40
Homosassa River, river mile 5.40													
Higher high	1968-78	1.35	1.28	1.20	1.07	1.14	1.23	1.32	1.44	1.48	1.52	1.52	1.54
	1984-85	1.62	1.37	1.50	1.57	1.35	1.34	1.33	1.67	1.76	1.74	1.95	1.69
Lower low	1968-78	.63	.52	.34	.14	.13	.28	.43	.60	.69	.74	.77	.81
	1984-85	1.00	.63	.58	.44	.27	.32	.41	.73	.85	.85	.99	.87

river just above its headwaters at Chassahowitzka Springs. Limestone of the Upper Floridan aquifer lies near land surface, and rock outcrops are prevalent along the river channel. Land bordering the river is flat and is less than 5 feet above sea level. Profuse, submerged aquatic growth occurs near its headwaters, but the density of submerged vegetation diminishes gulfward.

Chassahowitzka River is tidally affected along its entire length and water levels normally fluctuate 0.5 to 1.0 foot at a tide gage near its headwaters. Altitudes of the spring pool are topographically low, varying between 0.1 and 5.1 feet above sea level.

Springs that discharge to the Chassahowitzka River vary from fresh to brackish, which indicates the springs are in close proximity to the zone of diffusion in the Upper Floridan aquifer. The river and springs tend to be fresher upstream from the gulf where water levels in the aquifer are above sea level and the saltwater-freshwater interface is below sea level. Although a few springs near the head of the river are generally fresh (salinity less than 0.5 ppt), most springs are brackish and some springs near the coast are highly saline (salinity up to 16 ppt).

Flow of Chassahowitzka River, based on the average of 81 individual measurements made between 1930 and 1972 at the gaging site downstream of the confluence with Crab Creek, is about 140 ft^3/s. Flow is tidally affected, and discharge measurements ranged between 31.8 and 197 ft^3/s. Flow of the river is derived chiefly from Chassahowitzka Springs; however, many additional springs discharge into the river below the gaging site. Cherry and others (1970) estimate that these additional springs may contribute up to 50 percent more flow.

Continuous records of daily discharge of the Chassahowitzka River are difficult to define because the river is tidally affected along its entire length. The stage-discharge relation at the gaging site is very complex, and the data have not been collected to adequately define continuous discharge of the stream. Attempts made during this study to rate the site using an electromagnetic velocity meter also proved unsuccessful. Consequently, daily discharges have been estimated. Because the flow of springs is related primarily to ground-water levels, estimates are calculated from the relation between daily discharge from Chassahowitzka Springs and the altitude of nearby ground-water levels.

Correlation between the discharge of Chassahowitzka Springs and daily maximum water levels in ROMP 19-2 well is shown in figure 7. For every 1 foot of water-level change in the well, a change in discharge of 74 ft^3/s occurs at the gaging site. Daily mean discharge during October 1984 through September 1985, based on water levels in ROMP 19-2, averaged 115 ft^3/s and varied between -68 (negative due to tidal effect) and 180 ft^3/s.

Figure 7 shows that larger flows occur at lower ground-water levels and smaller flows occur at higher ground-water levels. The inverse relation is related to tides, which affect water levels in ROMP 19-2 and Chassahowitzka Springs. The flow of the river (spring) is a function of the difference in head between the aquifer and the river. At high tide, the head in the river increases more than the head in the aquifer, which decreases the gradient between the aquifer and the river, decreasing spring flow and discharge of the river. At low tide, the head in the river decreases more than the head in the aquifer, which increases the gradient between the aquifer and the river and permits water to flow out of storage, increasing spring flow and discharge of the river.

Waters in the Chassahowitzka River Estuary are characterized by vertical and longitudinal salinity gradients that vary with tides and

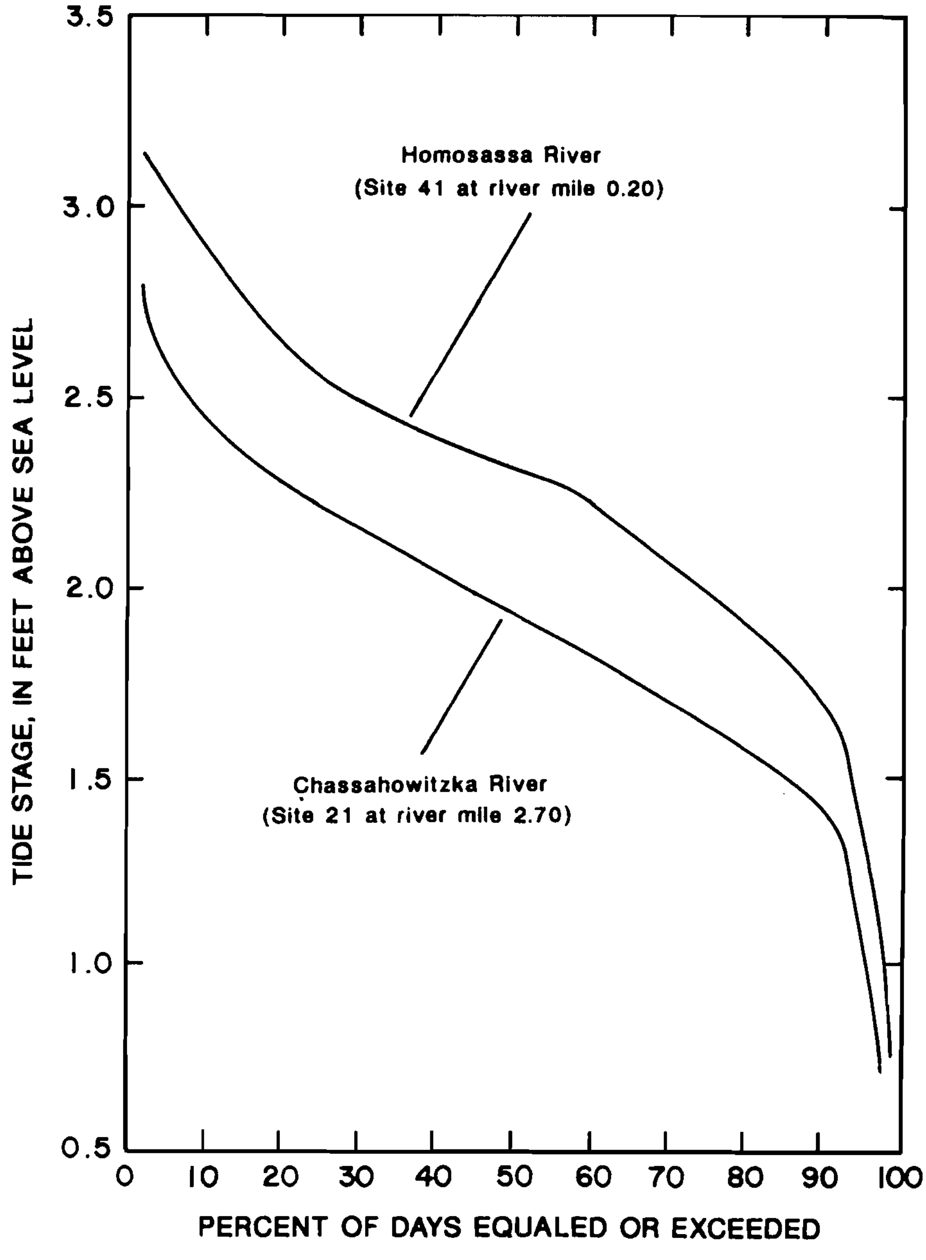


Figure 6.—High-high tide-stage duration curves for the Chasahowitzka and Homosassa Rivers, October 1984 through September 1985.

streamflow. Salinity profiles in Chassahowitzka River for various streamflow and high-tide conditions are shown in figure 8. Streamflows shown are the average daily discharge for the day of sampling. The tide stage is the high-tide stage recorded at river mile 2.70. Approximate locations of the lines of equal salinity were determined by linear interpolation between sampling points. The salinity profiles show that the Chassahowitzka River estuary is reasonably well mixed vertically for the streamflow and high-tide conditions sampled. Waters along most of the estuary are essentially uniform from top-to-bottom and the ratio of top-to-bottom salinity is generally greater than 85 percent in most sections of the river (fig. 9).

Variations of longitudinal salinity gradients along the Chassahowitzka River estuary for representative high-tide conditions are shown in figure 10. The data show that salinity generally decreases upstream and varies considerably at a given location. Salinity ranged from 21.4 to 30.1 ppt about 4.8 miles outside the river mouth, from 9.9 to 19.2 ppt at the river mouth, from 3.9 to 9.0 ppt at river mile 2.7, and from 1.3 to 2.3 ppt at river mile 4.3. The smallest variation in salinity

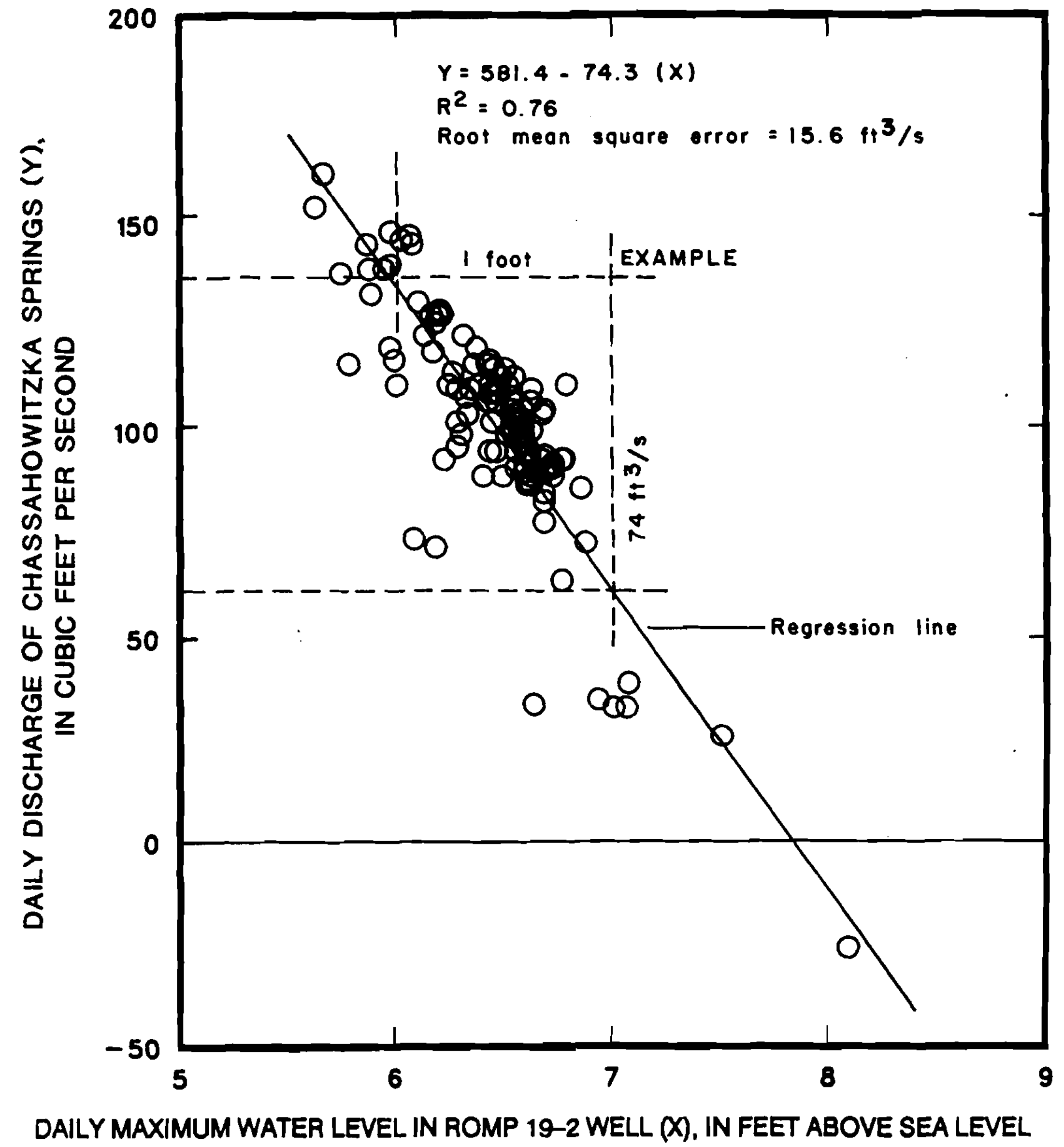
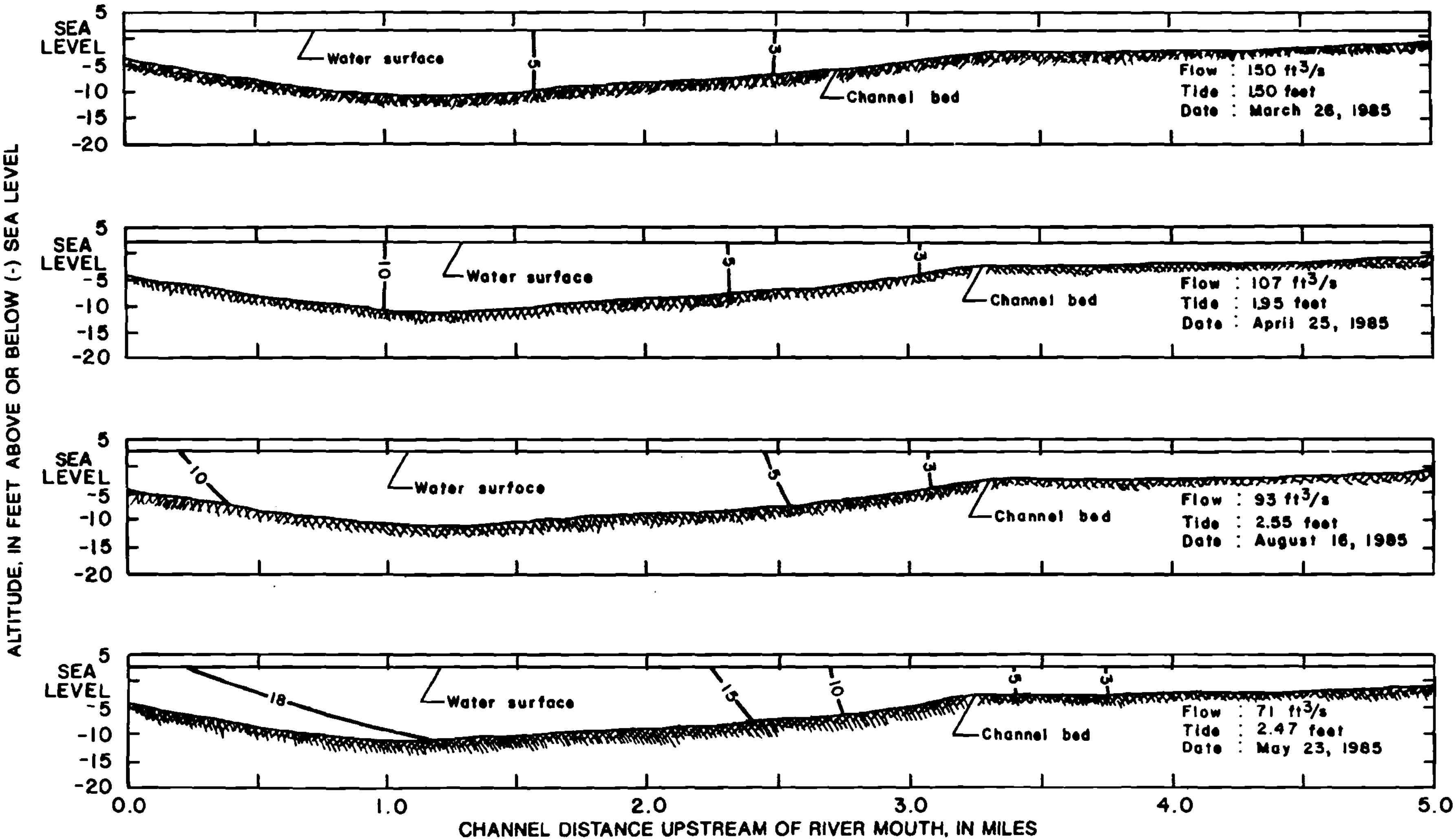


Figure 7. – Relation between daily discharge of Chassahowitzka Springs and daily maximum water levels in ROMP 19-2 well.



EXPLANATION

—15—

LINE OF EQUAL SALINITY--Interval 2, 3, and 5 parts per thousand

Figure 8.–Salinity profiles in the Chassahowitzka River Estuary for various discharge and high-tide conditions.

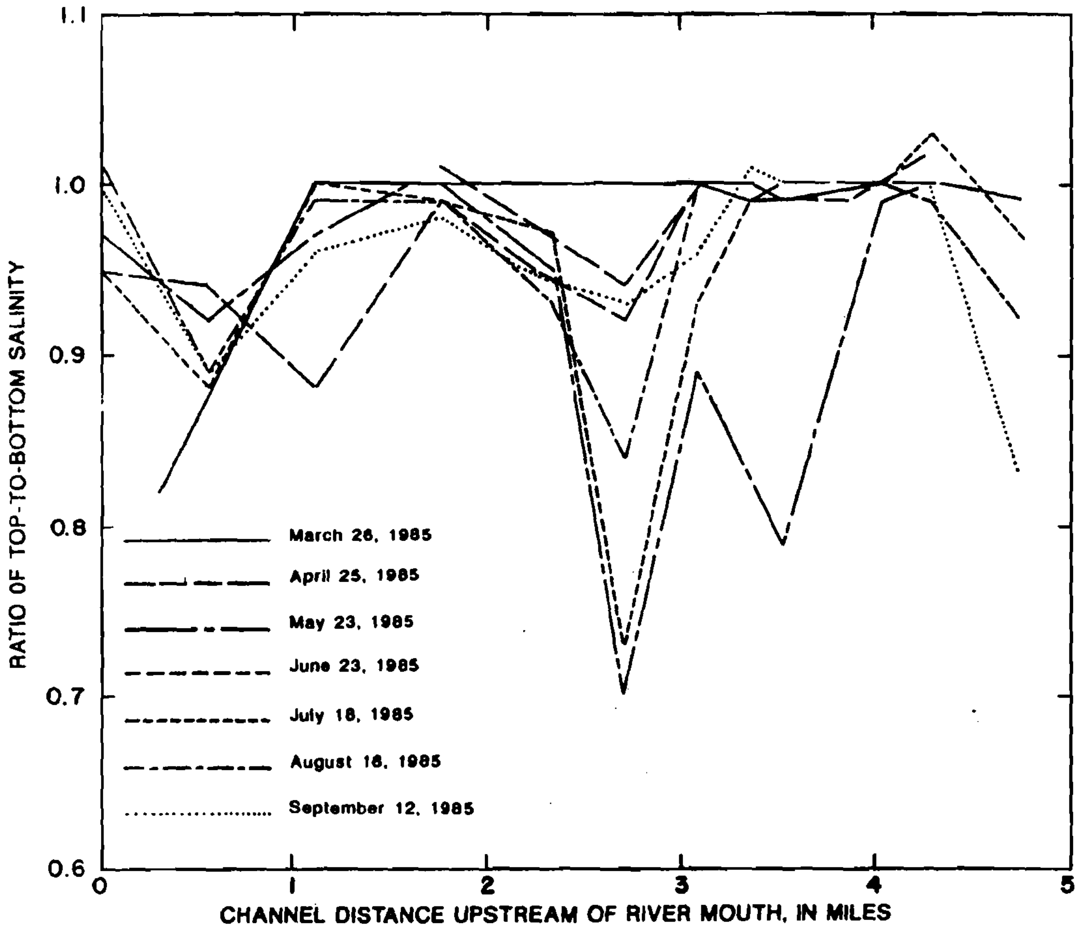


Figure 9. – Longitudinal variations of top-to-bottom salinity ratios for various discharge and high-tide conditions in the Chassahowitzka River.

was observed in the section of the river upstream of river mile 2.40, and the largest variation was observed in the section of the river between river miles 1.7 and 2.4. The graphs show a fairly constant range of salinity from the gulf to about 1.7 miles inside the river mouth. Upstream of river mile 1.7, salinity decreases rapidly, reflecting a transition from gulf to river waters.

The extreme locations and ranges in locations of selected salinities for high-tide conditions in the Chassahowitzka River during the period of study are listed below:

The range was variable and decreased inland. The locations of low-concentration salinities appear to be less sensitive to changes in flow and tides and migrate over a smaller distance than high-concentration salinities. The 25-ppt salinity had a range in movement that was more than three times as great as the range in movement of the 3-ppt salinity.

The upstream extent of the zone of saltwater mixing (3-ppt salinity) in the Chassahowitzka River was found to be dependent upon streamflow and high-tide conditions. However,

Salinity, in parts per thousand	Maximum upstream extent of the salinity, in miles upstream or downstream (-) of river mouth: Minimum	Maximum	Range
3	2.5	3.7	1.2
5	1.6	3.4	1.8
10	-.4	2.6	3.0
18	-3.0	.6	3.6
25	-6.9	-2.3	4.6

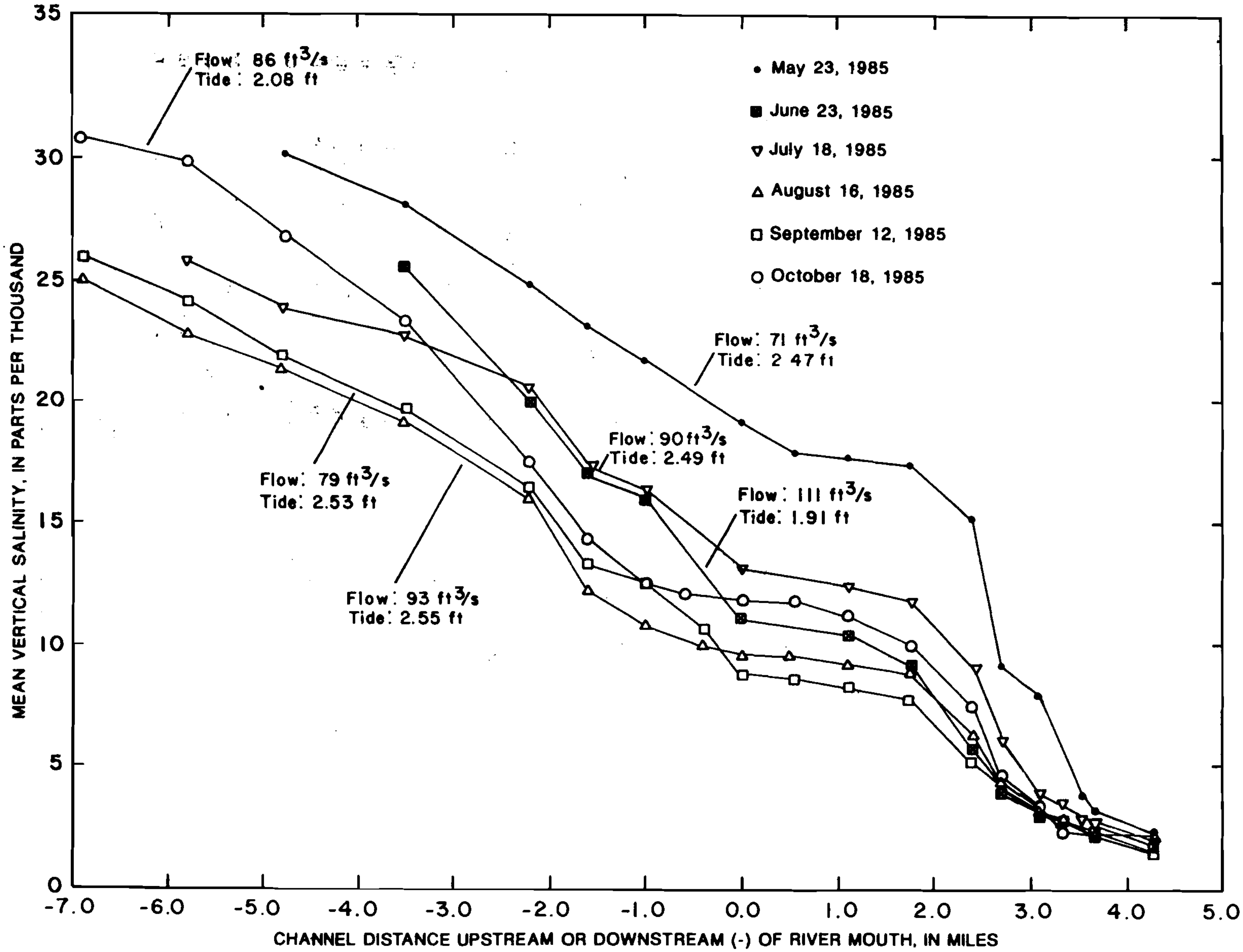


Figure 10.—Longitudinal salinity distributions for high-tide conditions in the Chassahowitzka River Estuary.

differences in the upstream extent of the 3-ppt salinity were relatively small when differences in streamflow and high-tide conditions were considered. The maximum encroachment of the 3-ppt salinity was observed at river mile 3.74 at a discharge of 71 ft^3/s and high-tide stage of 2.47 feet; the minimum penetration of the 3-ppt salinity was observed at river mile 2.52 at a discharge of 155 ft^3/s and high-tide stage of 1.50 feet. At streamflows of less than 90 ft^3/s and high-tide stages above 2.0 feet, the 3-ppt salinity extended upstream of river mile 3.20. At streamflows greater than 93 ft^3/s and high-tide stages of less than 2.55 feet, the 3-ppt salinity did not extend upstream of river mile 3.17.

Salinity duration curves for the continuous-record sites at river miles 0.55 and 2.70 on the Chassahowitzka River are shown in figure 11. Salinity above 3 ppt was present about 90 percent of the time at river mile 0.55 and about 24 percent of the time at river mile 2.70. A list of selected salinities and their frequency of occurrence follows:

Salinity, in parts per thousand	Percent of time equaled or exceeded at river mile	
	0.55	2.70
3	90	24
5	58	10
10	18	0
15	4	0
18	2	0
25	0	0

Of the 283 days of record collected during October 1984 through September 1985 at river mile 2.70, salinity above 3 ppt reached the station with high tides on 190 of those days. With salinity exceeding 3 ppt about 24 percent of the time, the average duration time for each occurrence was about 6 hours. At river mile 0.55, water with salinity exceeding 3 ppt was present about 90 percent of the time and reached the station on all of the 188 days of record. The average duration for each occurrence was about 22 hours.

The Homosassa River is in southwestern Citrus County, about equal distance between Crystal River on its north and Chassahowitzka River on its south, and flows westward about 7 miles through swampy lowlands to the Gulf of Mexico (fig. 1). The river heads near the town of Homosassa Springs and is formed by flow from Homosassa Springs, Halls River, and numerous small springs of the Southeast Fork of Homosassa Springs (fig. 3). Homosassa Springs is a tourist attraction with nature trails, underwater viewing, and botanical gardens. Numerous homesites have been built along parts of the river and many housing developments are currently under construction or have been proposed.

The channel of the Homosassa River is about 200 to 700 feet wide and about 5 feet deep in the headwaters and about 1,000 feet wide and 15 to 20 feet deep near the gulf. Near its mouth, the river meanders through a wide, marshy area, and river and gulf waters are interconnected by drainage through numerous tidal creeks and bayous. Artificial waterways have been constructed in the upper reaches of the river, providing tributary drainage. Limestone strata of the Upper Floridan aquifer are near land surface and rock outcrops are common along the river channel. Land bordering the river is flat and is less than 5 feet above sea level. The upper reaches of the river channel are obstructed by submerged aquatic weeds during parts of the year.

The entire length of the river is tidally affected, and water levels normally fluctuate 1.5 to 2.0 feet at the tide gage located 5.40 miles upstream of the river mouth. Springs in the headwater are topographically low and average about 1 foot above sea level. Water from Homosassa Springs and Halls River is brackish, whereas water from the numerous small head springs of the Southeast Fork is fresh.

The average daily discharge of Homosassa River, measured at the town of Homosassa, is about 390 ft^3/s (Cherry and others, 1970). Of this flow, springs in the headwaters contribute about 140 ft^3/s, the Southeast Fork of Homosassa Springs about 80 ft^3/s, and Halls River about 170 ft^3/s. Observed discharges for the period 1931 through 1974 from Homosassa Springs and spring complex ranged between 80 and 165 ft^3/s, and discharge from the Southeast Fork of Homosassa Springs ranged between 33 and 129 ft^3/s. Seaburn and others (1979) reported flow of 280 ft^3/s at the mouth of Homosassa River on April 16, 1974, of which Halls River and Homosassa Springs complex contributed 200 ft^3/s and marshy swamplands along the river contributed 80 ft^3/s. Daily discharge from October 1984 through September 1985, gaged at the town of Homosassa, averaged 218 ft^3/s and ranged between -223 (negative due to tidal effects) and 554 ft^3/s.

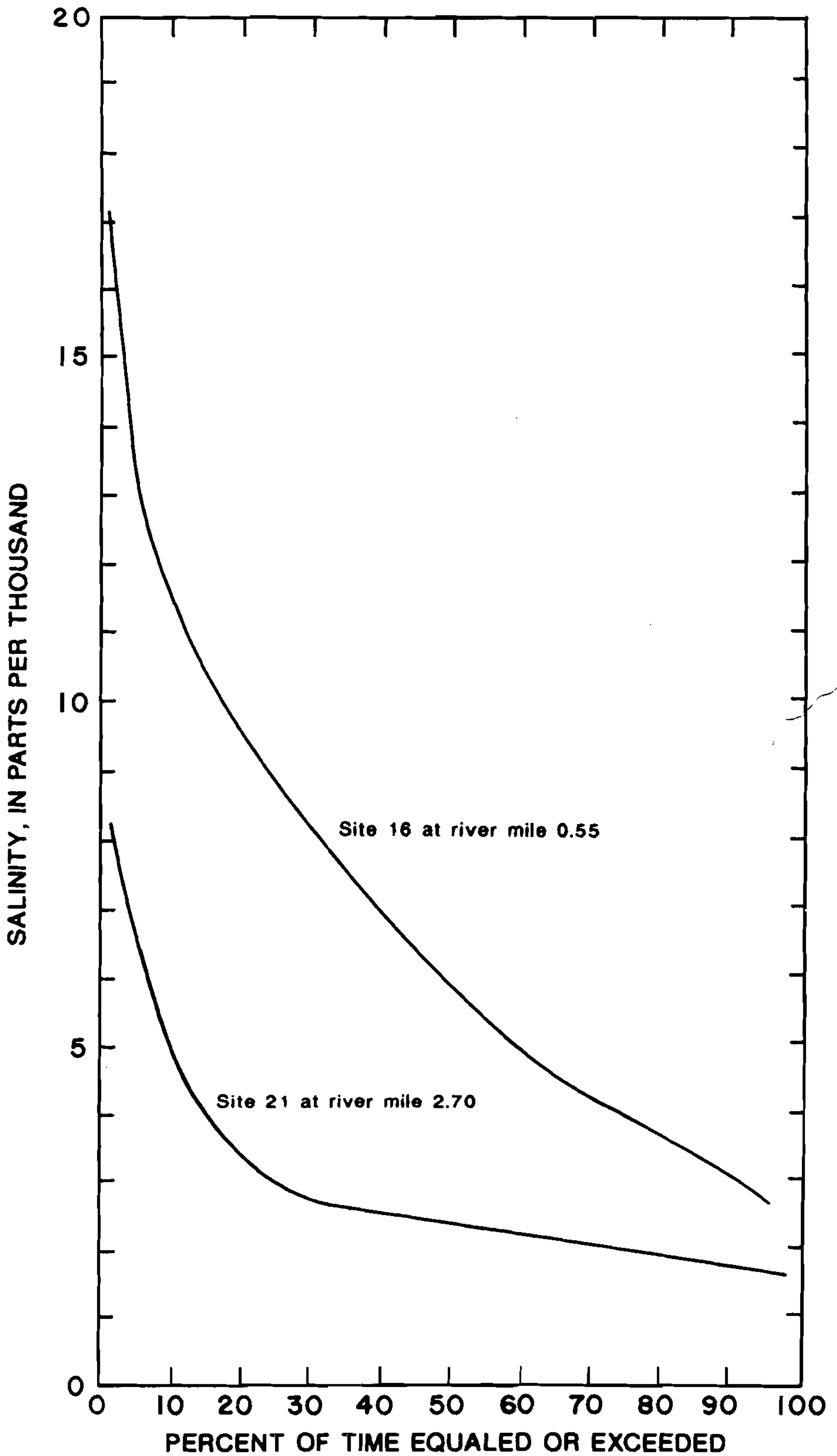


Figure 11.—Salinity duration curves for gages at river miles 0.55 and 2.70 on the Chassahowitzka River for the period of record, October 1984 through September 1985.

Salinity profiles for the Homosassa River Estuary during various streamflow and high-tide conditions are shown in figure 12. Discharge shown is the average flow of the day of sampling and the day prior to sampling. The tide stage is the high-tide stage recorded at river mile 0.20. Approximate locations of the lines of equal salinity were determined by linear interpolation between sampling points.

The salinity profiles show that waters are reasonably well mixed for the streamflow and high-tide conditions sampled. Lines of equal salinity are extended, indicating a wide transition zone between gulf and river waters. Although there are some differences between top and bottom salinities, the ratio of top-to-bottom salinity generally ranges from 0.85 to 1.00 (fig. 13).

Variations of longitudinal salinity gradients in the gulf and along the Homosassa River for representative high-tide conditions are shown in figure 14. The graphs show that salinity along the Homosassa River Estuary increases downstream and varies considerably at a given location. Salinities fluctuated from 16.4 to 28.0 ppt about 1 mile outside the river mouth, from 5.0 to 20.0 ppt at river mile 3.0, and from 1.2 to 2.2 ppt at river mile 6.5. The smallest variation in salinity was observed in the section of the river upstream of river mile 5.0, and the largest variation in salinity was observed in the section of the river between river miles 1.0 and 4.0.

The extreme ranges in locations of selected salinities for high-tide conditions in the Homosassa River for the period of study are listed below:

Salinity, in parts per thousand	Maximum upstream extent of the salinity, in miles upstream or downstream (-) of river mouth		
	Minimum	Maximum	Range
2	4.5	6.2	1.7
5	3.3	5.7	2.4
10	.8	4.9	4.1
18	-2.2	3.6	5.8
25	-5.0	.4	5.4

The range was variable and decreased inland. As in the Chassahowitzka River Estuary, the locations of low-concentration salinities appear to be less sensitive to changes in flow and tides and migrate over a smaller distance than high-concentration salinities. The 25-ppt salinity had a range in movement that was more than three times as great as the range in movement of the 2-ppt salinity.

The upstream extent of the zone of saltwater mixing (2-ppt salinity) in the Homosassa River was found to be dependent upon streamflow and tide-stage conditions. However, differences in upstream extent of the 2.0-ppt salinity were relatively small considering the differences in streamflow and high-tide conditions. The maximum encroachment of the 2-ppt salinity was observed at river mile 6.2 at a discharge of 58 ft^3/s and high-tide stage of 3.26 feet; the minimum penetration of the 2-ppt salinity was observed at river mile 4.45 at a discharge of 202 ft^3/s and a high-tide stage of 1.37 feet. At streamflows less than 170 ft^3/s and high-tide stages above 2.87 feet, the 2-ppt salinity was found upstream of river mile 5.25. At streamflows greater than 170 ft^3/s and high-tide stages less than 2.93 feet, the 2-ppt salinity did not reach river mile 5.18.

Salinity duration curves for continuous-record sites at river miles 0.15, 1.51, and 3.72 on the Homosassa River are shown in figure 15. The 2-ppt salinity was present at river mile 3.72 about 98 percent of the time and 100 percent of the time at river miles 0.15 and 1.51. A list of selected salinities and their frequency of occurrence are as follows:

Salinity, in parts per thousand	Percent of time equaled or exceeded at river mile		
	0.15	1.51	3.72
2	100	100	98
5	98	95	42
10	88	60	5
15	47	19	1
18	20	6	0
25	1	0	0

SALINITY AND FLOW RELATIONS

Chassahowitzka River

Multiple linear-regression analysis was used to relate the maximum upstream extent of the vertically averaged 5- and 3-ppt salinities to calculated daily mean discharge at river mile 4.76 and observed high-tide stage recorded at river mile 2.70. Maximum upstream locations of the vertically averaged 5- and 3-ppt salinities were

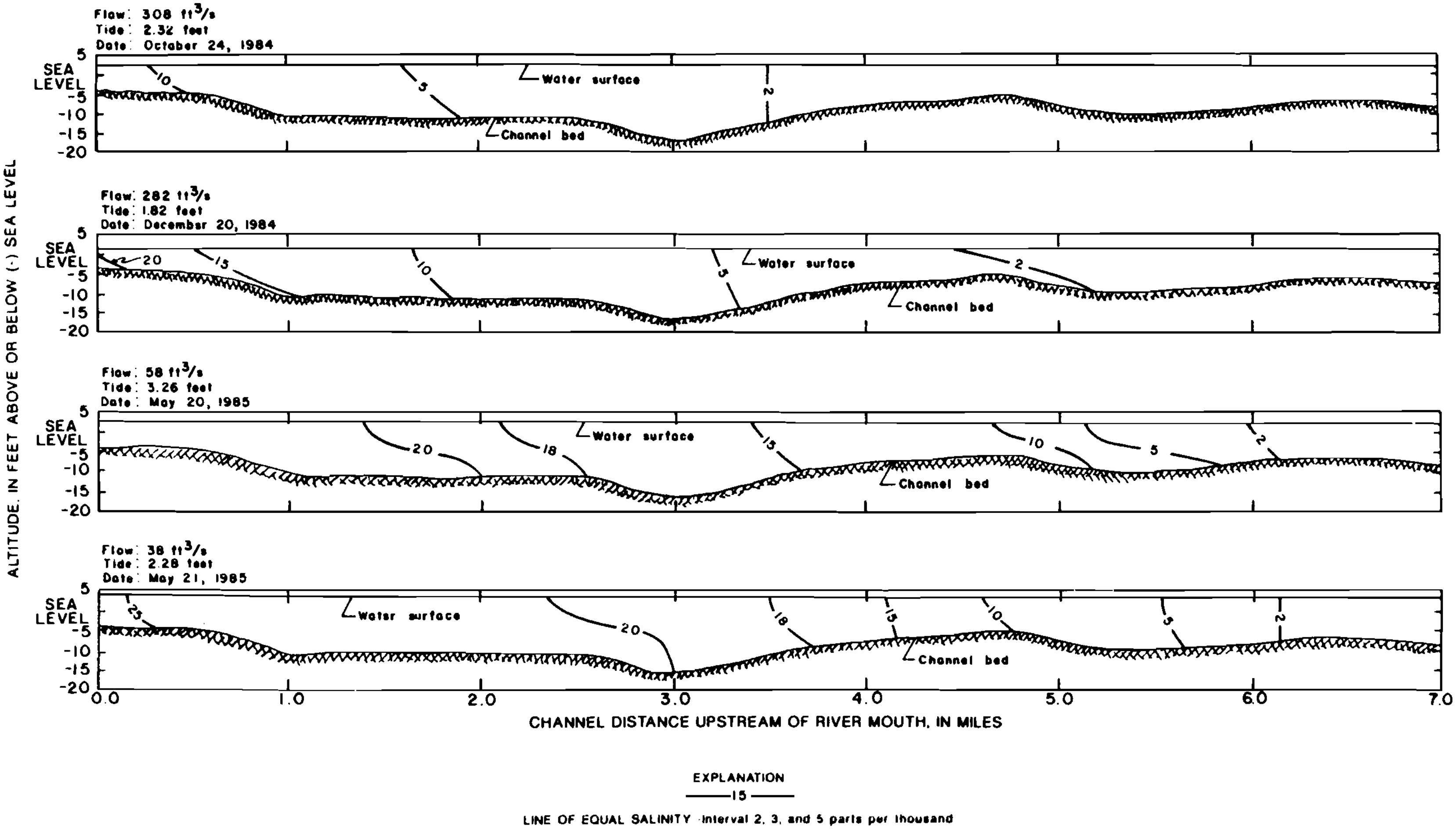


Figure 12.--Salinity profiles in the Homosassa River for various discharge and high-tide conditions.

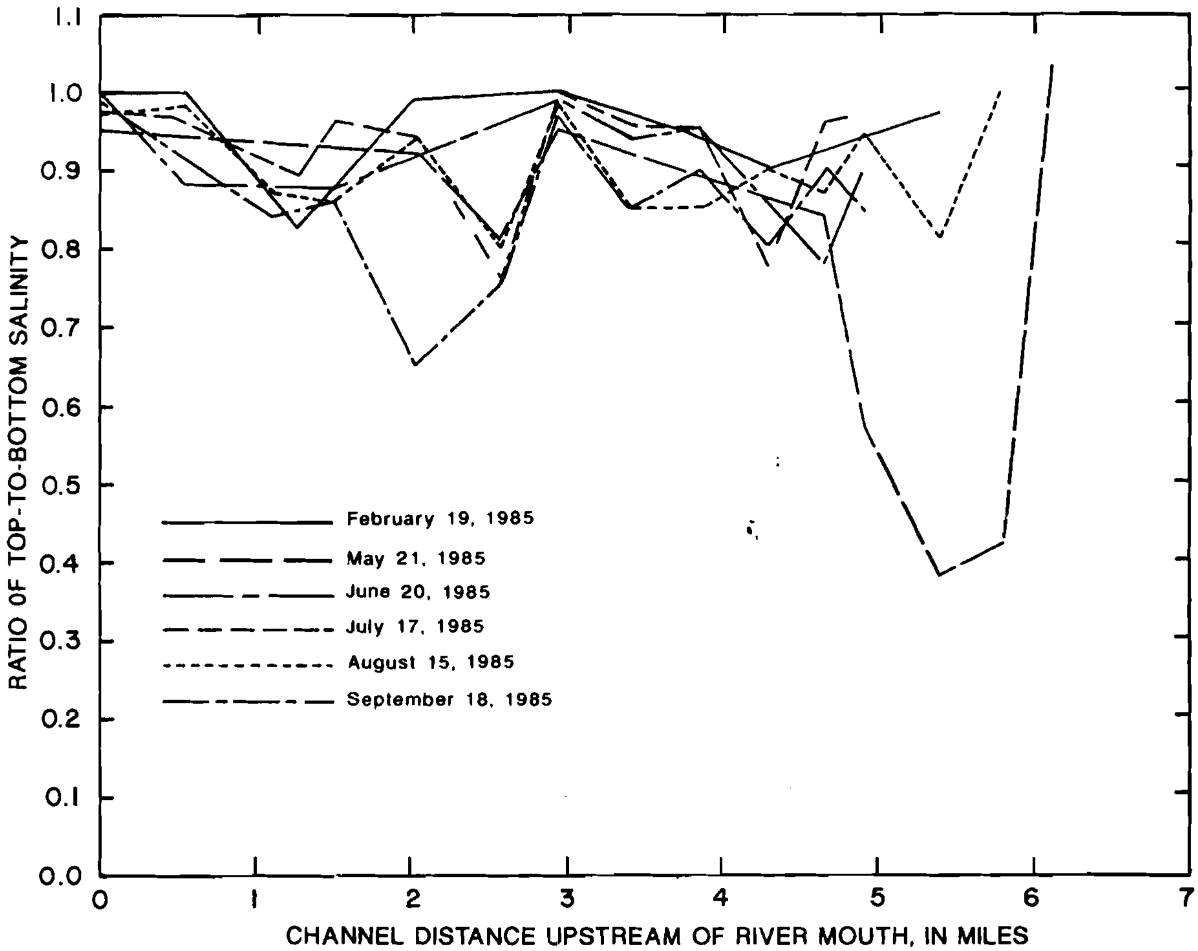


Figure 13.—Longitudinal variations of top-to-bottom salinity ratios for various discharge and high-tide conditions in the Homosassa River.

determined on eight separate occasions. Observed values used for development of regression equations are as follows:

Observation date	Daily mean discharge, in cubic feet per second	High-tide stage, in feet	Maximum upstream extent of the salinity, in miles upstream of river mouth: 5 parts per thousand	3 parts per thousand
3/26/85	155	1.50	1.61	2.52
4/25/85	107	1.95	2.47	3.00
5/23/85	71	2.47	3.41	3.74
6/23/85	111	1.91	2.48	3.17
7/18/85	90	2.49	2.85	3.48
8/16/85	93	2.55	2.53	3.07
9/12/85	79	2.53	2.37	3.21
10/18/85	86	2.08	2.66	3.20

Discharge data used in the regression analysis ranged from 71 to 155 ft^3/s, which was exceeded 95 and 8 percent, respectively, of the days from

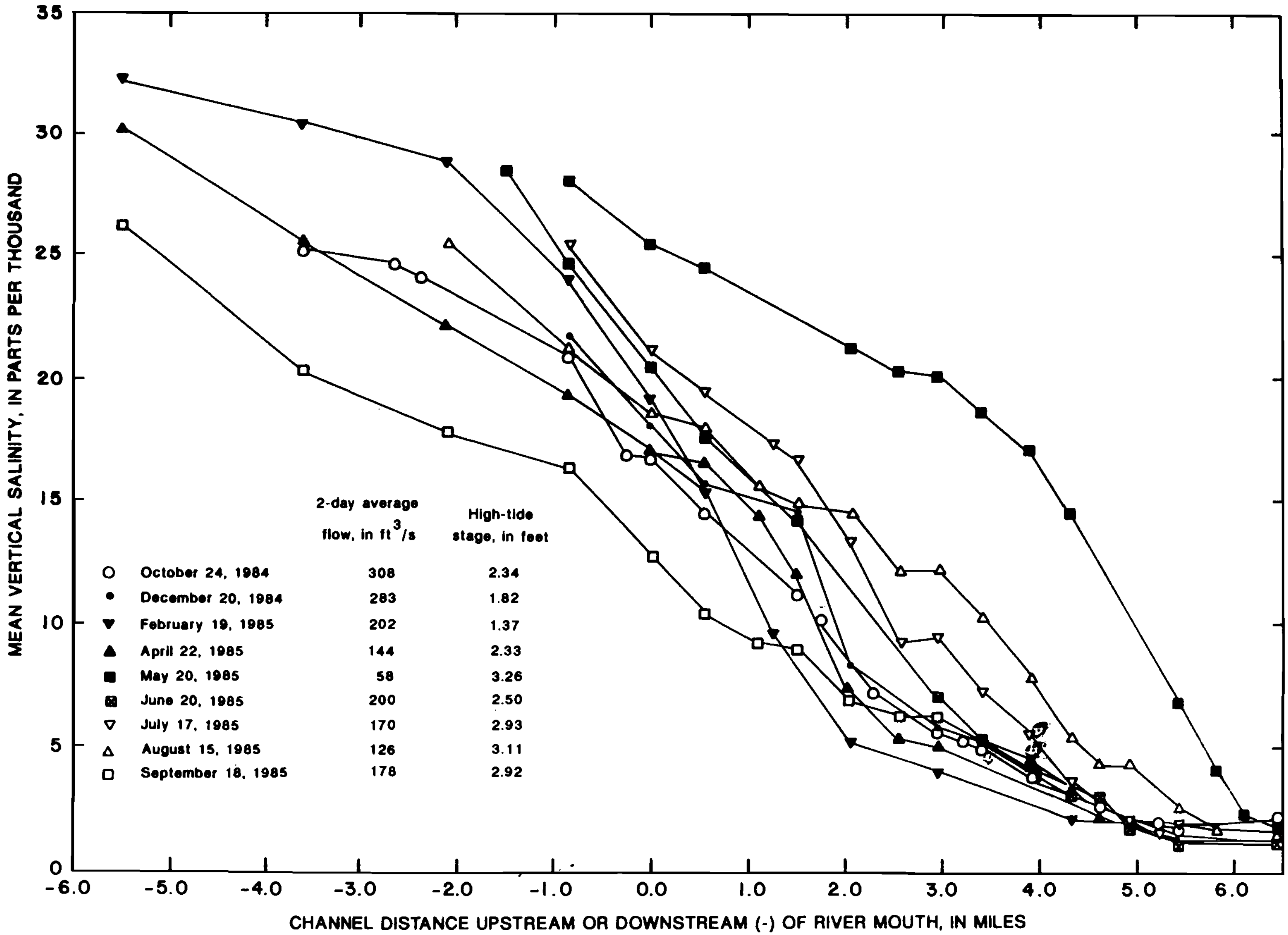


Figure 14.—Longitudinal salinity distributions for high-tide conditions in the Homosassa River Estuary.

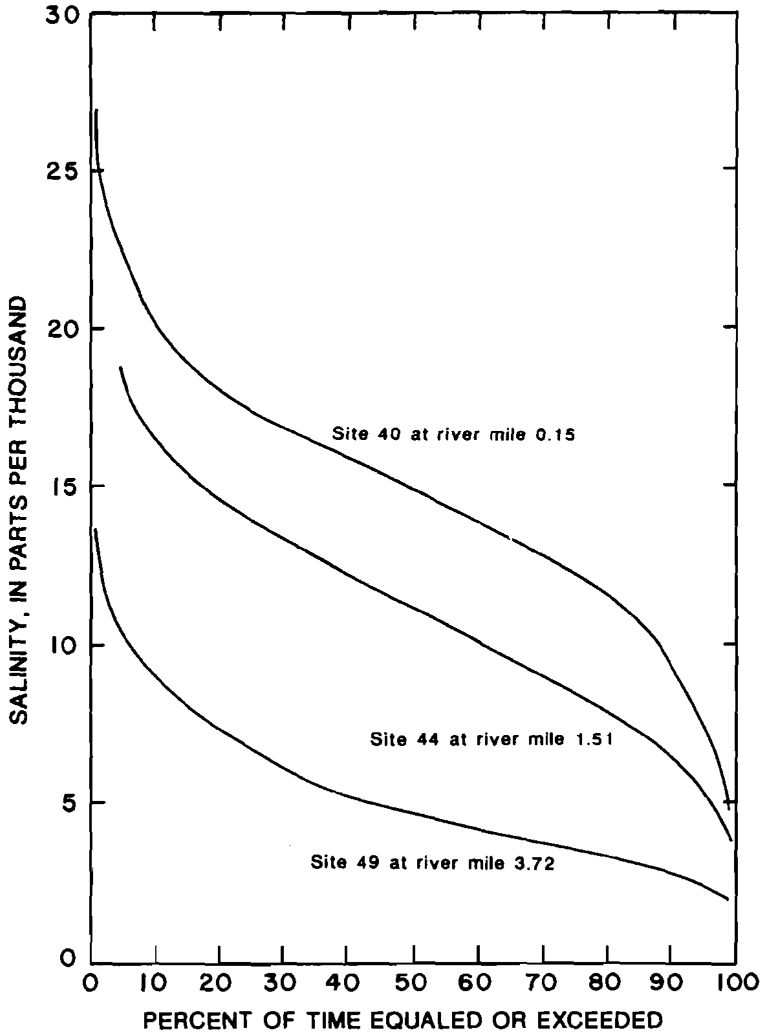


Figure 15.—Salinity duration curves for gages at river miles 0.15, 1.51, and 3.72 on Homosassa River for the period of record, October 1984 through September 1985.

October 1984 through September 1985. High-tide stages ranged from 1.50 to 2.55 feet, which were exceeded 84 and 6 percent, respectively, of the days from October 1984 through September 1985. A summary of the predictive equations and statistics of the regression analysis are as follows:

Equation number	Salinity, in parts per thousand	Predictive equation	Statistics R^2	Statistics RMSE	Statistics PR
1	5	$L = 4.16 - 0.0163(Q)$	0.73	0.28	0.0073
2	3	$L = 4.35 - 0.0119(Q)$	.77	.19	.0044

where

L = location of the maximum upstream extent of the vertically averaged 5- and 3-ppt salinities, in miles upstream of river mouth;
Q = daily mean discharge, in cubic feet per second;
R^2 = square of the correlation coefficient;
RMSE = root mean square error, in ± miles; and
PR = probability that the regression coefficient of Q equals zero.

The average R^2 is 0.75, and the average RMSE is 0.2 mile.

Results of the regression analysis show that discharge is the only independent variable that significantly affects the maximum upstream extent of the 5- and 3-ppt salinities. High tides between 1.50 and 2.55 feet appear to be of minor importance in substantially influencing the maximum extent of salinity intrusion, or else tide stage was confounded with discharge, and discharge alone is sufficient to describe location of the salinities.

Predictive equations that describe the maximum upstream extent of the vertically averaged 25- and 18-ppt salinities were developed in a simple linear-regression analysis using the salinity location as the dependent variable and the maximum salinity recorded at high tide at river mile 0.55 as the independent variable (fig. 16). The 25- and 18-ppt salinities were observed or estimated at high tide eight and seven times, respectively. A summary of the predictive equations and statistics of the regression analysis are as follows:

Equation number	Salinity, in parts per thousand	Predictive equation	Statistics		
			R^2	RMSE	PR
3	25	$L = 0.45(S) - 10.50$	0.86	1.06	0.0026
4	18	$L = 0.44(S) - 7.32$	.91	.39	.0008

where

L = location of the maximum upstream extent of the 25- and 18-ppt salinities, in miles upstream or downstream of river mouth;

S = maximum salinity at river mile 0.55 at high tide, in parts per thousand;

R^2 = square of the correlation coefficient;

RMSE = root mean square error, in ± miles; and

PR = probability that the regression coefficient of S equals zero.

Distance duration curves of the predicted daily maximum upstream extent of the vertically averaged 3-, 5-, 18-, and 25-ppt salinities were computed for the period October 1984 through September 1985 (fig. 17). Equations 1 and 2 were used to compute the curves for the 3- and 5-ppt salinities, and equations 3 and 4 were used for the 18- and 25-ppt salinities. The curves show that the 3-ppt salinity generally is found about 2 to 4 miles upstream of the river mouth; the 5-ppt salinity generally is found about 1 to 3 miles upstream of the mouth; the 18-ppt salinity can be expected to be found downstream of the river mouth about 90 percent of the days; and the 25-ppt salinity can be expected to be found 3 miles or more outside the river mouth about 90 percent of the days. Locations and durations of the vertically averaged 5- and 3-ppt salinities in the Chassahowitzka River for the period of study are shown in figure 18.

Homosassa River

Predictive equations describing the maximum upstream extent of the vertically averaged 5- and 2-ppt salinities were developed in a regression analysis using 2-day average discharge at river mile 5.40 and observed high-tide stage recorded at river mile 0.20. Maximum upstream locations of the vertically averaged 5- and 2-ppt salinities were determined on 10 separate occasions. Observed values used for development of regression equations are as follows:

Observation date	2-day average discharge, in cubic feet per second	High-tide stage, in feet	Maximum upstream extent of the salinity, in miles upstream of river mouth	
			5 parts per thousand	2 parts per thousand
10/24/84	308	2.34	3.45	5.18
12/20/84	283	1.82	3.27	4.76
2/19/85	202	1.37	3.32	4.45
4/22/85	144	2.33	3.66	5.33
5/20/85	58	3.26	5.74	6.20
5/21/85	38	2.87	5.53	6.04
6/20/85	200	2.50	3.83	4.97
7/17/85	170	2.93	4.33	5.25
8/15/85	126	3.11	4.51	5.67
9/13/85	178	2.92	3.43	4.92

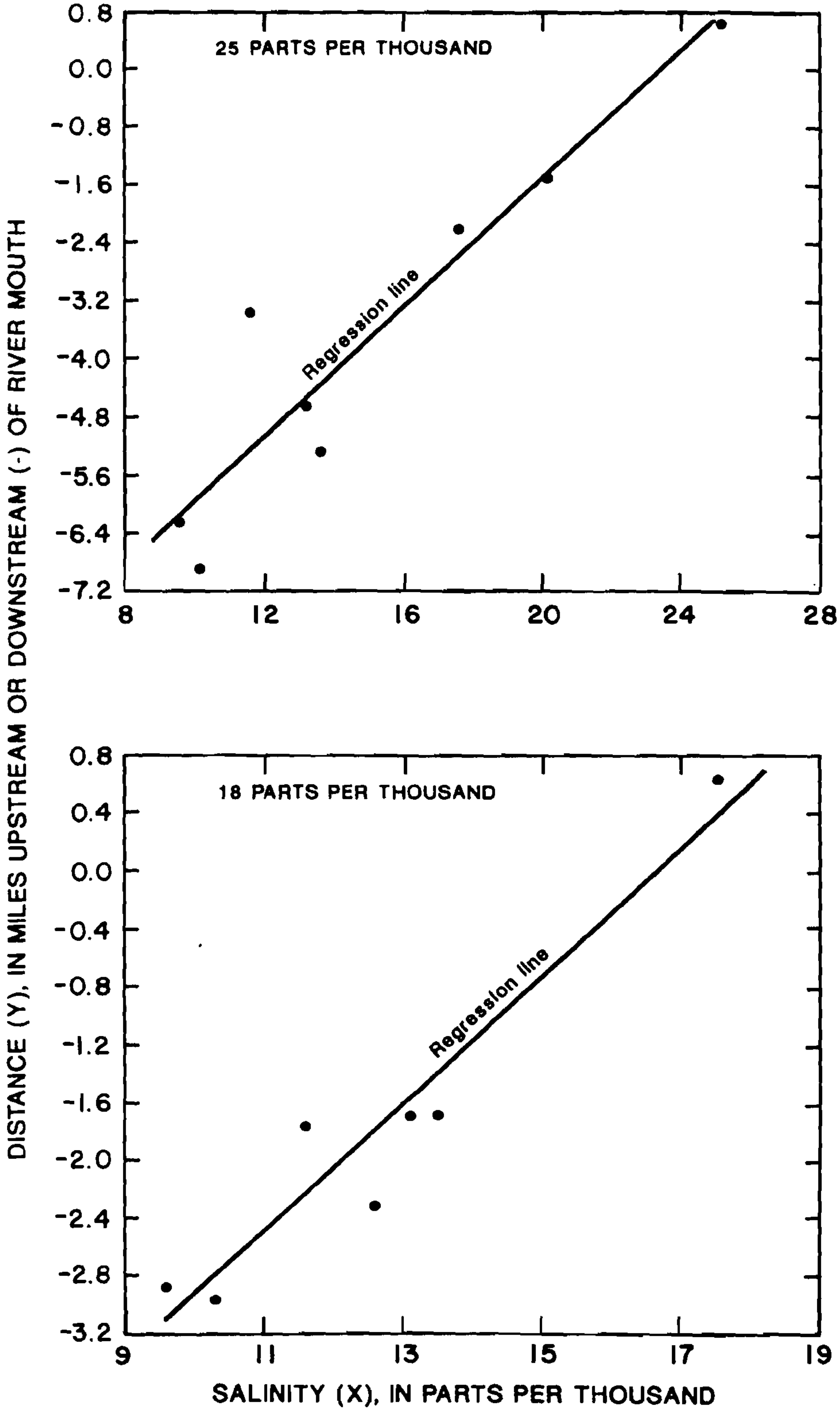


Figure 16.—Relation between salinity at river mile 0.55 and maximum upstream extent of the vertically averaged 25- and 18-parts-per-thousand salinities at high tide in the Chassahowitzka River Estuary.

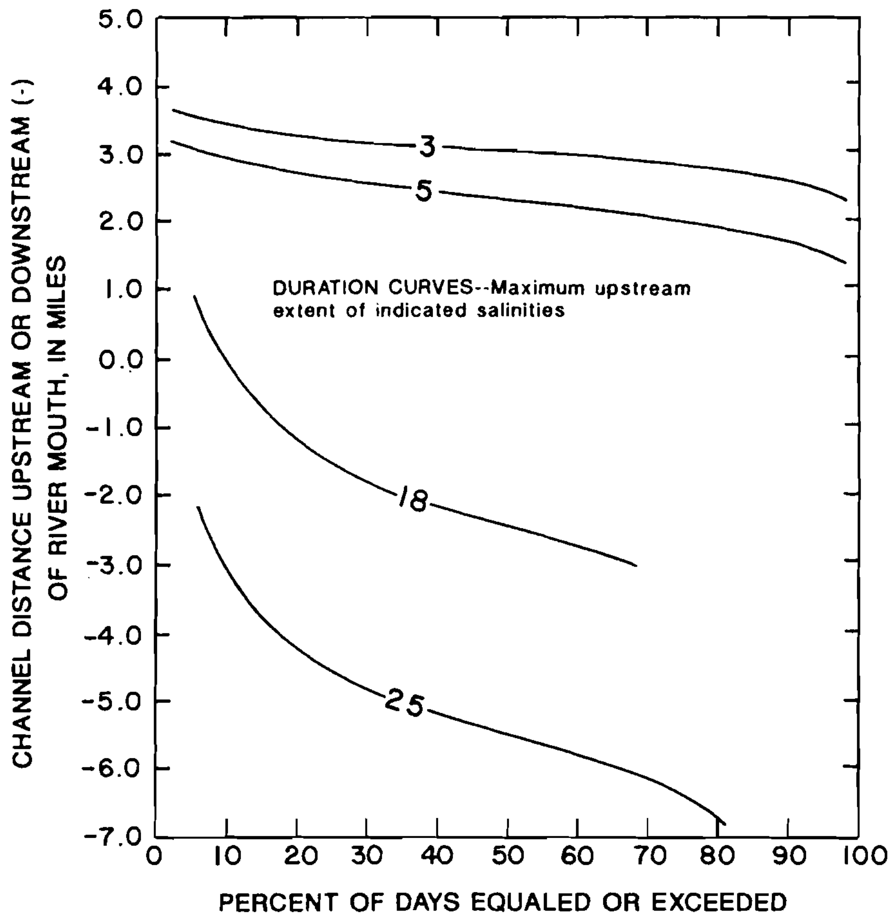


Figure 17.—Duration curves for computed daily maximum upstream extent of the vertically averaged 3-, 5-, 18-, and 25-parts-per-thousand salinities in the Chassahowitzka River Estuary, October 1984 through September 1985.

Discharge data used in the regression analysis were the average flow for the day of sampling and the day prior to sampling. Two-day average discharge ranged from 38 to 308 ft^3/s, which was equaled or exceeded 100 and 12 percent, respectively, of the days for October 1984 through September 1985. High-tide stages ranged from 1.37 to 3.26 feet, which were exceeded 95 and 0 percent, respectively, of the days for October 1984 through September 1985.

A summary of the predictive equations and statistics of the regression analysis are as follows:

Equation number	Salinity, in parts per thousand	Predictive equation	Statistics: R^2	Statistics: RMSE, in percent	Statistics: PR, Q	Statistics: PR, HT
5	5	$L = \frac{10.69\,(HT)^{0.22}}{Q^{0.24}}$	0.88	8.0	0.0016	0.1008
6	2	$L = \frac{6.87\,(HT)^{0.19}}{Q^{0.09}}$	.85	4.6	.0138	.0248

where

L = location of the maximum upstream extent of the vertically averaged 5- and 2-ppt salinities, in miles upstream of the river mouth;

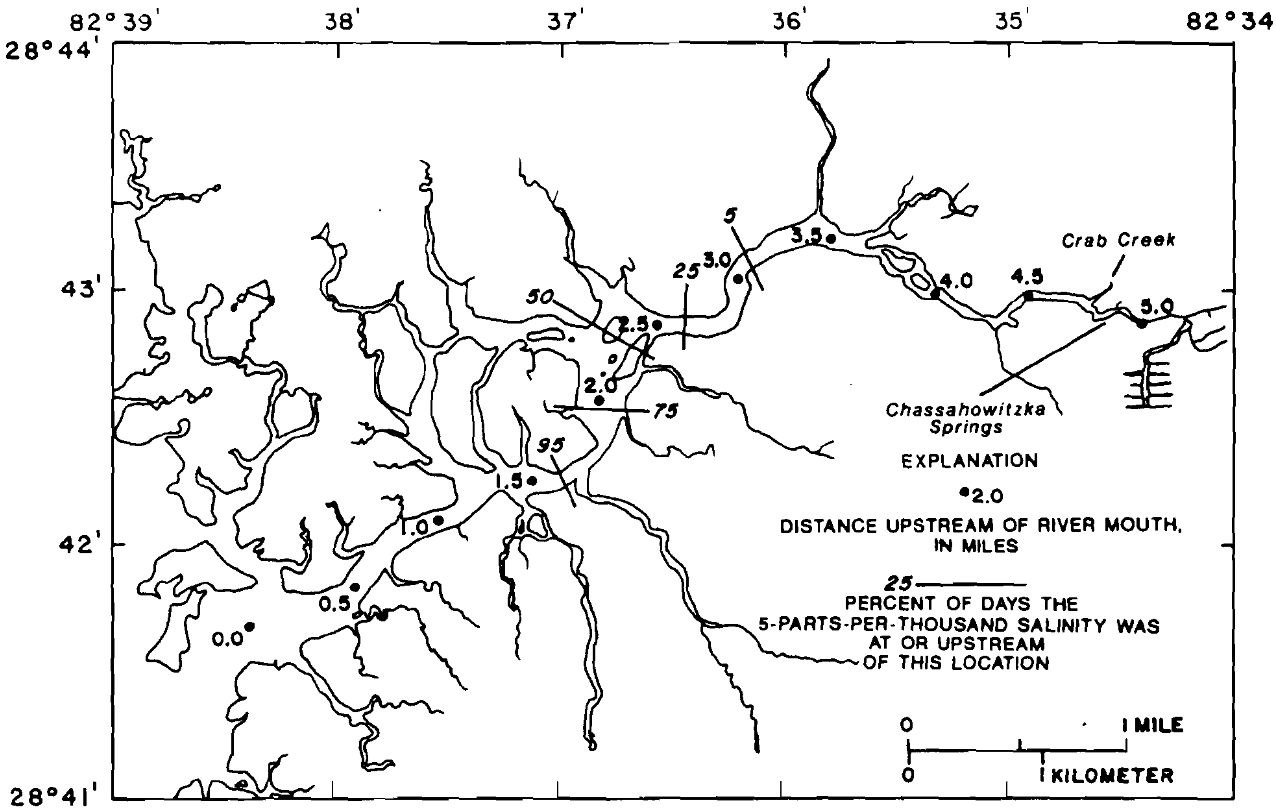
HT = high-tide stage (river mile 0.20), in feet above sea level;

Q = 2-day average discharge, in cubic feet per second;

R^2 = square of the correlation coefficient;

RMSE = root mean square error, in percent; and

PR = probability that the regression coefficients of Q and HT equals zero.



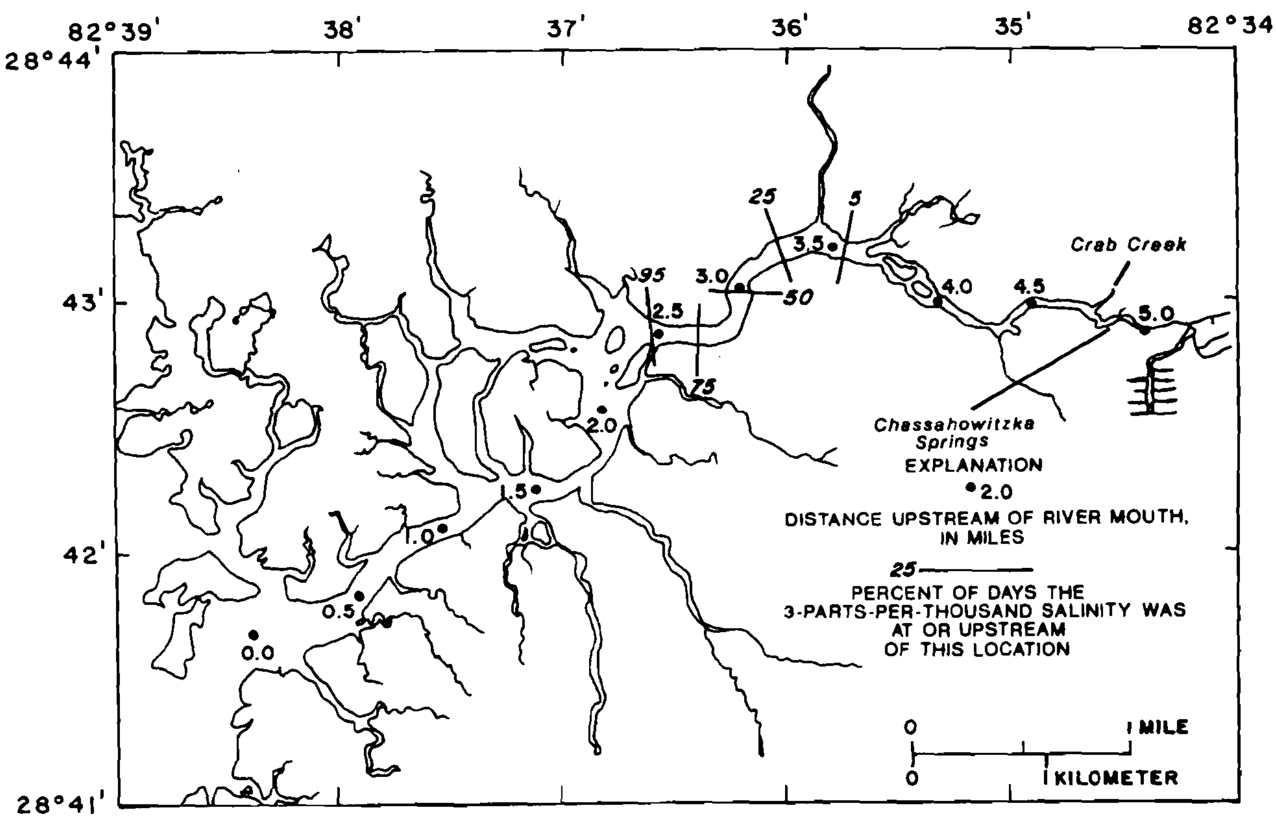


Figure 18. – Duration of the daily maximum upstream extent of the vertically averaged 5- and 3-parts-per-thousand salinities in the Chassahowitzka River, October 1984 through September 1985.

The average R^2 is 0.86 and the average RMSE is 6.3 percent.

The response of the predictive equations to a 25-percent decrease in streamflow, from 209 to 157 ft^3/s, and to a 25-percent increase in tide stage, from 2.31 to 2.89 feet, is shown below.

2-day average streamflow, in cubic feet per second	High-tide stage, in feet	Daily maximum upstream extent of the salinity, in miles upstream of river mouth	
		5 parts per thousand	2 parts per thousand
209	2.31	3.56	4.98
209	2.89	3.75	5.20
157	2.31	3.82	5.11

Discharge has a slightly greater effect on the 5-ppt salinity than does tide stage, whereas for the 2-ppt salinity, tide stage has a slightly greater effect than does streamflow.

Predictive equations describing the daily maximum upstream extent of the vertically averaged 25- and 18-ppt salinities were developed in a simple linear-regression analysis using the salinity location as the dependent variable and the maximum salinity recorded at high tide at river mile 0.15 as the independent variable (fig. 19). The 25- and 18-ppt salinities were determined or estimated at high tide 8 and 10 times, respectively. A summary of the predictive equations and statistics of the regression equations are as follows:

Equation number	Salinity, in parts per thousand	Predictive equation	Statistics		
			R^2	RMSE	PR
7	25	$L = 0.40(S) - 9.40$	0.84	0.73	0.0013
8	18	$L = 0.45(S) - 7.68$	.95	.39	.0000

where

L = location of the maximum upstream extent of the vertically averaged 25- and 18-parts-per-thousand salinities, in miles upstream or downstream of river mouth;
S = maximum salinity at river mile 0.15 at high tide, in parts per thousand;
R^2 = square of the correlation coefficient;
RMSE = root mean square error, in ± miles; and
PR = probability that the regression coefficient of S equals zero.

Distance duration curves of the daily maximum upstream extent of the vertically averaged 2-, 5-, 18-, and 25-ppt salinities for the period October 1984 through September 1985 using equations 5 through 8 are shown in figure 20. The curves show that the 2-ppt salinity generally is found about 4 to 6 miles upstream of the mouth; the 5-ppt salinity generally is found between 3 and 5 miles upstream of the mouth; the 18-ppt salinity generally is found between 2 miles outside the mouth to about 4 miles upstream of the mouth; and the 25-ppt salinity generally is found between 6 miles outside the mouth to about 1 mile upstream of the mouth. Locations and durations of the vertically averaged 5- and 2-ppt salinities in the Homosassa River for the period of study are shown in figure 21.

EFFECTS OF REDUCED FLOW

Chassahowitzka River

Streamflow affects water-quality conditions in estuaries and maintains salinity gradients that affect estuarine fauna and flora. To illustrate the effects of discharge on the daily maximum upstream extent of the vertically averaged 5- and 3-ppt salinities in the Chassahowitzka River, discharges varying from 75 to 150 ft^3/s were used with equations 1 and 2 to estimate salinity locations. Computed daily maximum upstream positions of the vertically averaged 5- and 3-ppt salinities are listed below:

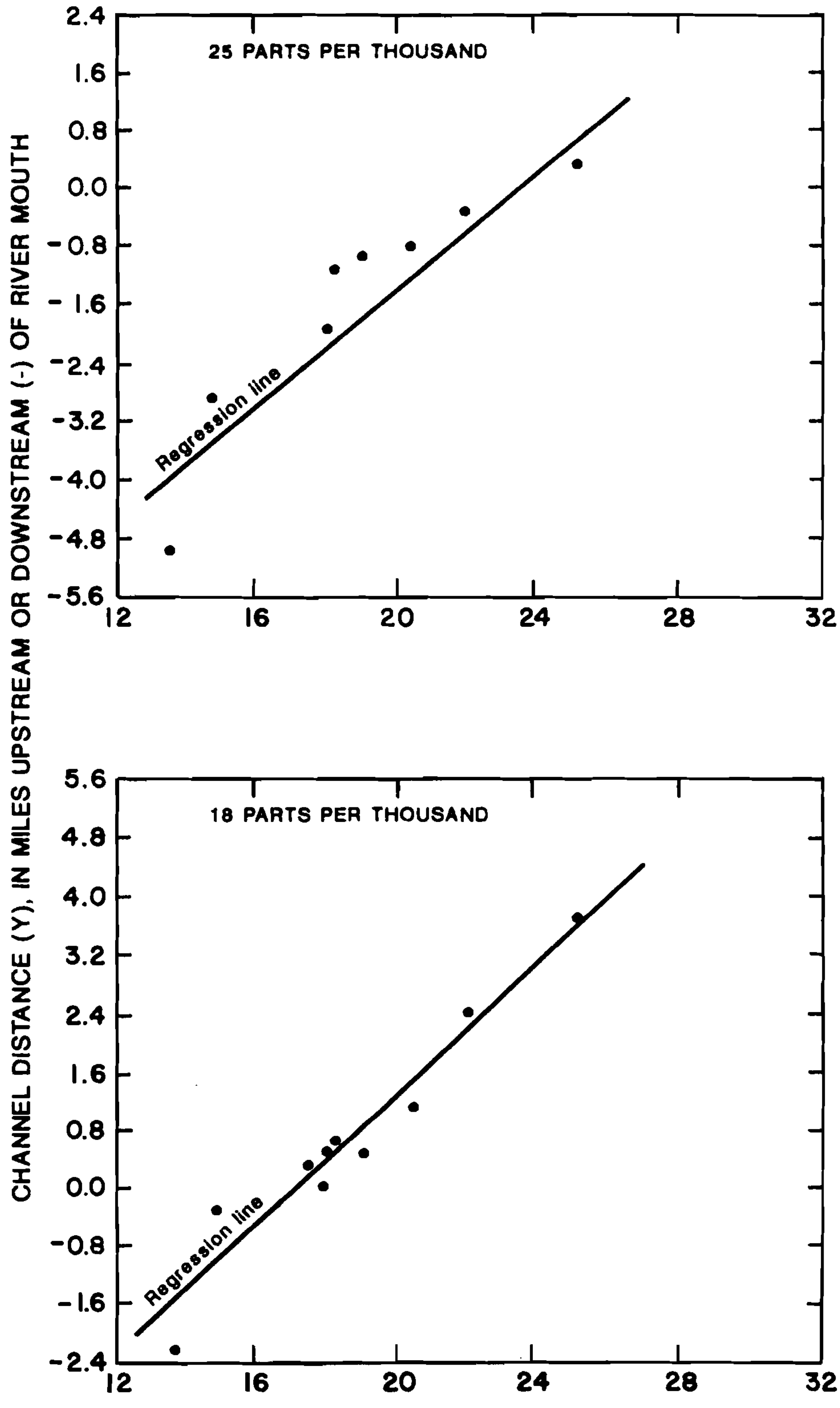


Figure 19.—Relation between salinity at river mile 0.15 and maximum upstream extent of the vertically averaged 25- and 18-parts-per-thousand salinities at high tide in the Homosassa River Estuary.

Daily mean discharge, in cubic feet per second	Daily maximum upstream extent of the salinity, miles upstream of river mouth	
	5 parts per thousand	2 parts per thousand
75	2.94	3.46
100	2.53	3.16
125	2.12	2.86
150	1.72	2.56

The 5-ppt salinity is slightly more sensitive to discharge than is the 3-ppt salinity. Reducing discharge from 150 to 75 ft^3/s results in an upstream movement of 1.2 miles for the vertically averaged 5-ppt salinity and 0.9 mile for the vertically averaged 3-ppt salinity.

Surface-water withdrawals from the Chassahowitzka River for water use may be unlikely because of the river's brackish conditions. The most probable impact on the flow of the Chassahowitzka River would be from ground water withdrawn from the Upper Floridan aquifer. To estimate the impact of ground-water development on spring flow in coastal Citrus and Hernando Counties, a digital ground-water flow model was developed to approximate the steady-state flow system (Yobbi, 1989). The model was used to show the maximum impact (worst case) on spring flow. Sixteen computer runs were made, one at a time, with a total pumpage of 40 Mgal/d (61.9 ft^3/s) during each run from a single well in the center of each grid block of the spring groups. A pumping rate of 40 Mgal/d was selected because it is generally the maximum permitted average daily pumpage from a well within the Southwest Florida Water Management District (Fretwell,

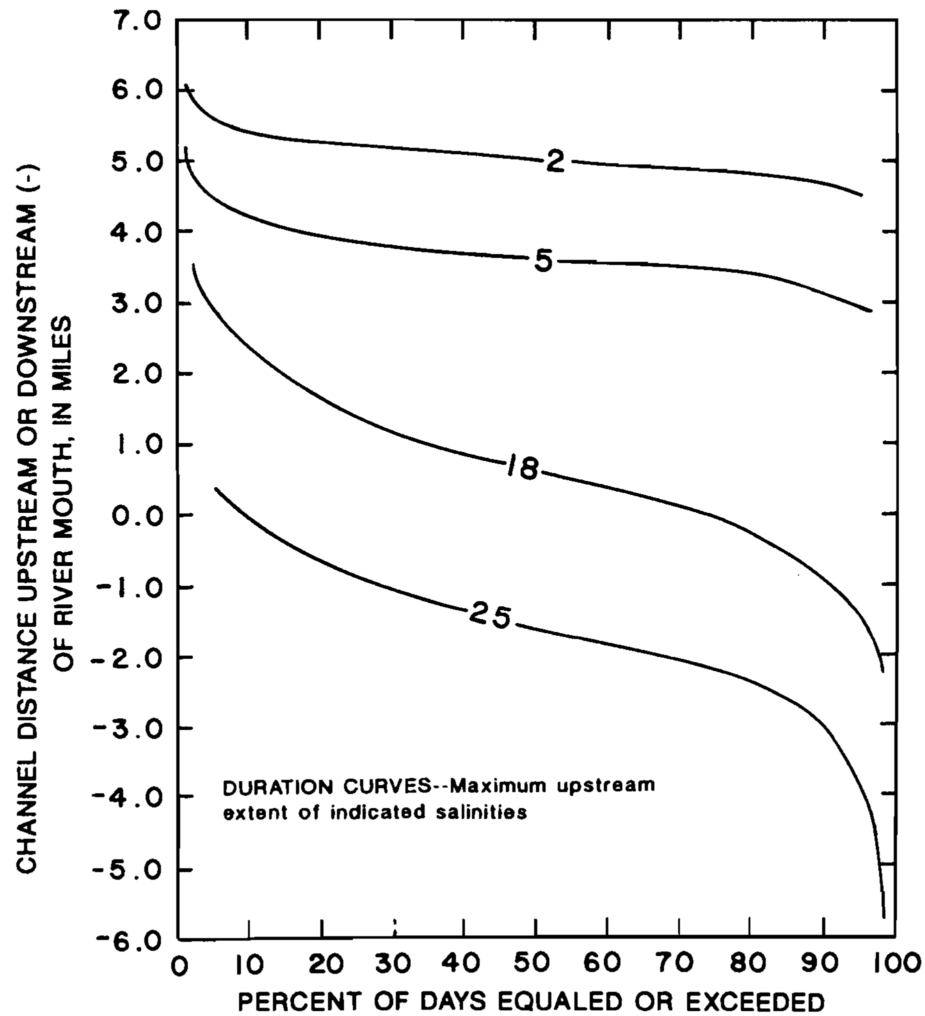


Figure 20. – Duration curves for computed daily maximum upstream extent of the vertically averaged 2-, 5-, 18-, and 25-parts-per-thousand salinities in the Homosassa River Estuary, October 1984 through September 1985.

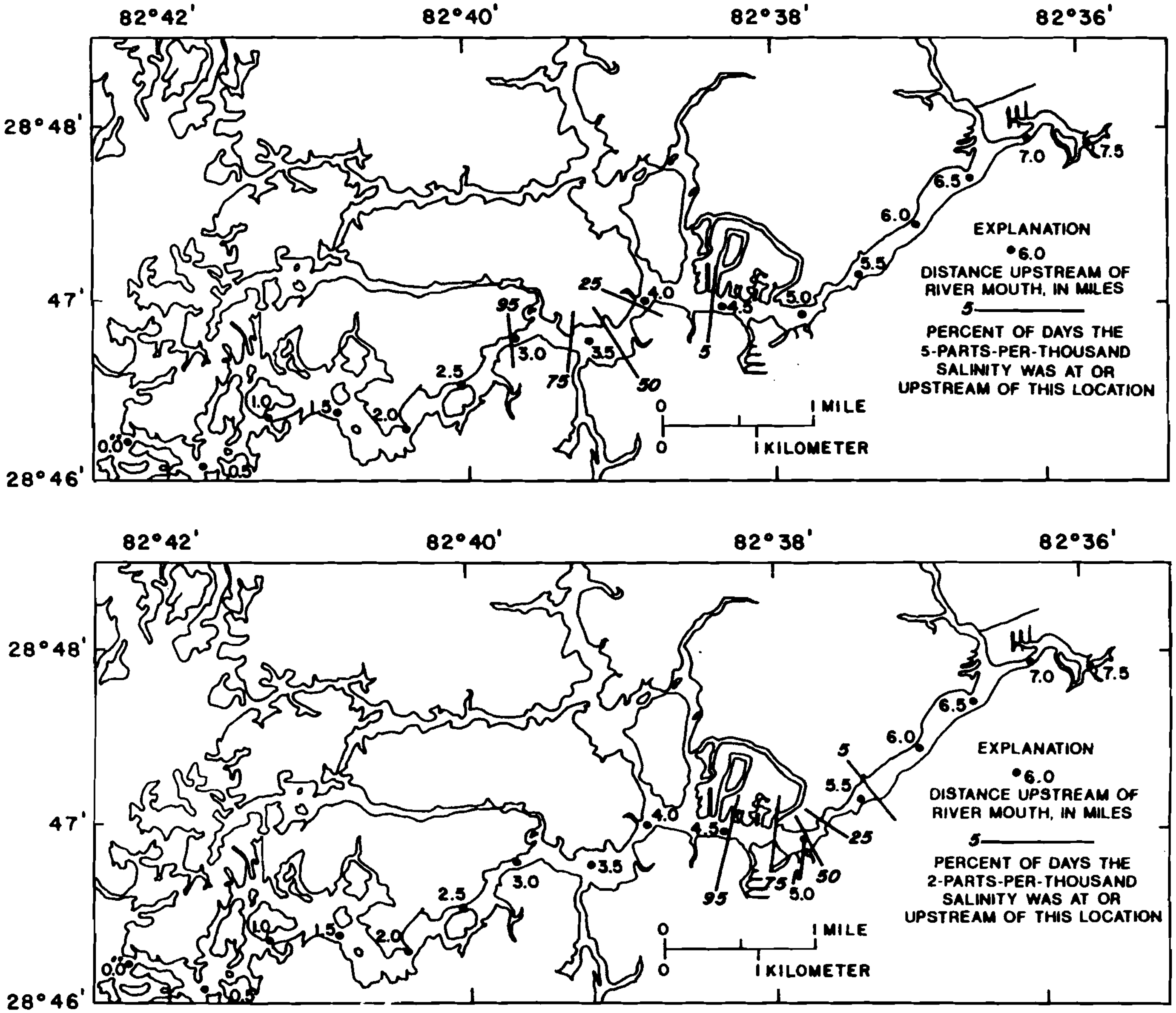


Figure 21.—Duration of the daily maximum upstream extent of the vertically averaged 5- and 2-parts-per-thousand salinities in the Homosassa River, October 1984 through September 1985.

1983). The springs considered and the results of the simulations are summarized in table 5. The impacts would be less if pumpage were distributed over a wider area, as is the common practice in west-central Florida.

Table 5 shows that a 40-Mgal/d ground-water withdrawal from the aquifer within 2 miles of Chassahowitzka Springs would reduce spring flow by 15 percent. To show the effect of a 15-percent reduction of spring flow, average daily flow data were used with equations 1 and 2 to estimate changes in salinity locations. If the average daily flow of Chassahowitzka River was reduced by 15 percent, from 139 to 118 ft^3/s, it is estimated that an upstream movement of both the vertically averaged 5- and 3-ppt salinities of approximately 0.3 mile would be induced.

Homosassa River

Reduction of flow will affect the upstream extent of saltwater in the Homosassa River. Locations of the maximum upstream extent of the vertically averaged 5- and 2-ppt salinities for various low-flow and higher high-tide conditions, based on equations 5 and 6, are shown in figure 22. At a higher high-tide stage of 1.5 feet, the estimated daily maximum upstream extent of the vertically averaged 5- and 2-ppt salinities, for discharges that vary from 50 to 250 ft^3/s, ranges from river miles 4.57 to 3.11 and from river miles 5.22 to 4.51, respectively. At a higher high-tide stage of 3.0 feet, the estimated daily maximum upstream extent of the vertically averaged 5- and 2-ppt salinities ranges from river miles 5.32 to 3.62 and from river miles 5.95 to 5.14, respectively. The graphs show that the 5-ppt salinity is more sensitive to changes in discharge than is the 2-ppt salinity.

To estimate possible changes in the frequency of salinity intrusion caused by reduced streamflow, higher high-tide stages of known durations and various constant low-flow discharges were used with equations 5 and 6 to estimate salinity locations. The computed daily maximum upstream extent of the vertically averaged 5- and 2-ppt salinities and duration percentages are presented in figure 23. At a discharge of 50 ft^3/s, the vertically averaged 5- and 2-ppt salinities will be at or above river

Table 5.—*Simulated reduction of springflow due to withdrawing 40 million gallons per day within 2 miles of springs*

[ft^3/s, cubic feet per second; Mgal/d, million gallons per day]

Spring name	Simulated spring flow (ft^3/s): No pumpage	Simulated spring flow (ft^3/s): Pumpage of 40 Mgal/d near the spring	Reduction of flow due to pumping (ft^3/s)	Percent decrease
No. 1, Boat	11.8	0	11.8	100
No. 2, Bobhill	4.8	0	4.8	100
No. 4, No. 5	34.7	17	17.7	51
Salt, Mud, No. 6	73.9	26	47.9	65
Weeki Wachee	173	130	43	25
Blind Creek, No. 8	32.0	0	32	100
No. 9, No. 10, No. 11, No.12	45.6	10	35.6	78
Chassahowitzka, Baird Creek	177	150	27	15
Ruth, Potter	34.3	28	6.3	18
Hidden River	35.7	30	4.7	14
Homosassa, Southeast Fork Homosassa, and Halls River	338	294	44	13
Crystal River[1]	874	813	61	7
Rainbow	733	671	62	8

[1]Well located in grid block 9,15. Simulated flows for grid blocks 10,14–15 and 9,14 are 816, 814, and 816 ft^3/s, respectively.

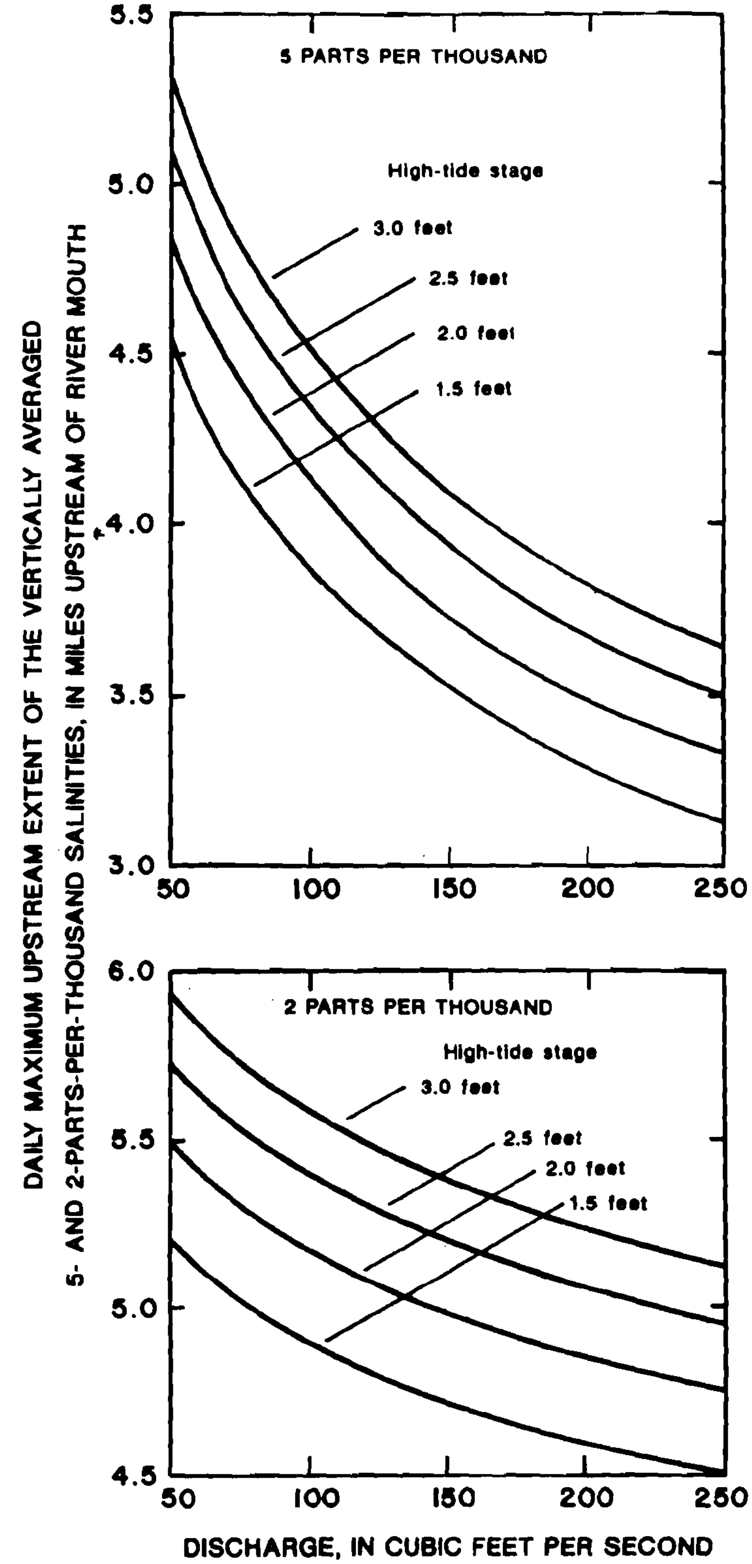


Figure 22.—Relation between discharge and daily maximum upstream extent of the vertically averaged 5- and 2-parts-per-thousand salinities for various high tides in the Homosassa River.

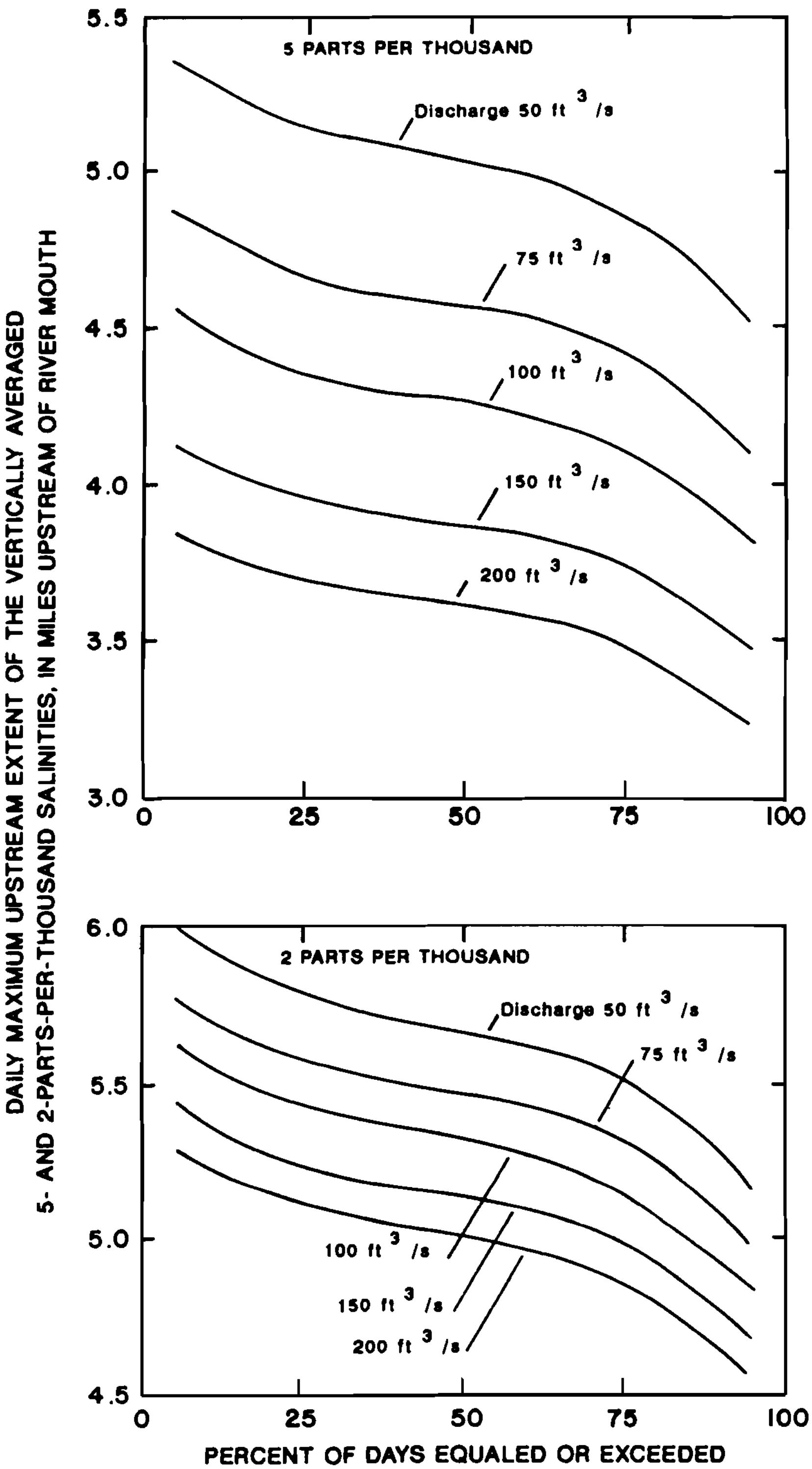


Figure 23.—Duration curves for the daily maximum upstream extent of the vertically averaged 5- and 2-parts-per-thousand salinities in the Homosassa River for variable high tides and discharge.

miles 5.03 and 5.67, respectively, about 50 percent of the days. At a discharge of 200 ft^3/s, the vertically averaged 5- and 2-ppt salinities will be at or upstream of river miles 3.61 and 5.00, respectively, about 50 percent of the days.

As with the Chassahowitzka River, the most probable impact on the flow of the Homosassa River would be from ground-water development from the Upper Floridan aquifer. Table 5 shows that a 40-Mgal/d ground-water withdrawal from the grid block containing the Homosassa Springs complex would result in a 13-percent reduction in spring flow. The reduction of spring flow would be most critical at higher high-tide and low-flow conditions.

To show the effect of a 13-percent reduction of spring flow on the upstream movement of the vertically averaged 5- and 2-ppt salinities, average daily discharge data for the period of study (218 ft^3/s) was used with equations 5 and 6 to estimate changes in salinity locations. A 13-percent reduction (from 218–190 ft^3/s) in spring flow at a mean higher high tide of 2.31 feet would cause the vertically averaged 5- and 2-ppt salinities to move upstream only about 0.1 mile from river miles 3.53 to 3.65 and from river miles 4.96 to 5.02, respectively. The net change in upstream extent of saltwater intrusion is within the range of predicted error and not statistically different. The main effect on locations of the vertically averaged 5- and 2-ppt salinities under these low-flow conditions is higher high tide. If discharge is decreased, the extent of salinity intrusion will increase.

SUMMARY AND CONCLUSIONS

The Chassahowitzka and Homosassa Rivers are streams in southwestern Citrus County that flow westerly about 5 to 7 miles into the Gulf of Mexico. Each river originates from a group of springs that provide almost the entire flow of the rivers. Many springs discharge saline water and the spring discharge is generally fresher near the head of the rivers.

Waters of the Chassahowitzka River and Homosassa River Estuaries were well mixed for the streamflow and high-tide conditions sampled. The Chassahowitzka River Estuary was characterized by broad horizontal salinity gradients downstream of river mile 1.7 and steep salinity gradients between river miles 1.7 and 2.4. The Homosassa River Estuary was characterized by broad salinity gradients along the entire estuary. Salinity changes along the estuaries were large and varied significantly at a given location.

The range in salinity locations at high tide in the estuaries was variable and decreased upstream. In both estuaries, the 25-ppt salinity had a range in movement that was more than three times as great as the range in movement of the upstream extent of the zone of saltwater mixing.

The upstream extent of the zone of saltwater mixing in the rivers was dependent on streamflow and high-tide stage. Maximum encroachment occurred during low-flow and higher high-tide conditions, and minimum intrusion was observed during high-flow and lower high-tide conditions.

Salinity-duration analyses were used to indicate the percentage of time saltwater from the gulf was present at continuous-record sites in the estuaries. In the Chassahowitzka River, salinity above 3 ppt was present at river mile 0.55 about 90 percent of the time and at river mile 2.70 about 24 percent of the time. In the Homosassa River, salinity above 2 ppt was present 100 percent of the time at river miles 0.15 and 1.51 and at river mile 3.72 about 98 percent of the time. The upstream extent of the zone of saltwater mixing was assumed to be the location of the 3-ppt and 2-ppt salinities, respectively, for the Chassahowitzka and Homosassa Rivers.

Predictive equations that relate streamflow, high-tide stage, and maximum upstream location of the vertically averaged 5- and 3-ppt salinities in the Chassahowitzka River and the vertically averaged 5- and 2-ppt salinities in the Homosassa River were developed using regression techniques. Streamflow proved to be the only significant parameter in the Chassahowitzka River equations, whereas tide stage and streamflow proved to be significant in the Homosassa River equations. For the Chassahowitzka River equations, the average R^2 was 0.75, and the average root mean square error was $\pm$0.2 mile. For the Homosassa River equations, the average R^2 was 0.86 and the average root mean square error was 6.3 percent. The range of data for streamflow and high-tide stage in the Chassahowitzka River equation is from 71 to 155 ft^3/s and from 1.50 to 2.55 feet. For Homosassa River, streamflow ranged from 38 to 308 ft^3/s and high-tide stage ranged from 1.37 to 3.26 feet.

A duration analysis of the Chassahowitzka and Homosassa Rivers indicates the percent of days selected salinities were located at points in the rivers at higher high tide during October 1984 through September 1985. In the Chassahowitzka River, the vertically averaged 5- and 3-ppt salinities generally were found 1 to 3 miles and 2 to 4 miles, respectively, upstream of the river mouth. In the Homosassa River, the vertically averaged 5- and 2-ppt salinities generally were found between 3 and 5 miles and 4 and 6 miles, respectively, upstream of the river mouth.

A good relation was observed between salinity at a reference station and maximum upstream locations of the vertically averaged 25- and 18-ppt salinities. In the Chassahowitzka River Estuary, the vertically averaged 18-ppt salinity can be expected to be found downstream of the river mouth about 90 percent of the days, and the vertically averaged 25-ppt salinity can be expected to be found 3 miles or more outside the river mouth about 90 percent of the days. In the Homosassa River Estuary, the vertically averaged 18-ppt salinity generally is found between 2 miles outside the river mouth and about 4 miles upstream of the river mouth. The vertically averaged 25-ppt salinity generally is found between 6 miles outside the river mouth and about 1 mile upstream of the mouth.

Predictive equations were used to illustrate the effects of discharge on the vertically averaged 3- and 5-ppt salinities in the Chassahowitzka River and the vertically averaged 2- and 5-ppt salinities in the Homosassa River. In the Chassahowitzka River, for discharge ranging from 150 to 75 ft^3/s, the daily maximum upstream extent of the vertically averaged 3- and 5-ppt salinities will be located between river miles 2.56 and 3.46 and river miles 1.72 and 2.94, respectively. In the Homosassa River, at a high-tide stage of 3.0 feet and discharge ranging from 250 to 50 ft^3/s, the estimated daily maximum upstream extent of the vertically averaged 5- and 2-ppt salinities will be located between river miles 5.32 and 3.62 and from river miles 5.95 to 5.14, respectively.

The most probable impact on the flow of the Chassahowitzka and Homosassa Rivers would be from well-field pumpage from the underlying aquifer. Results of computer simulations show that a 40-Mgal/d ground-water withdrawal within 2 miles of the heads of the Chassahowitzka and Homosassa Rivers would result in a 15- and 13-percent reduction of spring flow, respectively. In the Chassahowitzka River, a 15-percent reduction in streamflow, from 139 to 118 ft^3/s, would cause an upstream movement of both the vertically averaged 5- and 3-ppt salinities of about 0.3 mile. In the Homosassa River, a 13-percent reduction in streamflow, from 218 to 190 ft^3/s, would cause an upstream movement of both the vertically averaged 5- and 2-ppt salinities of about 0.1 mile. The movement is small, indicating that ground-water development would probably have little effect on the upstream location of saltwater in the two rivers.

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