SALINITY CHARACTERISTICS AND DISTRIBUTION AND EFFECTS OF ALTERNATIVE PLANS FOR FRESHWATER WITHDRAWAL, LITTLE MANATEE RIVER ESTUARY AND ADJACENT AREAS OF TAMPA BAY, FLORIDA

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Factors for converting inch-pound units to International System of Units (SI) and abbreviations of units

Multiply	By	To obtain
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)	0.02832	cubic meter per second (m^3/s)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons	3,785	cubic meter (m^3)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
micromho per centimeter at 25° Celsius (umho/cm at 25°C)	1.000	microsiemens per centimeter at 25° Celsius (uS/cm at 25°C)
parts per thousand ($^{o}/oo$)	1,000	milligrams per liter (mg/L)

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ABSTRACT

The Little Manatee River, a coastal stream that flows into Tampa Bay, may be used as a source of freshwater. Fifty percent reduction of streamflow will result in upstream movement of saltwater.

Data on streamflow, tide stage, and specific conductance describe the salinity distribution of the Little Manatee River estuary. Vertical conductivity profiles indicate that the river is vertically homogeneous during low flows.

The maximum upstream location of the saltwater-freshwater interface in the river was described by multiple regression analysis using mean daily streamflow and high-high tide data. The coefficient of determination is 0.94 with a root mean square error of $\pm$0.4 mile. The analysis for the river ranged from mean daily discharges of 42 to 118 cubic feet per second, high-high tides of 0.81 to 2.48 feet above sea level, and a location of the observed saltwater-freshwater interface of from 5.8 to 10.4 miles above the reference station at Shell Point.

The location of the river where the estuarine system ends and the riverine system begins is about 9.9 miles above the reference station at Shell Point. The 800-micromho conductivity line (260 milligrams per liter chloride) demarcates the estuarine and riverine systems. A duration analysis of conductivity indicates that the saltwater-freshwater interface exceeded the 24th Street site, 9.7 miles above the reference station, about 17 percent of the days for the period of study. A duration analysis of the computed location of the interface indicates that the location will exceed 9.7 miles about 12 percent of the days.

Reduction of streamflow for the 90-day, 2-year recurrence-interval low flow (30.7 cubic feet per second) by 50 percent would cause the maximum intrusion of the interface to move upstream from mile 10.4 to mile 11.1 for a mean high-high tide of 1.65 feet above sea level. Fifty percent reduction of the 90-day, 20-year recurrence-interval low flow (9.37 cubic feet per second) would move the saltwater-freshwater interface 0.2 mile upstream, or from river mile 11.4 to mile 11.6 for a high-high tide of 1.65 feet.

INTRODUCTION

The Tampa Bay area (fig. 1) is one of the most rapidly growing coastal areas in Florida and the nation. The competition for water by municipal, industrial, and agricultural development will continue to increase sharply as growth in population continues. Estimated freshwater use in Hillsborough and Manatee Counties for public supply, rural, industry, and irrigation was about 333 Mgal/d in 1981, an increase from 235 Mgal/d in 1970 (Pride, 1973; Duerr and Sohm, 1983). The increase in demand was about 98 Mgal/d. The increase in ground-water demand is from 69.8 percent of total use in 1970 to 72.4 percent of total use in 1981. Most of the surface water used is for public supply and is obtained from river impoundments.

As demands for freshwater in coastal areas of west-central Florida increase, streams, such as the Little Manatee River (fig. 1), that flow into Tampa Bay may be used to augment present ground-water supplies. Problems that result from diversion of freshwater from coastal streams include upstream encroachment of saltwater and elevated levels of salinity in the estuarine reaches and receiving waters. An estuarine reach is that part of a stream where seawater and freshwater mix; salinity distributions range from near seawater concentrations at the mouth to freshwater at the upstream end of the estuary.

Estuaries are areas of high biological productivity; they often contain large areas of aquatic vegetation and have generous amounts of phytoplankton and zooplankton. Estuaries, therefore, are important breeding, rearing, and feeding grounds for many aquatic species that support commercial and sport fishing. Changes in salinity may produce adverse biological changes to the well-being and productivity of the Little Manatee River estuary and adjacent areas of Tampa Bay. The magnitude and pattern of freshwater diversion that can be supported by the Little Manatee River without causing serious environmental changes are unknown. Changes in the salinity of biologically productive areas in Tampa Bay near the mouth of the Little Manatee River due to altered patterns of freshwater inflow are also unknown. Salinity characteristics in those areas under existing and possible future development conditions need to be evaluated prior to permitting diversion of additional water from the Little Manatee River.

Purpose and Scope

The purpose of the project is to provide analysis and supporting data required in evaluating the probable effects of alternative plans of freshwater withdrawal on the Little Manatee River estuary and adjacent areas of Tampa Bay. Probable effects include changes in the physical, chemical, and biological environments. The scope of the study includes the following specific objectives:

1. Describe the salinity characteristics of the Little Manatee River estuary and adjacent areas of Tampa Bay for a range of base flows and tides;
2. Delineate the distribution of vegetation along the shore of the Little Manatee River estuary;

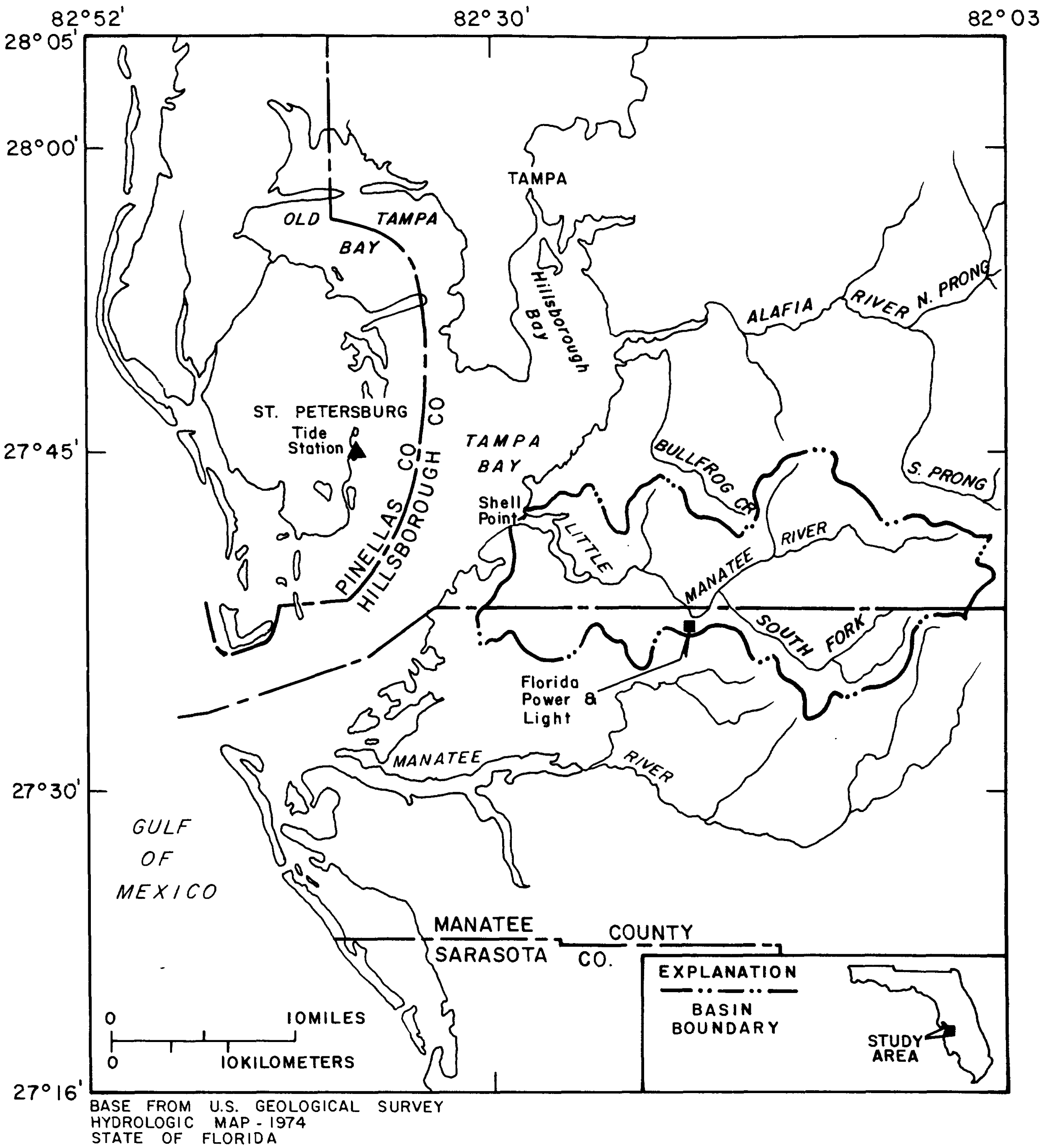

Figure 1.--Location of the Little Manatee River basin.

3. Develop relations that describe salinity distributions as a function of freshwater inflow and astronomical tide, particularly, location of the saltwater front; and

4. Evaluate the change in location of the saltwater front for alternative plans for water-supply diversion.

Previous Studies

The Little Manatee River and adjacent areas (fig. 1) have been studied by several local agencies and consultants. A report by Menke and others (1961, p. 68) described the river as being suitable for municipal water use with respect to dissolved materials, but with a high color intensity. The river was recommended as a future source of public water supply for southern Hillsborough County in a report to the Tampa Bay Regional Planning Council (Briley, Wilde, and Associates, 1970, p. 69). In the early 1970's, the Florida Power and Light Corporation commissioned a feasibility study on using water from the Little Manatee River to operate a cooling pond for a proposed powerplant site in Manatee County. The impact of reduced flow on the salinity in two nearby streams discharging to Tampa Bay, the Alafia River and Bullfrog Creek, is described in a report by Giovannelli (1981).

A general presentation of freshwater and saltwater mixing in estuaries is given by Prichard and Carter (1971) and Dyer (1972). Ippen (1966) gives a complete theoretical description of freshwater-saltwater mixing, including results and interpretations of flume experiments.

DESCRIPTION OF STUDY AREA

The study area includes the Little Manatee River estuary and adjacent area of Tampa Bay that is influenced by freshwater inflow (fig. 2). The Little Manatee River drainage basin encompasses about 221 mi^2 (fig. 1). The tidally affected reach is from the mouth to about 1 mile upstream from the gaging station at U.S. Highway 301 (fig. 2). The station is affected by the tidal prism that causes a backwater effect and not by intrusion of the interface. The stage-discharge relation at U.S. Highway 301 is tidally affected on most days and correction for tidal influence can be as much as 0.04 foot.

Stream width ranges from about 4,000 feet at Shell Point to about 400 feet at U.S. Highway 41 (2.5 miles above Shell Point). From U.S. Highway 41 to about 8 miles upstream from Shell Point, the stream width ranges from about 160 to 450 feet; the stream width narrows to about 40 to 150 feet for the remaining 6 miles to U.S. Highway 301.

There are rock outcrops along the upper study reach between 13 and 14 miles above the reference station at Shell Point. Altitudes of these outcrops are:

Distance above Shell Point, in miles	Altitude, in feet above sea level
13.4	1.9
13.5	1.9

These outcrops can act as tidal barriers for tides equal to or less than their altitudes. For example, it is not expected that the interface of a 1.9-foot high-high tide would travel beyond the location of the outcrop at river mile 13.4 even under the most extreme low-flow conditions.

The average discharge of the Little Manatee River at the U.S. Highway 301 gage from 1939 through 1981 (42 years) is 169 ft^3/s. During the period of study

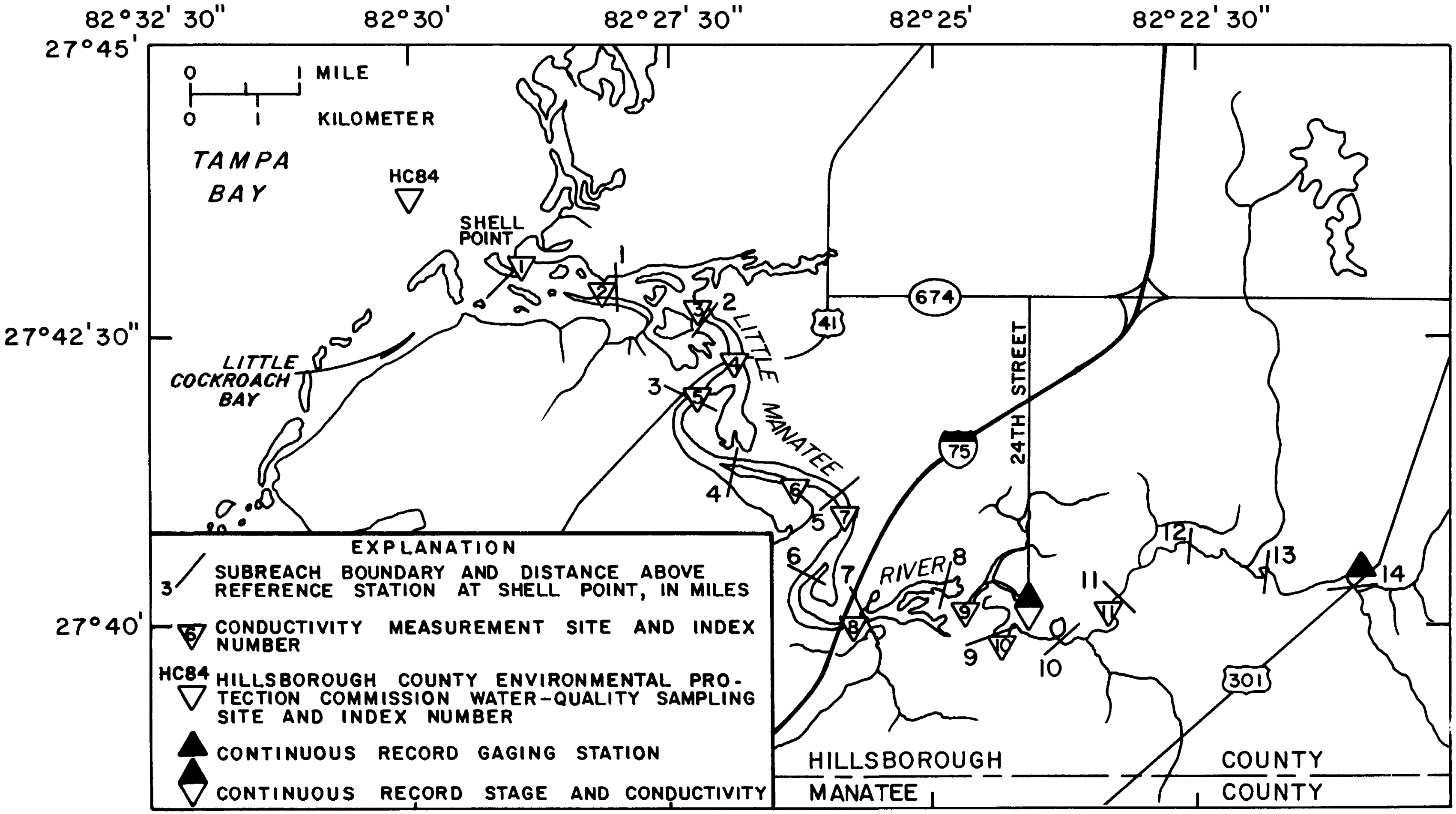

Figure 2.--Locations of monitoring sites on the Little Manatee River study reach and Tampa Bay.

(February 1982 through May 1983), the average discharge was 279 ft^3/s. A comparison of historical average monthly discharges and average discharges for the period of study is presented in figure 3.

Diversion of streamflow by the Florida Power and Light Corporation (fig. 1) for cooling and makeup water occurs at a point about 3.3 miles upstream from U.S. Highway 301. Diversion of water to the cooling pond occurs only when the river stage is higher than 8.8 feet above sea level at the intake point (Glenn O'Neil, Florida Power and Light Corporation, Parrish plant, oral commun., 1984). The amount of diversion makeup water during the relatively dry 1981 water year is presented in table 1. Diversions did not occur from October 1980 through January 1981 and in April 1981. Most diversions occurred from May through September 1981. The total diversion for the water year was 3,830 Mgal or about 10.5 percent of the total flow at U.S. Highway 301.

Table 1.--Amount of water diverted by the Florida Pcwer and Light Corporation, 1981 water year

Month and year	Diversion by FP&L Corp.[1/] (Mgal)	Discharge at U.S. Highway 301 (Mgal)	Total discharge corrected for diversion (Mgal)
October 1980	0	921.2	921.2
November 1980	0	771.3	771.3
December 1980	0	795.0	795.0
January 1981	0	883.1	883.1
February 1981	142.2	2,242.9	2,385.1
March 1981	15.4	929.2	944.6
April 1981	0	565.9	565.9
May 1981	233.6	819.1	1,052.7
June 1981	275.1	1,224.8	1,499.9
July 1981	510.7	1,784.3	2,295.0
August 1981	1,275.0	15,400	16,675
September 1981	1,378.0	10,310	11,688
Total	3,830.0	36.646.8	40,476.8

[1/] Florida Power and Light Corporation.

Tides

There are usually four tides daily in Tampa Bay: a low-low, high-low, low-high, and high-high tide (fig. 4). The tides used in this study were those recorded at the city of St. Petersburg (fig. 1). The station is directly across the bay from the reference station at Shell Point near the mouth of the Little Manatee River (fig. 2). Correction was not required for predicted tide stage at

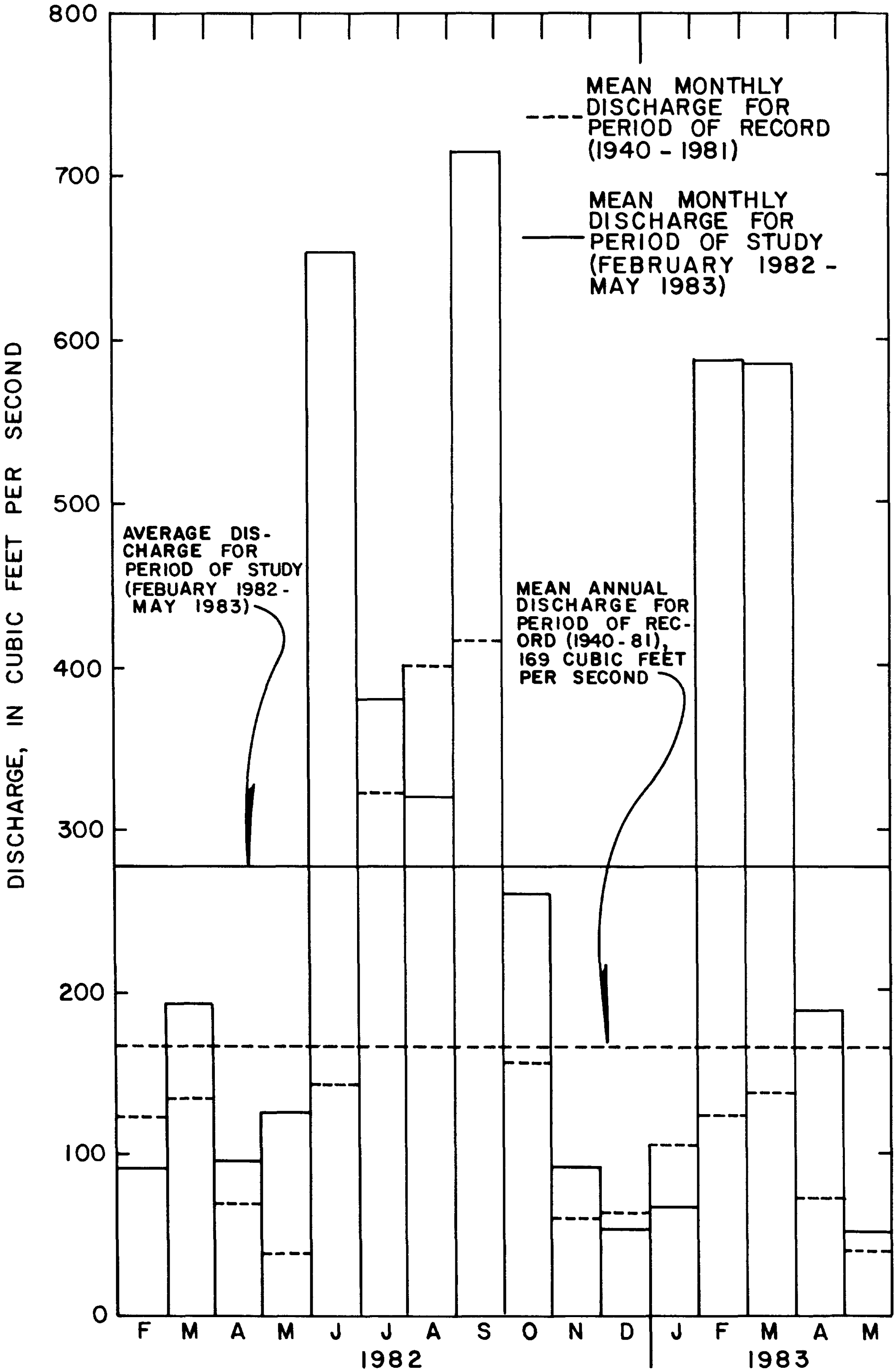

Figure 3.--Mean monthly discharge for the Little Manatee River near Wimauma.

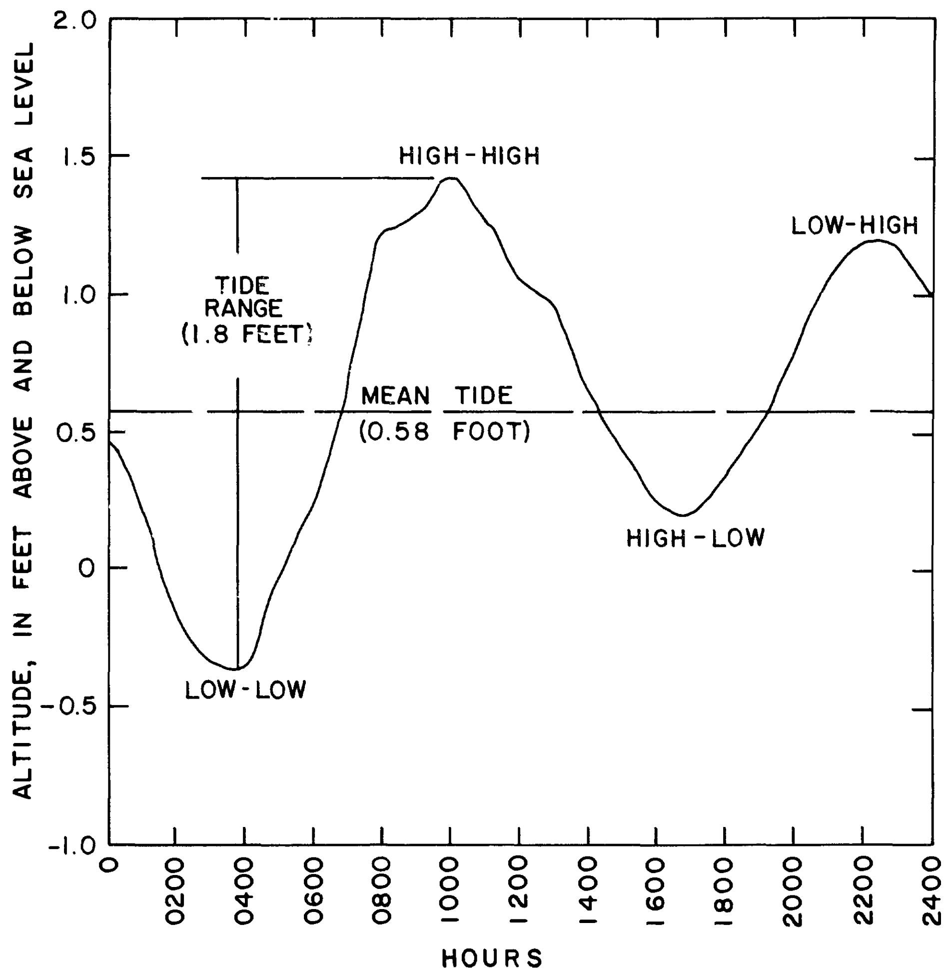

Figure 4.--Typical four-tide cycle for Tampa Bay at St. Petersburg, May 31, 1982.

St. Petersburg and Shell Point (U.S. Department of Commerce, 1982). The tide data were obtained from the Tides Branch, National Oceanic and Atmospheric Administration. Since the critical driving force of seawater into an estuary is dependent on high tides, a duration curve of the high-high tides at the mouth of the Little Manatee River was developed (fig. 5). The peak tidal altitudes for each day of the study period were used in developing the curve. The altitudes of the high-high tides used in developing regression equations for the period of study ranged from 0.81 to 2.48 feet above sea level. From figure 5, these tidal altitudes occur on about 93 percent of the days. Tides of 0.81 and 2.48 feet are exceeded about 97 and 4 percent of the time, respectively. Thus, the high-high tide range of 0.81 to 2.48 feet represents, for all practical purposes, the complete high-high tide range.

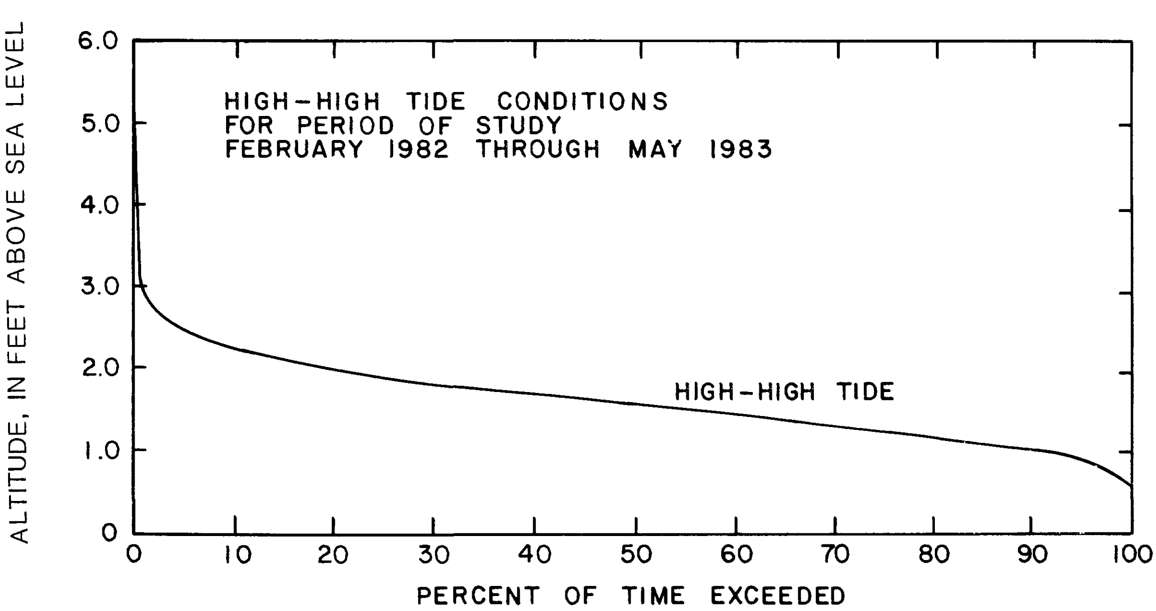

Figure 5.--High-high tide duration for Tampa Bay at St. Petersburg.

Distribution of Vegetation

The Little Manatee River wetland system consists of estuarine and riverine environments. In general, the estuarine environment is from the mouth of the river to about 9.9 miles upstream from Shell Point where the riverine system begins (fig. 2).

The estuarine system "consists of deepwater tidal habitats and adjacent tidal wetlands" and "extends upstream and landward to where ocean-derived salts measure less than 0.5 ^{o}/oo (260 mg/L of chloride) during the period of average annual low flow" (Cowardin and others, 1979, p. 8). The riverine system is defined to "include all wetlands and deepwater habitats contained within a channel with two exceptions: (1) wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens; and (2) habitats with water containing ocean-derived salts in excess of 0.5 ^{o}/oo" and "terminates at the downstream end where concentrations of ocean-derived salts in the water exceed 5 ^{o}/oo during the period of annual average low flow" (Cowardin and others, 1979, p. 9-10).

A botanical survey was made to identify plants that are or can be affected by the conductivity of the river. Results of the survey are presented in table 2, with the location identified in figure 6. Mangroves (red, black, and white) seem to exist up to around 4.7 miles above Shell Point. Between 3.5 and 9.7 miles, blackrush and cordgrass are found, and their greatest abundance is around 7 miles upstream from Shell Point. The rush and cordgrasses thin out as the river system goes from estuarine to riverine at about 9.9 miles (fig. 6). The first instance of a true riverine plant, spatterdock, was found to begin at about 9.9 miles.

Table 2.--Botanical survey along the water's edge of the Little Manatee River from Shell Point to near U.S. Highway 301

[Letters refer to sites in figure 6]

A

(From 0 to 3.5 miles upstream from Shell Point)

1. Red mangrove (*Rhizophora mangle*)
2. Black mangrove (*Avicennia germenans*)
3. White mangrove (*Laguncularia racemosa*)
4. White buttonwood (*Conocorpus erecta*)

B

(At 3.7 miles upstream from Shell Point)

1. Mangrove communities as "A" above but less Red mangrove
2. Blackrush (*Juncus roemerianus*)
3. Slender cordgrass (*Spartina patens*)
4. Florida holly (*Schinus terebinthifolius*)
5. Australian pine (*Casuarina equisetifolia*)
6. Sand pine (*Pinus clausa*)

C

(At 4.7 miles upstream from Shell Point)

1. All three mangroves and buttonwood as "B" above
2. Blackrush (*Juncus roemerianus*)
3. Slender cordgrass (*Spartina patens*)
4. Saltgrass (*Distichilis spicata*)
5. Saw palmetto (*Serenoa repens*)
6. Cabbage palm (*Sabal palmetto*)
7. Florida holly (*Schinus terebinthifolius*)
8. Wax myrtle (*Myrica cerifera*)

D

(At 5.4 miles upstream from Shell Point)

1. Blackrush (*Juncus roemerianus*)
2. Smooth cordgrass (*Spartina alterniflora*)
3. Slender cordgrass (*Spartina alterniflora*)
4. Cattail (*Typha domingensis*)

E

(At 6.8 miles upstream from Shell Point)

1. Slender cordgrass (*Spartina patens*)
2. Smooth cordgrass (*Spartina alterniflora*)
3. Saltgrass (*Distichilis spicata*)
4. Sawgrass (*Cladium jamaicensis*)
5. Cattail (*Typha domengensis*)
6. Reed (*Phargmites communis*)
7. Saltbush (*Baccharis halimifolia*)
8. Blackrush (*Juncus roemerianus*)
9. Cabbage palm (*Sabal palmetto*)
10. Red cedar (*Juniperus silicicola*)
11. Oak (Quercus sp.)
12. Wax myrtle (*Myrica cerifera*)
13. Saw palmetto (*Serenoa repens*)
14. Florida holly (*Schinus terebinthifolius*)

Table 2.--Botanical survey along the water's edge of the Little Manatee River from Shell Point to near U.S. Highway 301--Continued

F

(From 8.4 to 9.9 miles upstream from Shell Point)

1. Slender cordgrass (*Spartina patens*)
2. Smooth cordgrass (*Spartina alterniflora*)
3. Blackrush (*Juncus roemerianus*)
4. Saw palmetto (*Serenoa repens*)
5. Cabbage palm (*Sabal palmetto*)
6. Golden polypody (*Phlebodium aureum*)
7. Butterfly orchid (*Epidindrum conopseum*)

G

(From 9.9 to 11.4 miles upstream from Shell Point)

1. Spatterdock (*Nuphar luleum*)
2. Primrose willow (*Ludwigia peruviana*)
3. Wax myrtle (*Myrica cerifera*)
4. Cattail (*Typha latifolia*)
5. Royal fern (*Osmunda regalis*)
6. Thelyptris fern (Thelypteris sp.)
7. Water ash (*Fraximus coroliniana*)
8. Natal grass (Rhynchelytrum repens)
9. Bald cypress (*Taxodium distichum*)
10. Cabbage palm (*Sabal palmetto*)
11. Southern red maple (*Acer rubrum*)
12. Slash pine (*Pinus elliotii*)
13. Wax myrtle (*Myrica cerifera*)

H

(From 11.8 to 12.6 miles upstream from Shell Point)

1. Smartweed (Polygonium sp.)
2. Spatterdock (*Nuphar luteum*)
3. Primrose willow (*Ludwigia peruviana*)
4. Bald cypress (*Taxodium distichum*)
5. Arrowhead (*Saggitaria lancifolia*)
6. Cattail (Typha sp.)
7. Sand pine (*Pinus clausa*)
8. Slash pine (*Pinus elliotii*)
9. Wax myrtle (*Myrica cerfera*)
10. Dwarf wax myrtle (*Myrica pusilla*)
11. Saw palmetto (*Serenoa repens*)
12. Saltbush (*Baccharis halimifolia*)
13. Southern red maple (*Acer rubrum*)
14. Water oak (*Quercus nigra*)
15. Live oak (*Quercus virginiana*)
16. Calusa grape (*Vitis shuttleworthii*)
17. Virginia creeper (*Parthenocissus quinquefolia*)

I

(From 12.6 to 12.7 miles upstream from Shell point)

1. Royal fern (*Osmunda regalis*)
2. Thelypteris fern (Thelypteris sp.)
3. Braken fern (*Pteridium aquilinum*)
4. Spatterdock (*Nuphar luteum*)
5. Blechnum fern (*Blechnum serrulatum*)
6. Water ash (*Fraxinus caroliniana*)
7. Water oak (*Quercus nigra*)

J

(From 13.0 to 13.8 miles upstream from Shell Point)

1. Spatterdock (*Nuphar luteum*)
2. Water ash (*Fraxinus caroliniana*)
3. Willow (*Salix caroliniana*)
4. Water oak (*Quercus nigra*)
5. Wild olive (*Osmanthus americanus*)

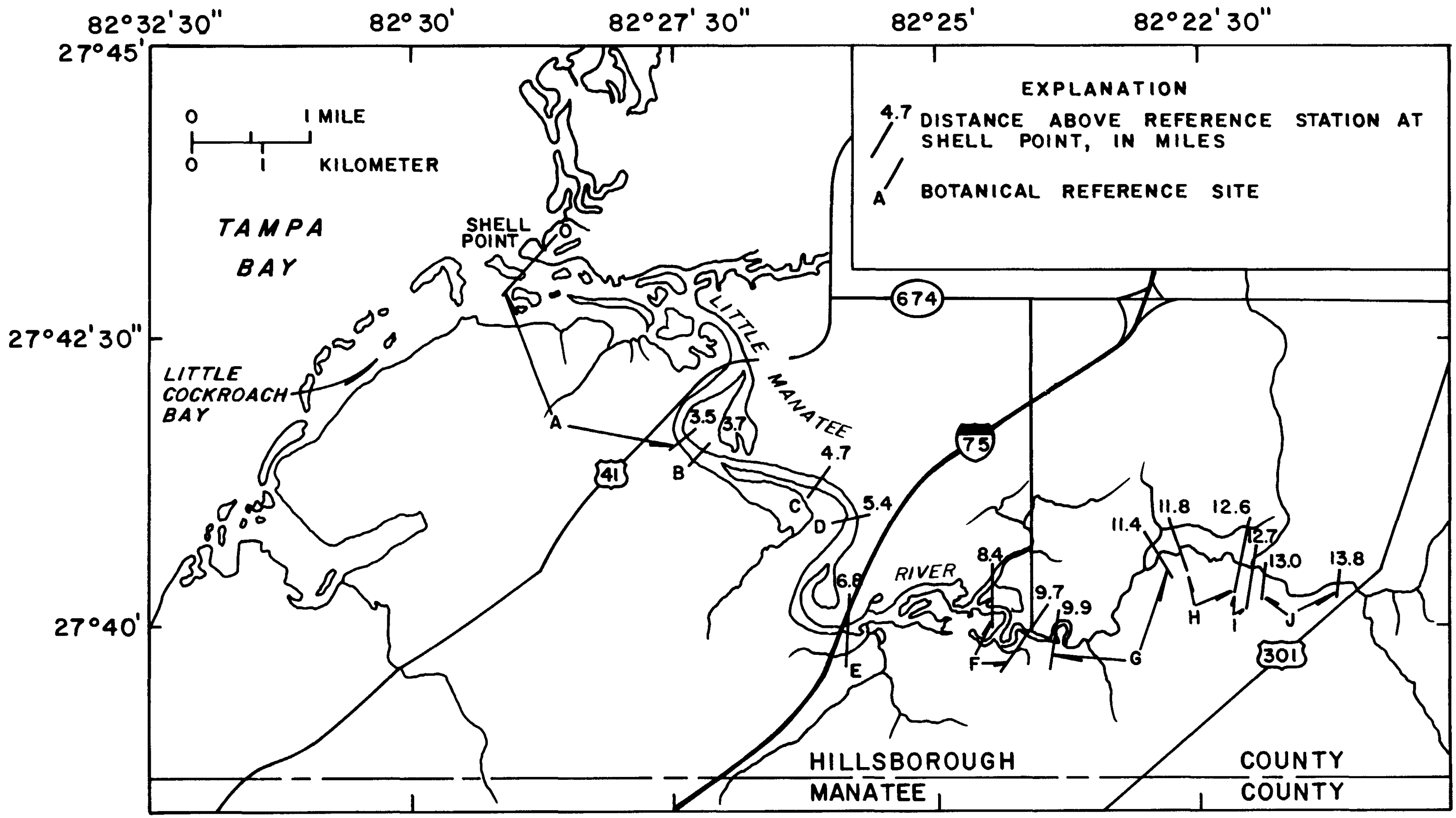

Figure 6.--Locations of botanical survey sites along the Little Manatee River estuary.

METHODS OF STUDY

Data-Collection Network

Data collection consisted of field reconnaissance surveys and measurement of streamflow, tidal stage, conductivity, and identification and delineation of wetland vegetation. The continuous-record gaging station, Little Manatee River near Wimauma, at U.S. Highway 301 was used to compute daily freshwater discharge into the estuary. Two sites were selected based on a reconnaissance field investigation for establishment of continuous stage and conductivity recording stations. The two sites were 4.7 miles (site 6) and 9.7 miles (24th Street site) above the reference station at Shell Point (fig. 2). Site 6 was selected because it was expected to be highly saline during periods when discharge was less than the average discharge (169 ft^3/s). The 24th Street site was selected because the site was near the 800-umho line (conductivity at the saltwater-freshwater interface, Cowardin and others, 1979, p. 36) during the reconnaissance run, and the site had been measured during periods approximating base flow. The 24th Street site was established to record the approximate location of the interface during low-flow periods. Tide stage and conductivity were recorded at 15-minute intervals. The conductivity sensors were serviced and cleaned weekly to prevent barnacle encrustation.

Field measurements of conductivity were made at selected points over a range of discharge and tides. Field survey sites were selected based on channel geometry and length of subreach (fig. 2). Descriptions of the monitoring sites are given in table 3. Six field surveys were made and consisted of measuring the river depth and conductivity at depths that ranged from 1 foot below water surface to the bottom of the channel. Depth intervals were 1 foot for total depths of less than 6 feet and 2 feet for total depths greater than 6 feet.

Determination of Salinity

Direct measurement of salinity in the field is very difficult; therefore, alternate methods of indicating salinity have been developed. Since chloride is the predominant ion in seawater, it is possible to determine salinity by measuring chloride concentration. A relation between chloride concentration and salinity, based on determinations from a variety of samples of seawater (American Public Health Association, 1975, p. 99), is as follows:

$$S = 1.805(Cl) + 0.03 \qquad (1)$$

where S = salinity, in parts per thousand ($^{o}/oo$); and
Cl = chloride concentration, in parts per thousand ($^{o}/oo$).

Because seawater has a high concentration of dissolved ions, especially chloride ions, and the higher the concentration of ions, the greater the ability of the seawater to conduct electricity, measurement of the electrical conductance of seawater can also be used as an indicator of salinity.

Table 3.--Description of monitoring sites

[Sites 1 through 11 were periodic field determinations. Sites No. 6, 24th Street, and U.S. 301 were continuous monitoring sites]

Site number	Latitude-longitude	Distance above Shell Point (miles)	Parameters
1	274304082285400	0	Conductivity
2	274252082280300	.9	Do.
3	274236082271000	2.0	Do.
4	274215082265300	2.5	Do.
5	274137082273000	3.5	Do.
6	274118082261900	4.7	Do.
7	274051082255200	5.4	Do.
8	273957082260100	6.8	Do.
9	274007082244300	8.4	Do.
10	273950082243100	9.1	Do.
11	274014082232000	10.8	Do.
1/TB84	274341082295400	2/1.25	Do.
No. 6	3/02300546	4.7	Stage, conductivity
24th Street	3/02300532	9.7	Stage, conductivity
U.S. 301	3/02300500	14.0	Stage, discharge

1/Hillsborough County Environmental Protection Commission, site HC84, Tampa Bay.

2/Miles from or below Shell Point.

3/Downstream order number.

The relation between conductivity and chloride concentration is shown in figure 7. The chloride data were obtained by collecting a total of 35 water samples along the tidal reach, based on field conductivity measurements. The samples were then analyzed for chloride concentration and conductivity.

The equation for the relation between chloride and conductivity for all the data collected, n=35, is presented in figure 7a. The equation (fig. 7a) has a coefficient of determination and a root mean square error of 0.995 and ±280 mg/L of chloride, respectively.

The relation between chloride and conductivity on the lower end of the curve (fig. 7a) for conductance up to 8,000 umhos, n=12, also was determined and is presented in figure 7b. The equation (fig. 7b) has a coefficient of determination and a root mean square error of 0.995 and ±53 mg/L of chloride, respectively.

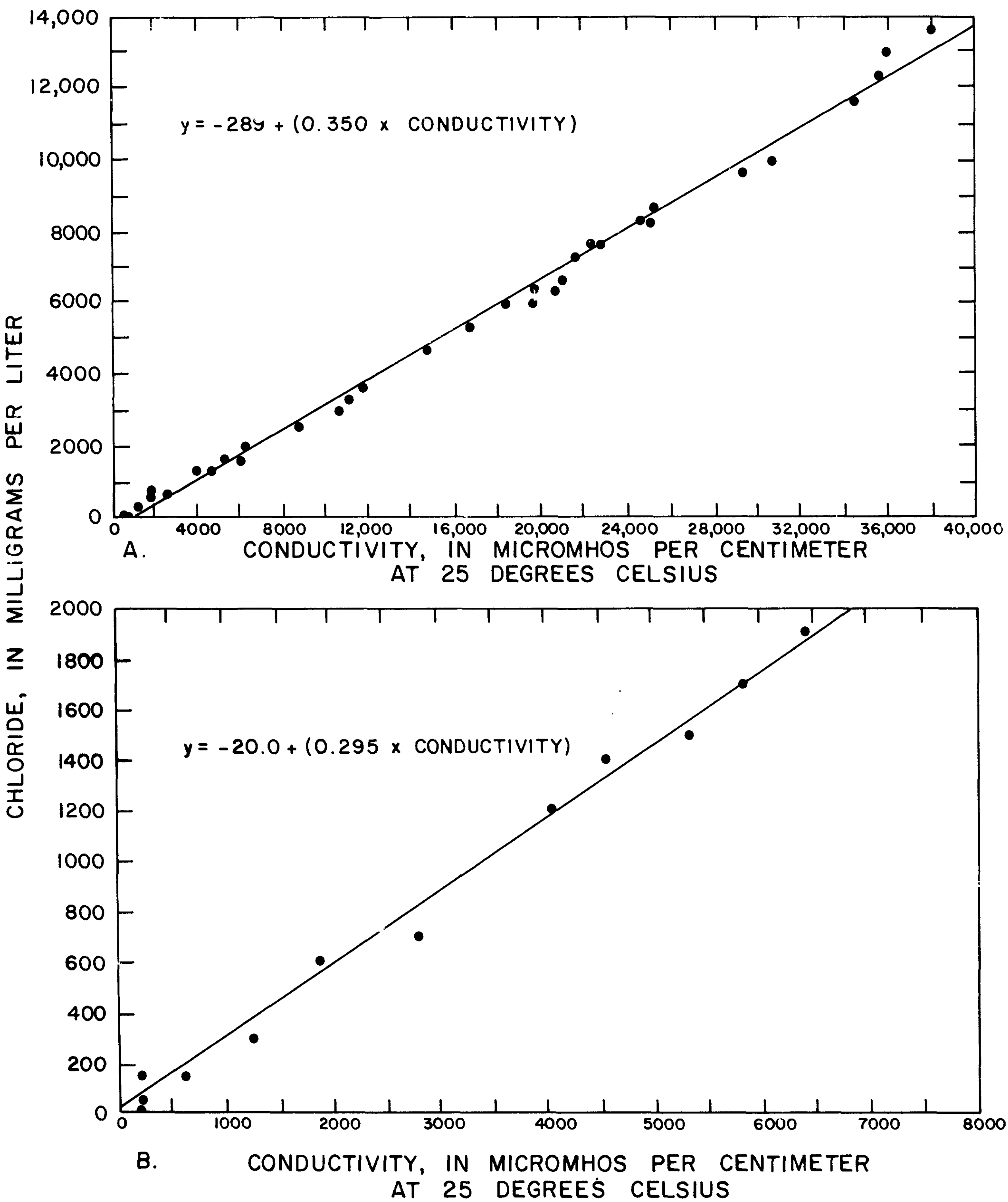

Figure 7.--Relation between conductivity and chloride concentration for the Little Manatee River estuary: (A) conductivity 0 to 48,000 micromhos per centimeter, (B) 0 to 8,000 micromhos per centimeter.

Analysis of Data

The method of analysis used in establishing the maximum upstream location of the saltwater-freshwater interface was based on regression analysis using the observed and computed saltwater-freshwater interface locations as the dependent variable and the reference site conductivity, mean daily discharge, and daily high-high tide as the independent variables. A relation was first established using the observed location of the interface and regressed against the reference site conductivity. The recorded daily high conductivity from the reference site was then used to compute the daily maximum upstream location of the interface. The computed daily maximum upstream location and the observed interface location were used to establish a relation between maximum upstream location of the interface, mean daily discharge, and altitude of the daily high-high tide using multiple regression analysis. A discussion and findings of location of the interface versus reference conductivity and mean daily discharge and high-high tide follows:

Saltwater-freshwater interface location versus reference conductivity: The approach used is similar to that reported by Giovannelli (1981). The relation between the location of the interface, in miles above Shell Point, and the conductivity (salinity) at a reference site (site 6, fig. 2) were investigated, and a relation was established using regression analysis. During each set of field conductivity observations, the interface was located about 2 hours before maximum intrusion and the interface was then followed by making conductivity measurements about every half hour or until maximum intrusion was observed. Maximum intrusion was established when the interface movement was observed to cease. The relation between the location of the interface and conductivity at site 6 is presented in figure 8a.

The regression equation for figure 8a is:

$$\text{Distance} = 5.5 + 1.5\text{x}10^{-4}(K') \qquad (2)$$

where K' = conductivity at reference site 6 for each observed location of the saltwater-freshwater interface.

The equation has a coefficient of determination (R^2) of 0.88, a root mean square error of $\pm$0.5 mile, and a coefficient of variation of 6.0 percent. The data cluster between river miles 5 and 8 and conductivities of between 5,000 and 11,000 umhos (fig. 8a) do not behave in a linear manner. Analysis of these data concluded that the upper group of five data points should have had a higher corresponding conductivity based on the assumption that, as the saltwater-freshwater interface moves up the estuary, an increase in conductivity should occur at the reference site. However, this situation did not occur. Evaluation of conductivity data for Tampa Bay indicated that conductivity in the bay was unusually low (29,000 umhos) when data were collected due to unusually heavy rains in April. To account for the effects of low conductivity in Tampa Bay, the data (conductivity at site 6) were normalized against conductivity in Tampa Bay near the mouth of the river (this site in Tampa Bay has been sampled monthly by the Hillsborough County Environmental Protection Commission since 1976). The normalized data (fig. 8b, ratio of conductivity at site 6 to site HC84 in the bay) were then used in a regression analysis to define the location of the interface. The resultant regression equation is:

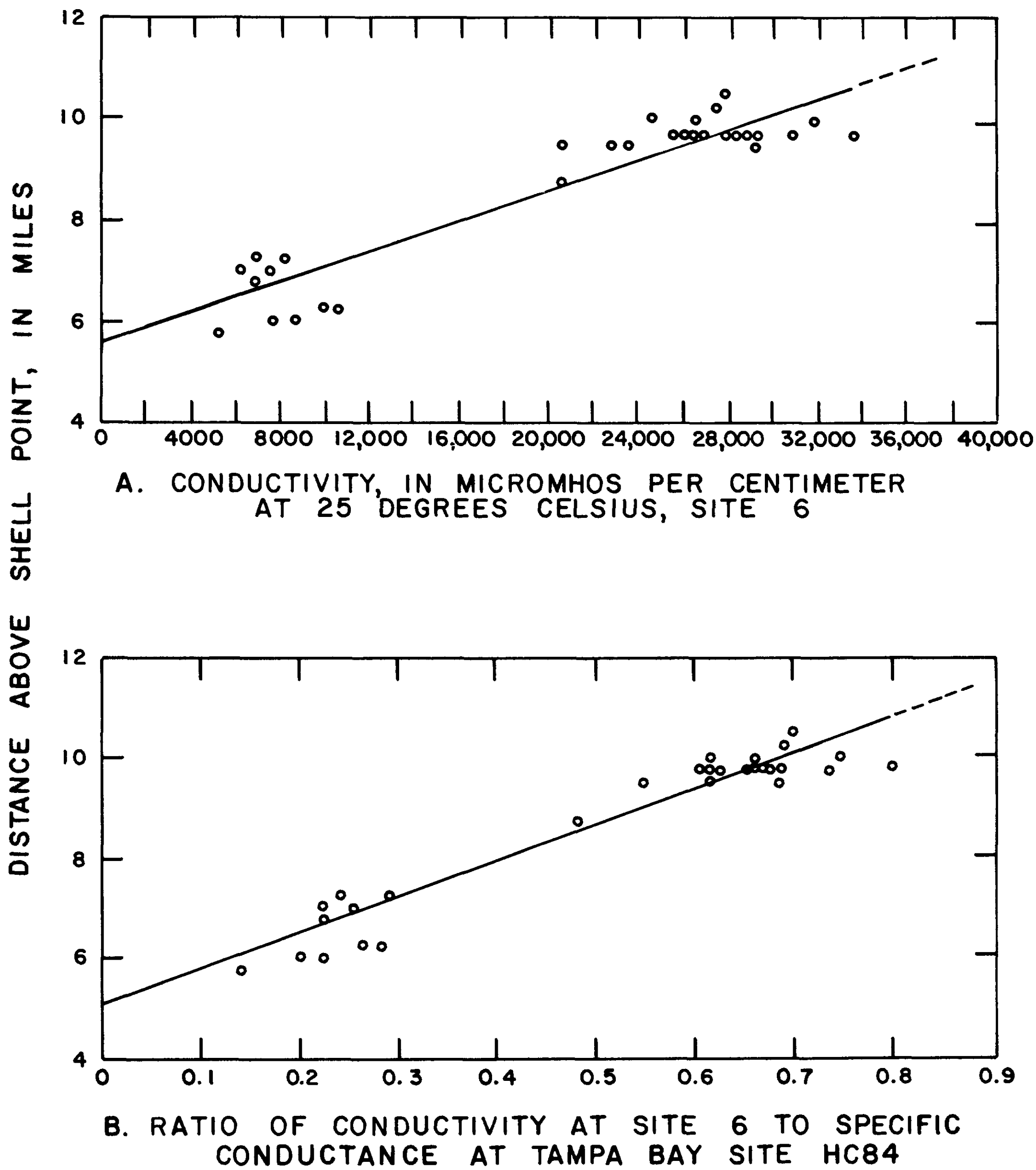

Figure 8.--Regression curves for the maximum upstream location of the saltwater-freshwater interface in relation to conductivity: (A) upstream distance to conductivity at reference site 6, (B) upstream distance to ratio of conductivity of reference site 6 to Tampa Bay site HC84.

$$\text{Distance} = 5.0 + 7.17\ (\text{Ratio}) \qquad (3)$$

where Ratio = ratio of conductivity at site 6 to mean conductivity at site HC84 in Tampa Bay.

The equation has a coefficient of determination (R^2) of 0.92, a root mean square error of $\pm$0.4 mile, and a coefficient of variation of 4.8 percent.

The above findings indicate that by normalizing the data at the reference site, the statistical relation is enhanced. However, to use the normalization method, continuous conductivity data for the bay are required if continuous data from site 6 are going to be used, as reported by Giovannelli (1981). This method was used to compute the maximum upstream location of the saltwater-freshwater interface using recorded conductivity data at the reference site. This increased the dependent variable's (location of the saltwater-freshwater interface) degrees of freedom when regressing it against mean daily discharge and daily high-high tide.

Saltwater-freshwater interface location versus mean daily discharge and high-high tide: The method discussed above, in addition to increasing the dependent variable degrees of freedom, also induced an uncertainty about the error involved in a final regression as this supplementary data set was perfectly correlated because of its computation from equation 3. Combining this supplementary data with the field data (which were used to obtain equation 3) created a data set that was biased toward the supplementary data set. Upon analysis, it was found that using the original field data for regression analysis provided the best results and are the data upon which the final equation is based.

There were six field trips made to collect data on the interface. During these six trips, the interface was observed and measured 21 times.

Discharges used for the final equation ranged from 42 to 118 ft^3/s. Tidal stages were the peak high-high tide for each salinity run. Variations in daily high-high tide and mean daily discharge for the period of study are presented in figure 9. Altitude of the high-high tide ranged from 0.68 to 5.24 feet. The peak of 5.24 feet was probably due to wind action. The equation for estimating the maximum upstream location of the saltwater-freshwater interface (800-umho line) is as follows:

$$L = 10.6 - (0.048Q) + (0.77HHT) \quad (4)$$

where L = maximum upstream location of the saltwater-freshwater interface, in miles above Shell Point;
Q = mean daily discharge, in cubic feet per second; and
HHT = observed high-high tide for the day, in feet above sea level.

The coefficient of determination (R^2) for the equation is 0.94, and the root mean square error is $\pm$0.4 mile. The F statistic or probability that one of the variables equals zero is 0.001; the T statistic or the probability that the intercept, discharge, or high-high tide equal is are 0.001, 0.001, and 0.0192, respectively. The maximum acceptable probability of F and T were set at 0.05. The range of input data and limitations of equation 4 are as follows:

Parameter	Minimum value	Maximum value
Discharge (site 5, fig. 3), in cubic feet per second	42	118
Altitude of high-high tide, in feet above sea level	0.81	2.48
Location of interface, in miles above Shell Point	5.8	10.4

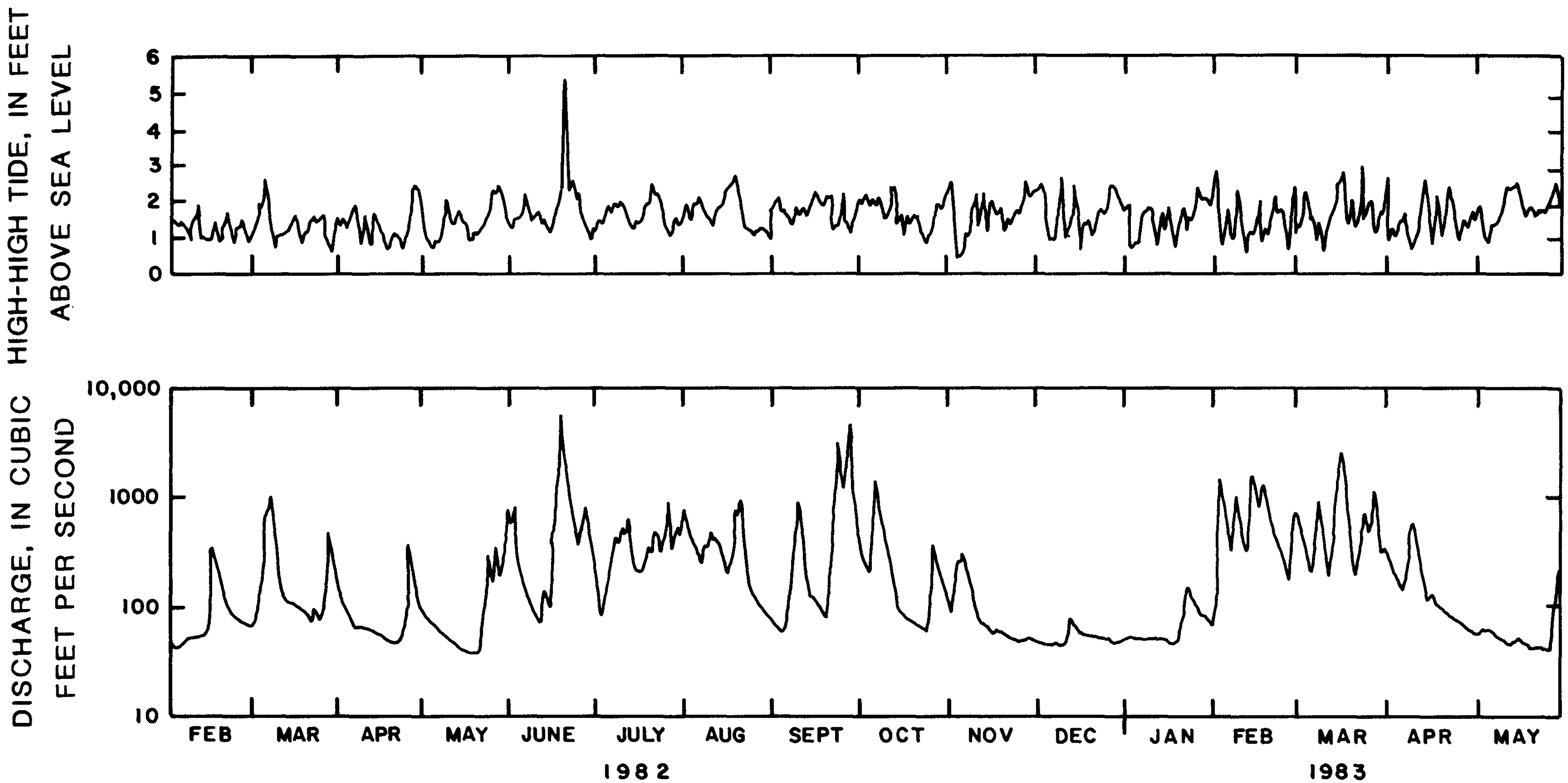

Figure 9.--Daily high-high tide at St. Petersburg and discharge of the Little Manatee River, February 1982 to May 1983.

The discharge used in developing equation 4 ranged from 42 to 118 ft^3/s, discharges that are exceeded about 56 and 27 percent of the time, respectively. A duration curve for the mean daily discharge for the period of record is presented in figure 10. Estimates of the location of the interface when streamflow is less than 42 ft^3/s may be made by assuming that a linear relation exists.

A computed distance duration curve of the maximum upstream location of the 800-umho line for the period of study using data within the range used in developing equation 4 is presented in figure 11. Figure 11 shows, for example, that the maximum upstream location of the saltwater-freshwater interface (800-umho line) was at or above 9.7 miles from Shell Point (location of 24th Street site) about 12 percent of the time.

Storage Analysis

Continuous withdrawals of large amounts of water from the Little Manatee River would be difficult without storage due to the low-flow characteristics of the river and the regulatory minimum discharge imposed by the Southwest Florida Water Management District regulations (1982). Since December 1976, some water has been diverted by the Florida Power and Light Corporation (fig. 1). The average diversion for the period December 1976 through September 1981 was 8.6 Mgal/d (13.38 ft^3/s).

A storage analysis was made to examine what effect withdrawals would have on the location of the saltwater-freshwater interface. Low-flow discharges for consecutive periods of 1, 7, 14, 30, 60, 90, and 120 days having a 20-year recurrence interval (fig. 12) were used to determine the storage required to sustain various draft rates (fig. 13). Based on this analysis, for example, about 200 Mgal of storage would be required to support a draft rate of 12 ft^3/s with a chance of being inadequate about once every 20 years on the average.

Because of regulatory requirements of the Southwest Florida Water Management District regarding minimum average monthly discharge rates, draft and storage, as determined in figure 13, may not be applicable when determining storage requirements for a 20-year drought. Therefore, a basic and an iterative method were used to show the deficiencies in the draft-storage ratio presented in figure 13. The basic method (Giovannelli, 1981, p. 34) uses the 20-year, 90-day drought flow for the period of record. The iterative method computes consecutively the available draft, storage, and final discharge by month for the period of record and summarizes the findings for each month.

Basic method

The Southwest Florida Water Management District has established criteria for determining minimum rates of streamflow (Southwest Florida Water Management District, 1982, p. 38). Regulations state that the five lowest mean monthly discharges for the preceeding 20 years shall be averaged. Minimum rates of discharge shall be established as follows: for each month, the five lowest mean monthly discharges for the preceeding 20 years shall be averaged. The minimum rates of

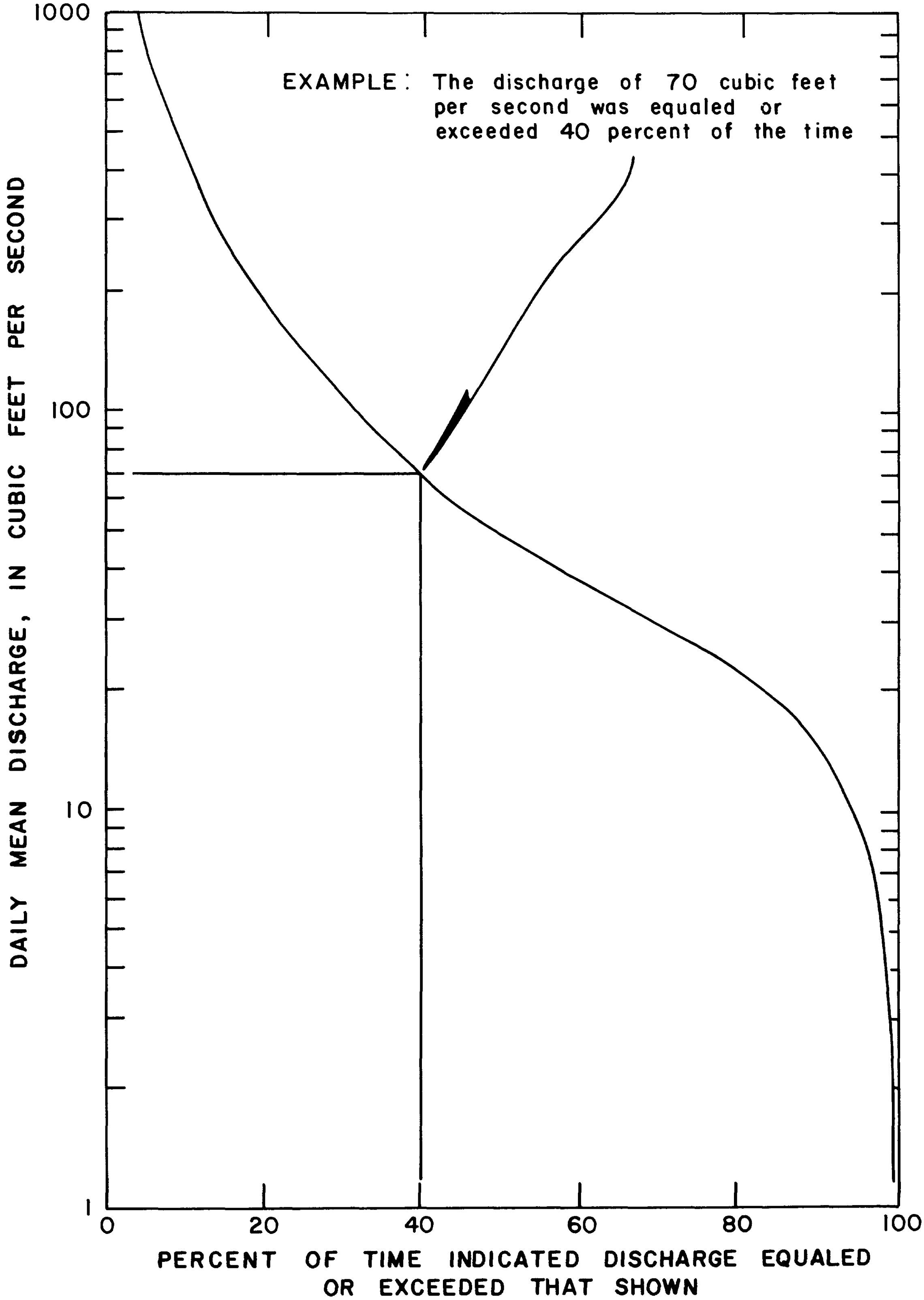

Figure 10.--Flow duration curve for the Little Manatee River near Wimauma for October 1940 through September 1981.

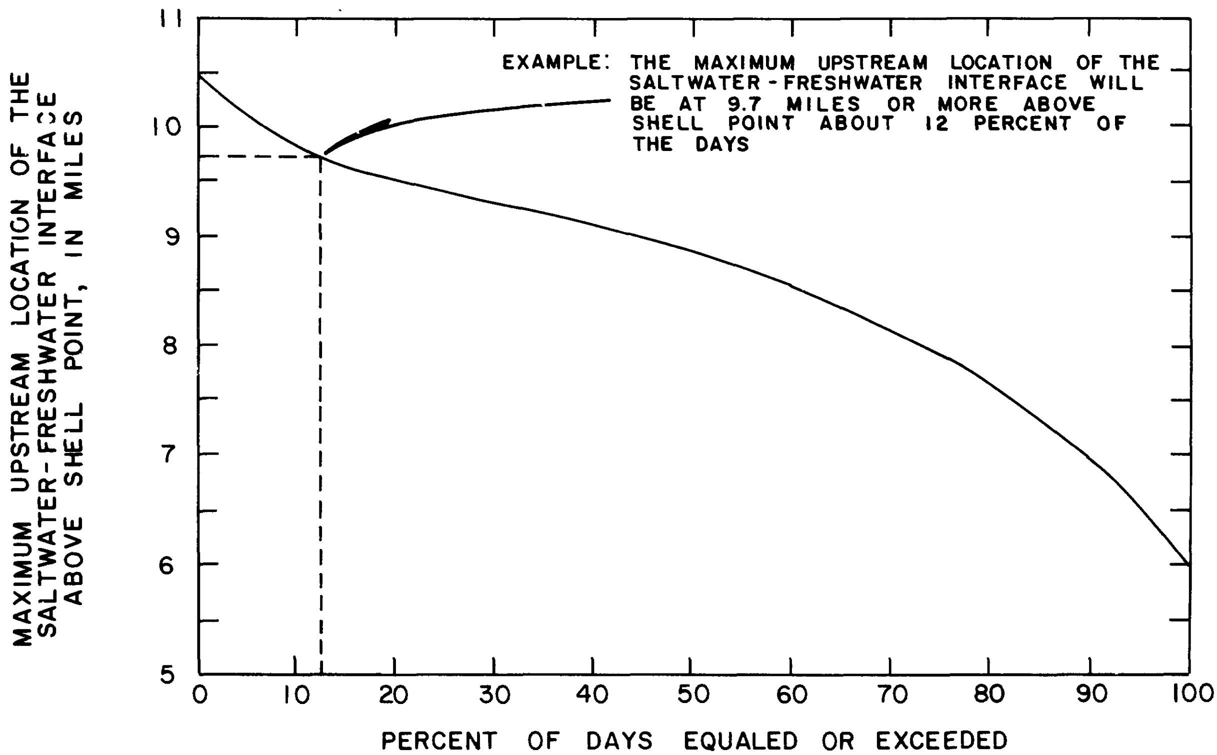

Figure 11.--Duration curve for computed maximum upstream location of the saltwater-freshwater interface (800 micromhos per centimeter) based on multiple-regression analyses.

flow are then established as 70 percent of the values for the 4 wettest months and 90 percent of the values for the remaining 8 months. The average of the lowest five monthly discharges for the Little Manatee River near Wimauma (fig. 2) during the preceeding 20 years was in May with an average discharge of 9.31 ft^3/s. The discharge of 9.31 ft^3/s is comparable to the 30-day consecutive low flow for a recurrence interval between 2 and 5 years.

For this study, the 10 lowest mean monthly discharges for the period of record, 42 years, were used. The mean monthly discharge for the months of April, May, and June, the historical dry period in Florida, were determined to be 11.1, 9.18, and 16.1 ft^3/s, respectively. Assuming a reservoir that has 200 Mgal of storage is developed for the Little Manatee River and is full at the beginning of the annual dry period, average inflow to the reservoir using the 20-year, 90-day drought flow is 12.9 ft^3/s. The average discharge of 12.9 ft^3/s (8.33 Mgal/d) may be prorated for the 90 days of April through June, using the average of the 10 lowest monthly discharges for the 42-year period of record. The method used for prorating the 20-year, 90-day drought flow of 12.9 ft^3/s (8.33 Mgal/d) is as follows:

The average 10 lowest discharges for the 42 years of record for April, May, and June are 11.1, 9.18, and 16.1 ft^3/s, respectively. Averaging the discharges and then computing the ratio of the monthly low flow to the mean of the

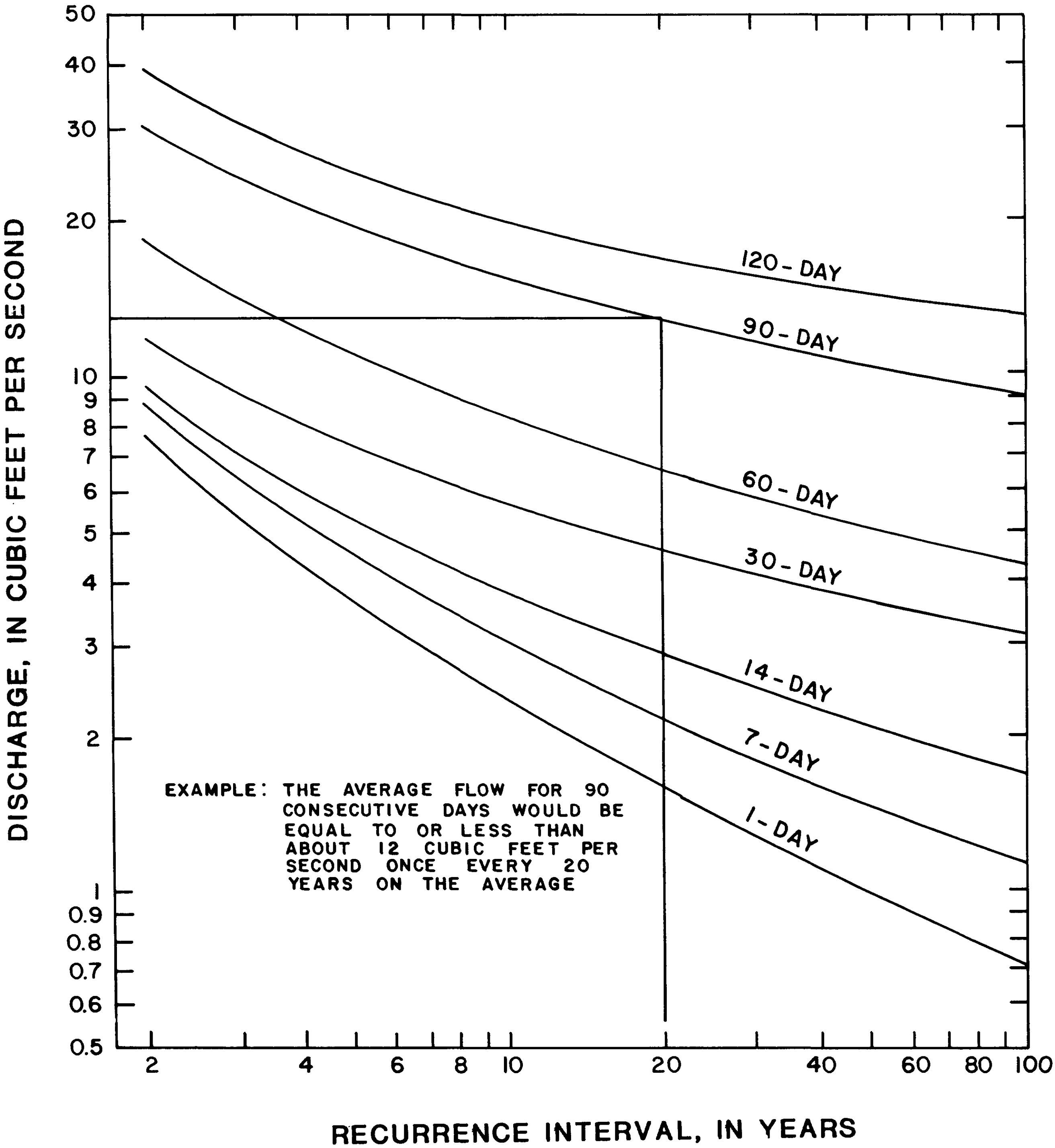

Figure 12.--Magnitude and frequency of annual low flow of the Little Manatee River near Wimauma.

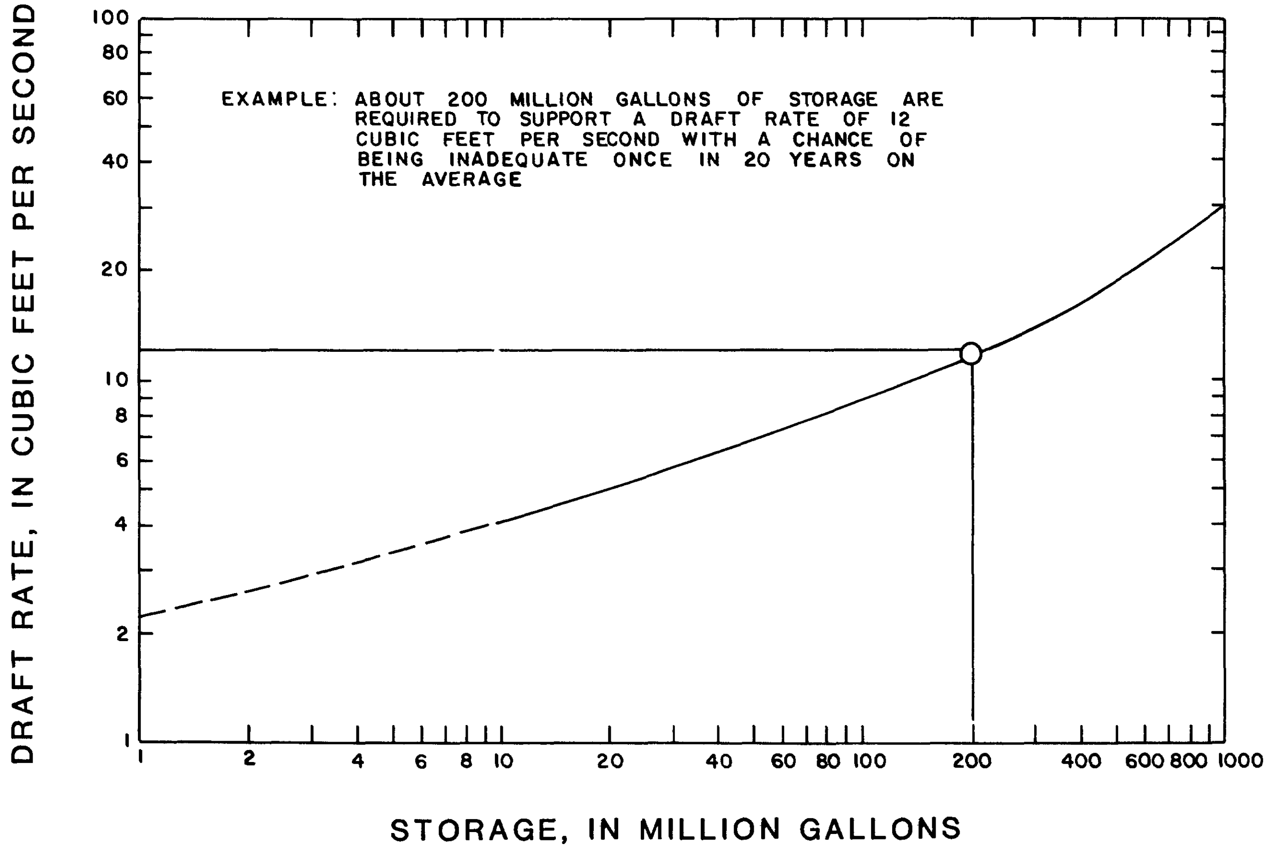

Figure 13.--Draft-storage relation for 20-year low flows of the Little Manatee River near Wimauma.

3 months will give a factor for each month that, when the drought flow of 12.9 ft^3/s (8.33 Mgal/d) is multiplied by them, will give prorated drought discharges for April, May, and June of 7.66, 6.33, and 11.1 Mgal/d, respectively. An example of how the minimum flow criteria is applied in evaluating present uses and possible future development as a source of water supply is presented. Water use of 5.20 Mgal/d, which represents the needs for a population of about 35,000 (about 150 gal/d per capita), was considered for this example. Table 4 illustrates the storage analysis.

Part of the draft for April must be made up by water from storage (119.7 Mgal) because the regulatory minimum flow (6.45 Mgal/d) takes up most of the inflow (7.66 Mgal/d). This leaves a net volume of 1.21 Mgal/d from inflow for the planned water-supply need of 5.20 Mgal/d. A total of 3.99 Mgal/d (120.3 Mgal) would be needed from storage. The beginning storage for May, after adjustment for storage depletion, is now 80.3 Mgal. In May, the regulatory minimum (5.33 Mgal/d) takes up most of the inflow (6.33 Mgal/d) leaving a net flow of 1.00 Mgal/d. Because the total volume available in May for draft is now only 3.59 Mgal/d (80.3 Mgal from storage plus 1.00 Mgal/d from the net inflow), the draft has to be reduced to 3.59 Mgal/d. Thus, storage would be

Table 4.--Summary of draft-storage analyses for water supply and 100 percent and 50 percent of the regulatory minimum discharge, Little Manatee River

Outflow requirement: 100 percent of regulatory minimum
Draft: 8.05 ft^3/s (5.20 Mgal/d)
Storage: 200 Mgal

Month	Required draft (Mgal/d)	Storage (Mgal)	Average monthly flow			Allowable monthly withdrawal from		Average draft (Mgal/d)
			Inflow (Mgal/d)	Regulatory minimum (Mgal/d)	Outflow (Mgal/d)	Inflow (Mgal/d)	Storage (Mgal)	
April	5.20	200	7.66	6.45	6.45	1.21	119.7	5.20
May	5.20	80.3	6.33	5.33	5.33	1.00	80.3	3.59
June	5.20	0	11.1	9.37	9.37	1.73	0	1.73

Outflow requirement: 50 percent of regulatory minimum
Draft: 8.05 ft^3/s (5.20 Mgal/d)
Storage: 200 Mgal

Month	Required draft (Mgal/d)	Storage (Mgal)	Average monthly flow			Allowable monthly withdrawal from		Average draft (Mgal/d)
			Inflow (Mgal/d)	Regulatory minimum (Mgal/d)	Outflow (Mgal/d)	Inflow (Mgal/d)	Storage (Mgal)	
April	5.20	200	7.66	3.22	3.22	4.44	22.8	5.20
May	5.20	177	6.33	2.66	2.66	3.67	47.4	5.20
June	5.20	130	11.1	4.68	4.68	6.42	0	5.20

depleted before the end of May, and any water supply in June would have to be from the net inflow (after regulatory minimum flows are taken out). In June, the net inflow available is 1.73 Mgal/d. Thus, the demand rate of 5.20 Mgal/d could not be sustained.

If only 50 percent of the regulatory minimum flow rates were required, the draft of 5.20 Mgal/d would be maintained, as outlined in table 4. In April, a storage of 200 Mgal is available. Inflow of 7.66 Mgal/d is greater than the reduced regulatory minimum flow rate of 3.22 Mgal/d; however, it is not enough to satisfy the draft demand. Therefore, the remaining draft demand must come from storage. Beginning in May when the available storage is 177 Mgal, inflow is still greater than the regulatory minimum flow of 2.66 Mgal/d. However, the draft demand still has to be augmented by water from storage. By June, the storage available has been reduced to 130 Mgal; however, the draft of 5.20 Mgal/d is still possible since there is 6.42 Mgal/d available from the excess inflow. The excess (36.6 Mgal for June) is added to the reservoir storage, bringing the water available at the beginning of the month of July to 166.6 Mgal.

Iterative method

The iterative method, like the basic method, assumes a reservoir of 200 Mgal of storage is developed and is full at the beginning of the computations. Computations begin with October, the first month of the water year. Reservoir releases were determined in the same manner as the basic method; however, all 12 months of the year are used. Reservoir releases are determined in the same manner as previously described. Regulatory minimum flow rates, in cubic feet per second (million gallons per month), for the 12 calendar months are as follows:

January 20.3 (407)	May 8.26 (165)	September 56.0 (1,085)
February 20.6 (373)	June 14.5 (281)	October 20.2 (406)
March 16.9 (338)	July 35.1 (703)	November 16.6 (322)
April 10.0 (194)	August 79.8 (1,598)	December 18.2 (364)

The same population and withdrawals, 35,000 and 5.20 Mgal/d, respectively, were used as those considered in the basic method. The computations are made up of the following equations:

$$\text{Inflow } (Q_I) - \text{regulatory minimum discharge } (Q_{min}) = \text{excess discharge } (Q_E)$$

$$Q_E - \text{draft } (D) = \text{adjusted excess discharge } (Q_{EA})$$

$$\text{Outflow} = Q_{EA} + Q_{min}.$$

When $Q_E > D$, withdrawal from storage is not required. If $Q_E < D$, then $(Q_E\text{-}D)$ is taken from storage; or if storage is insufficient, D is reduced. Final storage is presented as adjusted storage. A flow diagram of the intertive method is presented in figure 14. Descriptions of draft, storage, and total discharge under various inflow conditions are presented in figure 15.

An example of the computation is presented in table 5. The computations for the 1951 water year are based on the condition that 100 percent of regulatory minimum discharges are met. Where inflow is less than the regulatory minimum discharge, the inflow becomes the required discharge, even if there is water in storage. A discussion of table 5 follows:

INPUT DATA: Average monthly discharge (Q), in cubic feet per second; regulatory minimum flow (QMIN), in million gallons per month; proposed draft (D), in cubic feet per second; proposed storage (S), in million gall ns

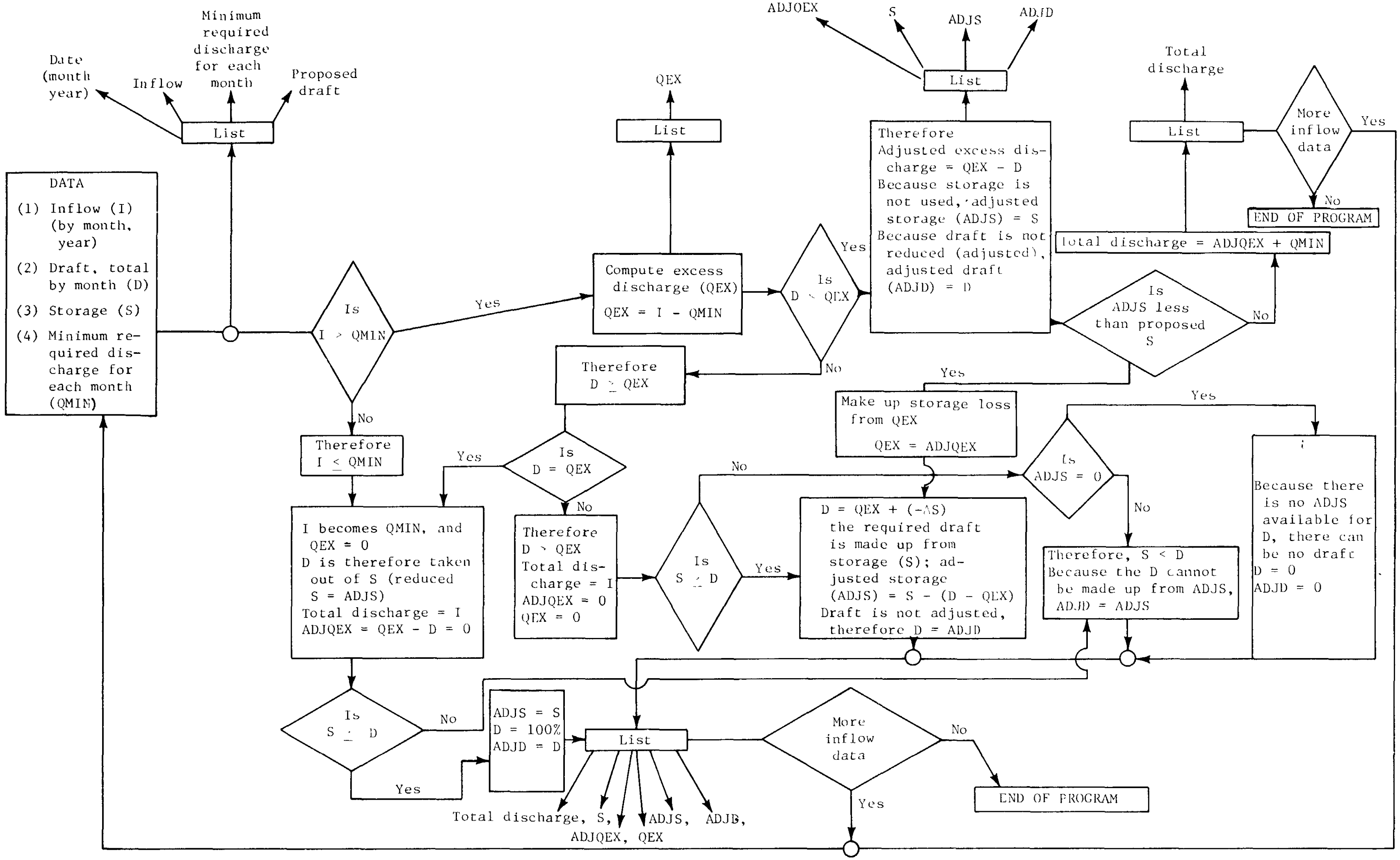

Figure 14.--Flow diagram of iterative method for draft-storage analysis.

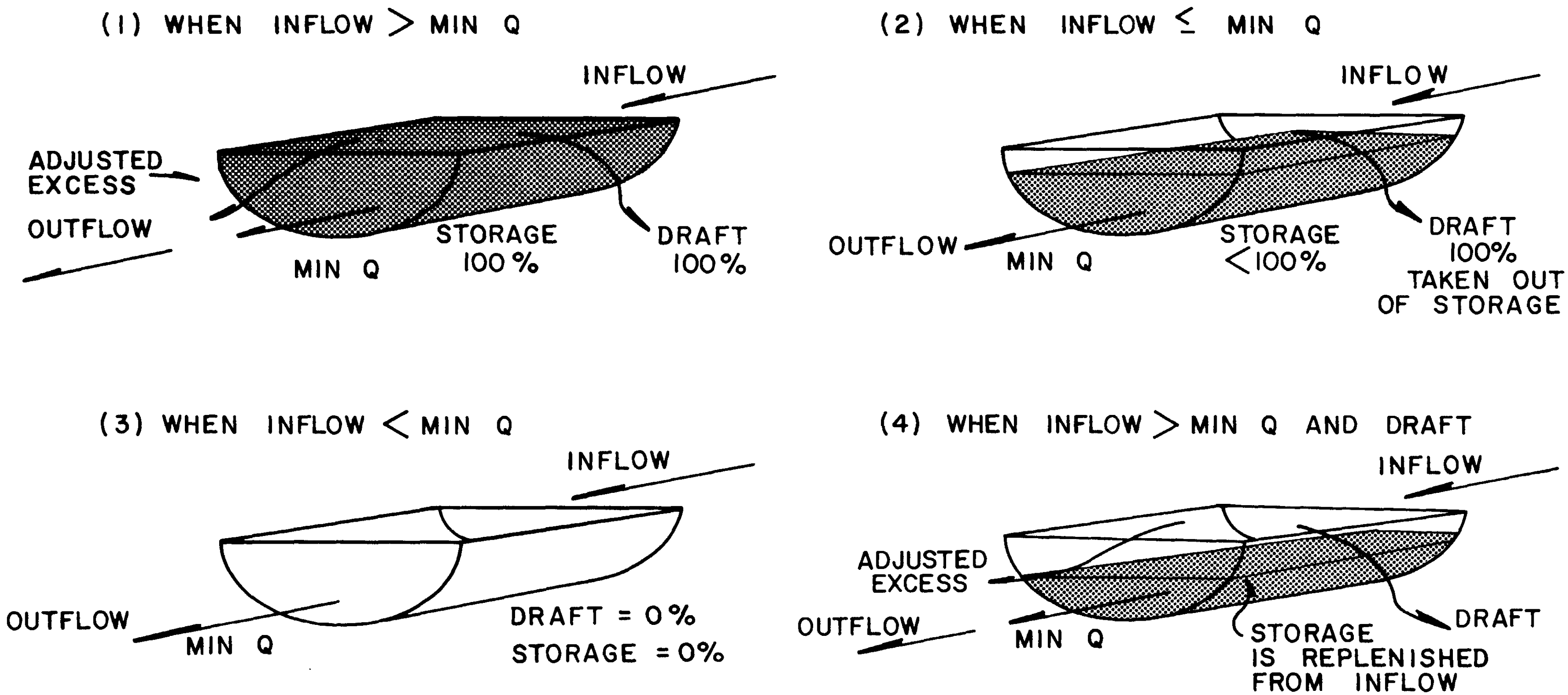

Figure 15.--Description of draft, storage, and total discharge under various inflow conditions.

Table 5.--Results of iterative method for flow, draft, and storage analysis for 1951 water year based on 100 percent of minimum required discharge

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

Year	Month	Inflow (ft^3/s)	Inflow (Mgal)	Minimum required Q (Mgal)	Excess (Mgal)	Draft (Mgal)
1950	Oct.	350.0	7,009.1	405.0	6,604.1	161.2
1950	Nov.	52.6	1,019.4	322.0	697.4	156.0
1950	Dec.	28.4	568.7	364.0	204.7	161.2
1951	Jan.	22.0	440.6	407.0	33.6	161.2
1951	Feb.[1/]	16.6	300.3	300.3	0	145.6
1951	Mar.[1/]	17.7	354.5	338.0	16.5	161.2
1951	Apr.[1/]	14.1	273.2	194.0	79.2	156.0
1951	May[1/]	13.5	270.4	165.0	105.4	161.2
1951	June[1/]	17.5	339.2	281.0	58.2	156.0
1951	July	275.0	5,507.2	703.0	4,804.2	161.2
1951	Aug.	258.0	5,166.7	1,598.0	3,568.7	161.2
1951	Sept.	569.0	11,027.2	1,085.0	9,942.2	156.0

Year	Month	Adjusted draft (Mgal)	Adjusted excess (Mgal)	Outflow (Mgal)	Storage (Mgal)	Adjusted storage (Mgal)
1950	Oct.	161.2	6,442.9	6,847.9	200.0	200.0
1950	Nov.	156.0	541.4	863.4	200.0	200.0
1950	Dec.	161.2	43.5	407.5	200.0	200.0
1951	Jan.	161.2	0	407.0	200.0	72.4
1951	Feb.[1/]	72.4	0	300.3	72.4	0
1951	Mar.[1/]	16.5	0	338.0	0	0
1951	Apr.[1/]	79.2	0	194.0	0	0
1951	May[1/]	105.4	0	165.0	0	0
1951	June[1/]	58.2	0	281.0	0	0
1951	July	161.2	4,443.0	5,146.0	0	200.0
1951	Aug.	161.2	3,407.5	5,005.5	200.0	200.0
1951	Sept.	156.0	9,786.2	10,871.2	200.0	200.0

[1/] Months when adjusted draft was less than proposed draft.

October 1950 begins with a full reservoir, 200 Mgal, and an inflow of 7,009.1 Mgal (350 ft^3/s). Subtracting the regulatory minimum discharge for October of 405 Mgal leaves 6,604.1 Mgal as excess. Draft for October (161.2 Mgal) is then subtracted from the excess discharge, which leaves 6,442.9 Mgal as the adjusted excess. Adding the regulatory minimum discharge (405 Mgal) to the adjusted excess (6,442.9 Mgal) gives an outflow of 6,847.9 Mgal for

October. Because the draft was less than the excess discharge, the storage remains at 200 Mgal. The same situation occurs through December 1950; however, in January 1951, conditions change. The excess discharge of 33.6 Mgal is less than the required draft of 161.2 Mgal. The difference between excess discharge and required draft is a deficit of 127.6 Mgal that must be obtained from storage. Storage is reduced from 200 to 72.4 Mgal. Therefore, for January 1951, the regulatory minimum discharge (Q_{min}) is satisfied, and the required draft is satisfied from storage. Because the inflow of 300.3 Mgal is less than the regulatory minimum discharge for February (373 Mgal), the inflow becomes the minimum required discharge, which leaves nothing as excess. Because a draft of 145.6 Mgal is required in February and it cannot be derived from the excess flow, it will have to be obtained from storage; however, storage has been depleted to 72.4 Mgal. Therefore, to satisfy draft demands, 72.4 Mgal of storage will be used. The draft has to be reduced or adjusted to 72.4 Mgal. During March, excess flow of 16.5 Mgal is used entirely for draft, and the adjusted draft is now 16.5 Mgal. Similar conditions occur in April, May, and June. However, in July, sufficient inflow has occurred to satisfy draft demands, replenish the reservoir, and still have an outflow of 5,146.0 Mgal.

The above methodology was used for the period of record from October 1939 through September 1982. The results for the 42 years of record with a draft of 5.2 Mgal/d and a storage of 200 Mgal are summarized by months in table 6. Findings indicate that for 43 months, or about 8.5 percent of the time, the draft would have had to be reduced. Storage would be less than full for 108 months or about 21.4 percent of the time. The individual draft and storage values, by month for period of record, are presented in table 7.

The results of the iterative method using 50 percent reduction of regulatory minimum discharge for the 1951 water year are presented in table 8. Analysis indicates that draft would not be reduced; however, storage was reduced twice. A summary, by months for the period of record from October 1929 through September 1982, that shows percentage of time required draft and storage are reduced with 50 percent reduction of regulatory minimum discharge criteria is presented in table 9. Analysis indicates that draft was not reduced in March, June, and August through October. The other months were insufficient once, except for May, which was insufficient twice. Adjusted storage does not show any reduction for August and September; the remainder of the months ranged from 1 to 10 times. The analysis presented in table 9 indicates that, during 8 months or about 1.6 percent of the time, draft had to be reduced, and storage was reduced during 38 months, or about 7.5 percent of the time. The individual values for table 9, by month for the period of record, are presented in table 10.

Discussion of methods

The basic method uses the 90-day low flow and a 20-year recurrence interval to estimate the average low-flow discharge. However, it does not determine which 3 months or parts of months will be included in the 90 consecutive days; the 3 consecutive months that include the 90-day period have to be obtained from historical record. The iterative method can be used to determine what 3 or more consecutive months need to be used in the low-flow analysis. The following is an example.

Table 6.--Percent of time required draft and storage are reduced with 100 percent minimum required discharge

[Required draft and storage are 8.02 ft^3/s and 200 Mgal, respectively]

Month	Number of months draft is reduced					Number of months draft requirement is met
	Total	As percent of draft				
		0.00%	0<%<50	50<=%<=75	75<%<100	
January	4	1	2	1	0	30
February	4	1	1	1	1	38
March	6	1	9	1	1	36
April	7	3	2	2	0	35
May	5	3	1	1	0	37
June	2	0	2	0	0	40
July	2	0	2	0	0	40
August	0	0	0	0	0	42
September	1	0	1	0	0	41
October	3	1	1	0	1	39
November	4	1	1	2	0	38
December	5	2	2	0	1	37

Month	Number of months storage is reduced					Number of months storage requirement is met
	Total	As percent of storage				
		0.00%	0<%<50	50<=%<=75	75<%<100	
January	13	4	7	2	0	29
February	10	4	4	2	0	32
March	8	6	1	1	0	34
April	12	7	2	2	1	30
May	20	5	4	7	4	22
June	9	2	6	0	1	33
July	3	2	1	0	0	39
August	3	0	2	0	1	39
September	4	1	2	1	0	38
October	5	3	2	0	0	37
November	11	4	2	2	3	31
December	10	5	1	3	1	32

Number of water years	42
Number of months (total)	504
Number of months draft reduced	43 (8.531 percent)
Number of months storage reduced	108 (21.428 percent)

Table 7.--Computed adjusted drafts and storage with 100 percent of minimum required discharge

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

Adjusted drafts (ft^3/s)		Adjusted storages (Mgal)			
Jan.	June	Jan.	Apr.	June	Nov.
0.000	3.000	0.000	0.000	0.000	0.000
0.676	3.900	0.000	0.000	0.000	0.000
3.676		0.000	0.000	12.150	0.000
5.050		0.000	0.000	16.156	0.000
	July	40.581	0.000	43.991	16.181
Feb.	2.196	56.341	0.000	43.991	43.991
0.000	3.842	65.599	0.000	45.552	121.219
4.000		72.362	43.991	76.947	125.095
5.107	Sept.	84.378	63.171	174.823	167.731
6.643	2.001	92.388	105.807		192.925
		95.865	142.629		194.863
Mar.	Oct.	100.659	194.955	July	
0.000	0.000	136.445		0.000	Dec.
0.821	2.196			0.000	0.000
2.862	7.398	Feb.	May	46.713	0.000
3.690		0.000	0.000		0.000
5.187	Nov.	0.000	0.000		0.000
7.116	0.000	0.000	0.000	Aug.	0.000
	2.001	0.000	0.000	38.790	5.479
Apr.	5.128	28.844	0.000	38.790	115.135
0.000	5.584	51.949	84.248	167.291	130.316
0.000		54.391	84.050		135.388
0.000		73.901	84.310	Sept.	165.427
1.089	Dec.	103.887	94.063	0.000	
3.189	0.000	141.603	100.071	43.991	
4.044	0.000		103.424	86.551	
4.089	0.807	Mar.	104.076	145.047	
	1.923	0.000	116.092		
May	6.246	0.000	124.362		
0.000		0.000	128.107	Oct.	
0.000		0.000	144.128	0.000	
0.000		0.000	153.101	0.000	
2.196		0.000	156.144	0.000	
5.760		6.867	168.159	38.790	
		127.344	172.165	78.367	

Table 8.--Results of iterative method for flow, draft, and storage analysis for 1951 water year based on 50 percent of minimum required discharge

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

Year	Month	Inflow (ft^3/s)	Inflow (Mgal)	Minimum required flow (Mgal)	Excess (Mgal)	Proposed draft (Mgal)
1950	Oct.	350.0	7,009.1	202.0	6,807.1	161.2
1950	Nov.	52.6	1,019.4	161.0	858.4	156.0
1950	Dec.	28.4	568.7	182.0	386.7	161.2
1951	Jan.	22.0	440.6	204.0	236.6	161.2
1951	Feb.	16.6	300.3	186.0	114.3	145.6
1951	Mar.	17.7	354.5	169.0	185.5	161.2
1951	Apr.	14.1	273.2	97.5	175.7	156.0
1951	May	13.5	270.4	82.5	187.9	161.2
1951	June	17.5	339.2	140.0	199.2	156.0
1951	July	275.0	5,507.2	352.0	5,155.2	161.2
1951	Aug.	258.0	5,166.7	799.0	4,367.7	161.2
1951	Sept.	569.0	11,027.2	542.0	10,485.2	156.0

Year	Month	Adjusted draft (Mgal)	Adjusted excess (Mgal)	Total outflow (Mgal)	Storage (Mgal)	Adjusted storage (Mgal)
1950	Oct.	161.2	6,645.9	6,847.9	200.0	200.0
1950	Nov.	156.0	702.4	863.4	200.0	200.0
1950	Dec.	161.2	225.5	407.5	200.0	200.0
1951	Jan.	161.2	75.4	279.4	200.0	200.0
1951	Feb.	145.6	0	186.0	200.0	168.7
1951	Mar.	161.2	0	169.0	168.7	193.0
1951	Apr.	156.0	12.7	110.2	193.0	200.0
1951	May	161.2	26.7	109.2	200.0	200.0
1951	June	156.0	43.2	183.2	200.0	200.0
1951	July	161.2	4,994.0	5,346.0	200.0	200.0
1951	Aug.	161.2	4,206.5	5,005.5	200.0	200.0
1951	Sept.	156.0	10,329.2	10,871.2	200.0	200.0

Table 9.--Percent of time required draft and storage are reduced with 50 percent of minimum required discharge

[Required draft and storage are 8.02 ft^3/s and 200 Mgal, respectively]

Month	Number of months draft is reduced: Total	As percent of draft: 0.00%	0<%<50	50<=%<=75	75<%<100	Number of months draft requirement is met
January	1	0	0	0	1	41
February	1	0	0	1	0	41
March	0	0	0	0	0	42
April	1	0	0	0	1	41
May	2	1	1	0	0	40
June	0	0	0	0	0	42
July	1	0	1	0	0	41
August	0	0	0	0	0	42
September	0	0	0	0	0	42
October	0	0	0	0	0	42
November	1	0	0	1	0	41
December	1	0	0	1	0	41

Month	Number of months storage is reduced: Total	As percent of storage: 0.00%	0<%<50	50<=%<=75	75<%<100	Number of months storage requirement is met
January	1	1	0	0	0	41
February	3	1	0	0	2	39
March	4	0	0	3	1	38
April	6	1	2	1	2	36
May	10	2	2	0	6	32
June	5	0	3	1	1	37
July	1	1	0	0	0	41
August	0	0	0	0	0	42
September	0	0	0	0	0	42
October	2	0	1	0	1	40
November	3	1	1	1	0	39
December	3	1	1	1	0	39

Number of water years 42
Number of months (total) 504
Number of months draft reduced 8 (1.587 percent)
Number of months storage reduced 38 (7.539 percent)

Table 10.--Computed adjusted draft and storage with 50 percent of minimum required discharge

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

Adjusted drafts (ft^3/s)	Adjusted storages (Mgal)		
Jan.	Jan.	May	Oct.
7.013	0.000	0.000	77.102
		0.000	199.261
Feb.	Feb.	8.471	
5.971	0.000	88.656	Nov.
	168.652	159.748	0.000
Apr.	190.358	161.550	98.109
7.456		171.563	117.489
	Mar.	177.571	
May	106.468	181.576	Dec.
0.000	110.102	193.592	0.000
3.658	136.136		62.654
	192.903	June	145.165
July		43.991	
3.986	Apr.	68.333	
	0.000	73.372	
Nov.	18.383	149.239	
4.580	76.927	169.497	
	133.232		
Dec.	160.171	July	
5.411	162.109	0.000	

In the basic method, the months of April, May, and June were used for the 20-year, 90-day low flow; however, table 5 shows that perhaps a 120- or 180-day low flow could have been used, starting with March or even December. Table 5 indicates that, based on historical data, the months where the draft would have to be reduced because of low-flow conditions would be March through May instead of April through June, as was assumed in the basic method. The iterative method can be used to optimize the draft-storage relation against draft and storage reduction, assuming that sufficient data exist.

SALINITY CHARACTERISTICS AND DISTRIBUTION

Little Manatee River: The Little Manatee River estuary was found to be vertically homogeneous for flows less than 118 ft^3/s, as shown in figures 16 through 18. In most verticals, salinity was essentially uniform from top to bottom. Figures 16 through 18 present conductivity distribution along midstream of the river for discharges of 118, 80, and 42 ft^3/s and high-high tides of 1.82, 1.19, and 1.75 feet above sea level, respectively. During a streamflow of 118 ft^3/s, some vertical nonhomogeneity is noticeable near the mouth of the river. Between sites 1 and 4, the effects of freshwater discharge, overriding the incoming saltwater, are observed.

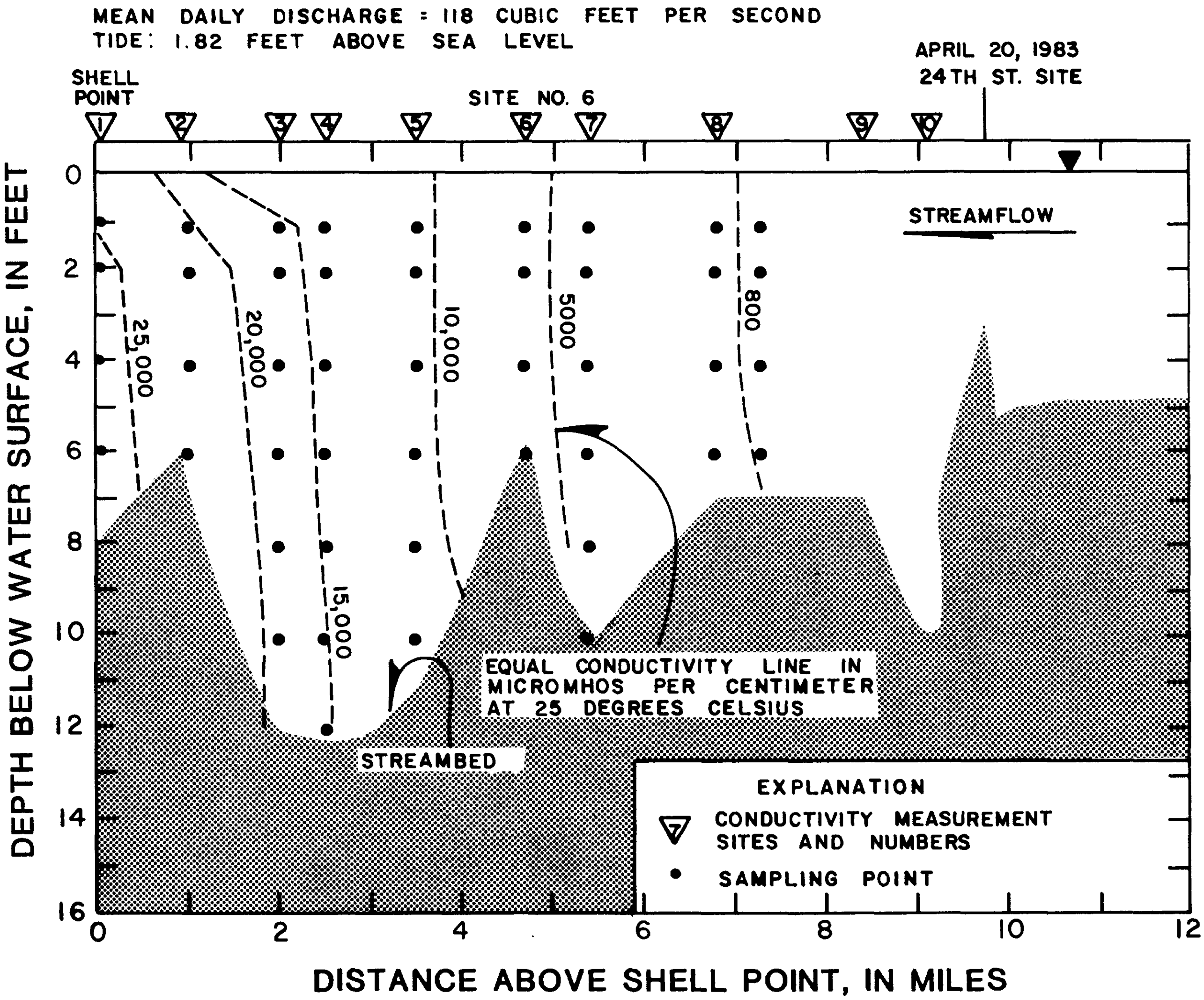

Figure 16.--Conductivity characteristics of the Little Manatee River estuary at a discharge of 118 cubic feet per second.

As discharge decreases, some changes in the vertical salinity distributions are noted, but homogeneity from top to bottom is evident. Locally, variations occur that are probably attributed to temporary disturbances or less saline water overriding incoming saline water that causes change with depth. Figures 16 through 18 also show the changes in salinity that occur horizontally along the estuarine reach with changes in discharge. Locations of lines of equal conductivity for conductances that range from 800 to 40,000 umhos are shown. As discharge decreases, saline water moves further upstream and conductivity increases, as shown by the upstream movement of the lines of equal conductivity in figure 18. The saltwater-freshwater interface or the conductivity (or salinity) that demarcates the brackish or estuarine system from the freshwater or riverine system is the 800-umho line.

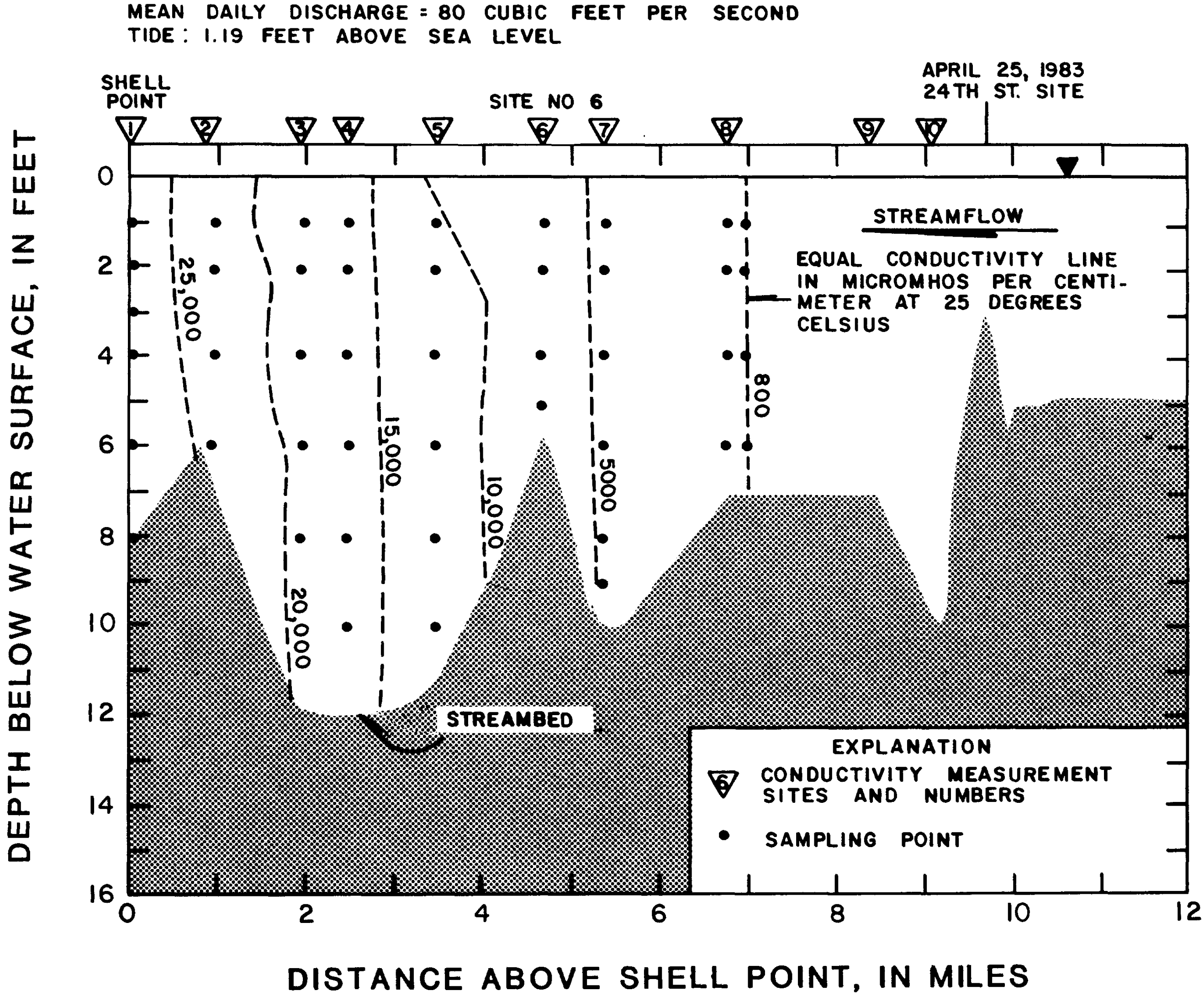

Figure 17.--Conductivity characteristics of the Little Manatee River estuary at a discharge of 80 cubic feet per second.

A generalized relation between selected vegetation and range of selected conductivities for the reach of the river is presented in figure 19. The shape of the bar graphs for the vegetation (fig. 19) are not quantitative, and the species density was not quantified. The shape of the vegetative bars indicates only the approximate location along the river where the species was first observed, where it was observed to be predominant, and finally where the density decreased until the plants were no longer observed.

Based on field measurement of conductivity (salinity) made during the period of study, the range in locations of the 30,000-umho conductivity (18 $^{o}/oo$), 8,000-umho conductivity (5 $^{o}/oo$), and the 800-umho (0.5 $^{o}/oo$) lines were identified and are presented in figure 19. The 30,000-umho conductivity line ranges

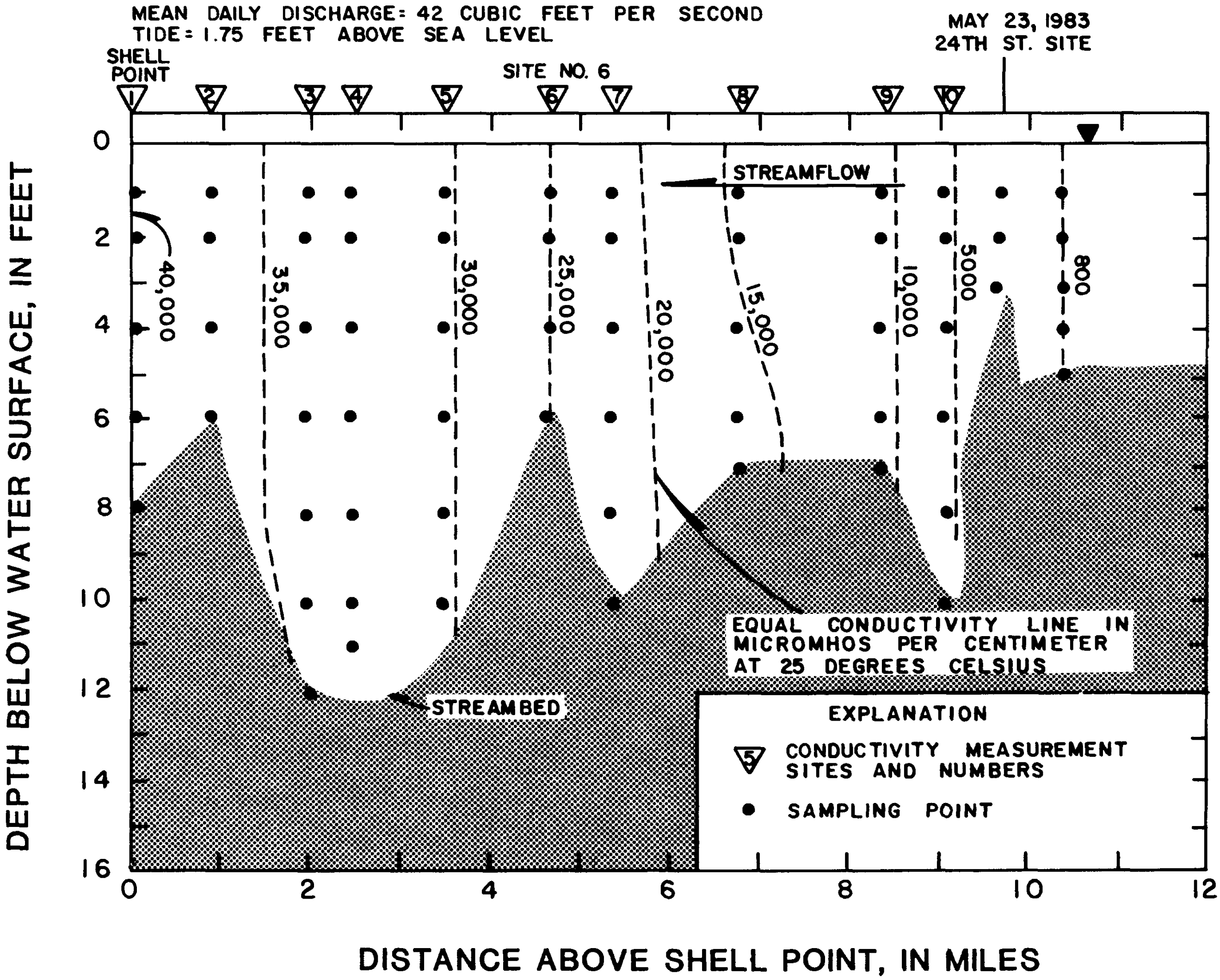

Figure 18.--Conductivity characteristics of the Little Manatee River estuary at a discharge of 42 cubic feet per second.

in location from Shell Point to about 3.5 miles above Shell Point; the 8,000-umho conductivity line ranges from about river mile 4 to 9; and the 800-umho line ranges from about river mile 5.8 to 10.4. The range of streamflow for these conductivities was from 42 to 118 ft^3/s. A conductivity duration curve for the 24th Street site (fig. 20) indicates that, during the period of study, the 800-umho conductivity was at or beyond this site about 17 percent of the days. The 24th Street site is about 0.2 mile downstream from the estimated location of the estuarine-riverine boundary.

Selected results from A duration curve using equation 4 to compute the maximum upstream location of the interface during the study is included in figure 19 to show the relation between percentage exceedance interval for the maximum upstream location of the saltwater-freshwater interface and the observed

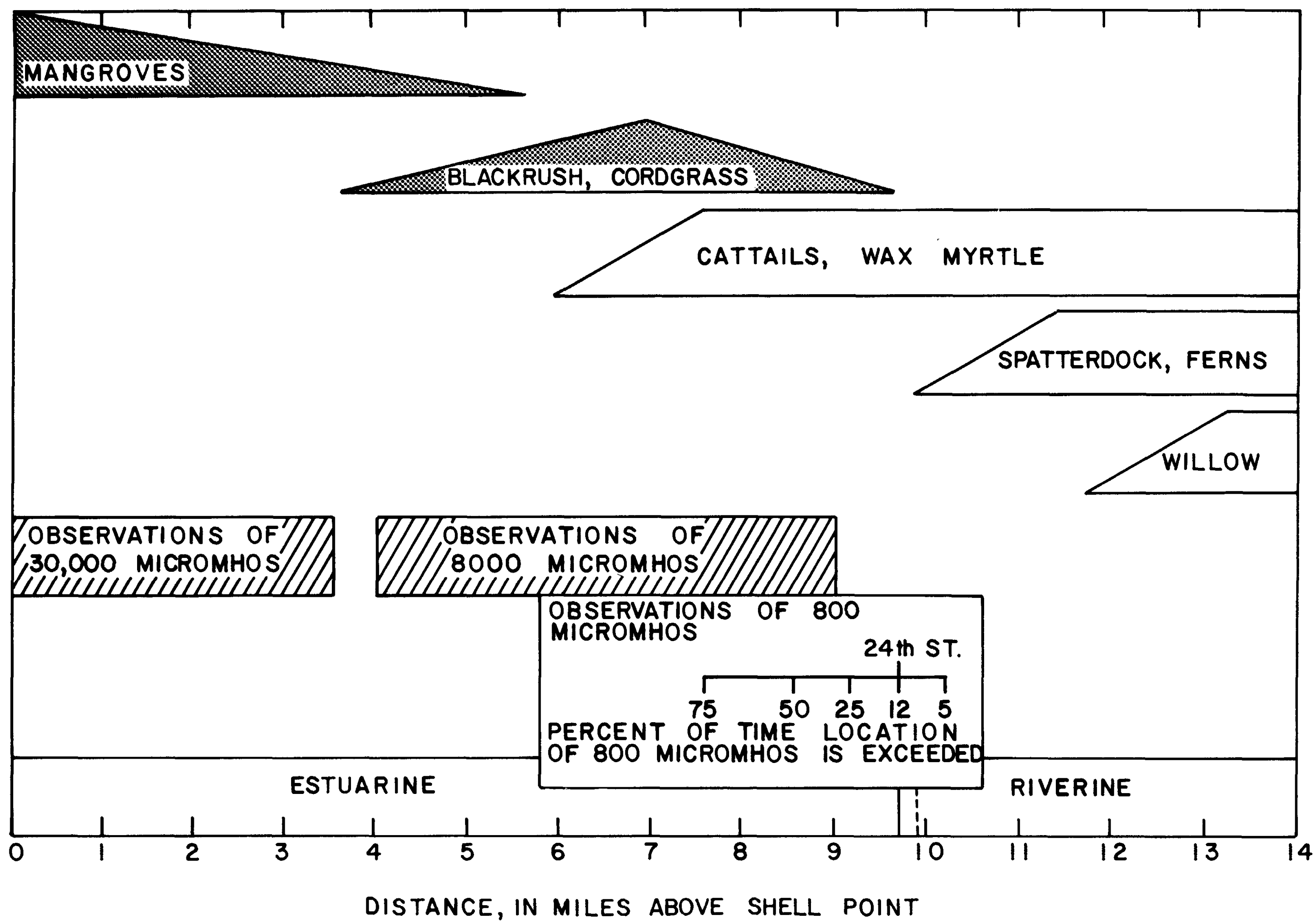

Figure 19.--Generalized relation between conductivity and vegetative distribution.

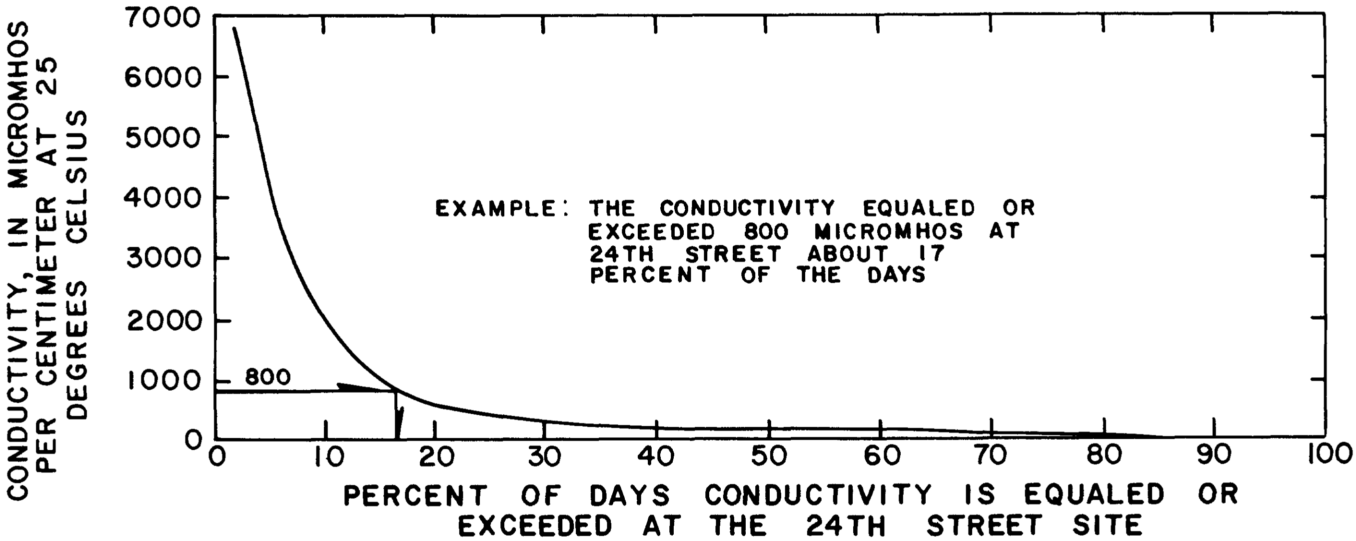

Figure 20.--Conductivity duration curve for the 24th Street site.

range of the interface. As shown, 75 percent of the days, the 800-umho line was upstream from mile 7.5, and 5 percent of the days it was above mile 10.2. The interface was at or upstream from river mile 9.7 (24th Street site) during the period of study about 12 percent of the days; this approximates the 17 percent of the days (fig. 20) that the conductivity was equal to or greater than 800 umhos at 24th Street.

Little Cockroach Bay: To determine the effects of reduced streamflow on the salinity of Little Cockroach Bay, a salinity survey was made in the bay, in nearby Tampa Bay, and at the mouth of the Little Manatee River. The measurements were made during a period of low discharge, 48 ft^3/s, and low-low tide conditions, 0.57 foot below sea level. The overall depth of water in Little Cockroach Bay was 0.5 foot or less, except for areas of channelization. Salinity, shown as conductivity for the area, is presented in figure 21. Low-low tide and low streamflow conditions were selected because they represent conditions where a decrease in the normal discharge of the river could affect the salinity distribution most. Figure 21 shows that during this period, the overall conductivity in Little Cockroach Bay was not appreciably different from that near the mouth of the river. This indicates that the river flow was through the bay following the coast and offshore islands.

During the conductivity measurement period, the conductivity in Little Cockroach Bay averaged about 36,000 umhos and ranged from 34,000 to 37,000 umhos near the offshore island. The conductivity of Tampa Bay increased from about 41,000 umhos within 0.5 mile from Little Cockroach Bay to 44,000 umhos about 2.5 miles offshore. A reduction of discharge in the Little Manatee River would cause the 41,000- and 42,000-umho lines to move closer to the mouth of the river. However, any attempt to quantify the extent of movement would require further investigation.

Tampa Bay: Tampa Bay, offshore from the mouth of the Little Manatee River (fig. 21), is also vertically homogeneous. Homogeneous conditions have also been identified for that part of Tampa Bay and lower Tampa Bay by the Hillsborough County Environmental Protection Commission (unpublished data). The lower conductivity near the mouth of the Little Manatee River appears to be only within a radius of 1 mile or less from Shell Point. Any attempt to predict the changes in salinity distribution in the bay due to reduced streamflow from the Little Manatee River would require extensive monitoring of salinity distributions in Tampa Bay and in the river and also delineation of the directional paths of flow from the river.

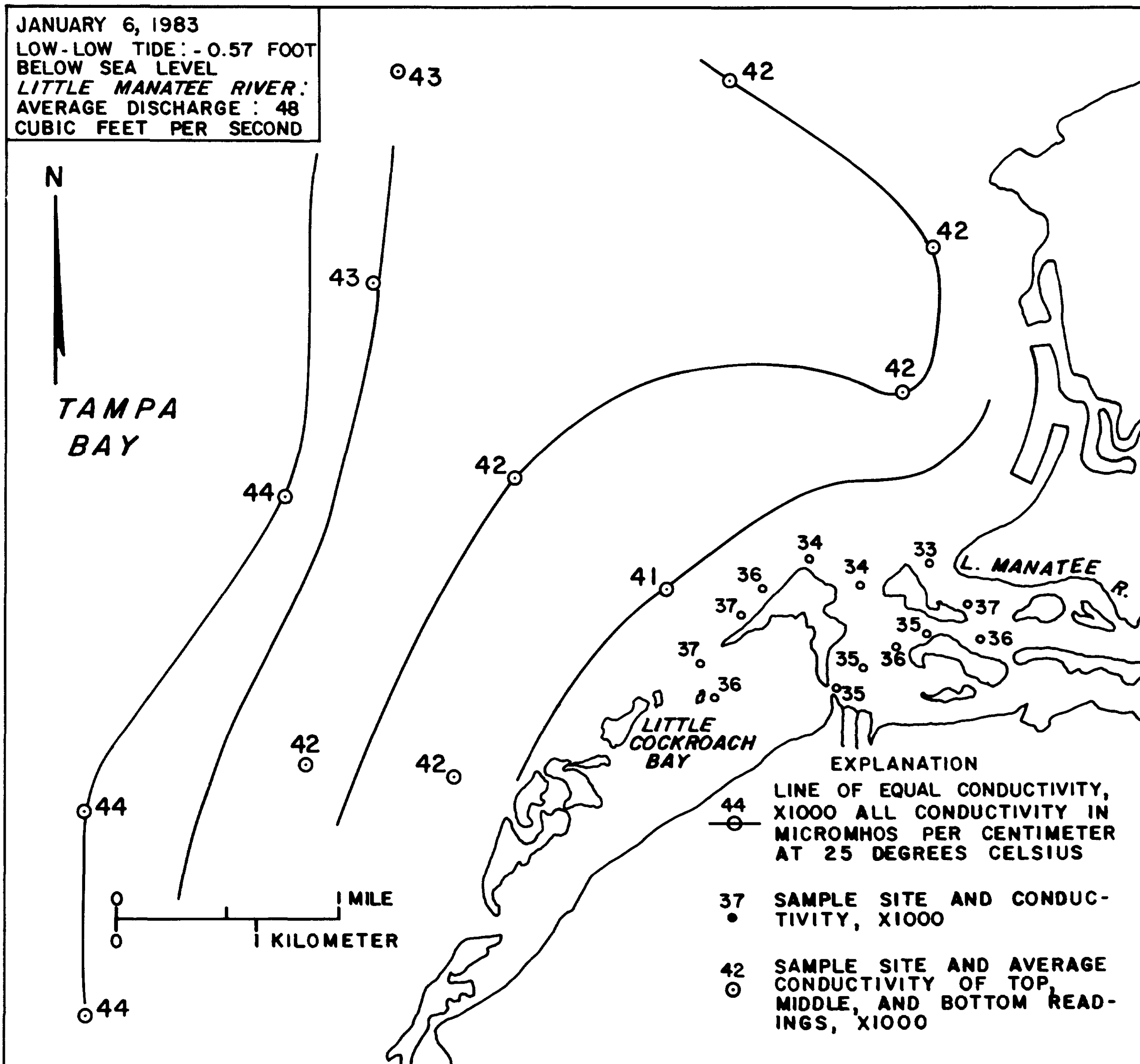

Figure 21.--Conductivity distribution at mouth of the Little Manatee River, Little Cockroach Bay, and adjacent Tampa Bay, January 6, 1983.

EFFECTS OF DRAFT ON SALTWATER-FRESHWATER INTERFACE LOCATION

The effects of draft on the outflow of the Little Manatee River for the 90-day low flow, 20-year recurrence interval and for 100 and 50 percent of regulatory minimum discharges are summarized in table 4. The reduced discharge will affect the maximum upstream location of the saltwater-freshwater interface. The location of the interface under varying high-high tides and low-flow discharges, based on equation 3, is presented in figure 22. An example of the effect of the maximum upstream location of the interface is presented using the mean high-high tide, 1.65 feet, and the June outflow from table 4. Although outflow or discharge is reduced by 50 percent (9.37 to 4.68 ft^3/s), the net effect in the location of the interface is only about 0.2 mile (mile 11.4 to 11.6). Because the standard error of equation 4 is $\pm$0.4 mile, it can be concluded that the change in location of the interface will be within the standard error of estimate. Under these low-flow conditions, the main effect on location of the interface is high-high tide. If discharge is increased, the difference in location will increase.

The maximum upstream location of the saltwater-freshwater interface also can be computed for the 90-day, 2-year recurrence-interval low flow as shown by using figure 22. Applying figure 22, the maximum upstream location of the interface during the 90-day low flow (30.7 ft^3/s) with mean high-high tide of 1.65 feet above sea level would be 10.4 miles above the reference station at Shell Point. The graph can also be applied for other recurrence intervals. For example, reduction of streamflow for the 90-day, 2-year recurrence-interval low flow (30.7 ft^3/s) by 50 percent (15.35 ft^3/s) would cause the maximum intrusion of the interface to move upstream from mile 10.4 to mile 11.1 for a mean high-high tide of 1.65 feet above sea level. Fifty percent reduction of the 90-day, 20-year recurrence-interval low flow (9.37 ft^3/s) would move the saltwater-freshwater interface 0.2 mile upstream, or from river mile 11.4 to mile 11.6 for a high-high tide of 1.65 feet.

SUMMARY AND CONCLUSIONS

This report presents a statistical model for locating the saltwater-freshwater interface during periods of low flow and for predicting the maximum upstream location of the interface for low-flow discharges that have 2-year and 20-year low-flow recurrence intervals.

The Little Manatee River drainage basin encompasses 221 mi^2. The tidally affected reach is from the mouth to just upstream from the gaging station at U.S. Highway 301, a reach of about 14 miles above the reference station at Shell Point. Diversion of water by the Florida Power and Light Corporation at Parrish, Fla., occurs about 3.3 miles upstream from U.S. Highway 301. During 1981, about 10.5 percent of the total streamflow for the year was diverted. This diversion occurred from May through September. Stream width varies from about 4,000 feet at the mouth to 40 feet in the upper reaches. There are rock outcrops at 13.4 and 13.5 miles above Shell Point. The altitude of these outcrops is 1.9 feet above sea level. These outcrops can act as barriers for tides equal to or less than their altitude. Average discharge for the period of record from 1939 through 1981 (42 years) is 169 ft^3/s. During the period of study, the average discharge was 279 ft^3/s.

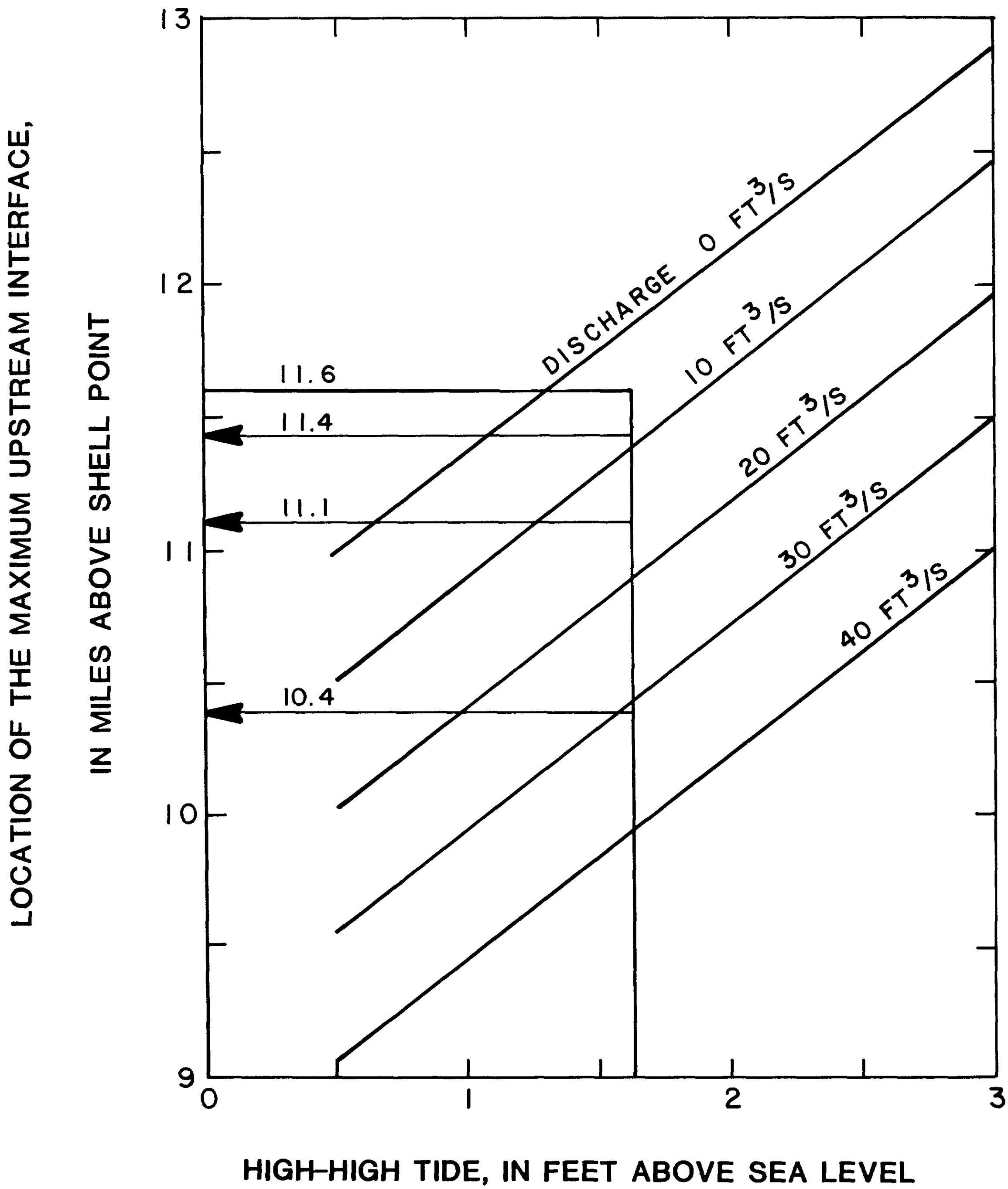

Figure 22.--Relation between high-high tide and the maximum upstream location of the saltwater-freshwater interface for low flows.

There are usually four tides daily in Tampa Bay: a low-low, high-low, low-high, and high-high tide. The observed tides were at the city of St. Petersburg across the bay from the mouth of the Little Manatee River. The high-high tide used in developing the regression equations ranged from 0.81 to 2.48 feet above sea level. These tides, based on the duration curve for the period of study, are exceeded about 97 and 4 percent of the days, respectively.

The Little Manatee River estuary is vertically homogeneous at low flows. Vertical salinity measurements were made for discharges of 42, 80, and 118 ft^3/s. During discharge of 118 ft^3/s, some vertical nonhomogeneity was noticeable near the saltwater-freshwater interface. The freshwater flow was overriding the incoming tide near the mouth. Salinity changes horizontally along the estuarine reach with changes in streamflow.

During a low-low tide of 0.57 feet below sea level and a discharge of 48 ft^3/s, Little Cockroach Bay had conductivities that ranged from 34,000 to 37,000 umhos. The conductivity in Tampa Bay was about 41,000 umhos within 0.5 mile of Little Cockroach Bay.

Linear-regression equations were developed for unnormalized (Tampa Bay conductivity not considered) and normalized (adjusted for Tampa Bay conductivity) conditions. For unnormalized conditions, R^2 was 0.88, and the root mean square error for the maximum upstream location of the interface was ±0.5 mile. For normalized conditions, R^2 was 0.92, and the root mean square error for the maximum upstream location was ±0.4 mile. Results of the regression analysis to locate the maximum intrusion under streamflow conditions approximating low flow, 118 ft^3/s or less, provided an R^2 of 0.94 and a root mean square error of ±0.4 mile. The range of data used indicates that the equation for the location of the 800-umho conductivity line is statistically valid for discharges ranging from 42 to 118 ft^3/s, high-high tides from 0.81 to 2.48 feet above sea level, and a saltwater-freshwater interface location between 5.8 and 10.4 miles above Shell Point. There were insufficient data to develop equations for the 8,000- (5 $^o/oo$) and 30,000-umho (18 $^o/oo$) conductivity lines. Duration analysis for the period of study indicates that the maximum upstream location of the interface will be above mile 9.7 about 12 percent of the days, and the conductivity at the site will exceed 800 umhos about 17 percent of the days.

The extent of the river's estuarine system is from the mouth to about 9.9 miles upstream from Shell Point, beyond which it is riverine. Field measurements indicated that a conductivity of 30,000 umhos extended from the mouth to about 3.5 miles upstream. The 8,000-umho conductivity ranged from about 4 to 9 miles from Shell Point, and the 800-umho conductivity ranged from 5.8 to 10.4 miles from Shell Point.

The effects of draft on the discharge of the Little Manatee River for the 90-day low flow, 20-year recurrence interval with 100 percent and 50 percent compliance with the regulatory minimum discharge criteria were determined. With a high-high tide of 1.65 feet above sea level and a June discharge of 9.37 and 4.68 ft^3/s for the 100 and 50 percent of the regulatory minimum discharge, the change in the maximum upstream location of the saltwater-freshwater interface was 11.4 to 11.6 miles upstream from Shell Point. Under low-flow conditions, the main effect on the location of the interface is the magnitude of the high-high tide. The maximum upstream location of the interface can also be computed for the 90-day, 2-year recurrence-interval low flow. The maximum upstream location of the interface during the 90-day low flow (30.7 ft^3/s) with a high-high tide of 1.65 feet above sea level was determined to be about 10.4 miles above Shell Point. Reduction of streamflow for the 90-day, 2-year recurrence-interval low flow (30.7 ft^3/s) by 50 percent would cause the maximum intrusion of the interface to move upstream from mile 10.4 to mile 11.1 for a mean high-high tide of 1.65 feet above sea level.

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