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AN EVALUATION OF LAKE WASHINGTON TEMPORARY WEIR FOR SURFACE WATER MANAGEMENT

PHASE I: HYDRAULIC/HYDROLOGIC ANALYSES

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LIST OF ABBREVIATIONS

The following abbreviations are used in this study:

AF = Acre Feet;

BCMCA = Blue Cypress Marsh Conservation Area;

BCWMA = Blue Cypress Water Management Area;

C- = Canal;

cfs = cubic feet per second;

ET = Evapotranspiration;

FAC = Florida Administrative Code;

FDMCA = Fort Drum Marsh Conservation Area;

F.S. = Florida Statutes;

FWCD = Fellsmere Water Control District;

GDM = General Design Memorandum;

HEC = Hydrologic Engineering Center;

L- = Levee;

MGD, mgd= Million Gallons per Day;

mg/l = milligrams/litre;

NGVD = National Geodetic Vertical Datum (formerly mean sea level, msl);

NIR = Net Irrigation Requirement;

RM = River Mile;

S- = Structure;

SBWA = South Brevard Water Authority;

SJMCA = St. Johns Marsh Conservation Area;

SJRWMD = St. Johns River Water Management District;

SJWMA = St. Johns Water Management Area;

TDS = Total Dissolved Solids;

USGS = United States Geological Survey; and

USJRB = Upper St. Johns River Basin.

CHAPTER I

INTRODUCTION

The St. Johns River originating from its headwaters near Florida's Turnpike in St. Lucie and Indian River counties, flows north for about 300 miles until it turns eastward to the Atlantic Ocean north of Jacksonville. The area drained by the river is mostly flat and the river has an average gradient of only 0.15 ft/mile at normal stages. As a result, some of the wider reaches of the river are formed into large shallow lakes, especially in the Upper and Middle St. Johns River basins. These include Blue Cypress Lake, Sawgrass Lake, and Lakes Hell'n Blazes, Washington, Winder, Poinsett, Harney, Jessup, Monroe and George (Fig. 1-1). While most of these lakes are used primarily for recreation, Blue Cypress Lake is an important source of agricultural water supply in Indian River County and Lake Washington is a public drinking water supply source for the South Brevard County area (about 109,000 population).

The water supply potential of Lake Washington was not fully evaluated when it was selected as a primary source of water supply for South Brevard County. The available water appeared to be plentiful when the City of Melbourne first turned to the lake in 1959 for its water supply and expanded its withdrawals in the 1960's. Later, however, drought conditions in the St. Johns River Basin, population growth in South Brevard County, and water quality concerns cast doubts regarding the potential of Lake Washington as a reliable source of water supply. The low water

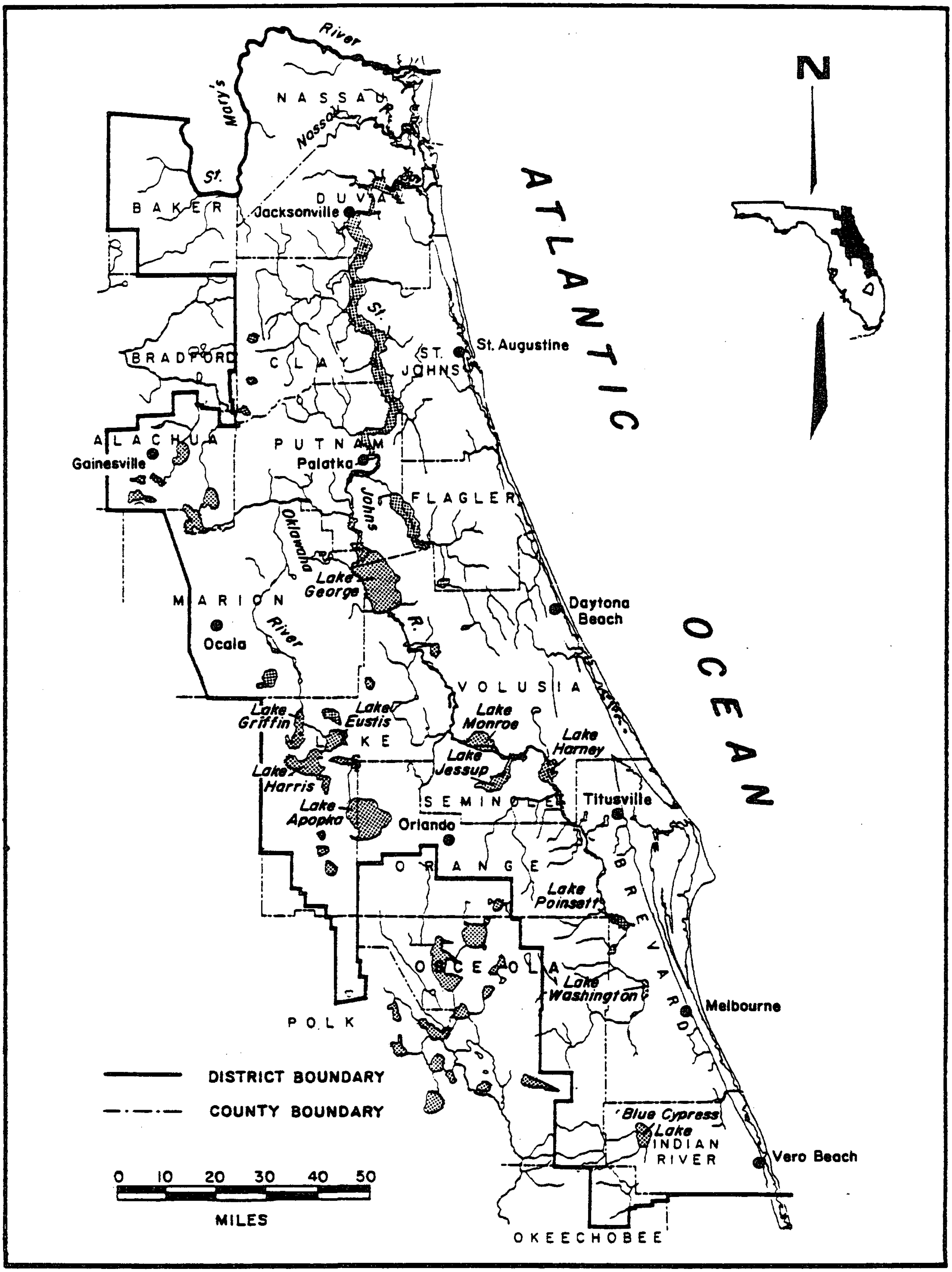


Figure 1-1. The St. Johns River

levels reached in the lake during the 1981 drought caused great concern culminating in a water-shortage declaration and mandatory restrictions on domestic water use.

To protect the water supplies of the lake, a semi-permanent dam was built in November 1961 across the narrow channel of the St. Johns River about 0.5 mi. downstream from the lake outlet. The crest of the dam was about 12.00 ft. NGVD at that time. Washouts occurred at times and repairs to the dam were made by the addition of concrete bags. The crest was observed to be about 13.40 ft NGVD in 1968 and about 9.50 ft. NGVD in 1975 (USGS, 1986). The construction of the existing sheet pile weir, the Lake Washington weir, at the north end of Lake Washington was completed in February, 1976. The crest elevation of this weir is 13.5 ft. NGVD. The structure is currently owned and maintained by the St. Johns River Water Management District (District).

South Brevard Water Authority (SBWA) was created by the legislature in the summer of 1983. The SBWA was vested with the responsibility of providing a safe and reliable water supply for the South Brevard area. In 1984, the SBWA submitted a project request to the District as part of the District's Regional Water Resources Assistance Program (Appendix I). The project request proposed a surface water management study including an evaluation of the Lake Washington Weir. The proposal addressed the following concerns:

1. The potential for modifying the weir to provide increased water supply benefits.

2. Modification to the weir necessary to satisfy minimum flow requirements downstream; and
3. Improvements necessary to convert the present Lake Washington weir to a permanent facility.

When constructed, the weir was regarded only as a temporary structure pending construction of the Upper St. Johns River Basin (USJRB) Project, a flood control project which was first authorized by the Congress in 1948 for South Florida and amended in 1954 to include the USJRB. The current project GDM approved in 1986, does not include consideration of the Lake Washington Weir.

The District, pursuant to the provisions of Chapter 373 F.S. is authorized to provide, maintain or modify works of the District which include dikes, dams, sluiceways, reservoirs, etc. and, therefore, initiated this study in 1985. The SBWA and the District entered into an agreement providing for the performance of the study. This agreement (Appendix II) executed on May 6, 1985, provides that the District will complete a hydrologic evaluation and develop a recommended modification to the existing temporary weir as follows:

1. develop complete hydraulic data for the existing weir; and
2. adapt and calibrate a hydrological simulation model for the basin above the said temporary weir; and
3. delineate floodplain of the Lake Washington and areas upstream; and

4. assess flooding damage potential associated with various alternatives evaluated for the proposed modification to the temporary weir.

By parallel agreement, the District and the SBWA also jointly funded another study for establishing minimum flow requirements downstream of Lake Washington. By proper scheduling, results from that study have been used as a basis for completing this study.

Under this study, detailed hydraulic and hydrologic analyses have been performed to evaluate the water availability from Lake Washington and its adequacy to meet minimum flow requirements. The frequency of low stages reached in the lake has been used as a criterion. The current water withdrawal from the lake is about 14 million gallons per day (MGD), on an average annual basis. The water demands projected at the time of commencement of this study were about 25 MGD by the year 2000 and 30 MGD by the year 2030. Recent information supplied by the SBWA indicates that these projections are low and that a more accurate projection is 30.40 MGD by the year 2000 and 43.81 MGD by the year 2030. The original water use projections have been used as the basis of this report. Studies have been conducted to determine whether Lake Washington can meet the projected water demands without adverse impacts to the environmental and socio-economic considerations discussed herein.

The conditions evaluated are:

I. Existing Basin Conditions

1. Existing Weir (crest at 13.50 ft NGVD)

2. Modified Weir Conditions

a. Weir Crest at 14.00 ft. NGVD

b. Weir Crest at 13.00 ft. NGVD

c. Weir Crest at 12.00 ft. NGVD

D. No Weir

II. The Upper St. Johns River Basin Project Conditions

1. Existing Weir

2. Modified Weir Conditions

a. Weir Crest at 14.00 ft. NGVD

b. Weir Crest at 13.00 ft. NGVD

c. Weir Crest at 12.00 ft. NGVD

d. No Weir

The following analyses (A,B,C and D below) are performed for the above listed conditions with three different quantities of lake withdrawal, i.e., 14 MGD, 25 MGD, and 30 MGD.

A. Estimate 1-day, 7-day, 14-day, 30-day, and 60-day low stages (for return periods T= 5 yr, 10 yr, 25 yr, 50 yr, 100 yr, and 200 yr) in Lake Washington.

B. For each condition described, determine whether the general hydrologic criteria established for the minimum stage and flow requirements of the river/floodplain marsh are satisfied.

C. For the critical location downstream of Lake Washington (RM 253.1) as described in TP 87-3 (Reference No.4), "Establishment of Minimum Surface Water Requirements for the Greater Lake Washington Basin," evaluate the low flow and stages described under A, and the results described under B.

D. Estimate 1-day to 60-day flood stages for return periods 5 yr, 10 yr, 25 yr, 50 yr, 100 yr, and 500 yr for various conditions described.

Chapters II and III give a brief description of the Upper St. Johns River Basin and its climatology. Chapter IV describes various procedures used in this study. Chapter V details the criteria to be considered for determining the water availability from Lake Washington and evaluation of the same under different alternative conditions. Chapters VI and VII present various water management considerations and the pertinent analyses and results. A summary and conclusions of the study are presented in Chapter VIII.

CHAPTER II

The Upper St. Johns River Basin

About 2000 square miles of drainage area from the headwaters of the St. Johns River near the Florida's Turnpike in St. Lucie and Indian River counties to State Road 46 south of Lake Harney (Fig. 2-1) is commonly designated as the Upper St. Johns River Basin (USJRB). For various water management study purposes, the St. Johns River in the USJRB has been divided into seven major river reaches and a special hydrologic unit named C-25 Extension (C-25X) Basin (Fig. 2-2). In general, major highways are the dividing lines for these major river reaches. Drainage areas associated with each major river reach have been further divided into sub-basins based on the drainage divides. Major changes have been taking place in the flow regime due to alterations in the river valley and floodplain upstream of Lake Washington in the past several decades. When the USJRB Project is implemented more significant changes will occur. Full details of the USJRB Project are available in the U.S. Army Corps of Engineer's GDM (1985). The following is a brief description of pertinent features of the existing river valley/floodway and the expected changes under the USJRB Project upstream of Lake Washington.

2.1 Existing Conditions

2.1.1 St. Johns River south of Fellsmere Grade

The existing floodway/floodplain (Fig. 2-3) is predominantly riverine marsh. It is separated by dikes from the adjoining agricultural and other undeveloped and semi-developed lands.

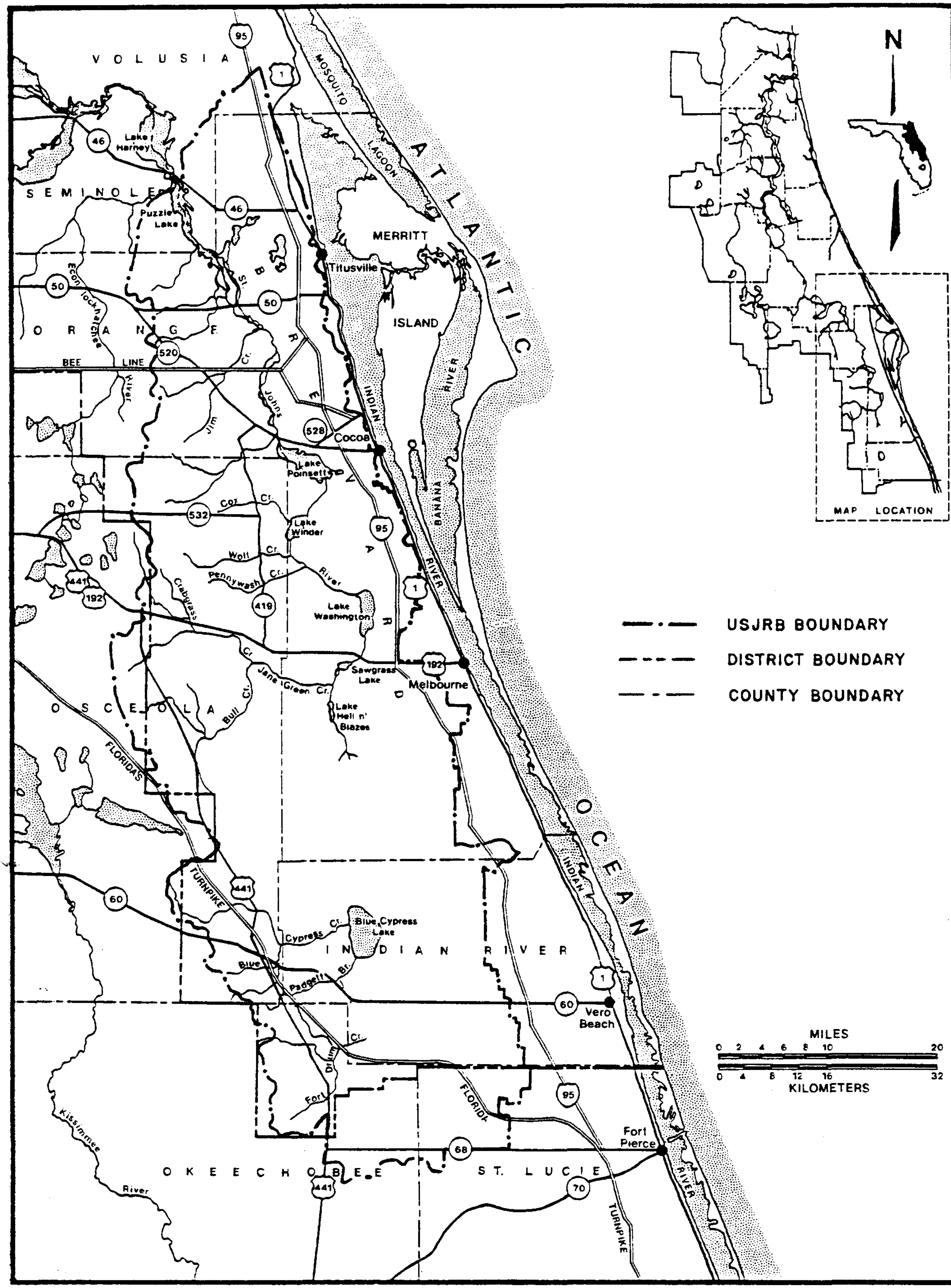


Figure 2-1. The Upper St. Johns River Basin

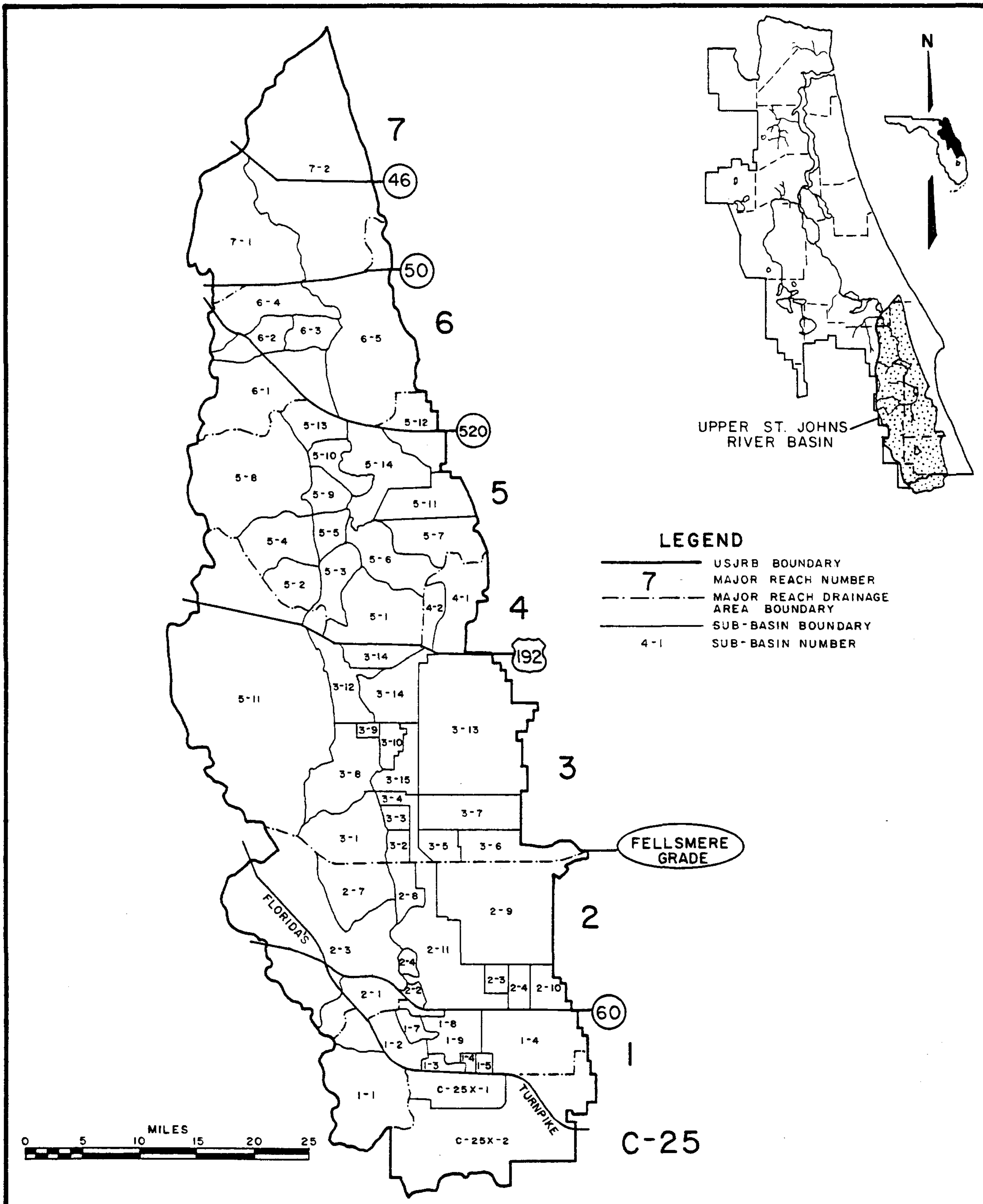


Figure 2-2. Major River Reaches and the Sub-basins of the Upper St. Johns River Basin

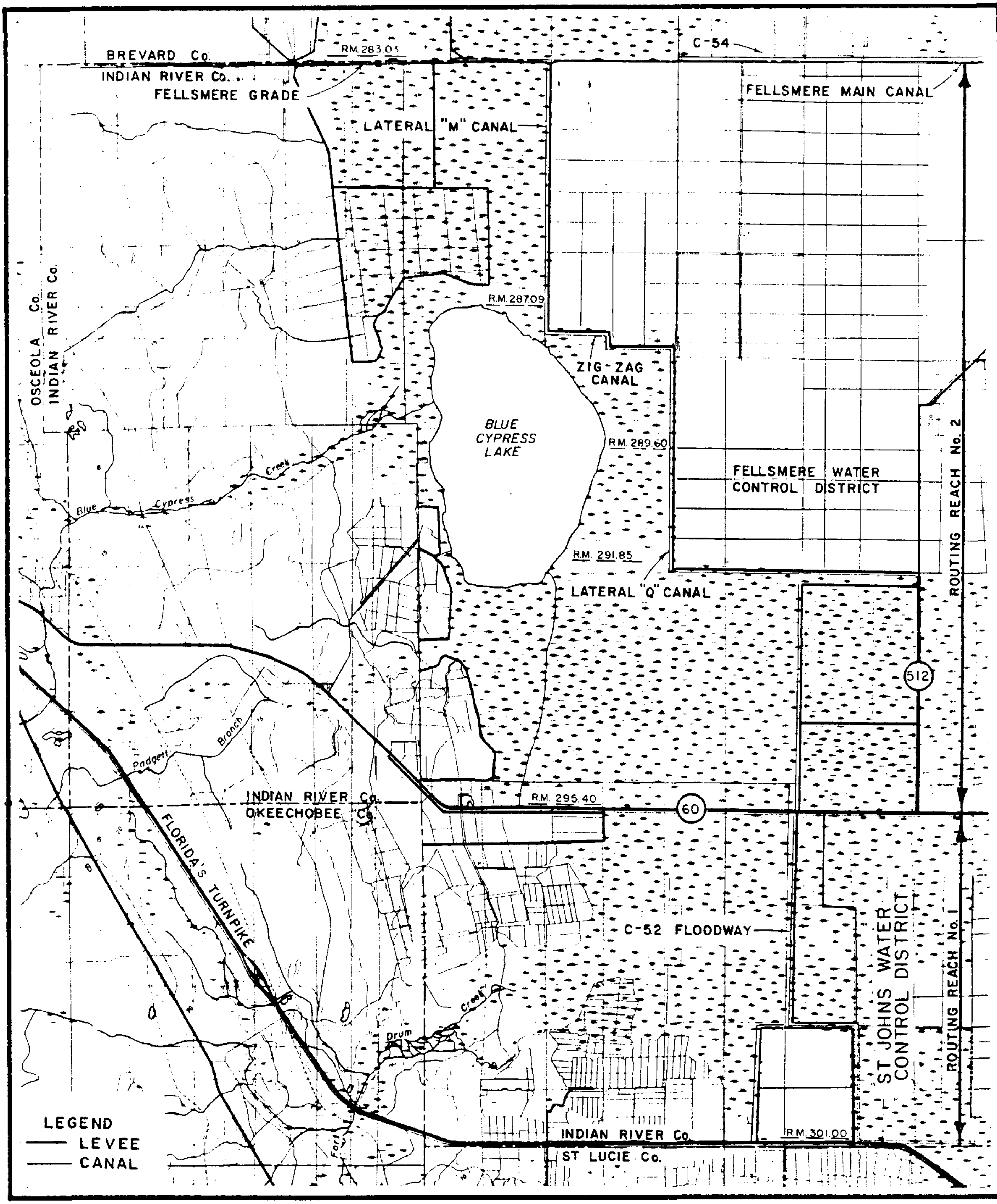


Figure 2-3. The St. Johns River South of Fellsmere Grade: Existing Conditions

Most of the marsh becomes dry during low water periods. Ditches on the marsh side along some of the dikes, e.g., C-52 floodway south of S.R.60 and Fellsmere's lateral Q, zig-zag and lateral M canals between Fellsmere Grade and S.R.60 carry most of the discharge when stages are low. The Fellsmere Grade, an abandoned highway, located on the Indian River/Brevard County line at River Mile (RM) 283.03, impounds water south of the Grade. Discharge to downstream reaches occurs through a gap and some minor washouts on the western side of the Fellsmere Grade (west-side gap) (Figure 2-4), through an outlet structure, S-1, and over the Grade when it is overtopped (24.5 ft. to 25.0 ft. NGVD).

To realize maximum storage benefits, a discharge regulation schedule has been developed for structure S-1 (S-1). The structure is closed when Blue Cypress Lake falls below 23.0 ft. NGVD during June through September and 24.5 ft. NGVD during October through May. Flow through the west-side gap is estimated to be 0 cfs at 21.5 ft NGVD, 70 cfs at 23.5 ft. NGVD and 130 cfs at 24.5 ft. NGVD. The total outflow, when S-1 is open, is estimated as 1680 cfs at 24.5 ft. NGVD, and 3750 cfs at 27.5 ft. NGVD.

Excess floodwaters from the St. Johns Water Control District (sub-basin 1-6, Fig. 2-2) are released into the marsh floodway above S.R. 60. About 60% of flood discharge originating in the Fellsmere Water Control District (Sub-basin 2-9, Fig. 2-2) is diverted to the Indian River through Fellsmere Canal (Fig. 2-4).

2.1.2 St. Johns River Between Fellsmere Grade and U.S.192

The St. Johns River is discernible as a channel near Lake Hell'n blazes northward (Fig. 2-5). As in the upper reaches,

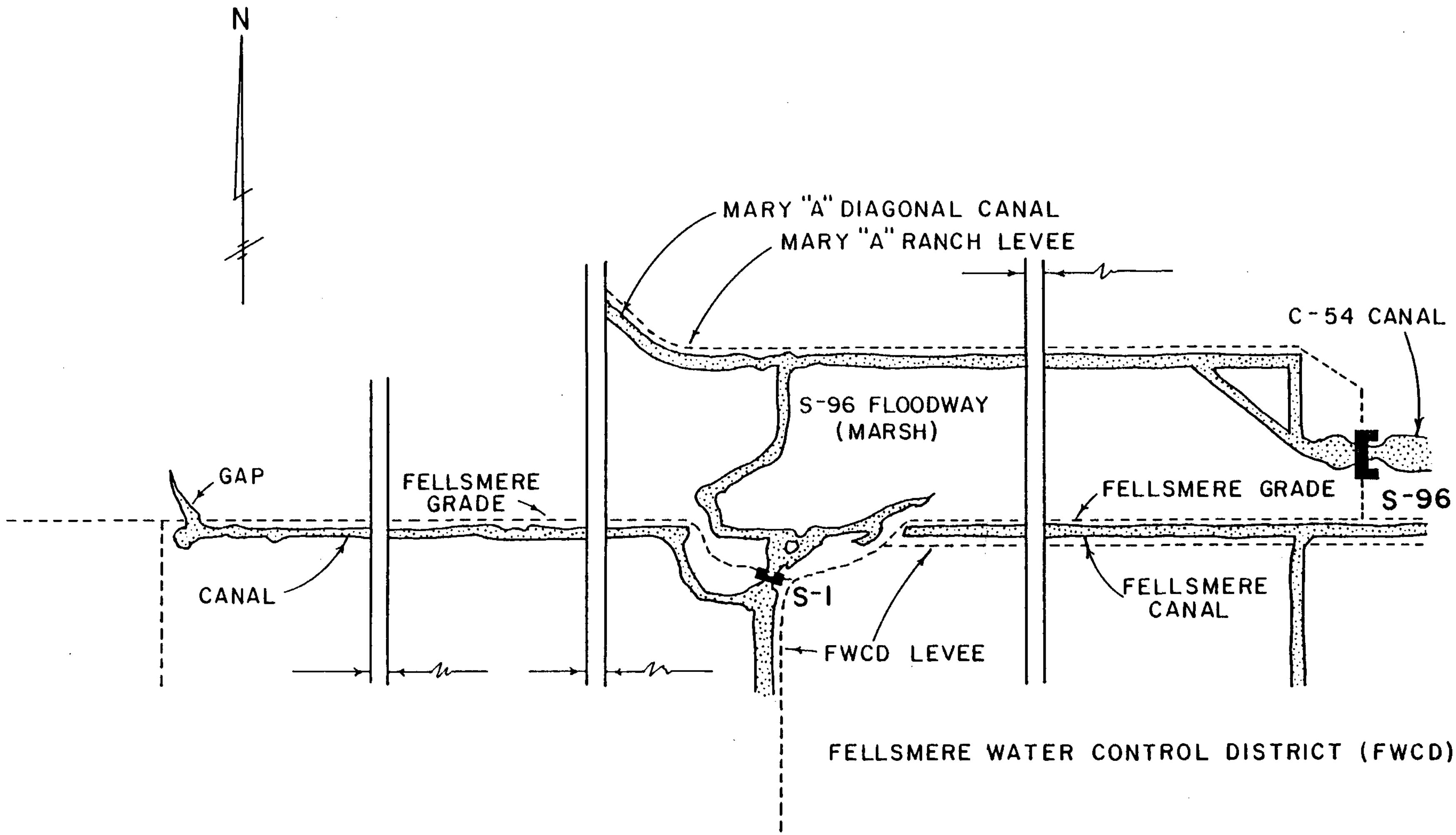


Figure 2-4. The Canal and Structure Configuration near Fellsmere Grade: Existing Conditions

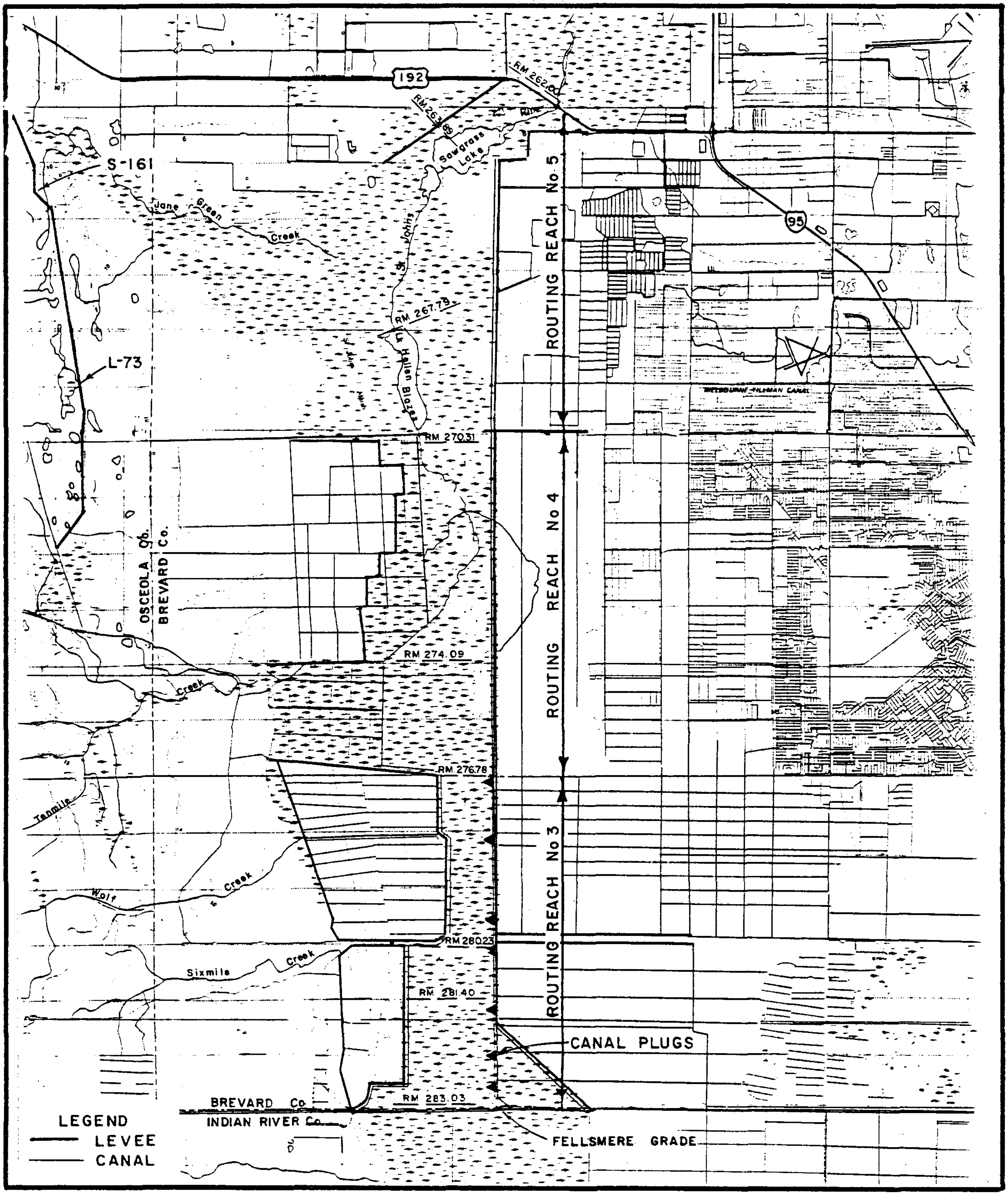


Figure 2-5. The St. Johns River Between Fellsmere Grade and State Road 500 (U.S. 192): Existing Conditions

dikes separate private lands from the reverine marsh. Ditches exist on the marsh side along the dikes, but they have been recently (March - July, 1986) plugged at many locations as a part of the USJRB project. The marsh conveys the discharge as sheet flow to the St. Johns River. Drainage originating in the Water Control District of South Brevard (Sub-basin 3-13, Fig. 2-2) and sub-basin 3-6 (Fig. 2-2) is entirely diverted to the Indian River.

To prevent downstream flooding and to provide a favorable tailwater condition for S-1, a portion of the discharge received from upstream can be diverted to the Indian River through Canal C-54 by operating Structure S-96 (Fig. 2-4) following an approved structure operations schedule. This schedule provides that the structure is opened when the elevation of Blue Cypress Lake exceeds 25.20 ft. NGVD. The diverted discharge varies from 1500 cfs at elevation 25.20 ft. NGVD to 2400 cfs at 28.00 ft. NGVD or greater.

The Jane Green Creek Basin west of the river valley is partially regulated by the Levee-73 system (Fig. 2-5). This levee with Structure S-161 (S-161) was constructed as a part of the 1962 USJRB Project to control flood waters from the western upland tributaries. The levee, however, has a gap located north of S-161 and thus is not fully effective.

2.1.3 Lake Washington Basin

The Lake Washington weir is the outlet for discharge from this area (Fig. 2-6). However, under high stages the weir and the surrounding marshland are fully submerged and the flow

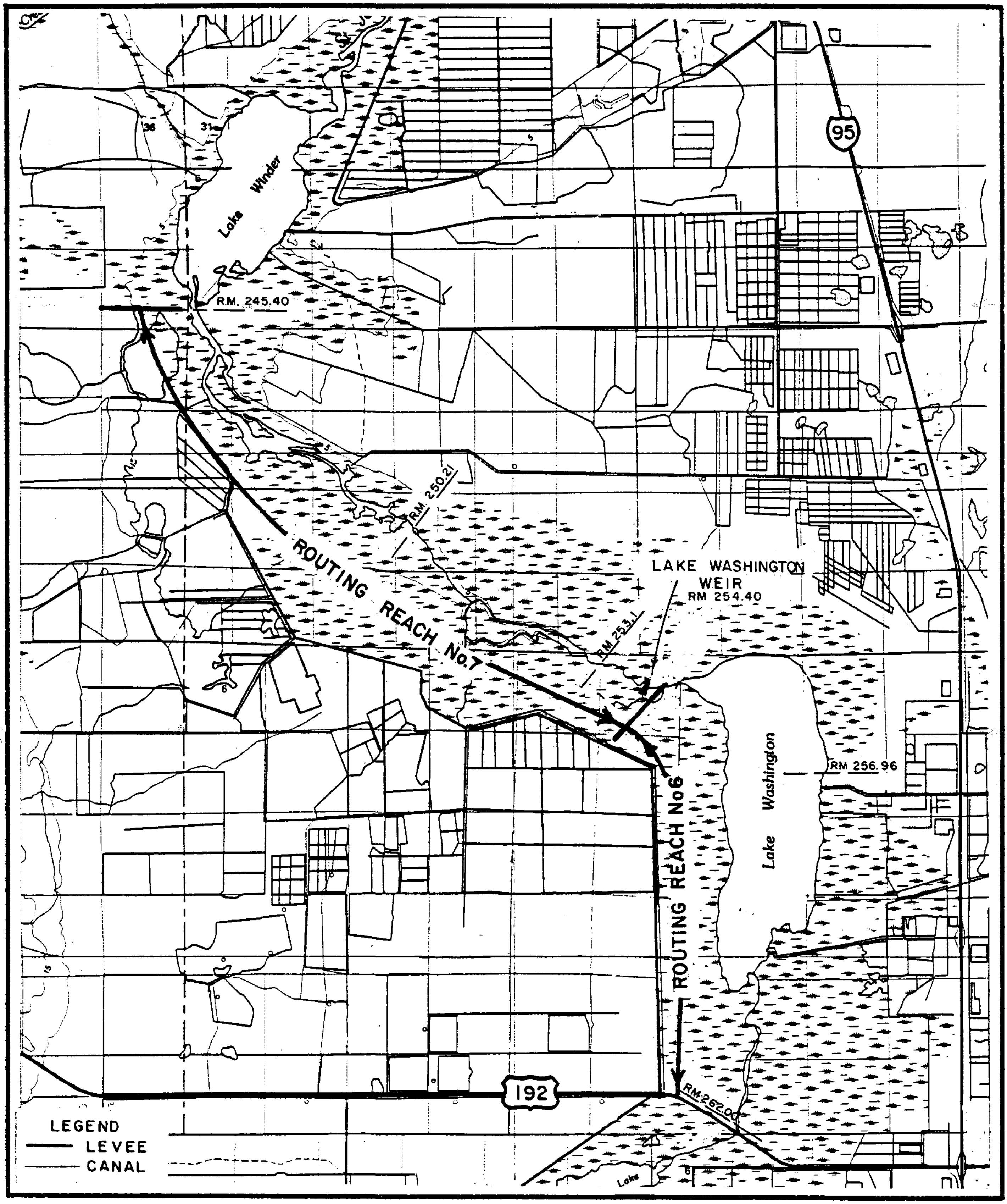


Figure 2-6. The St. Johns River Between State Road 500 (U.S. 192) and Lake Winder

stretches across a width of 2 to 4 miles. The lake has a poorly defined shoreline with dense vegetation separating the marsh along most of its boundary. This shoreline condition makes it difficult to define the water surface elevation at which flow downstream of the lake comes from around the weir rather than just over the weir. Based on the United States Geological Survey (USGS) records of stream flow data for the St. Johns River at U.S. 192, water surface elevation data in Lake Washington, and other hydraulic analyses (e.g., the U.S. Army Corps of Engineers' HEC-2 Computer Program) it is estimated that the lake holds water up to approximately 14.8 ft. NGVD with no appreciable spill over its perimeter.

The monthly mean, maximum and minimum elevations recorded for Lake Washington are presented in Tables 2-1 through 2-3, respectively. These tables are compiled from the USGS records. The mean low and high stages recorded for various durations are given in Tables 2-4 and 2-5, respectively. Fig. 2-7 presents the monthly stage hydrograph for the period of record (1942-present).

The lake levels fluctuate between 9.88 ft. NGVD and 20.39 ft NGVD during the period of record. Until 1953/54 the lake levels were high and remained above 14.00 ft. NGVD. Existence of river jams are considered the primary cause for these high stages (Cox, et al., 1976). The jams were floating islands of peat and vegetation lodged in the river channel for several miles north of Lake Washington. With the removal of the jams in the early 1950's the lake stages declined. Between 1961 and 1977, i.e., until the current sheetpile weir with crest elevation at 13.5 ft.

Table 2-1 Recorded Monthly Mean Elevations for Lake Washington, ft. NGVD

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1942								17.07	16.91	16.58	16.26	16.11
1943	15.96	15.80	15.82	15.67	15.43	15.52	16.46	17.49	17.60	17.90	17.02	16.53
1944	16.29	16.04	15.91	16.02	15.73	15.78	16.07	16.85	17.18	17.41	17.64	16.77
1945	16.76	16.50	16.07	15.71	15.45	15.40	17.32	17.12	17.48	17.72	17.18	16.89
1946	16.63	16.48	16.45	16.02	15.82	16.27	16.49	17.47	17.28	17.16	16.79	16.55
1947	16.28	16.40	16.99	16.81	16.30	16.67	17.58	17.59	18.04	19.19	18.32	17.57
1948	17.27	17.32	16.94	16.60	16.32	16.11	16.27	17.04	17.81	19.11	17.77	17.21
1949	16.88	16.64	16.29	16.11	15.73	15.72	16.41	17.08	18.06	18.75	17.76	17.10
1950	16.95	16.61	16.35	16.18	15.86	15.58	15.54	15.31	15.66	16.94	17.74	17.18
1951	16.79	16.69	16.40	16.49	16.69	16.38	16.35	16.91	16.97	17.70	17.27	17.16
1952	16.72	16.62	16.75	16.78	16.03	15.52	15.29	16.15	16.83	17.84	18.09	17.03
1953	16.64	16.64	16.31	16.37	15.87	14.72	14.83	16.77	18.96	19.56	18.18	17.81
1954	16.96	16.45	15.93	15.16	14.22	16.43	17.13	16.95	16.83	17.68	17.18	16.80
1955	16.43	16.32	15.73	15.02	13.71	13.38	16.39	16.37	17.17	16.95	16.01	14.83
1956	14.18	13.70	12.72	11.94	11.61	11.18	11.27	11.07	12.82	17.55	17.85	16.41
1957	15.66	15.00	15.18	15.39	14.82	15.63	15.68	16.04	16.84	16.76	15.73	14.92
1958	16.16	16.58	16.49	16.33	15.53	14.47	13.68	14.25	14.42	14.58	14.48	13.79
1959	14.04	14.61	15.94	16.49	15.25	15.33	17.09	16.62	16.43	17.32	17.54	16.13
1960	15.26	15.42	16.90	17.11	15.54	15.87	17.27	17.97	18.26	19.65	17.35	15.82
1961	15.44	15.26	14.32	13.78	12.50	11.58	13.40	12.60	12.58	12.63	11.53	11.54
1962	11.51	11.41	11.27	11.24	10.80	10.60	11.32	14.50	16.27	16.28	15.39	14.74
1963	13.95	14.56	15.69	14.14	12.69	12.96	13.57	13.50	14.30	15.74	15.46	15.71
1964	15.57	15.88	15.17	13.68	13.57	13.64	13.18	14.34	17.60	15.89	14.70	14.13
1965	13.74	13.57	13.71	13.21	12.66	12.87	13.78	14.30	13.98	15.29	15.15	14.17
1966	14.24	15.45	16.34	14.74	13.41	14.88	15.54	16.09	16.05	16.61	15.41	14.20
1967	13.27	13.53	13.51	12.79	12.10	11.97	14.07	15.18	14.60	14.02	13.48	13.35
1968	13.12	12.78	12.42	12.00	11.74	16.20	16.54	15.10	14.61	15.06	15.12	14.30
1969	14.04	13.66	14.84	14.74	14.31	14.54	14.13	15.37	15.47	17.29	16.83	15.78
1970	15.50	15.20	14.78	14.85	13.42	12.45	12.78	13.45	13.92	13.72	13.31	12.74
1971	12.36	12.95	13.38	12.55	11.62	11.25	12.20	14.30	13.66	13.63	14.42	13.70
1972	12.91	14.06	13.95	13.16	12.50	13.57	14.98	14.28	14.66	13.52	12.47	13.79
1973	14.19	14.87	13.98	14.47	13.22	12.91	14.24	14.92	15.28	16.16	15.60	14.34
1974	13.59	12.92	12.44	11.79	10.95	10.72	15.68	16.60	16.44	15.87	13.98	12.92
1975	12.59	12.13	11.83	10.99	10.11	10.88	12.75	14.09	14.47	15.51	14.69	13.33
1976	12.28	12.08	12.13	11.73	11.75	14.53	15.48	15.70	16.38	15.51	14.43	14.12
1977	13.99	13.85	13.66	13.20	12.65	12.87	12.72	12.71	13.94	14.21	14.26	14.75
1978	14.83	14.90	15.17	14.21	13.69	13.81	14.80	17.16	15.92	14.39	13.91	13.86
1979	14.80	15.31	14.37	13.63	14.42	14.79	13.99	14.15	17.12	17.21	15.26	14.22
1980	14.08	14.29	14.52	13.83	13.77	13.57	13.43	13.42	13.52	13.32	13.05	13.27
1981	13.61	13.78	13.63	13.30	12.66	12.25	11.83	11.73	13.18	13.94	13.96	13.78
1982	13.72	13.75	13.81	14.09	14.13	15.38	16.55	16.37	15.84	15.29	14.81	14.53
1983	14.20	15.43	16.35	15.69	14.13	14.35	14.60	14.43	14.95	14.98	15.50	15.12
1984	15.53	14.72	14.35	14.41	13.86	13.82	14.60	15.68	15.14	15.00	14.30	14.85
1985	14.24	13.82	13.67	13.81	13.62	13.46	13.83	14.44	16.00	17.27	15.66	14.41
1986	14.20	14.04	13.80	13.49	12.79	12.81	14.34	14.44	15.01	14.90	14.49	14.10
MEAN	14.85	14.86	14.82	14.45	13.84	14.06	14.81	15.32	15.81	16.20	15.62	15.05
MAX	17.27	17.32	16.99	17.11	16.69	16.67	17.58	17.97	18.96	19.65	18.32	17.81
MIN	11.51	11.41	11.27	10.99	10.11	10.60	11.27	11.07	12.58	12.63	11.53	11.54

Table 2-2 Recorded Monthly Minimum Elevations for Lake Washington, ft. NGVD

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1942								16.77	16.69	16.22	16.09	16.06
1943	15.87	15.66	15.67	15.55	15.25	15.39	15.75	17.29	17.43	17.49	16.71	16.42
1944	16.19	15.93	15.74	15.94	15.54	15.51	15.81	16.51	17.01	16.84	17.09	16.57
1945	16.49	16.34	15.80	15.58	15.16	14.82	17.08	16.76	16.71	17.35	17.00	16.74
1946	16.56	16.41	16.37	15.77	15.59	16.11	16.33	17.02	17.21	16.90	16.67	16.43
1947	16.17	16.13	16.74	16.52	16.15	16.10	17.42	17.48	17.43	18.76	17.84	17.37
1948	17.18	17.08	16.76	16.45	16.18	16.00	15.97	16.59	17.26	18.26	17.39	17.03
1949	16.72	16.54	16.15	15.98	15.46	15.48	16.14	16.81	17.59	18.32	17.37	16.93
1950	16.79	16.41	16.25	16.01	15.74	15.34	15.42	15.23	15.37	15.79	17.41	16.99
1951	16.61	16.59	16.19	16.10	16.56	16.25	16.30	16.54	16.85	17.34	16.97	16.91
1952	16.51	16.54	16.53	16.39	15.85	15.08	14.91	15.61	16.69	17.29	17.45	16.77
1953	16.52	16.53	16.11	16.30	15.08	14.46	14.27	16.36	17.94	18.83	17.77	17.32
1954	16.68	16.25	15.63	14.76	13.71	14.34	16.94	16.73	16.65	17.39	17.08	16.61
1955	16.32	16.25	15.22	14.38	13.33	12.92	15.37	16.31	16.52	16.63	15.31	14.48
1956	13.95	13.29	12.19	11.75	11.32	11.06	11.04	10.99	11.14	14.70	16.99	15.80
1957	15.44	14.72	14.90	14.97	14.51	15.32	15.52	15.94	16.49	16.27	15.29	14.57
1958	15.14	16.15	16.27	15.98	15.09	13.92	13.48	13.74	14.26	14.12	14.10	13.42
1959	13.81	14.36	14.79	15.90	14.74	14.59	16.89	16.17	15.93	16.73	16.85	15.68
1960	14.81	14.72	15.59	16.14	14.83	14.83	16.98	17.18	16.95	18.55	16.40	15.37
1961	14.98	14.76	14.09	13.31	11.69	11.42	11.93	11.96	11.95	11.79	11.41	11.43
1962	11.46	11.36	11.17	11.10	10.54	10.52	10.73	12.41	15.78	15.63	15.20	14.34
1963	13.73	13.71	15.12	13.15	12.42	12.79	13.32	13.29	13.59	15.22	14.97	15.28
1964	15.31	15.59	14.53	13.13	13.21	13.41	13.00	13.12	16.80	15.30	14.26	13.94
1965	13.59	13.33	13.37	12.85	12.34	12.26	13.48	14.02	13.87	14.17	14.65	13.98
1966	13.91	15.06	15.55	13.77	13.19	13.77	15.18	15.31	15.89	16.19	14.77	13.65
1967	13.03	13.27	13.17	12.43	11.79	11.75	12.85	14.88	14.49	13.66	13.34	13.24
1968	12.96	12.61	12.27	11.78	11.60	12.25	15.71	14.84	14.54	14.37	14.82	13.89
1969	13.84	13.59	13.59	14.16	14.11	14.13	13.73	14.49	15.23	15.82	16.21	15.51
1970	15.40	14.92	14.64	14.05	12.87	12.18	12.13	13.26	13.79	13.50	12.89	12.54
1971	12.14	12.04	12.98	12.11	11.29	11.02	11.23	13.88	13.26	12.97	14.03	13.19
1972	12.78	12.80	13.63	12.65	12.34	12.63	14.63	14.11	14.05	12.87	12.10	12.84
1973	13.83	14.54	13.48	13.34	12.41	12.20	14.04	14.67	15.02	15.76	14.79	14.08
1974	13.09	12.75	12.02	11.35	10.63	10.55	11.91	16.25	16.19	14.92	13.20	12.78
1975	12.36	11.97	11.49	10.50	9.88	10.05	11.61	13.77	14.36	14.93	14.05	12.79
1976	11.98	12.02	12.00	11.43	11.32	12.72	15.35	15.48	16.02	14.88	14.02	13.96
1977	13.85	13.76	13.50	12.96	12.45	12.61	12.52	12.56	12.79	14.03	14.01	14.47
1978	14.74	14.79	14.91	13.67	13.54	13.55	14.09	16.46	14.97	13.90	13.88	13.76
1979	14.15	14.83	13.88	13.48	13.61	14.40	13.82	13.96	14.34	16.25	14.60	13.92
1980	13.78	13.90	13.94	13.70	13.66	13.42	13.25	13.22	13.27	13.13	12.93	13.11
1981	13.57	13.59	13.50	13.05	12.38	11.97	11.70	11.48	12.14	13.80	13.80	13.71
1982	13.66	13.70	13.71	13.90	13.92	14.45	16.37	16.07	15.70	14.77	14.73	14.25
1983	13.99	14.60	16.12	15.00	13.63	13.76	14.22	14.04	14.84	14.76	15.15	14.81
1984	15.13	14.52	14.08	14.02	13.58	13.67	13.79	15.39	14.91	14.49	13.85	14.64
1985	13.92	13.74	13.60	13.59	13.49	13.23	13.61	14.18	14.85	16.57	14.81	13.98
1986	13.97	13.92	13.71	13.17	12.45	12.28	14.24	14.21	14.70	14.48	14.24	13.99
RECORD MIN.	11.46	11.36	11.17	10.50	9.88	10.05	10.73	10.99	11.14	11.79	11.41	11.43

Table 2-3 Recorded Monthly Maximum Elevations for Lake Washington, Ft. NGVD

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1942								17.42	17.05	16.69	16.48	16.21
1943	16.05	15.94	15.89	15.82	15.57	15.76	17.24	17.61	17.89	18.11	17.45	16.67
1944	16.43	16.17	16.02	16.10	15.96	15.99	16.50	17.19	17.31	18.26	18.22	17.06
1945	16.94	16.67	16.32	15.85	15.71	17.41	17.54	17.45	18.30	18.13	17.31	17.11
1946	16.74	16.57	16.58	16.27	16.10	16.33	16.96	17.78	17.37	17.43	16.95	16.68
1947	16.42	16.69	17.18	17.12	16.55	17.51	17.71	17.78	19.56	19.67	18.81	17.81
1948	17.44	17.48	17.09	16.80	16.45	16.17	16.55	17.32	19.74	19.80	18.22	17.42
1949	17.02	16.73	16.48	16.19	16.00	16.13	16.78	17.48	18.42	19.10	18.27	17.33
1950	17.05	16.77	16.44	16.35	16.09	15.81	15.68	15.42	15.79	18.68	18.34	17.39
1951	16.97	16.76	16.60	16.84	16.86	16.52	16.45	17.05	17.36	18.02	17.50	17.46
1952	16.91	16.71	17.00	17.03	16.37	15.89	15.67	16.69	17.27	18.85	18.79	17.40
1953	16.75	16.73	16.56	16.46	16.38	15.05	16.28	17.82	19.58	20.05	18.77	18.19
1954	17.29	16.67	16.18	15.70	14.75	17.32	17.34	17.10	17.35	17.88	17.42	17.07
1955	16.60	16.39	16.24	15.37	14.30	15.13	16.69	16.50	17.67	17.27	16.58	15.27
1956	14.48	13.99	13.27	12.17	11.77	11.34	11.39	11.25	14.60	20.06	18.92	16.92
1957	15.87	15.44	15.46	15.63	15.31	15.77	16.05	16.46	17.08	17.07	16.24	15.24
1958	16.95	17.03	16.60	16.59	15.94	15.06	13.89	14.81	14.66	14.84	14.71	14.09
1959	14.38	14.77	17.24	17.18	15.85	16.89	17.29	16.96	17.32	18.29	18.25	16.79
1960	15.66	15.76	18.86	18.26	16.10	16.92	18.24	18.56	20.37	20.39	18.49	16.33
1961	15.74	15.59	14.72	14.05	13.26	11.87	14.20	13.61	13.44	13.41	11.77	11.61
1962	11.57	11.47	11.41	11.37	11.08	10.70	12.29	15.75	16.86	16.86	15.58	15.17
1963	14.32	15.59	15.95	15.09	13.11	13.37	13.80	13.93	15.98	16.09	16.14	16.24
1964	15.78	16.08	15.77	14.49	13.86	13.91	13.42	16.97	17.89	16.71	15.28	14.27
1965	13.92	13.75	13.90	13.85	12.91	13.54	14.07	14.63	14.23	15.59	15.40	14.61
1966	15.27	16.55	17.03	15.50	13.75	15.73	15.91	16.36	16.24	16.91	16.15	14.73
1967	13.62	13.76	13.74	13.14	12.41	12.63	14.86	15.39	14.82	14.46	13.66	13.47
1968	13.31	12.95	12.70	12.26	12.13	17.57	17.11	15.61	14.86	15.58	15.44	14.80
1969	14.14	13.80	15.86	15.44	14.64	15.00	14.77	15.67	15.77	17.99	17.35	16.14
1970	15.62	15.42	15.11	15.28	13.97	12.82	13.53	13.73	14.09	14.08	13.70	12.89
1971	12.57	13.64	13.72	12.95	12.11	11.38	14.31	14.57	13.87	14.60	14.67	14.06
1972	13.15	14.54	14.24	13.66	12.75	15.16	15.21	14.58	14.97	14.02	12.84	14.07
1973	14.88	15.04	14.50	14.95	14.22	14.43	14.64	15.07	15.74	16.59	16.44	14.74
1974	14.05	13.06	12.77	12.11	11.30	11.70	16.75	16.80	16.62	16.40	14.85	13.20
1975	12.82	12.34	11.99	11.45	10.46	11.57	13.71	14.46	14.89	15.80	15.22	14.01
1976	12.75	12.15	12.28	11.98	12.63	15.45	15.62	16.00	16.76	16.20	14.82	14.23
1977	14.11	13.97	13.76	13.49	12.93	13.01	12.92	12.81	14.35	14.35	14.49	14.96
1978	14.95	15.08	15.32	14.87	13.86	14.09	16.13	17.45	16.75	15.00	13.92	14.15
1979	15.43	15.57	14.80	13.86	14.83	15.00	14.35	14.30	18.31	18.13	16.21	14.56
1980	14.35	14.87	14.92	13.97	13.91	13.79	13.59	13.60	13.65	13.52	13.16	13.62
1981	13.66	13.92	13.80	13.56	13.03	12.41	11.96	12.13	14.15	14.13	14.12	13.89
1982	13.81	13.80	13.93	14.26	14.36	16.51	16.80	16.79	16.06	15.72	14.90	14.74
1983	14.57	16.42	16.57	16.16	14.93	14.66	14.77	14.83	15.08	15.49	15.68	15.64
1984	15.74	15.08	14.52	14.64	14.31	14.24	15.35	15.86	15.35	15.17	14.83	14.95
1985	14.62	13.92	13.82	14.00	13.81	13.65	14.15	14.78	17.64	17.74	16.53	14.77
1986	14.35	14.17	13.91	13.73	13.15	14.18	14.40	14.76	15.27	15.25	14.72	14.25
RECORD MAX.	17.44	17.48	18.86	18.26	16.86	17.57	18.24	18.56	20.37	20.39	18.92	18.19

Table 2-4 Mean Low Stages Recorded for Various Durations for Lake Washington

@@@@@ LAKE WASHINGTON NR EAU GALLIE, ELEVATION (1943-1986) - FT NGVD

LOWEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING SEPT 30

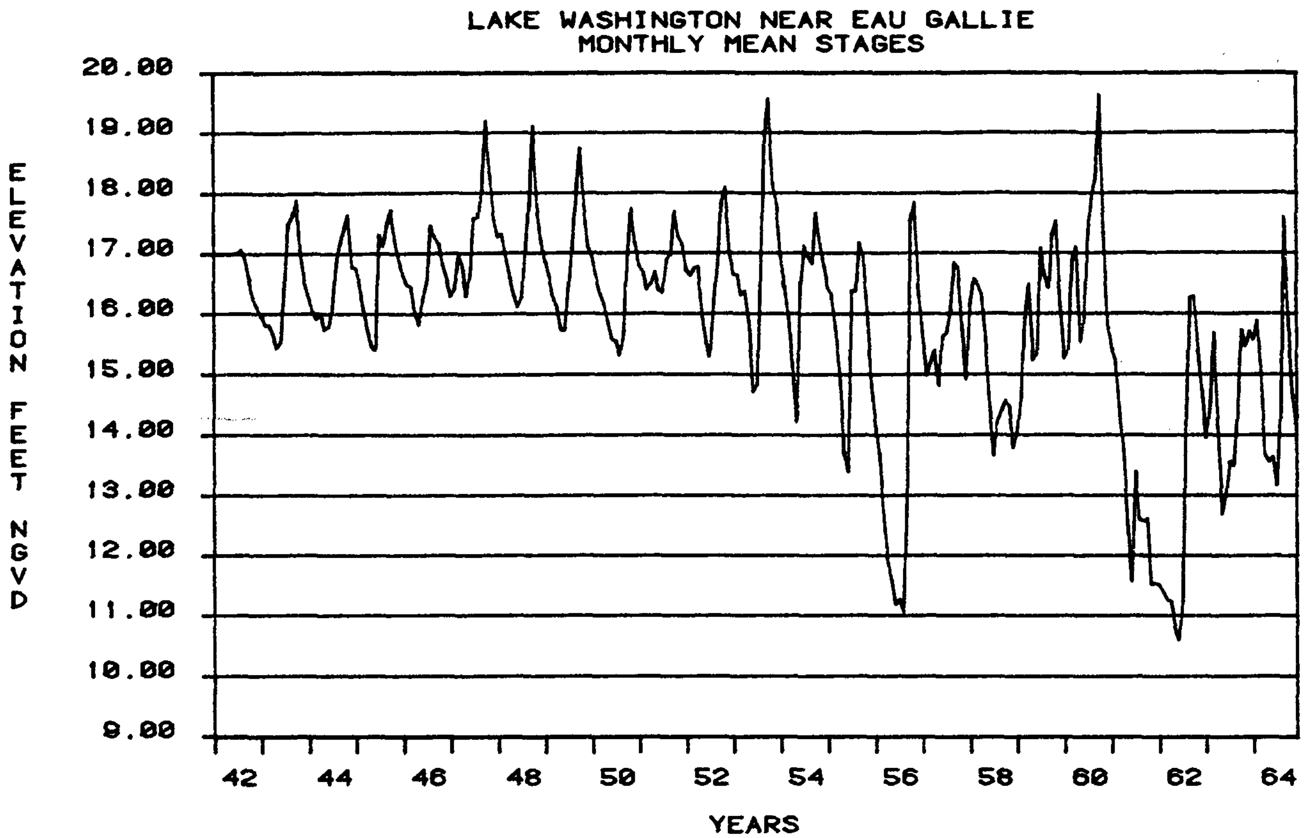
YEAR	1	7	14	30	60	120	183	274	1 YEAR
1943	15.25	15.32	15.35	15.41	15.46	15.61	15.70	15.87	16.23
1944	15.51	15.53	15.57	15.64	15.75	15.86	15.92	16.13	16.44
1945	14.82	14.86	14.90	15.03	15.30	15.62	15.97	16.34	16.64
1946	15.59	15.61	15.66	15.74	15.91	16.12	16.25	16.47	16.73
1947	16.10	16.13	16.17	16.20	16.31	16.50	16.53	16.67	16.93
1948	15.97	15.99	16.03	16.09	16.16	16.31	16.54	16.80	17.23
1949	15.46	15.49	15.49	15.56	15.72	15.93	16.15	16.45	16.92
1950	15.23	15.26	15.27	15.31	15.43	15.52	15.69	16.01	16.47
1951	15.79	15.85	15.86	16.29	16.36	16.47	16.50	16.63	16.79
1952	14.91	14.96	15.01	15.15	15.38	15.72	16.08	16.29	16.57
1953	14.27	14.29	14.32	14.45	14.68	15.43	15.78	16.13	16.67
1954	13.71	13.82	13.93	14.17	14.60	15.32	15.87	16.23	16.81
1955	12.92	12.97	13.02	13.18	13.51	14.41	15.07	15.56	16.02
1956	10.99	11.00	11.01	11.06	11.17	11.26	11.54	12.27	13.19
1957	14.51	14.55	14.58	14.77	15.08	15.09	15.27	15.53	16.01
1958	13.48	13.52	13.55	13.67	13.82	14.19	14.78	15.31	15.44
1959	13.42	13.49	13.58	13.77	13.89	14.21	14.59	14.95	15.39
1960	14.72	14.78	14.85	15.06	15.34	15.78	15.98	16.34	16.72
1961	11.42	11.45	11.50	11.57	11.91	12.43	12.74	13.49	14.52
1962	10.52	10.55	10.56	10.59	10.66	10.92	11.08	11.24	12.05
1963	12.42	12.43	12.49	12.66	12.81	13.15	13.51	13.89	14.31
1964	13.00	13.03	13.08	13.13	13.29	13.42	13.91	14.51	14.96
1965	12.26	12.28	12.34	12.47	12.66	13.08	13.28	13.54	13.88
1966	13.19	13.22	13.25	13.40	13.84	14.63	14.69	14.85	15.11
1967	11.75	11.80	11.81	11.86	12.03	12.56	12.85	13.40	13.94
1968	11.60	11.65	11.69	11.72	11.86	12.21	12.55	13.23	13.78
1969	13.59	13.60	13.63	13.64	13.81	14.13	14.30	14.40	14.63
1970	12.13	12.18	12.23	12.32	12.56	13.01	13.47	14.03	14.69
1971	11.02	11.10	11.20	11.25	11.33	11.83	12.24	12.47	12.84
1972	12.34	12.38	12.41	12.49	12.64	13.23	13.26	13.54	13.81
1973	12.10	12.15	12.24	12.45	12.92	13.47	13.78	13.71	13.98
1974	10.55	10.56	10.59	10.61	10.82	11.45	12.05	13.12	13.95
1975	9.88	9.92	9.98	10.07	10.36	10.93	11.38	12.00	12.72
1976	11.32	11.39	11.41	11.52	11.70	11.90	12.20	13.11	13.80
1977	12.45	12.46	12.50	12.62	12.71	12.73	12.94	13.27	13.64
1978	13.54	13.55	13.58	13.65	13.71	14.07	14.39	14.42	14.81
1979	13.50	13.53	13.56	13.61	13.86	14.22	14.24	14.35	14.57
1980	13.22	13.25	13.29	13.37	13.41	13.48	13.59	13.83	14.28
1981	11.48	11.52	11.58	11.67	11.77	12.04	12.45	12.84	12.96
1982	13.66	13.69	13.70	13.72	13.73	13.77	13.82	14.07	14.62
1983	13.63	13.67	13.72	13.89	14.22	14.37	14.69	14.85	14.89
1984	13.58	13.60	13.66	13.77	13.83	14.07	14.29	14.66	14.81
1985	13.23	13.28	13.35	13.44	13.53	13.64	13.70	13.95	14.26
1986	12.28	12.29	12.34	12.47	12.73	13.21	13.52	13.81	14.36

Table 2-5 Mean High Stages Recorded for Various Durations for Lake Washington

@@@@@ LAKE WASHINGTON NR EAU GALLIE, ELEVATION (1944-1986) - FT NGVD

HIGHEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING MAY 31

YEAR	1	7	14	30	60	120	183	274	1 YEAR
1944	18.11	18.08	18.05	17.96	17.76	17.54	17.20	16.82	16.42
1945	18.26	18.23	18.16	17.92	17.54	17.30	17.10	16.80	16.43
1946	18.30	18.28	18.19	18.00	17.67	17.41	17.30	17.05	16.62
1947	17.78	17.74	17.69	17.49	17.39	17.19	16.96	16.86	16.64
1948	19.67	19.62	19.55	19.29	18.93	18.32	18.05	17.78	17.31
1949	19.80	19.75	19.69	19.32	18.68	18.01	17.64	17.23	16.83
1950	19.10	19.05	18.98	18.76	18.45	17.95	17.62	17.24	16.81
1951	18.68	18.61	18.47	18.11	17.73	17.28	17.00	16.72	16.33
1952	18.02	17.97	17.90	17.71	17.49	17.28	17.12	16.98	16.67
1953	18.85	18.81	18.71	18.42	17.98	17.46	17.18	16.89	16.46
1954	20.05	19.98	19.86	19.69	19.33	18.66	18.05	17.33	16.54
1955	17.88	17.84	17.81	17.69	17.44	17.17	17.13	16.89	16.27
1956	17.67	17.63	17.54	17.31	17.07	16.76	16.30	15.45	14.51
1957	20.06	19.89	19.55	18.89	17.98	16.91	16.30	15.58	14.42
1958	17.08	17.05	17.02	16.99	16.81	16.39	16.16	16.19	15.95
1959	17.24	17.17	17.04	16.72	16.23	15.52	14.96	14.82	14.55
1960	18.86	18.74	18.47	17.87	17.46	16.98	16.90	16.56	16.25
1961	20.39	20.29	20.16	19.92	19.17	18.42	17.79	17.00	16.05
1962	14.83	14.16	14.09	13.75	13.04	12.83	12.39	12.09	11.79
1963	16.86	16.84	16.79	16.60	16.29	15.79	15.22	15.03	14.09
1964	16.24	16.20	16.11	15.89	15.77	15.70	15.62	15.01	14.47
1965	17.89	17.82	17.78	17.61	16.83	15.75	15.09	14.55	14.12
1966	17.03	16.95	16.80	16.43	15.90	15.16	15.13	14.83	14.38
1967	16.91	16.90	16.85	16.62	16.34	16.09	15.80	15.07	14.43
1968	15.39	15.37	15.34	15.19	14.92	14.50	14.13	13.68	13.13
1969	17.57	17.49	17.40	17.12	16.63	15.70	15.49	14.98	14.79
1970	17.99	17.92	17.76	17.52	17.09	16.37	16.06	15.67	15.17
1971	14.09	14.05	13.99	13.93	13.82	13.63	13.33	13.20	12.86
1972	14.67	14.63	14.61	14.52	14.25	14.00	13.82	13.77	13.19
1973	15.21	15.19	15.18	15.06	14.75	14.54	14.05	14.13	13.92
1974	16.59	16.57	16.48	16.27	15.98	15.51	15.10	14.47	13.70
1975	16.80	16.77	16.72	16.64	16.56	16.27	15.27	14.24	13.27
1976	15.80	15.79	15.73	15.54	15.17	14.71	14.18	13.49	12.88
1977	16.76	16.72	16.64	16.39	16.11	15.80	15.38	14.91	14.38
1978	15.32	15.29	15.27	15.19	15.04	14.92	14.70	14.41	13.93
1979	17.45	17.42	17.37	17.19	16.64	15.61	15.02	14.95	14.63
1980	18.34	18.28	18.20	18.03	17.34	16.04	15.44	15.04	14.79
1981	13.92	13.90	13.86	13.81	13.71	13.61	13.44	13.45	13.38
1982	14.36	14.24	14.23	14.18	14.11	13.95	13.88	13.81	13.34
1983	16.80	16.78	16.73	16.62	16.50	16.15	15.72	15.49	15.38
1984	15.74	15.73	15.71	15.59	15.34	15.30	15.14	14.93	14.73
1985	15.86	15.83	15.80	15.69	15.44	15.15	14.96	14.61	14.38
1986	17.74	17.72	17.66	17.42	16.86	15.91	15.33	14.85	14.45



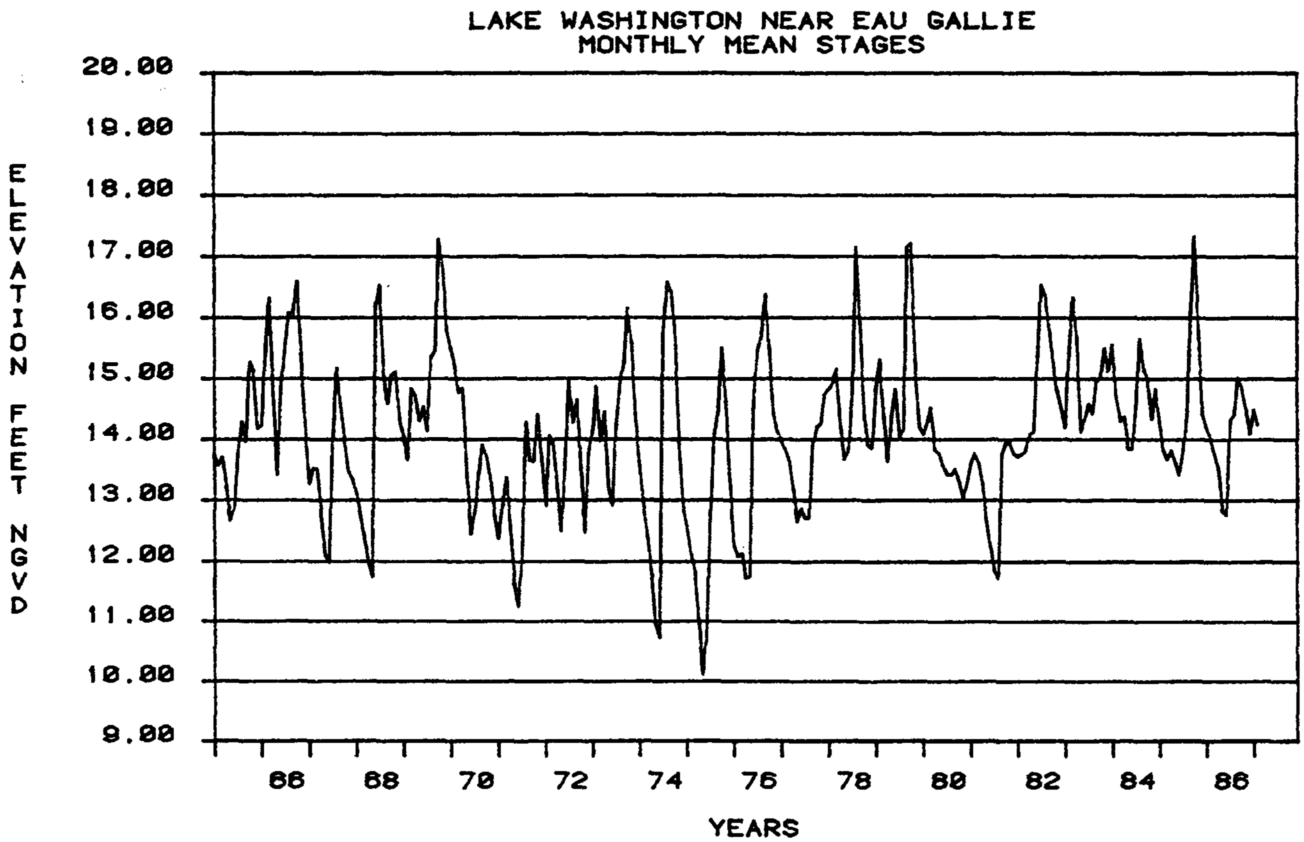


Figure 2-7 Monthly Stage Hydrograph for Lake Washington

NGVD was constructed the annual low stages were below 13.0 ft. NGVD, practically for all years (Table 2-4). After the construction of the weir the lake remained above 13.0 ft. NGVD except during the 1981 and 1986 droughts. The stages were below 14.0 ft. NGVD for a continuous 24 month period during 1980-1982. This was the longest such low stage (drought) period since the records began in 1942 (Fig. 2-6).

2.2 Changes Under the Upper St. Johns River Basin Project

2.2.1 St. Johns River South of Fellsmere Grade

The entire river marsh area lying between Florida's Turnpike and Fellsmere Grade will be converted into two extensive marsh conservation areas, the Fort Drum Marsh Conservation Area (FDMCA) and Blue Cypress Marsh Conservation Area (BCMCA) (Fig. 2-8). In Addition, two water management areas, designated as the St. Johns Water Management Area (SJWMA) and Blue Cypress Water Management Area (BCWMA) will be created adjoining the BCMCA on the east. The marsh conservation areas will provide temporary storage for floodwaters from the western uplands, long-term water storage for agricultural water supply and low flow augmentation downstream, and provide for maintaining an overall hydrologic regime which will promote a healthy marsh ecosystem in the valley. The two water management areas are designed for optimal management of stormwater runoff from the agricultural lands on the east. Objectives include water conservation, reduction of interbasin diversion to the Indian River, flood control

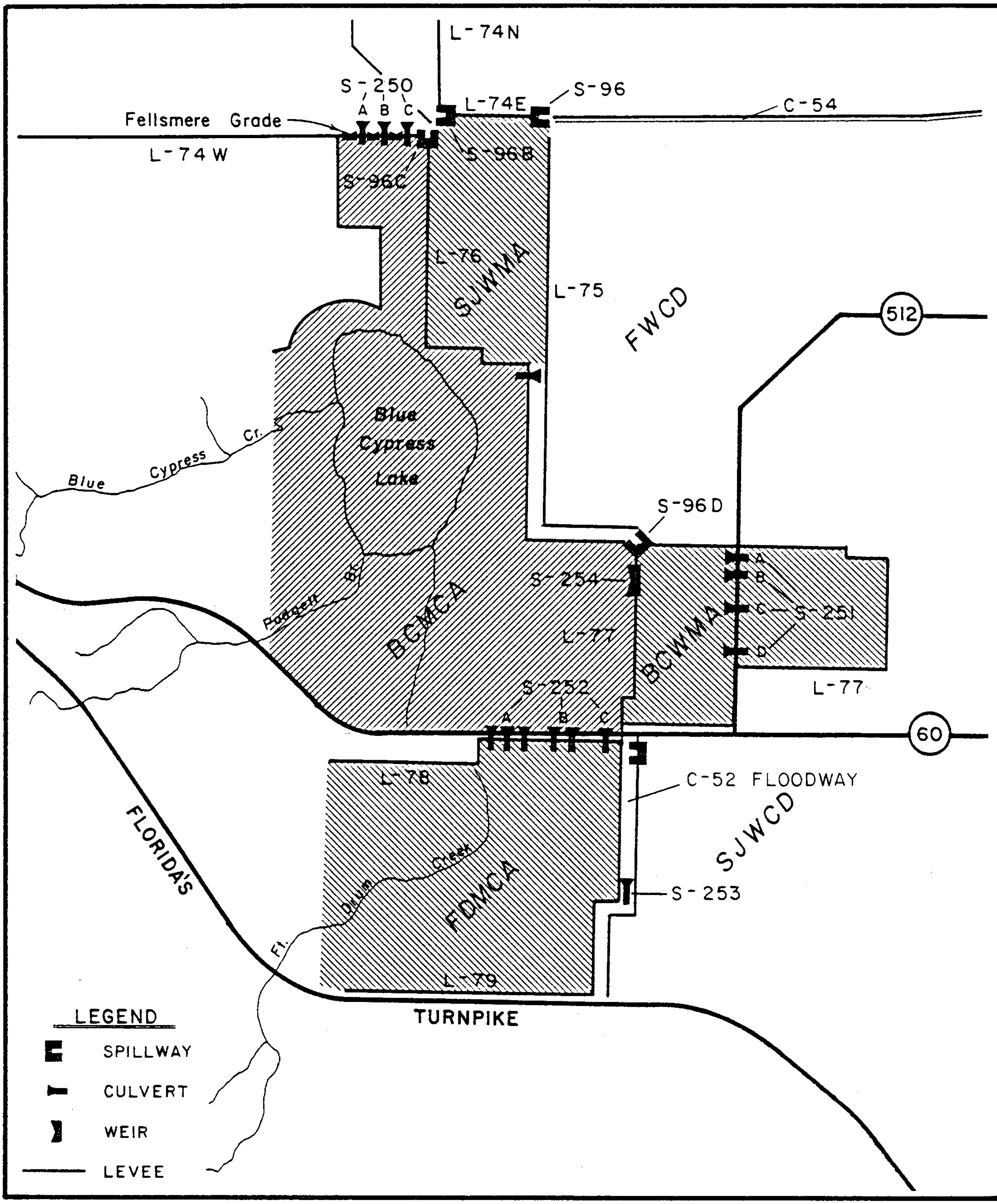


Figure 2-8. The St. Johns River South of Fellsmere Grade Under the USJRB Project.

downstream and water quality improvement by segregating agricultural discharge from the BCMCA.

The FDMCA, a 19,700 acre area located between State Road 60 on the north and Florida's Turnpike on the south, will be enclosed by a new levee system on three sides (Fig. 2-8). Culverts located in the northside levee release waters from the FDMCA (0 to 300 cfs during normal periods and 600 cfs if the FDMCA exceeds 27.50 ft. NGVD) into a borrow canal south of S.R. 60. The water then flows through the existing bridge openings into the BCMCA. Runoff from the C-25X Basin and St. Johns Water Control District is conveyed to the BCWMA via the C-52 floodway.

The BCMCA, comprised of Blue Cypress Lake and the adjoining floodplain marsh between Fellsmere Grade and S.R.60, is about 29,500 acres. Its outlet structure consists of three weirs (each 135 ft. wide) with a crest elevation of 25.00 ft. NGVD and three 72-inch culverts with control elevation at 22.00 ft. NGVD. The BCMCA has a storage volume of about 94,600 acre-ft (AF) at 25.00 ft. NGVD and 62,100 AF at 22.00 ft. NGVD. A major portion of this storage above 22.00 ft. NGVD would be available for low flow augmentation downstream.

The SJWMA and BCWMA, which will be interconnected, together have an area of about 16,000 acres and a storage capacity of about 80,000 AF. They serve as a major source of irrigation water for agricultural lands to the east. Additional water may be withdrawn from the BCMCA, if required. Excess flood waters from the SJWMA, which is located downstream of BCWMA, are released to the marsh downstream and/or diverted to the Indian River.

The two marsh conservation areas, and the two water management areas would be operated under designated discharge/elevation regulation schedules.

2.2.2 St. Johns River Between Fellsmere Grade and U.S.192

The floodway boundaries will be expanded as shown in Fig. 2-9 by the purchase of floodplain areas. A significant feature in this reach will be the 12,000-acre St. Johns Marsh Conservation Area (SJMCA). During low water periods the SJMCA will be a marsh area, but during high water periods it will be a part of the floodway. It will be bounded by a new levee (L-74N) on the east, and the existing levee separating the SJMCA and the existing floodway will be modified at several places and converted into a low berm with its crest elevation at 20.00 ft. NGVD to 22.00 ft. NGVD. The ground level of SJMCA varies from 13.00 ft. NGVD in the north to 19.00 ft. NGVD in the south providing a storage capacity of about 48,000 AF at elevation 20.00 ft. NGVD. This storage volume is about 3.5 times the storage in Lake Washington when Lake Washington is at 13.50 ft. NGVD (the crest elevation of the existing weir).

The allocation of water stored in the SJMCA was not addressed in the USJRB Project GDM (1985). It will be managed by the District for maintaining minimum flows downstream and for permitted consumptive use withdrawals. The SJMCA will be at low water surface elevation by the end of dry season and thus will be

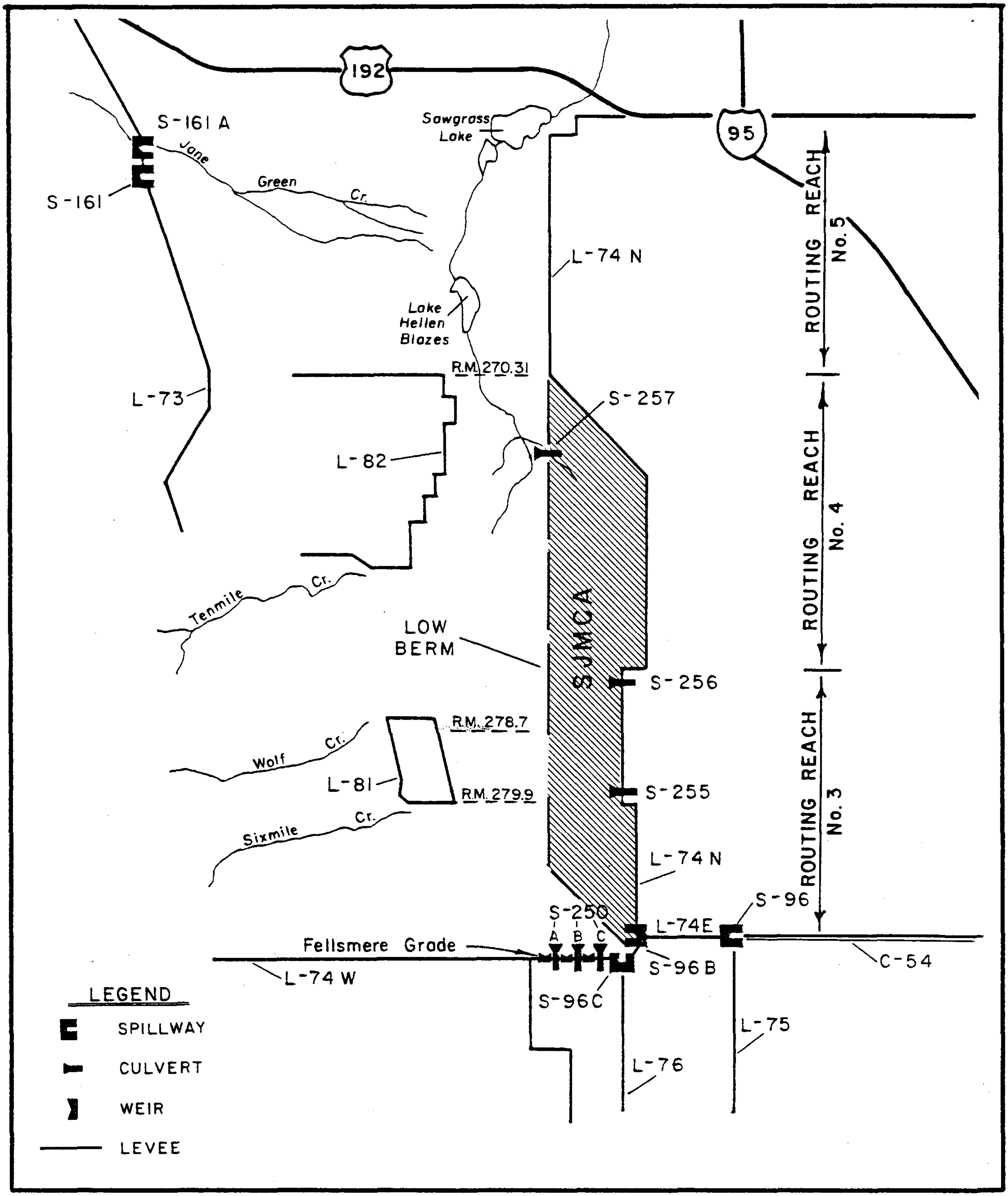


Figure 2-9. The St. Johns River Between Fellsmere Grade and State Road 500 (U.S. 192) Under the USJRB Project.

ready to receive floodwaters in the wet season, thereby providing flood relief downstream.

The Jane Green Detention Area is approximately 16,000 acres in size and includes lands below 45 ft. NGVD westward from L-73. A new structure (S-161A) will be constructed in the existing gap in L-73 north of S-161. The structure is designed to pass flood waters, thereby preventing any significant environmental damage to the upstream detention area.

Chapter III

Climate of the Basin

Situated between latitudes 27°30' and 28°45' north near east central Florida, the USJRB has a subtropical climate. Summers are long, warm and relatively humid; winters, although marked by periodic cold spells brought from the north, are mild because of the southern latitude and proximity to the Atlantic Ocean.

3.1 Temperature

Table 3-1 presents monthly and annual normal temperatures for 5 stations within and close to the basin (Fig. 3-1). Annual temperatures range from 71.7°F at Titusville to 73°F at Fellsmere with a basinwide average of about 72°F. Summertime (July/August) temperatures with a range of 81°F - 82.4°F do not vary much within the region. The wintertime temperatures, however, have greater variability, 60°F - 64°F. All stations have recorded maximum temperatures of 100°F or above.

3.2 Precipitation

The mean and extreme rainfall characteristics of the basin as described below are based on an analysis of the long-term rainfall data at 9 gaging stations.

Table 3-1. Normal temperature (30 year average 1951-1980), in degrees Fahrenheit.

Month	Titusville	Melbourne	Fellsmere*	Vero Beach	Fort Drum*	Fort Pierce
January	60.2	61.5	61.3	61.9	62.0	62.7
February	61.0	61.8	63.2	62.6	62.4	63.1
March	66.2	66.9	68.0	67.2	67.1	67.8
April	71.4	71.3	72.0	71.7	71.1	71.9
May	76.6	75.9	77.1	76.2	75.8	76.2
June	79.9	79.4	80.3	79.4	79.5	79.4
July	81.5	81.3	81.8	81.1	81.1	81.0
August	81.5	81.4	82.4	81.4	81.3	81.4
September	80.0	80.1	80.7	80.2	79.9	80.3
October	74.1	74.8	75.4	75.2	75.0	75.7
November	67.0	68.1	68.8	68.9	68.3	69.4
December	61.6	62.9	63.1	63.4	62.9	64.3
Annual	71.7	72.1	73.0	72.4	72.1	72.8

* For these stations, the data were missing for several months. The values shown are the averages based on available records for 1951-1980.

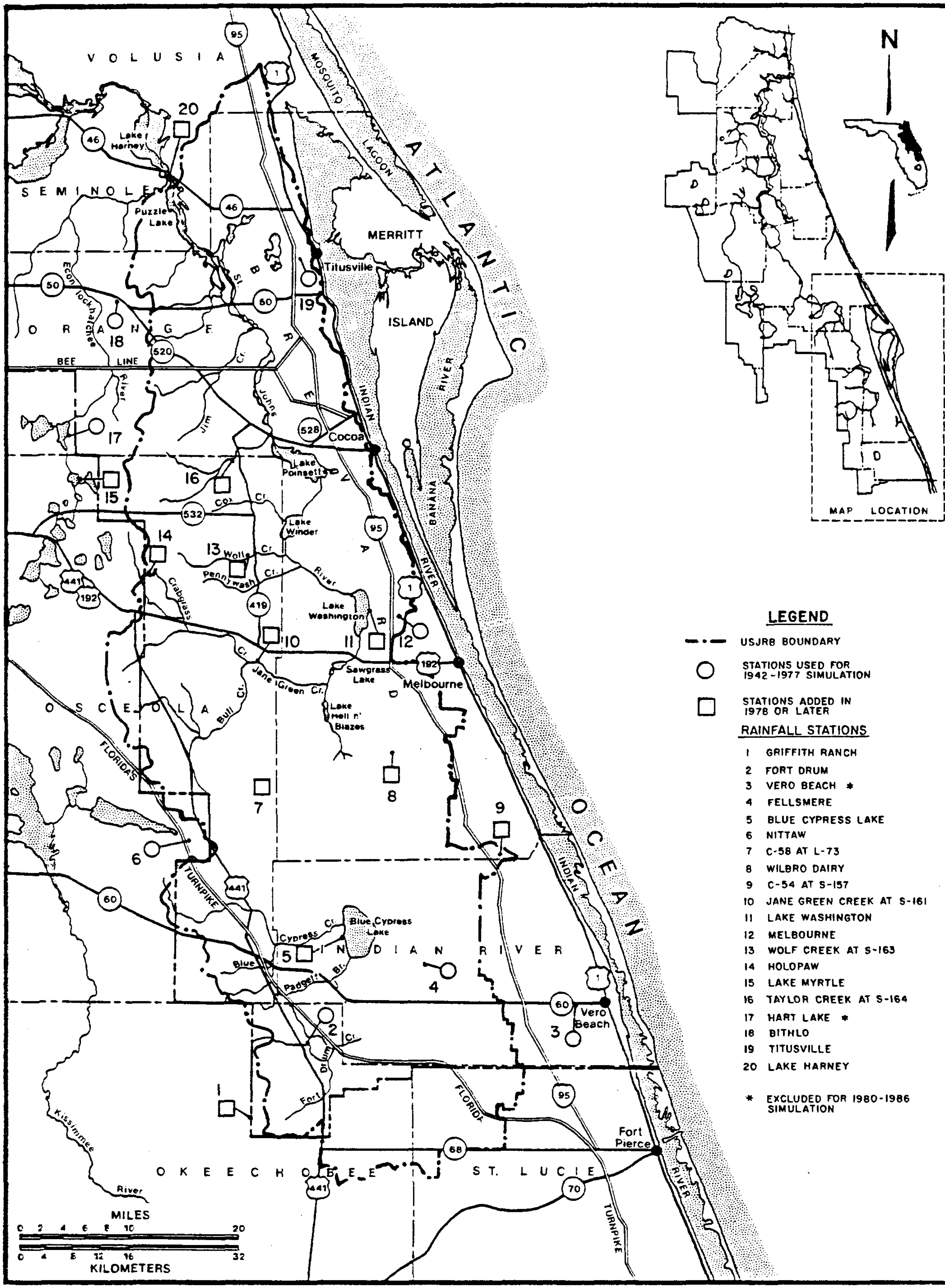


Figure 3-1. Climatic Stations Used in this Study

3.2.1 Mean Rainfall Characteristics

Normal Rainfall (Average for 1951 - 1980). The annual normal rainfall in the basin varies from about 48 inches at Melbourne to 56.7 inches at Titusville (Table 3-2). Fig. 3-1 indicates locations of various gaging stations. South of Lake Washington the basinwide average is about 50 inches. The arithmetic averages of monthly normals indicate June through September as the wet months for the basin and November through April as the dry months.

Long-Term Mean Rainfall. Table 3-3 presents the average monthly and annual rainfall for the period of record for 9 stations. Record length for these stations varied from 39 years at Bithlo to 108 years at Titusville. For Fellsmere and Titusville, which have relatively longer periods of record, the long-term mean annual rainfall differed from the normal by 3.6 inches and -2.3 inches, respectively. For other stations the difference is less than 1 inch. If Fellsmere records are regarded as representative of rainfall trends in the USJRB south of Lake Washington, there is a general decline in rainfall in recent times. However, the available literature on rainfall analyses suggests that there is no reliable means, at present, of projecting any trend very far into the future (Gilman, 1964). Thus, for practical planning, trends should be largely ignored.

Seasonal Rainfall. Average rainfall in the four warmest months (June through September) and the four coldest months (December through March) denoted as warm season and cold season respectively, have been evaluated for 9 stations and presented in

Table 3-2. Normal Rainfall (Average for 1951-1980) in Inches.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YRLY
BITHLO*	2.03	3.04	3.27	2.02	3.84	6.99	7.63	8.00	7.11	4.03	1.96	2.07	51.99
FELLSMERE*	2.08	2.36	2.93	2.41	4.44	7.26	6.29	6.89	6.76	5.48	1.72	1.69	50.31
FORT DRUM*	1.92	2.50	2.73	2.37	5.00	7.38	7.30	6.18	6.99	4.28	1.74	1.65	50.04
FORT PIERCE	2.11	2.92	2.90	2.97	4.46	6.50	5.93	5.37	7.69	7.05	2.29	2.34	52.53
MELBOURNE	2.26	2.87	2.91	2.22	4.04	6.22	5.61	5.01	7.49	5.02	2.64	1.87	48.16
NITTAW*	2.07	2.50	2.75	2.41	4.85	6.66	7.44	6.12	6.47	4.32	1.90	1.62	49.11
TITUSVILLE	2.20	3.10	3.28	2.16	4.07	6.94	8.41	7.75	8.36	5.47	2.72	2.22	56.68
VERO BCH	2.43	2.86	3.05	2.59	4.39	6.52	5.76	5.32	7.96	5.94	2.54	1.97	51.33
ARITHMETIC MEAN	2.14	2.77	2.91	2.39	4.35	6.84	6.79	6.33	7.37	5.19	2.20	1.94	

* The National Oceanic and Atmospheric Administration (NOAA) does not provide rainfall normals for these stations due to missing records. The values presented are compiled by the SJRWMD by estimating missing valuies and combining records from a nearby station in the case of discontinued stations, i.e., Fellsmere and Nittaw.

Table 3-3. Long-Term Mean Rainfall in Inches.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YRLY
BITHLO (1947 - 1985)	1.94	3.01	3.18	2.50	3.78	7.19	7.39	7.92	7.28	4.12	1.93	2.17	52.41
FELLSMERE (1912 - 1985)	2.15	2.43	2.87	2.73	4.47	7.11	6.81	7.19	8.08	5.98	2.28	1.84	53.94
FORT DRUM (1943 - 1985)	1.75	2.37	2.85	2.48	4.56	7.02	7.15	6.80	7.15	4.20	1.73	1.59	49.65
FORT PIERCE (1901 - 1985)	2.27	2.55	2.97	3.04	4.50	5.98	5.44	5.57	7.81	6.89	2.81	2.14	51.97
HART LAKE (1943 - 1978)	2.10	2.47	3.33	2.36	3.40	7.41	7.93	6.83	7.21	3.46	1.63	1.97	50.10
MELBOURNE (1939 - 1985)	2.15	2.85	3.12	2.20	3.88	6.09	5.67	5.24	7.61	4.86	2.72	1.95	48.34
NITTAW (1943 - 1985)	1.96	2.36	2.68	2.31	4.58	6.60	7.70	6.30	6.57	4.31	1.81	1.55	48.73
TITUSVILLE (1878 - 1985)	2.45	2.81	3.01	2.66	4.05	7.10	7.27	6.64	7.98	5.63	2.45	2.33	54.38
VERO BCH (1943 - 1985)	2.13	2.78	3.23	2.58	4.22	6.10	5.80	6.04	8.22	6.23	3.02	1.93	52.28

Table 3-4. For the basin south of Lake Washington, the cold season normal rainfall is about 9 inches and the warm season normal is about 27 inches.

3.2.2 Extreme Rainfall Characteristics

Historical Variation of Rainfall. Rainfall at all stations exhibits substantial variation from month to month and year to year. To give a pictorial presentation of the historic rainfall variation, the annual, warm season, and cold season rainfall amounts are depicted as bar graphs for the period of record for the 8 stations given in Table 3-2. These figures are presented in Appendix III (Figures III-1 through III-8). These figures show the year to year variation of rainfall giving an insight to the vagaries of weather in the USJRB.

Monthly, Yearly and Seasonal Extremes. Tables 3-5 and 3-6 present the observed rainfall maximums and minimums, respectively, for calendar years, calendar months, and for warm and cold seasons. Table 3-7 gives these extreme values for 6-,12-, 18- and 24- consecutive months. One month maximums varied from 18.05 inches at Nittaw to 25.15 inches at Fellsmere. The latter occurred during the September 1929 storm.

The maximum recorded calendar year rainfall was 81.74 inches (Titusville, 1953; Vero Beach, 1982) while the maximum rainfall over 12 consecutive months exceeded the preceding value for several stations (Table 3-7). Fellsmere recorded the highest 12 consecutive months rainfall with 92.83 inches. The warm season maximums varied from 40.6 inches at Melbourne to 50.5 inches at Fellsmere.

Table 3-4. Seasonal Rainfall in Inches.

STATION	---- PERIOD OF RECORD MEAN ----			-- NORMAL(AVG FOR 1951-1980) --		
	ANNUAL	WARM SEASON (JUN-SEP)	COLD SEASON (DEC-MAR)	ANNUAL	WARM SEASON (JUN-SEP)	COLD SEASON (DEC-MAR)
BITHLO (1947 - 1985)	52.41	29.78	10.28	51.99	29.73	10.52
FELLSMERE (1912 - 1985)	53.94	29.20	9.29	50.31	27.29	9.03
FORT DRUM (1943 - 1985)	49.65	28.12	8.59	50.04	27.86	8.74
FORT PIERCE (1901 - 1985)	51.97	24.80	9.93	52.53	25.49	10.24
HART LAKE (1943 - 1978)	50.10	29.38	9.87	-	-	-
MELBOURNE (1939 - 1985)	48.34	24.61	10.22	48.16	24.33	9.81
NITTAW (1943 - 1985)	48.73	27.17	8.62	49.11	26.69	8.93
TITUSVILLE (1878 - 1985)	54.38	28.99	10.49	56.68	31.46	10.87
VERO BCH (1943 - 1985)	52.28	26.16	10.10	51.33	25.56	10.27

Table 3-5. Rainfall Maximums Observed During the Period of Record, Inches.

STATION	YRLY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	WARM SEASON	COLD SEASON
BITHLO (1947 - 1985)	73.04	6.50	7.62	13.23	8.19	12.61	17.23	18.87	15.87	15.02	13.37	9.06	6.19	47.99	20.59
FELLSMERE (1912 - 1985)	78.83	8.42	8.88	10.31	9.38	12.78	19.17	13.95	14.31	25.15	19.35	17.78	6.50	50.47	21.07
FORT DRUM (1943 - 1985)	64.29	6.80	7.60	7.41	11.99	14.52	14.21	15.95	15.92	20.75	12.06	5.00	4.62	41.80	18.61
FORT PIERCE (1901 - 1985)	77.51	9.36	10.19	9.83	11.16	12.97	15.84	12.74	14.22	19.90	19.31	10.65	8.21	41.07	24.76
HART LAKE (1943 - 1978)	75.85	6.37	5.98	14.03	9.64	9.40	19.04	14.11	12.64	16.82	14.51	9.96	5.79	46.02	19.94
MELBOURNE (1939 - 1985)	74.16	8.17	11.14	10.13	8.15	13.83	16.37	11.95	12.12	19.68	13.86	9.72	7.89	40.62	22.28
NITTAW (1943 - 1985)	75.00	7.64	7.99	8.94	5.18	16.48	13.68	15.61	15.42	15.82	18.05	7.64	5.28	45.15	20.94
TITUSVILLE (1878 - 1985)	81.74	10.52	10.60	9.54	9.74	19.93	20.75	18.08	19.89	23.78	21.88	9.38	9.08	50.01	26.66
VERO BCH (1943 - 1985)	81.74	9.08	9.96	10.73	8.83	12.06	18.24	12.22	18.26	20.29	15.58	13.65	6.68	43.10	21.47

Table 3-6. Rainfall Minimums Observed During the Period of Record, Inches.

STATION	YRLY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	WARM SEASON	COLD SEASON
BITHLO (1947 - 1985)	36.43	0.00	0.40	0.05	0.00	0.09	2.15	1.43	3.21	0.89	0.24	0.00	0.10	16.73	2.29
FELLSMERE (1912 - 1985)	27.94	0.00	0.00	0.00	0.00	0.11	0.00	1.43	2.44	1.15	0.73	0.09	0.00	13.24	2.53
FORT DRUM (1943 - 1985)	32.73	0.00	0.00	0.08	0.00	0.05	1.74	2.68	2.28	0.68	0.34	0.11	0.16	16.52	2.05
FORT PIERCE (1901 - 1985)	31.73	0.12	0.00	0.19	0.00	0.37	0.69	0.75	1.09	0.75	0.00	0.09	0.08	11.24	1.51
HART LAKE (1943 - 1978)	29.30	0.03	0.00	0.04	0.20	0.00	0.00	2.94	2.61	0.81	0.38	0.00	0.00	15.41	2.57
MELBOURNE (1939 - 1985)	31.97	0.09	0.11	0.03	0.05	0.16	1.44	0.81	1.14	1.80	0.39	0.31	0.00	12.23	2.71
NITTAW (1943 - 1985)	24.12	0.11	0.00	0.09	0.00	0.00	0.85	3.05	1.36	1.60	0.48	0.00	0.00	12.27	2.56
TITUSVILLE (1878 - 1985)	33.43	0.00	0.04	0.00	0.00	0.27	0.63	0.86	0.28	1.78	0.35	0.00	0.03	10.47	1.50
VERO BCH (1943 - 1985)	32.70	0.17	0.05	0.09	0.02	0.29	1.53	1.69	1.22	2.55	0.75	0.11	0.08	12.24	2.05

Table 3-7. Maximum and Minimum Observed Rainfall for 6-, 12-, 18-, and 24-Consecutive Months, Inches

Station	Maximum				Minimum			
	6 Mo.	12 Mo.	18 Mo.	24 Mo.	6 Mo.	12 Mo.	18 Mo.	24 Mo.
Bithlo	53.63	78.14	114.73	142.04	5.87	32.24	47.50	76.11
Fellsmere	65.10	92.83	133.77	164.95	3.25	26.52	34.83	71.12
Fort Drum	49.22	69.88	108.27	126.20	5.79	27.21	43.05	68.86
Fort Pierce	54.94	83.98	122.00	142.73	5.88	30.27	46.10	73.35
Hart Lake	53.01	78.92	128.49	151.99	4.21	29.16	40.92	71.28
Melbourne	55.23	76.58	112.48	132.70	4.40	28.43	45.82	64.32
Nittaw	57.94	83.59	121.51	141.06	4.25	24.12	36.64	62.55
Titusville	62.91	81.74	124.13	148.91	4.03	30.68	45.68	73.79
Vero Beach	57.69	90.31	121.30	149.69	5.06	27.49	41.39	64.35

The lowest calendar year rainfall coinciding with the minimum 12-consecutive month value occurred at Nittaw during 1981. This rainfall of 24.12 inches was less than 50% of normal at the same station. Minimum cold season rainfall for the basin varied from 1.5 inches at Titusville to 2.53 inches at Fellsmere.

Storm Rainfall. Large amounts of rainfall occur over relatively short periods during hurricanes, tropical storms, and other storm activities. These rainfall events can produce major floods resulting in high rates of discharge. Table 3-8 presents the highest 24 hr, 48 hr, 72 hr, 96 hr, 5-day, and 10-day rainfall amounts recorded at 9 stations.

The 24 hr maximum rainfall varied from 8.3 inches (Melbourne) to 12.8 inches (Fellsmere). The 96-hr to 10-day maximum rainfall events which produce prolonged flooding, ranged from about 15 inches to 16.5 inches in the upper reaches of the basin (see Fellsmere and Fort Drum, Table 3-8).

3.3 Evaporation

Class A pan evaporation has been measured since 1952 at Vero Beach (Fig. 3-1). This weather station was originally located at the municipal airport ($27^{o}29'$ N. Lat. and 80^{o} $25'$ W. Long), but in 1965 it was moved to a new location (Vero Beach 4W station, 27^{o} $38'$ N. Lat. and 80^{o} $27'$ W. Long.) about four miles west of the airport. Significant differences are observed in the mean monthly and mean annual evaporation data recorded at the two locations (Table 3-9). The annual mean values differed by 12

Table 3-8. Maximum Recorded 24-Hour to 10-Day Rainfall, Inches.

RAINFALL STATION AND COUNTY	NOAA NUMBER	RAINFALL DURATION 24 HR	48 HR	72 HR	96 HR	5 DAY	10 DAY
BITHLO (ORANGE)	0758	12.05	12.81	13.45	13.54	13.54	15.36
FELLSMERE (INDIAN RIVER)	2936	12.83	14.66	14.78	14.98	15.45	16.74
FORT DRUM (OKEECHOBEE)	3137	9.85	11.69	13.82	14.75	15.34	16.11
FORT PIERCE((ST. LUCIE)	3207	10.16	10.42	10.60	12.06	12.76	14.51
HART LAKE (ORANGE)	3840	10.58	11.28	12.95	14.60	14.65	15.45
MELBOURNE (BREVARD)	5612	8.28	10.99	12.24	12.84	13.04	13.34
NITTAW (OSCEOLA)	6251	12.72	13.60	13.67	13.67	13.67	16.52
TITUSVILLE (BREVARD)	8942	11.99	13.30	14.35	15.05	15.46	16.36
VERO BCH. (INDIAN RIVER)	9219	9.45	10.83	11.55	12.14	12.23	15.26

Table 3-9. Pan Evaporation in Inches at Vero Beach, Florida.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Yearly
					Station: Vero Beach Airport (NOAA Index No. 9214)								
1952	-	-	6.42	8.31	8.26	8.11	7.77	7.47	6.73	4.61	4.87	3.81	-
1953	4.83	4.87	6.32	7.13	8.37	6.72	7.88	-	-	5.88	-	3.69	-
1954	4.16	4.54	5.51	6.60	8.23	6.62	7.07	7.44	6.38	6.31	4.50	4.33	71.69
1955	4.37	4.75	6.04	8.42	7.88	8.39	8.02	8.30	6.69	7.03	4.88	4.16	78.93
1956	5.04	5.33	6.41	5.97	8.34	7.81	8.22	8.57	7.09	6.39	5.22	5.02	79.41
1957	3.82	-	6.10	7.38	7.10	7.76	6.71	7.58	6.64	6.50	4.54	4.67	-
1958	4.49	5.03	5.35	6.37	7.72	8.13	6.74	6.56	6.62	6.13	4.55	4.51	72.20
1959	3.25	4.29	5.93	6.91	7.81	7.54	7.14	7.22	5.98	4.78	4.17	3.33	68.35
1960	4.38	4.40	-	6.78	8.48	7.57	7.09	7.12	5.99	5.92	5.09	4.34	-
1961	4.38	4.70	6.47	8.77	8.41	7.08	7.53	7.41	7.25	7.58	5.08	4.35	79.01
1962	3.97	4.75	7.34	6.90	8.34	6.66	7.10	6.57	6.34	6.98	5.11	3.58	73.64
1963	4.15	4.39	6.51	7.73	7.85	7.59	7.92	8.57	6.80	7.71	5.15	3.43	77.80
1964	2.96	3.25	6.93	-	8.97	7.90	7.98	7.56	7.60	5.44	4.32	3.45	
1965	4.06	-	6.86	-	-	(Station relocated)							
Mean	4.14	4.57	6.32	7.27	8.14	7.53	7.47	7.53	6.68	6.25	4.79	4.05	74.74*
						Station: Vero Beach 4W (NOAA Index No. 9219)							
1965	-	-	-	-	-	6.16	6.73	6.01	5.31	4.19	2.95	2.32	-
1966	2.23	2.86	5.06	6.21	6.26	6.08	6.76	6.33	4.54	4.20	3.38	2.21	56.12
1967	2.80	3.16	5.05	7.11	8.18	5.99	6.08	6.16	5.06	4.54	3.60	2.48	60.21
1968	2.66	3.95	5.62	6.87	6.46	-	6.53	6.42	5.49	4.49	2.97	2.59	-
1969	3.00	3.61	4.10	5.61	6.47	6.64	6.39	5.80	4.43	3.97	2.84	2.49	55.37
1970	2.47	3.35	4.70	6.20	7.45	7.22	6.18	6.49	6.09	4.58	3.47	2.61	60.81
1971	3.08	4.11	5.74	6.19	7.71	7.08	7.09	6.29	5.58	3.96	3.33	2.55	62.71
1972	2.74	3.55	5.81	6.37	6.53	-	7.64	6.41	5.84	5.22	3.18	2.47	-
1973	2.31	3.36	5.17	7.12	7.15	6.72	6.76	5.61	5.73	5.59	3.58	2.49	62.13
1974	2.69	4.32	6.34	6.46	7.86	6.16	5.43	5.97	5.57	5.20	3.24	2.88	62.12
1975	3.03	3.70	6.19	7.01	7.06	6.61	6.80	6.47	5.12	5.26	3.46	2.97	63.68
1976	3.10	4.06	5.75	6.86	6.14	6.88	6.70	6.81	5.92	5.32	3.02	2.53	63.09
1977	3.21	3.69	5.81	7.72	7.44	7.33	7.03	6.62	5.43	5.17	3.14	2.77	65.36
1978	2.86	3.56	5.12	6.42	7.23	6.39	6.18	6.77	5.04	4.29	3.47	3.29	60.62
1979	3.13	3.27	5.01	6.74	6.72	7.41	7.15	6.58	-	5.53	3.59	2.97	-
1980	3.09	5.81	5.36	5.91	7.99	7.60	7.11	6.34	5.90	4.67	3.93	2.49	66.20
1981	2.80	4.37	5.63	6.71	8.04	8.26	7.73	-	5.32	4.64	3.76	2.89	-
1982	2.93	3.66	5.01	5.84	6.77	5.78	6.96	6.74	6.56	4.97	3.40	3.18	61.80
1983	3.24	4.10	5.94	6.43	7.54	7.06	8.04	6.18	5.87	5.45	3.35	3.18	66.38
1984	-	4.20	5.84	6.95	7.50	6.62	7.43	-	7.71	6.16	4.49	2.75	-
1985	3.64	3.87	5.93	-	9.04	8.61	7.67	7.01	-	5.47	-	3.27	
Mean	2.90	3.83	5.46	6.56	7.28	6.87	6.88	6.37	5.61	4.90	3.41	2.73	62.80*

* Total of monthly mean values.

inches, the airport station having the higher value. No investigation has been conducted as to why these discrepancies occurred. However, since the Vero Beach 4W station is the current station with a longer period of record (and also closer to the basin), data from this station is used to reflect the evaporation conditions for the USJRB.

Using a pan coefficient of 0.78, the potential annual evaporation rate for the USJRB is determined as 49 inches. This nearly equals the normal rainfall for the basin. Similarly, potential monthly evaporation rates for the region can be obtained by multiplying mean monthly pan evaporation values given in Table 3-9 (for the Vero Beach 4W station) by a factor of 0.78.

CHAPTER IV

WATERSHED SIMULATION

Long-term streamflow data are necessary for determining the water supply potential of a stream. Although discharge records are available for a period of over 45 years in the river upstream of Lake Washington (St. Johns River at U.S. 192/State Road 500), use of this data in various analyses may not provide satisfactory results because of the continuously changing watershed conditions during the period. The hydrologic characteristics of the USJRB have been modified by levees, drainage canals, pumped drainage, runoff diversion and various control structures. Thus, the long-term record is not considered homogeneous. Consequently, in developing the USJRB Project, both the U.S. Army Corps of Engineers and the District have employed hydrologic modeling procedures.

The District has developed a continuous watershed simulation model which generates daily streamflow and stage/storage data at desired locations in the basin for any given (assumed) watershed conditions. This model is used for generating long-term streamflow and stage data needed for this study. The model consists of two main elements, a rainfall runoff simulation routine (Fig. 4-1) and a routing routine. The rainfall-runoff routine takes into account the basin evapotranspiration and continuously simulates soil moisture, surface retention, base flow and surface runoff by applying water balance methods. Further details of the model are given in References 9 (SJRWMD,

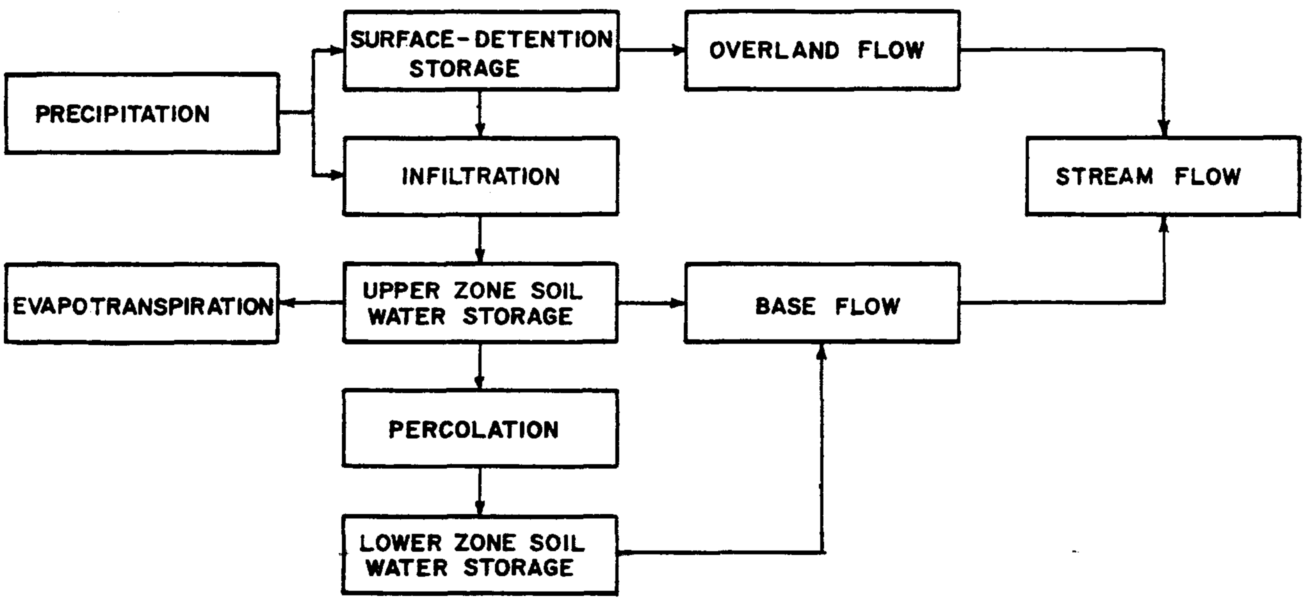


Figure 4-1. Flow Chart for the Rainfall-Runoff Simulation Routine

1979-80) and 10 (Suphunvorranop and Tai, 1982). Runoff calculations are performed for each sub-basin (Fig. 2-2). Streamflow generated in each sub-basin is routed through appropriate routing processes and an imaginary channel by the Muskingum Method.

For routing mainstream discharge, the St. Johns River, including its valley floodplain from Florida's Turnpike to S.R. 46 has been divided into 12 reaches, six of which lie upstream of the Lake Washington weir (Figs. 2-3, 2-5, and 2-6). Because of the flat topography of the river valley, the storage routing method is used with each reach. Each reach receives runoff from the adjacent sub-basin tributaries and discharge from the upstream reach. Flow from an upstream reach discharges into the downstream reach based on a discharge-storage relationship (Puls Method). The stage-storage-discharge data for different reaches are developed by the U.S. Army Corps of Engineers' HEC-2 Water Surface Profiles Program (1982).

4.1 Upstream Water Users

4.1.1 Existing Conditions

Under existing conditions Fellsmere Water Control District (Fig. 2-3) is the only major user of the St. Johns River upstream of Lake Washington. The current irrigated acreage in the FWCD is as follows (private communication from the FWCD, 1986):

		GROWING SEASON
Oranges	9,537 Acres	Year around
Grapefruits	4,056 Acres	Year around
Vegetables and Rice	1,114 Acres	Year around
Row Crops	800 Acres	January to August
Water Cress	160 Acres	August to May
Sod	150 Acres	Year around
Pasture & Other	8,848 Acres	Year around
	24,665 Acres	

The source of irrigation water is Blue Cypress Lake, located south of the Fellsmere Grade (Routing Reach No. 2, Fig. 2-3) for all of the above mentioned areas except 4,550 acres of citrus and 200 acres of vegetables which are irrigated with ground water. In modeling the existing conditions, it was assumed that water would be drawn from River Reach No. 2 for irrigating 20,000 acres of citrus or a crop with an equivalent irrigation requirement.

In addition, it is assumed that the irrigation withdrawal will be made on an as needed basis calculated based on rainfall, evapotranspiration, and irrigation efficiency.

4.1.2 USJRB Project Conditions

Under project conditions, it is assumed for this simulation analysis, withdrawal will be first made from the St. Johns Water Management Area (SJWMA) (Fig. 2-7) supplemented when necessary with releases from the BCWMA. If the SJWMA cannot satisfy the permitted irrigation requirements then the additional water will be withdrawn from the BCMCA. An additional withdrawal assumption for this simulation analysis is that no withdrawals will occur when the water level in BCMCA is below 19.5 ft NGVD.

In simulating the USJRB Project conditions, as a conservative approach, it was assumed that the FWCD will withdraw water at the maximum permitted quantity each year. In issuing consumptive use permits, the District applies a 2-in-10 year drought criterion, i.e., the maximum annual withdrawal must not exceed a quantity equal to the gross irrigation requirement of a crop during a 2-in-10 year drought. In the present case, the crop was assumed as citrus and the gross irrigation requirement was calculated for each month by the aforementioned criterion. The withdrawal was applied uniformly over the month. For 21,400 acres of citrus (irrigated area from surface water assumed in this study) the gross irrigation requirement calculated equals 16.37 billion gallons/year. In the February, 1987 consumptive use permit issued to the FWCD, the District allowed a maximum annual withdrawal of 14.57 billion gallons from surface water sources. Thus, the upstream withdrawal assumed in this study is quite conservative.

There exist some closed irrigation systems in addition to the FWCD, i.e., St. Johns Water Control District (Figs. 2-3 and 2-7), Mary-A Property (Sub-basin 3-5, Fig. 2-2), and Sartori Property (Sub-basin 3-7, Fig. 2-2). These systems do not withdraw any water from the St. Johns River, but rely on their own storage reservoirs. However, when storage capacity of these reservoirs is exceeded, the excess surface water is discharged into the St. Johns River system. In simulating the project condition this runoff is calculated and included as surface water contribution from these areas.

4.2 Model Calibration

The input data for the model has been developed to reflect the most recent conditions of the basin. All physiographic and hydrologic changes that have taken place in the USJRB for the past several decades have been incorporated in the model to represent existing basin conditions. Physiographic changes include basin alterations by dikes, ditches and land use.

Hydrologic changes are alterations in drainage patterns such as discharge by pumpage, interbasin diversion, etc. The data for this purpose have been collected from several sources and updated, where necessary, by extensive field survey. A major portion of Reference 9 (SJRWMD, 1979-80) was devoted to inventorying all available basin data as of 1979. These data, with several updates, have been used in the final streamflow modeling.

The hydraulic and hydrologic responses of the basin have been calibrated against two recent major events, i.e., flooding conditions due to Hurricane David in 1979 and the drought of 1980-1981. Various model parameters also have been adjusted based on simulation of annual hydrographs. Recorded discharge and/or stage data at the following locations were used in the calibration: 1) Blue Cypress Lake, 2) Jane Green Creek, 3) U.S. 192 (S.R. 500), 4) Lake Washington, 5) S.R. 520, 6) S.R. 50, and 7) S.R. 46. Over 100 river cross-sections were used to determine the storage and conveyance characteristics of the river valley. The Manning's roughness coefficient values (used in HEC-2 model) for the river channel and floodplain were calibrated against stage/discharge data at various locations. Rainfall data is available at 18 gaging stations since 1978.

4.3 Model Verification

By using the calibrated model, daily streamflow and stage data were obtained for various major locations on the St. Johns River for the period 1979 through June 1986. Fig. 4-2 gives a comparison of the recorded and simulated stage hydrographs for Lake Washington. Fig. 4-3 presents the discharge hydrographs for

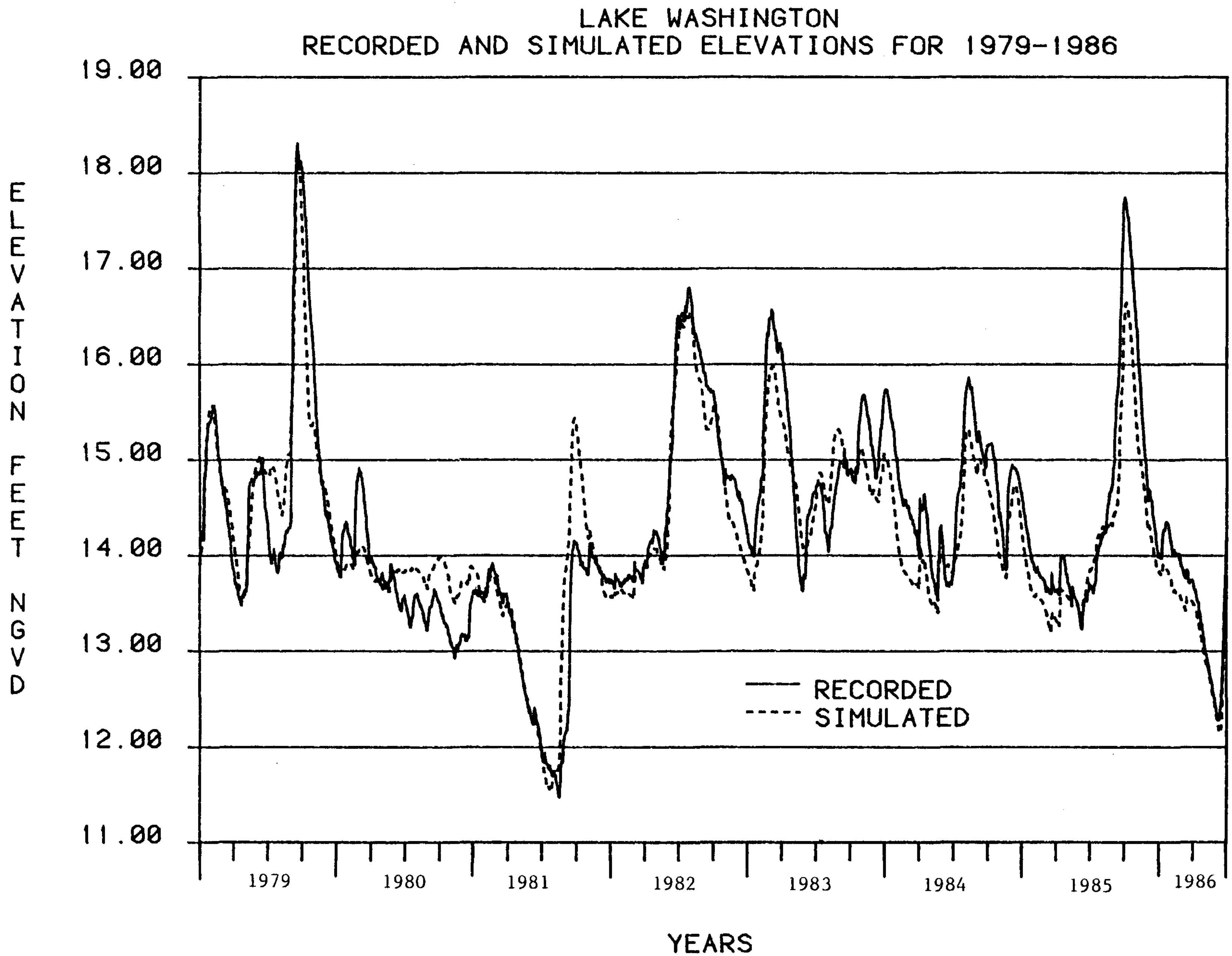


Figure 4-2. A Comparison of the Recorded and Simulated Stage Hydrographs for Lake Washington (1979-1986)

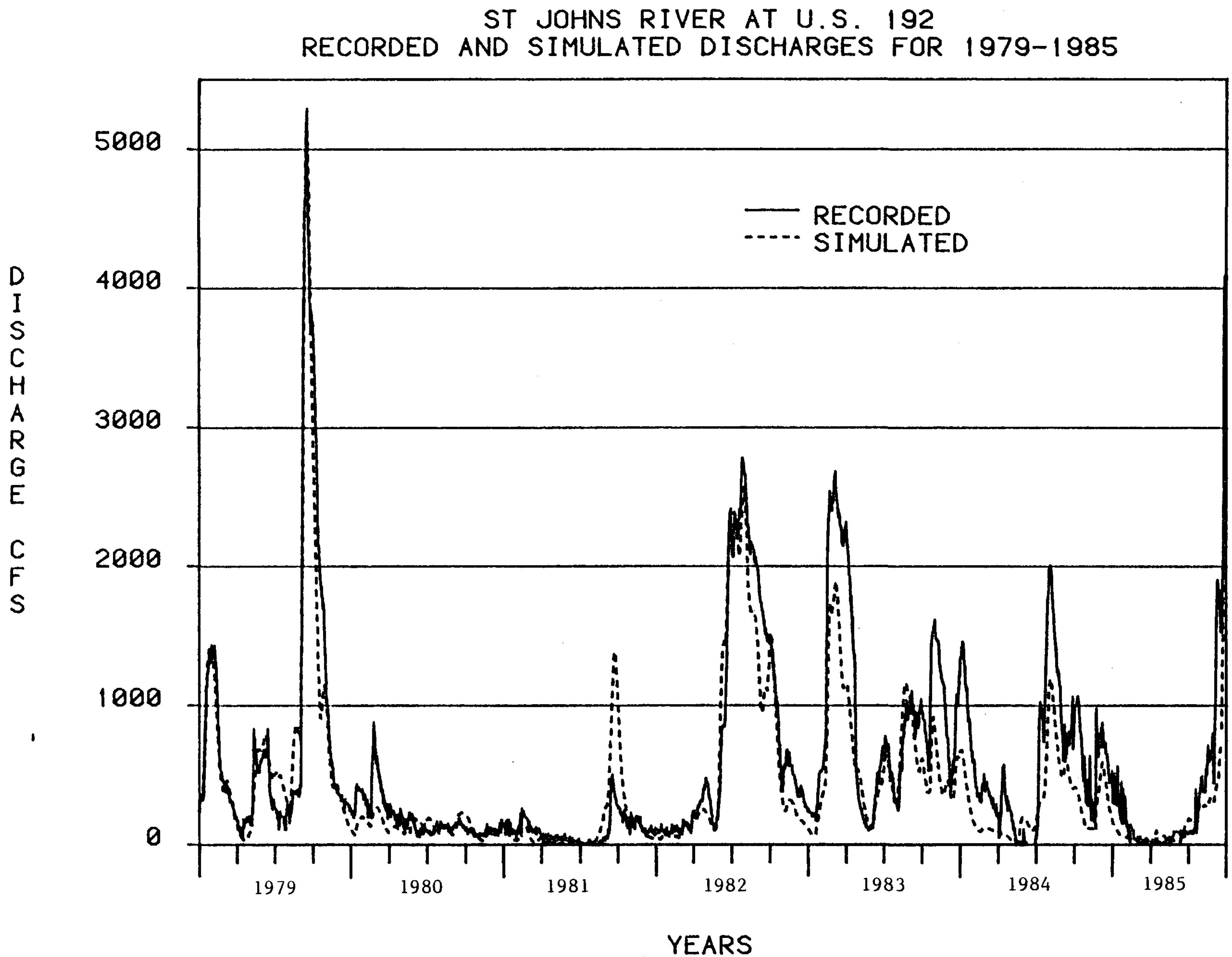


Figure 4-3. A Comparison of the Recorded and Simulated Discharge Hydrographs for the St. Johns River at U.S. 192 (1979-1985)

the St. Johns River at U.S. 192. Recorded streamflow data for the 1986 water year was not available at the time of this study.

The natural rainfall-runoff and other hydrologic/hydraulic processes occurring over a large river basin like the USJRB are very complex. An exact reproduction of nature's response through mathematical equations is nearly impossible. Additionally, rainfall data input to the model plays a major role in producing results closely matching those recorded. The model assumes rainfall data available at a limited number of gaging stations as representative of rainfall over the whole basin, an assumption rarely satisfied. Nevertheless, Figs. 4-2 and 4-3 show that, in general, the low flow regime is well simulated and most flood hydrographs are satisfactorily reproduced. Thus, the selected model is deemed adequate for the present study.

4.4 Simulation Results

4.4.1 Test Runs

Test simulation runs were made for the most recent watershed conditions choosing 1942-1986 as the simulation period. This period included several major storm events as well as droughts. Note that the period 1942-1986 bears no specific significance for the analyses except that it provides a long-term series of hydrologic input data (e.g., rainfall and evapotranspiration) representative of general climatic conditions of the basin. The simulated data provided by the model are used in developing generalized results for the basin, i.e., frequencies of flood flows, low flows, storage volumes, stages, etc. The model can generate data for any alternative design (hypothetical) condition in the basin.

Prior to 1940 only two long-term climatic stations existed in the basin, Titusville since 1878 and Fellsmere since 1912. The Melbourne station was started in 1939, and Fort Drum, Hart Lake, Nittaw, and Vero Beach were added in 1943, and Bithlo in 1947 (see Fig. 3-1 for locations of these stations). Thus, 1942 was chosen as the starting year for simulation. Rainfall data from the preceding 8 stations were used in simulation for 1942-1977 starting with Fellsmere, Melbourne, and Titusville data in 1942 and progressively adding other stations as the data became available. In 1978, the District established several raingage stations throughout the basin and data from 10 additional stations became available for 1978-1986 simulation (July-Sept 1986 rainfall data was not available for some of the simulation runs; appropriate data substitutions were made).

4.4.2 Pre-Canal-Plugging Conditions vs. Existing Conditions

The borrow canals which existed along the levees in the St. Johns marsh floodway between Fellsmere Grade and US 192 were plugged at several locations by July 1986. The objective of this canal plugging program was to establish sheetflow conditions and prevent overdrainage of soil waters in the marsh between Fellsmere Grade and the St. Johns River channel near Lake Hell'n Blazes (Fig. 2-5). These canals provided extra conveyance to both flood flows and low flows and dewatered the marsh including its soil water zone during dry periods. To study the effect of canal plugs on the streamflow regime downstream, simulation runs were made for the no-plug condition and the existing (with plugs) basin conditions. A withdrawal of 14 mgd was assumed from Lake Washington.

The Effect of Canal Plugging on Low Flows -- Mean low flows for the period 1943-1985 as derived from the two simulations and the recorded data are compared in Table 4-1 for St. Johns River at U.S. 192. The one-day and 60-day low flows showed an increase of 6.8% and 1.0%, respectively, as a result of canal plugging. No effect is seen on flows for higher durations. Simulated volumes are low by about 1.8% compared to the recorded values (see 1-year values). However, the simulated 1-day to 30-day low flows for the no-plugs condition differ from the historic flows by about 3% to 15%. Although not conclusive, this decrease may partly be attributed to changes in the USJRB during the last 5 decades.

The Effect of Canal Plugging on Low and High Stages -- The results of low stage frequency analysis for Lake Washington indicate improvements in the order of 0.05 ft. to 0.15 ft. due to canal plugging (Table 4-2). In conclusion, the sheetflow conditions established in the upstream marsh as a result of canal plugs would increase the marsh storage which in turn would improve low stages in Lake Washington. If the plugs had been in place, the lowest stage reached in the lake during the 1981 drought would have been about 0.2 ft. higher than recorded. (Fig. 4-4). The plugs do not have any effect on high stages in Lake Washington.

Table 4-1 St. Johns River at US 192: Mean Low Flows for the Period 1943-1985

Duration	Simulated discharge, cfs		Percent Increase in low flows due to Canal Plugging	Recorded Discharge cfs	Percent Departure of simulat discharge from the recorded	
	No-Plugs	Existing (w/plugs)			No-Plugs	Existing (w/plugs)
1-Day	38.5	41.1	6.8	39.8	-3.3	+3.3
7-Day	42.1	44.7	6.2	49.5	-14.9	-9.7
14-Day	47.6	50.0	5.0	55.2	-13.8	-9.4
30-Day	62.6	64.3	2.7	66.6	-6.0	-3.5
60-Day	89.8	90.7	1.0	87.5	+2.6	+3.7
120-Day	157	157	None	144	+9.0	+9.0
183-Day	213	213	None	225	-5.3	-5.3
274-Day	353	353	None	356	-0.8	-0.8
1 Year	659	659	None	671	-1.8	-1.8

Table 4-2: Lake Washington: Estimated Low Stages (ft. NGVD) for Droughts of different Return Periods

Duration Days	Mean Annual Low	Recurrence interval, years 5	10	25	50	100	200
		No-Plugs Condition: Withdrawal = 14 mgd					
1	13.3	12.85	12.3	12.1	11.8	11.5	11.2
7	13.3	12.85	12.35	12.15	11.85	11.55	11.25
14	13.35	12.9	12.4	12.2	11.9	11.6	11.3
30	13.4	12.9	12.5	12.25	11.95	11.65	11.35
60	13.55	13.1	12.7	12.45	12.15	11.9	11.6
		Existing Conditions: Withdrawal = 14 mgd.					
1	13.3	12.9	12.4	12.2	11.9	11.65	11.35
7	13.35	12.95	12.45	12.25	11.95	11.7	11.4
14	13.35	12.95	12.5	12.3	12.0	11.7	11.45
30	13.4	13.0	12.55	12.35	12.05	11.8	11.5
60	13.55	13.1	12.75	12.55	12.25	12.0	11.75

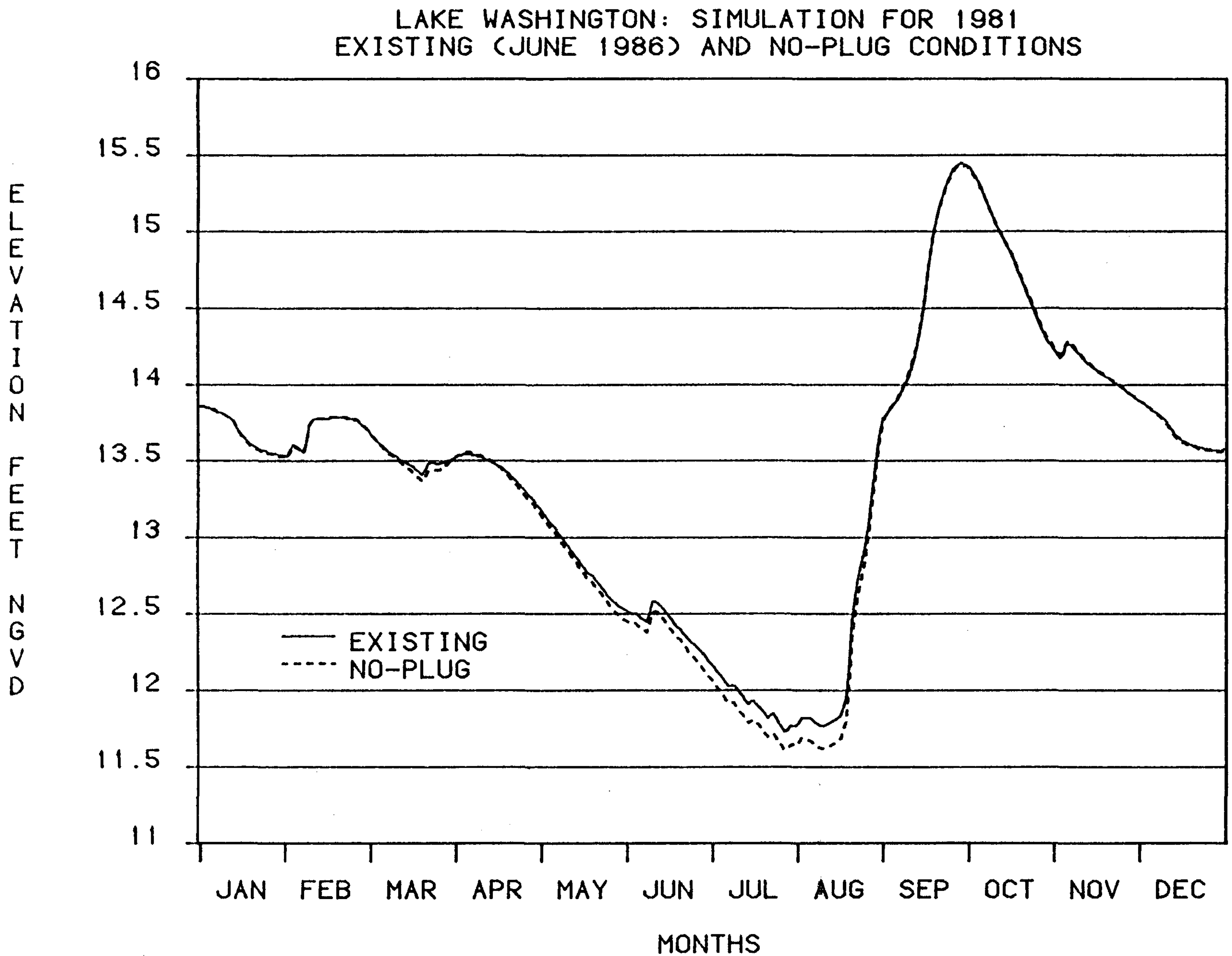


Figure 4-4. The 1981 Simulated Stage Hydrographs for Lake Washington for No-Plug and Existing Conditions

4.5 Development of Data Series and Frequency Analysis

Most analyses in this study require annual series of low flows/stages, high flows/stages for different durations and the estimates of the same events for different return periods. The low flows and high flows have different annual cycles and thus require different reference years for developing annual series. The following procedures are used for this purpose.

1) Low stage frequencies: The USGS Water Year (Oct 1 through Sept 30) is used as reference for evaluating annual series of mean low stages for different durations (1-day, 7-day, etc. see Table 4-3). Since the St. Johns River normally peaks during the period August-October the low stages occur well within the bounds of the water year. The Log Pearson type 3 analysis (Rao, 1980a) is used as the base method. However, the data are plotted on log probability paper and frequency curves are graphically adjusted to conform with the trend of the data.

2. High stage frequencies: Annual series of mean high stages for different durations are evaluated using June 1 through May 31 as the reference year (Table 4-4). This is done because the flooding season in this part of Florida continues through October (and sometimes into November). The USGS water year commences in the middle of the flooding season. Therefore, the USGS water year is not appropriate for evaluating annual maximum flows/stages. The Log Pearson type 3 analysis (Rao, 1980b, 1983) is used for estimating maximum values for various return periods.

Table 4-3 Annual Series of Low Stages for Lake Washington

@@@@@ ELEVATION IN LAKE WASHINGTON, FT NGVD - EXISTING CONDITIONS, 14 MGD WITHDRAWAL

LOWEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING SEPT 30

YEAR	1	7	14	30	60	120	183	274	1 YEAR
1943	13.55	13.58	13.59	13.61	13.66	13.68	13.70	13.86	14.42
1944	13.42	13.43	13.47	13.55	13.65	13.71	13.80	14.22	14.97
1945	13.23	13.23	13.25	13.35	13.50	13.52	13.88	14.39	14.79
1946	13.42	13.45	13.47	13.51	13.62	13.71	13.85	14.20	14.63
1947	13.59	13.60	13.61	13.62	13.75	14.18	14.30	14.63	15.03
1948	13.68	13.68	13.69	13.74	13.85	13.94	14.07	14.31	14.92
1949	12.83	12.85	12.90	12.93	13.12	13.35	13.63	14.16	14.78
1950	13.45	13.47	13.48	13.56	13.64	13.71	13.73	13.81	14.26
1951	13.59	13.61	13.63	13.69	13.82	14.05	14.15	14.40	14.76
1952	13.66	13.67	13.68	13.69	13.76	14.21	14.20	14.51	14.78
1953	13.61	13.62	13.67	13.77	13.93	14.02	14.04	14.28	14.88
1954	13.56	13.57	13.59	13.61	13.66	13.84	14.24	14.64	15.14
1955	13.56	13.57	13.59	13.60	13.64	13.70	13.82	13.99	14.32
1956	12.71	12.76	12.77	12.78	12.84	13.10	13.37	13.79	14.23
1957	13.71	13.73	13.76	13.81	13.90	14.10	14.36	14.76	15.34
1958	13.87	13.88	13.89	13.95	14.15	14.39	14.56	14.74	14.81
1959	13.83	13.86	13.90	13.94	13.97	14.13	14.35	14.59	14.81
1960	13.98	14.01	14.03	14.11	14.29	14.65	14.93	15.30	15.68
1961	13.59	13.63	13.65	13.71	13.81	13.88	13.97	14.17	14.67
1962	13.25	13.29	13.30	13.37	13.41	13.49	13.56	13.70	14.12
1963	13.42	13.45	13.47	13.52	13.65	13.87	13.85	14.04	14.30
1964	13.82	13.85	13.86	13.93	14.14	14.16	14.44	14.65	14.95
1965	12.99	13.01	13.06	13.19	13.36	13.54	13.57	13.78	14.19
1966	13.54	13.55	13.59	13.72	13.99	14.58	14.55	14.76	15.04
1967	12.41	12.46	12.47	12.51	12.72	13.10	13.28	13.65	14.00
1968	12.90	12.93	12.97	13.00	13.08	13.30	13.40	13.83	14.33
1969	13.59	13.61	13.63	13.64	13.77	14.24	14.41	14.49	14.71
1970	13.54	13.59	13.59	13.64	13.68	13.81	14.10	14.48	14.77
1971	13.28	13.32	13.34	13.40	13.49	13.70	13.67	13.85	14.18
1972	13.59	13.62	13.63	13.65	13.67	13.78	13.86	14.25	14.59
1973	13.61	13.65	13.70	13.80	14.06	14.31	14.31	14.40	14.81
1974	12.47	12.49	12.50	12.56	12.72	13.06	13.27	13.83	14.52
1975	13.43	13.43	13.45	13.49	13.54	13.59	13.64	14.03	14.42
1976	12.30	12.36	12.41	12.53	12.78	13.10	13.36	13.89	14.32
1977	12.44	12.48	12.50	12.63	12.87	13.21	13.39	13.54	13.88
1978	13.72	13.74	13.78	13.85	13.86	14.03	14.19	14.41	14.75
1979	13.54	13.55	13.57	13.65	13.82	14.30	14.31	14.46	14.73
1980	13.61	13.63	13.64	13.65	13.71	13.78	13.79	13.84	14.19
1981	11.73	11.76	11.78	11.80	11.95	12.34	12.74	13.07	13.30
1982	13.55	13.57	13.58	13.58	13.59	13.66	13.77	14.10	14.58
1983	13.66	13.70	13.75	13.82	13.92	14.23	14.71	14.63	14.76
1984	13.40	13.44	13.48	13.54	13.70	13.77	13.88	14.20	14.40
1985	13.20	13.25	13.30	13.32	13.40	13.47	13.56	13.78	13.98
1986	12.18	12.20	12.23	12.36	12.63	13.05	13.29	13.73	14.41

Table 4-4 Annual Series of High Stages for Lake Washington

@@@@@ ELEVATION IN LAKE WASHINGTON, FT NGVD - EXISTING CONDITIONS, 14 MGD WITHDRAWAL

HIGHEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING MAY 31

YEAR	1	7	14	30	60	120	183	274	1 YEAR
1943	17.18	17.13	16.97	16.59	16.45	15.92	15.42	14.86	14.57
1944	17.12	17.09	16.99	16.68	16.49	16.24	15.73	15.09	14.75
1945	18.30	18.27	18.17	17.92	17.61	16.75	16.12	15.50	15.01
1946	16.83	16.81	16.75	16.64	16.31	16.09	15.75	15.17	14.77
1947	16.02	15.99	15.94	15.91	15.79	15.49	15.13	14.88	14.71
1948	18.53	18.50	18.41	18.10	17.48	16.72	16.51	15.88	15.39
1949	18.29	18.25	18.12	17.60	16.63	15.85	15.34	14.89	14.52
1950	17.39	17.37	17.29	16.98	16.66	16.31	15.75	15.10	14.72
1951	18.25	18.16	17.91	17.16	16.33	15.49	15.01	14.76	14.51
1952	15.98	15.95	15.89	15.69	15.48	15.39	15.20	14.95	14.73
1953	16.57	16.55	16.50	16.30	15.92	15.71	15.40	14.93	14.70
1954	18.93	18.89	18.77	18.36	18.05	17.06	16.33	15.60	15.12
1955	16.68	16.66	16.61	16.42	16.03	15.45	15.41	15.08	14.73
1956	15.99	15.98	15.95	15.88	15.70	15.14	14.77	14.45	14.11
1957	20.08	19.99	19.74	18.96	17.68	16.50	15.89	15.27	14.95
1958	16.45	16.41	16.29	16.13	15.93	15.71	15.50	15.30	15.23
1959	15.65	15.64	15.59	15.43	15.13	14.68	14.49	14.53	14.47
1960	17.75	17.68	17.49	16.97	16.58	15.91	15.82	15.42	15.38
1961	18.24	18.19	18.07	17.67	17.19	17.01	16.41	15.70	15.24
1962	15.62	15.57	15.53	15.40	15.03	14.78	14.50	14.18	14.03
1963	15.80	15.79	15.78	15.75	15.66	15.42	15.01	14.67	14.42
1964	15.98	15.96	15.90	15.72	15.51	15.30	15.23	15.04	14.79
1965	17.59	17.54	17.41	17.00	16.47	15.73	15.20	14.71	14.44
1966	16.23	16.18	16.06	15.71	15.19	15.01	14.94	14.87	14.56
1967	16.76	16.74	16.68	16.48	16.08	15.80	15.49	14.89	14.47
1968	14.97	14.96	14.93	14.87	14.81	14.74	14.40	14.12	13.84
1969	16.75	16.72	16.63	16.51	16.35	15.84	15.72	15.17	15.07
1970	16.12	16.09	16.05	15.88	15.72	15.61	15.47	15.21	14.96
1971	15.30	15.29	15.23	15.10	14.93	14.51	14.24	14.10	13.96
1972	15.57	15.56	15.55	15.49	15.23	15.14	14.95	14.60	14.37
1973	17.06	17.02	16.92	16.59	15.93	15.49	15.03	14.85	14.73
1974	16.57	16.55	16.49	16.35	16.23	16.04	15.64	15.01	14.51
1975	17.72	17.67	17.54	17.28	16.89	16.29	15.58	14.94	14.57
1976	15.88	15.88	15.87	15.83	15.71	15.36	15.10	14.62	14.22
1977	16.34	16.29	16.22	16.04	15.71	15.59	15.28	14.78	14.40
1978	15.59	15.59	15.56	15.44	15.17	15.00	14.79	14.55	14.31
1979	16.89	16.86	16.81	16.60	16.06	15.48	14.99	14.91	14.69
1980	18.25	18.20	18.07	17.57	16.63	15.78	15.46	15.00	14.70
1981	13.98	13.97	13.97	13.94	13.88	13.85	13.80	13.78	13.65
1982	15.45	15.43	15.38	15.20	14.80	14.33	14.07	14.02	13.56
1983	16.57	16.56	16.53	16.49	16.34	15.96	15.54	15.18	15.13
1984	15.36	15.36	15.35	15.29	15.12	15.01	14.93	14.72	14.47
1985	15.33	15.32	15.29	15.17	15.04	14.69	14.56	14.30	14.09
1986	16.65	16.63	16.58	16.37	15.85	15.15	14.78	14.42	14.11

CHAPTER V

EVALUATION OF LAKE WASHINGTON WATER SUPPLY POTENTIAL

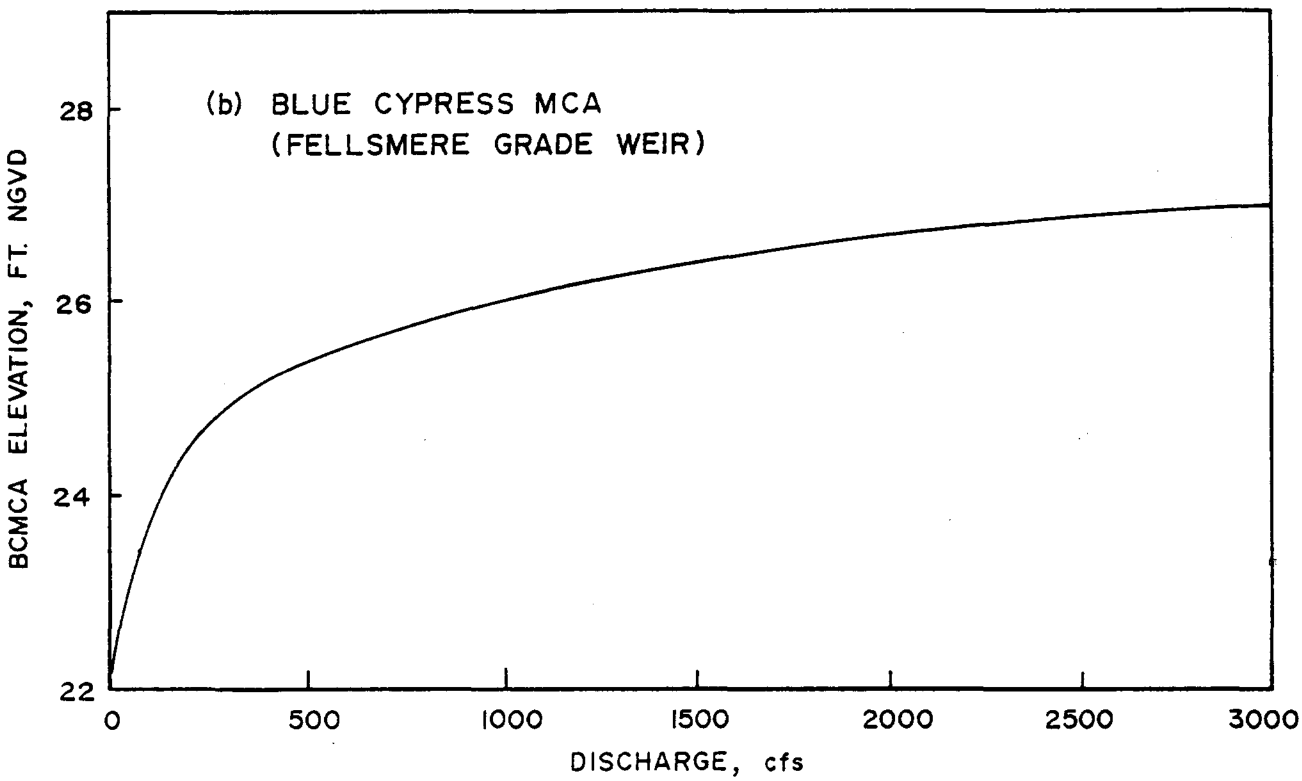
5.1 Description of Selected Alternatives

5.1.1 Existing Conditions

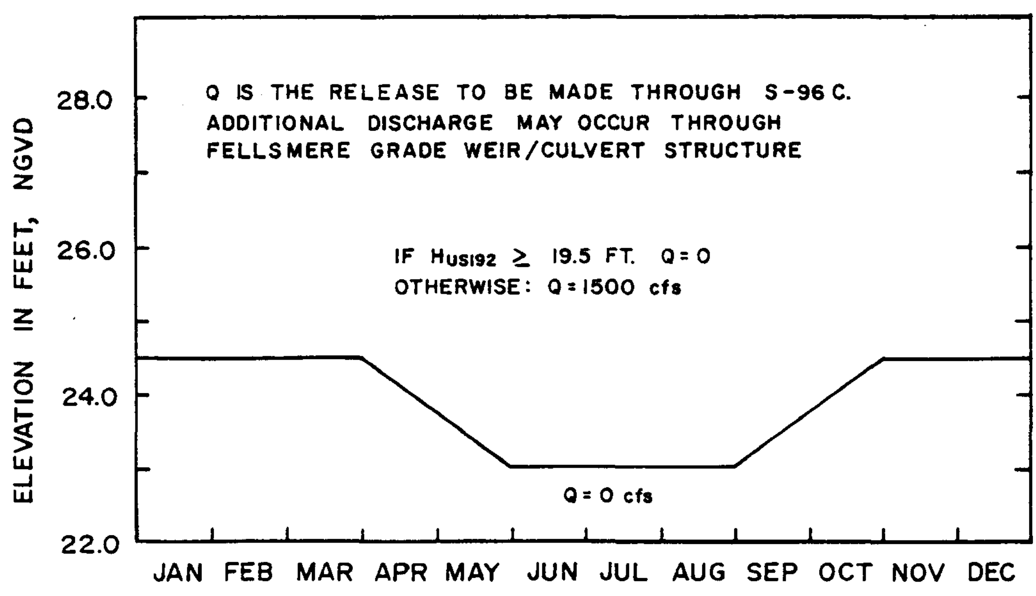
The existing sheetpile weir at the outlet of Lake Washington has a length of 160 feet with its crest elevation at 13.50 ft. NGVD. The ground level (channel bottom) at the weir is about 8.50 ft. NGVD. Various other features of the lake and the existing basin conditions including canal plugs have been described in Chapters II and IV. Pertinent results were evaluated only for the existing weir condition. Results for alternative weir heights under the existing basin conditions are not evaluated as a part of this report. If these results are found necessary for any decision making, they will be evaluated separately.

5.1.2 USJRB Project Conditions with the Existing Lake Washington Temporary Weir Structure

Considerable low flow augmentation benefits are expected at Lake Washington, when the USJRB Project is completed, as a result of minimum flow releases from the Blue Cypress and St. Johns Marsh Conservation Areas (Figs. 2-7 and 2-8). During the low rainfall period (November through March), flow releases from the BCMCA will vary from 0 cfs to about 250 cfs when the BCMCA is at elevations 22.0 ft. NGVD to 24.5 ft. NGVD (Fig. 5-1). If the water level exceeds 24.5 ft. NGVD, additional discharge occurs as per the schedules shown in Fig. 5-1. Discharge from the BCMCA weir and culvert structures is a function of the hydraulic head



(A) Rating Curve for Blue Cypress MCA Weir/Culvert Structures



(B) Discharge Schedule for S-96C

Figure 5-1. Discharge Schedules for the Blue Cypress Marsh Conservation Area only (Fig. 5-1A) while the flow releases through structure 96C are governed by the elevation in BCMCA at specific times of the year (Fig. 5-1B). These changes in the flow regime have been incorporated in the hydrologic simulation.

5.1.3 USJRB Project Conditions with Modified Weir Structures

Since the existing streamflow regime will be altered under the USJRB Project providing considerable low flow augmentation at Lake Washington, three additional weir settings are considered for the project conditions. Keeping the length of the weir the same as at present, the following crest elevations are considered: 1) 14.00 ft. NGVD, 2) 13.00 ft. NGVD, 3) 12.00 ft. NGVD. In addition, the no weir condition is considered.

5.2 Criteria for Evaluating Lake Washington Water Supply Potential

Three areas of concern are examined in formulating the criteria for determining water availability from Lake Washington: 1) long-term low or drought stages expected at different rates of consumptive use withdrawal and the accompanying water quality concerns (chloride concentration in the lake), 2) hydrologic considerations for minimum flow/stage requirements of the floodplain marsh around and downstream of Lake Washington, and 3) socio-economic impacts due to flooding and low flows under the different alternative designs considered. Problems which may result from the presence of aquatic weeds in the lakes are not addressed in this study. Details regarding the first criterion are given below. The other two criteria will be discussed in subsequent chapters.

5.2.1 Criteria for Desirable Long-Term Drought Stages

Lake Washington can recede much below the current weir level (13.5 ft. NGVD) during droughts due to reduced runoff contribution of the basin, evapotranspiration loss from the Lake and municipal withdrawal. The lake bottom is approximately at 7.0 ft. NGVD. Water levels below 13.5 ft. NGVD were recorded during five years since the construction of the present weir in 1976. Available data has shown that chloride concentration and total dissolved solids (TDS) increase in the lake with declining stages. Other water quality parameters are not examined in this study. Several conditions contributed to degradation of water quality in Lake Washington during the low flow season, among which are: 1) the existence of borrow canals in the marsh upstream (Fig. 2-5) which convey highly mineralized seepage discharge, 2) agricultural drainage from several land parcels upstream, 3) drainage canals directly connected to Lake Washington, and 4) evaporation.

In the following analysis an attempt is made to relate the drought and annual low elevations to the chloride concentration of Lake Washington. The stage and chloride data for the lake indicate that during severe low flow or drought conditions the highest chloride concentration in the lake for the year coincided with the annual low-stage. During years when the chloride concentration is less than 150 mg/l the chloride concentration in the lake increases with decreasing stage. However, the annual low stage and the annual highest chloride concentration do not occur simultaneously. It appears that during such years the highest chloride concentration in the lake results from local events such as pump discharge of agricultural drainage water with high mineral content. Table 5-1 gives a compilation of the annual low stages in Lake Washington, the highest chloride concentration during low flow periods and the annual highest chloride concentrations. This mineralized drainage water is probably derived in large part from abandoned artesian (free flowing) wells which penetrate the Floridan aquifer.

Figure 5-2 presents a scatter diagram of annual lowest stages and the highest chloride concentrations (during the low flow season) in Lake Washington for 1960-1986. In general, it is seen that chloride concentrations were low in the 1960's for given elevations. The regression relationship between chloride concentration and elevation as shown on Fig. 5-2 was poor with a low correlation coefficient, R= 0.55. The data collected after the construction of the present sheetpile weir, i.e, for the period 1977-1986, are plotted separately on Fig. 5-3.

The highest chloride concentration was recorded in 1981 during prolonged drought conditions in the basin. During August 1981, water samples collected at several locations upstream of Lake Washington contained chlorides in the range of 260 mg/l to 290 mg/l, exceeding the Class I standard of 250 mg/l for drinking water supplies. Thus, while the low elevations reached in the lake are an indication of general dry conditions of the basin, the quality of the lake water (during such periods) is primarily

Table 5-1: Chloride Levels Recorded During the Annual Lowest Stages in Lake Washington

Water Year	Date	Lowest Elevation Ft. NGVD	Highest Chloride Concentration, mg/l During Low Flow Period	Annual
1960	2/03/60	14.72	46	56
1961	6/24/61	11.42	47	56
1962	6/01/62	10.52	160	168
1963	5/19/63	12.42	74	88
1964	7/02/64	13.00	74	75
1965	6/06/65	12.26	108	118
1966	5/16/66	13.19	66	86
1967	6/02/67	11.75	240	240
1968	5/08/68	11.60	174	184
1969	2/07/69	13.59	80	140
1970	7/03/70	12.13	104	112
1971	6/07/71	11.02	176	200
1972	5/19/72	12.34	110	116
1973	11/25/72	12.10	82	92
1974	6/06/74	10.55	200	200
1975	5/28/75	9.88	227	227
1976	5/06/76	11.32	200	208
1977	5/25/77	12.45	162	201
1978	5/29/78	13.54	124	157
1979	4/24/79	13.48	129	142
1980	8/29/80	13.22	142	154
1981	8/17/81	11.48	302	302
1982	1/12/82	13.66	177	205
1983	5/28/83	13.63	69	69
1984	5/21/84	13.58	92	106
1985	6/11/85	13.23	150	166
1986	6/10/86	12.28	144	144

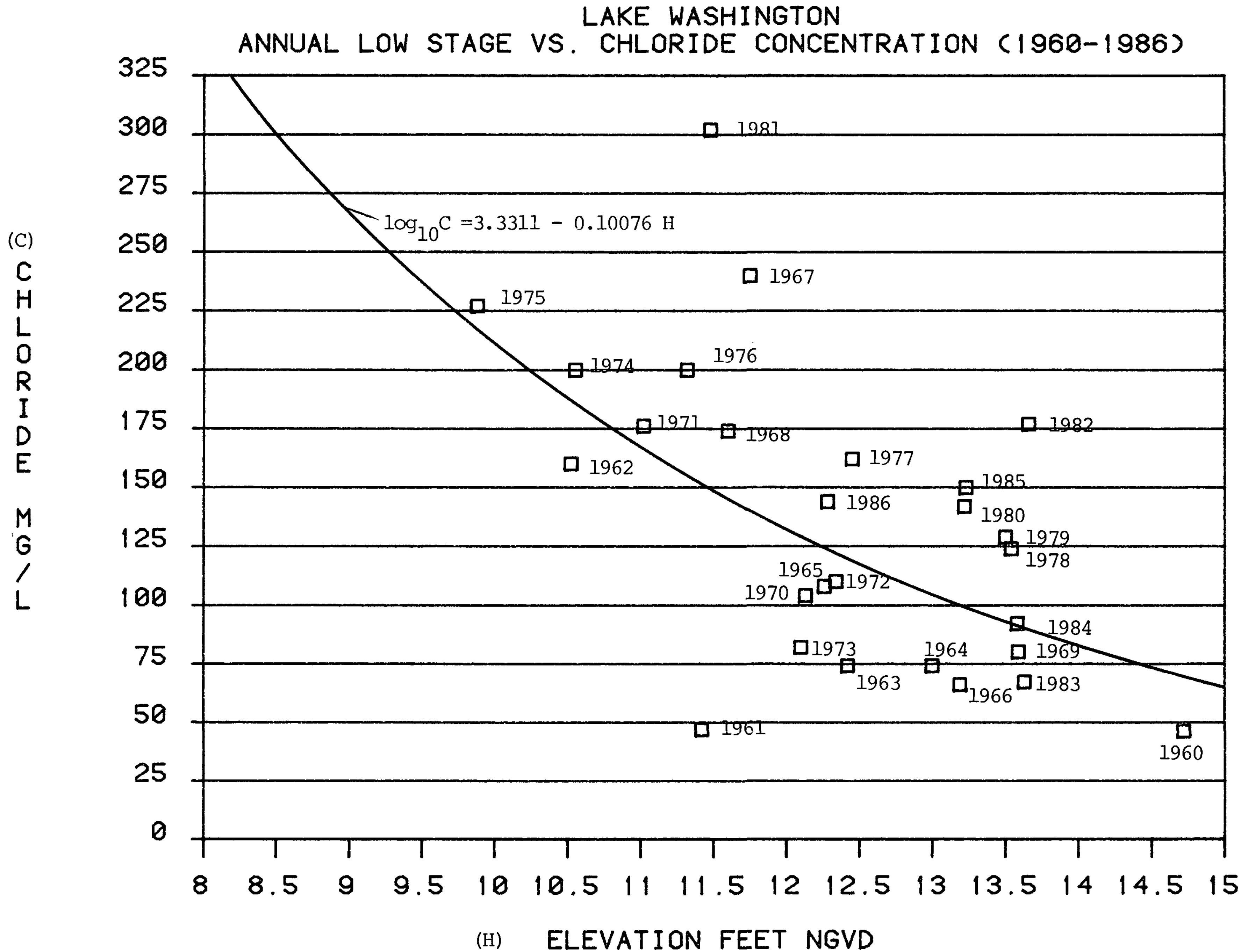


Figure 5-2. Scatter Diagram of Chloride Concentration Versus the Annual Low Stages for Lake Washington (1960-1986)

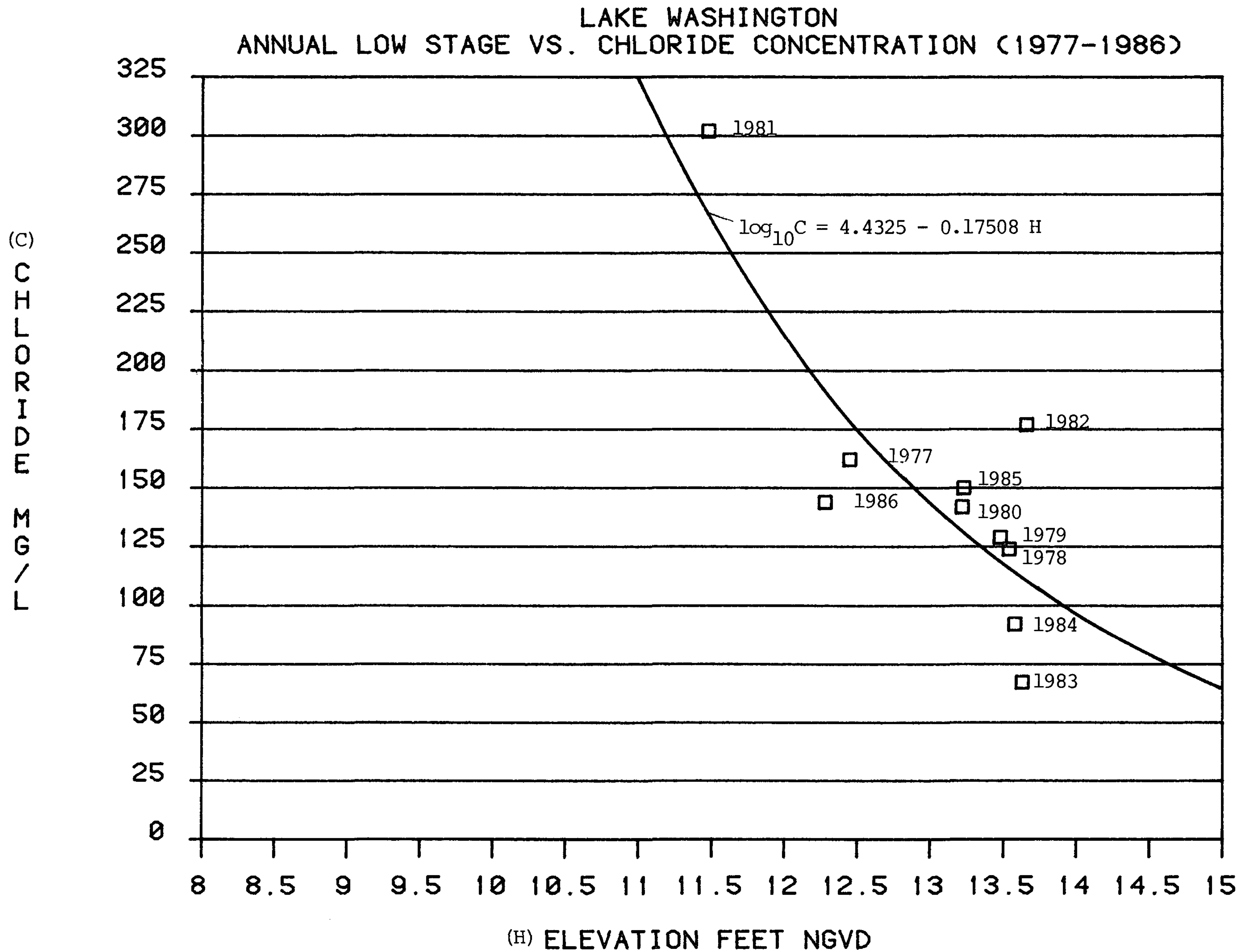


Figure 5-3 Relationship Between Chloride Concentration and Annual Low Stages for Lake Washington (1977-1986 Data)

dependent upon the quality of water entering the lake. Lowe et al. (1984) express the opinion that plugging the canals in the marsh upstream would reduce the water deficit of the floodplain wetlands (due to restoration of marsh sheet flow) which in turn would improve water quality. Additional measures suggested were the restoration of lost floodplain and elimination or curtailment of diversion of water to the coast. Construction of canal plugs began in 1986. Several other measures for improving water quality and low flow augmentation will be implemented under the USJRB Project. Before the lowest stage of 1986 (June) was reached in Lake Washington, canal plugs were completed at several places and the northward conveyance of seepage flow by the canals was drastically reduced. Although it is too early to conclude, 1986 chloride concentrations (see Fig. 5-3) are noticeably less than the concentrations for 1980, 1982, and 1985. Data in Fig. 5-3 yield the following relationship between chloride concentration and the annual low stages.

$$\log_{10} C = 4.4325 - 0.17508\, H \qquad (5.1)$$

in which C = chloride concentration in mg/l and H = elevation in Lake Washington in feet NGVD. Chloride levels calculated by Eq. 5.1 would be rather conservative, i.e., over-estimates, because most data were collected before the installation of canal plugs.

In this chapter, the water supply potential of Lake Washington is estimated based on the expected low or drought stages and the accompanying chloride concentrations as calculated by Equation 5.1.

During these low flow periods total dissolved solids (TDS) also increased with decreasing stages. In some instances, the Class I standards were exceeded with respect to TDS and chloride concentration. As discussed above, the construction of canal plugs will very likely improve the relationship between TDS and stage. No attempts are made in this study to predict TDS concentration under various alternative conditions.

5.3 Evaluation of Water Supply Potential

5.3.1 Existing Conditions

The current demand and withdrawal from Lake Washington is approximately 14 mgd. To study how low stages in Lake Washington would be affected by increased withdrawals under existing conditions (i.e., with canal plugs) six simulation runs were made with withdrawal rates of 14 mgd, 16 mgd, 20 mgd, 22 mgd, 25 mgd, and 30 mgd. For a 50-year drought, the 1-day low stages would decrease from 11.9 ft. NGVD to 8.9 ft. NGVD, and 60-day low stages from 12.25 ft. NGVD to 9.85 ft. NGVD as the withdrawal is increased from 14 mgd to 30 mgd (Table 5-2). The storage available in Lake Washington at a given elevation can be obtained from Fig. 5-4. The chloride levels predicted by Eq. 5.1 for these drought events are given in Table 5-3.

5.3.2 The USJRB Project Conditions with the Existing Lake Washington Weir Structure

As mentioned earlier, operation of the SJMCA was not addressed in the 1985 GDM for the USJRB Project. A low berm will separate the SJMCA from the existing marsh floodway (Fig. 2-9). During low stages, the discharges released from the BCMCA and

Table 5-2: Lake Washington: Estimated Low Stages (ft. NGVD) for Droughts of Different Return Periods (Existing Conditions)

Consumptive Use Withdrawal	Duration Days	Mean Annual Low	Recurrence interval, years 5	10	25	50	100	200
14	1	13.3	12.9	12.4	12.2	11.9	11.65	11.35
	7	13.35	12.95	12.45	12.25	11.95	11.7	11.4
	14	13.35	12.95	12.5	12.3	12.0	11.7	11.45
	30	13.4	13.0	12.55	12.35	12.05	11.8	11.5
	60	13.55	13.1	12.75	12.55	12.25	12.0	11.75
16	1	13.25	12.75	12.25	12.05	11.7	11.4	11.05
	7	13.3	12.8	12.3	12.05	11.75	11.4	11.1
	14	13.3	12.85	12.3	12.1	11.75	11.45	11.1
	30	13.4	12.9	12.4	12.15	11.85	11.5	11.2
	60	13.5	13.05	12.6	12.4	12.05	11.75	11.5
20	1	13.1	12.45	11.85	11.45	11.00	10.55	10.15
	7	13.15	12.45	11.9	11.5	11.05	10.6	10.2
	14	13.15	12.5	11.9	11.55	11.1	10.65	10.25
	30	13.25	12.55	12.0	11.65	11.2	10.75	10.35
	60	13.4	12.85	12.2	11.9	11.5	11.1	10.7
22	1	13.05	12.3	11.6	11.2	10.65	10.2	9.7
	7	13.1	12.35	11.65	11.2	10.7	10.2	9.75
	14	13.1	12.35	11.7	11.25	10.75	10.25	9.8
	30	13.2	12.45	11.8	11.4	10.9	10.4	9.95
	60	13.35	12.75	12.0	11.65	11.2	10.75	10.3
25	1	13.0	12.2	11.4	10.85	10.25	9.65	9.1
	7	13.0	12.2	11.45	10.85	10.25	9.7	9.15
	14	13.05	12.25	11.5	10.95	10.35	9.75	9.2
	30	13.15	12.35	11.6	11.1	10.5	9.95	9.4
	60	13.3	12.65	11.85	11.4	10.9	10.35	9.85
30	1	12.75	11.75	10.75	9.8	8.9	8.1	*
	7	12.8	11.8	10.8	9.85	8.95	8.15	*
	14	12.85	11.85	10.9	9.9	9.05	8.2	*
	30	12.95	11.95	11.0	10.1	9.25	8.5	7.75
	60	13.1	12.35	11.3	10.6	9.85	9.15	8.45

* The lake goes dry.

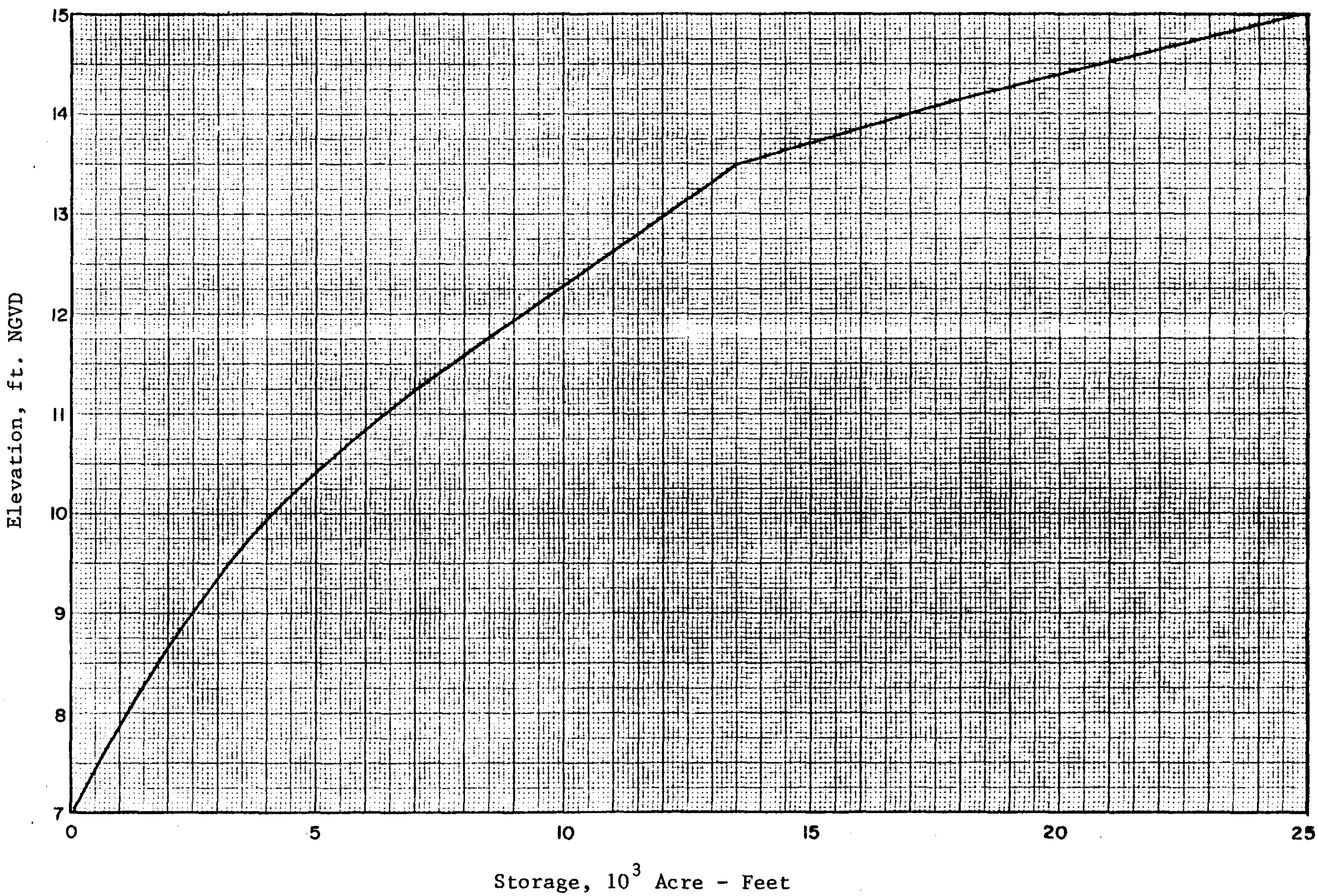


Fig. 5-4. Stage - Storage Relationship for Lake Washington

Table 5-3 Lake Washington: Estimates of Chloride Levels for Droughts of Different Return Periods (Existing Basin Conditions)

Lake Withdrawal mgd.	Drought Duration Days	Chloride concentration mg/l 50 yr.	100 yr.	200 yr.
14	1	223	247	*
	30	210	233	*
16	1	242	*	*
	30	228	*	*
20	1	*	*	*
	30	*	*	*
22	1	*	*	*
	30	*	*	*
25	1	*	*	*
	30	*	*	*
30	1	*	*	**
	30	*	*	*

* Exceeds 250 mg/l
** The lake goes dry.

other runoff will flow directly north. Exchange of flow between the SJMCA and the marsh will take place when the marsh water level exceeds 22.00 ft. NGVD between Fellsmere Grade and RM 279.9, 21.00 ft. NGVD between river miles 279.9 and 278.7, and 20.00 ft. NGVD north of RM 278.7 (Fig. 2-9). The stage-storage-area relationships for the SJMCA are as shown in Fig. 5-5. Flow releases from the SJMCA can be made through Structure S-257 at a maximum rate of 128 cfs. After some simulation tests, the following operation schedule for S-257 was determined as beneficial for the marsh habitat within the SJMCA and for low flow augmentation downstream: flow releases through S-257 should be such that the total discharge from Reach No. 3 (Fig. 2-9) and S-257 is at least, 1) 100 cfs when the SJMCA is above 18.0 ft. NGVD, 2) 50 cfs when the SJMCA is between 16.0 ft. NGVD and 18.0 ft. NGVD, and 3) 25 cfs when the SJMCA is below 16.0 ft. NGVD. These conditions will be related to the elevations in Lake Washington for easy operation of S-257. Simulation with this schedule and other USJRB Project conditions yielded the annual series of low and high stages (for the SJMCA) shown in Tables 5-4 and 5-5, respectively. The 1-day annual low stages ranged from 14.65 ft. NGVD to 19.71 ft. NGVD, and the high stages from 17.08 ft. NGVD to 23.08 ft. NGVD. Studies by Hall (Personal Communication, 1986) showed the SJMCA operation schedule described satisfies the hydrologic criteria for minimum flow/stage requirements of the marsh in the SJMCA. The estimates of low stages for various drought events are given in Table 5-6.

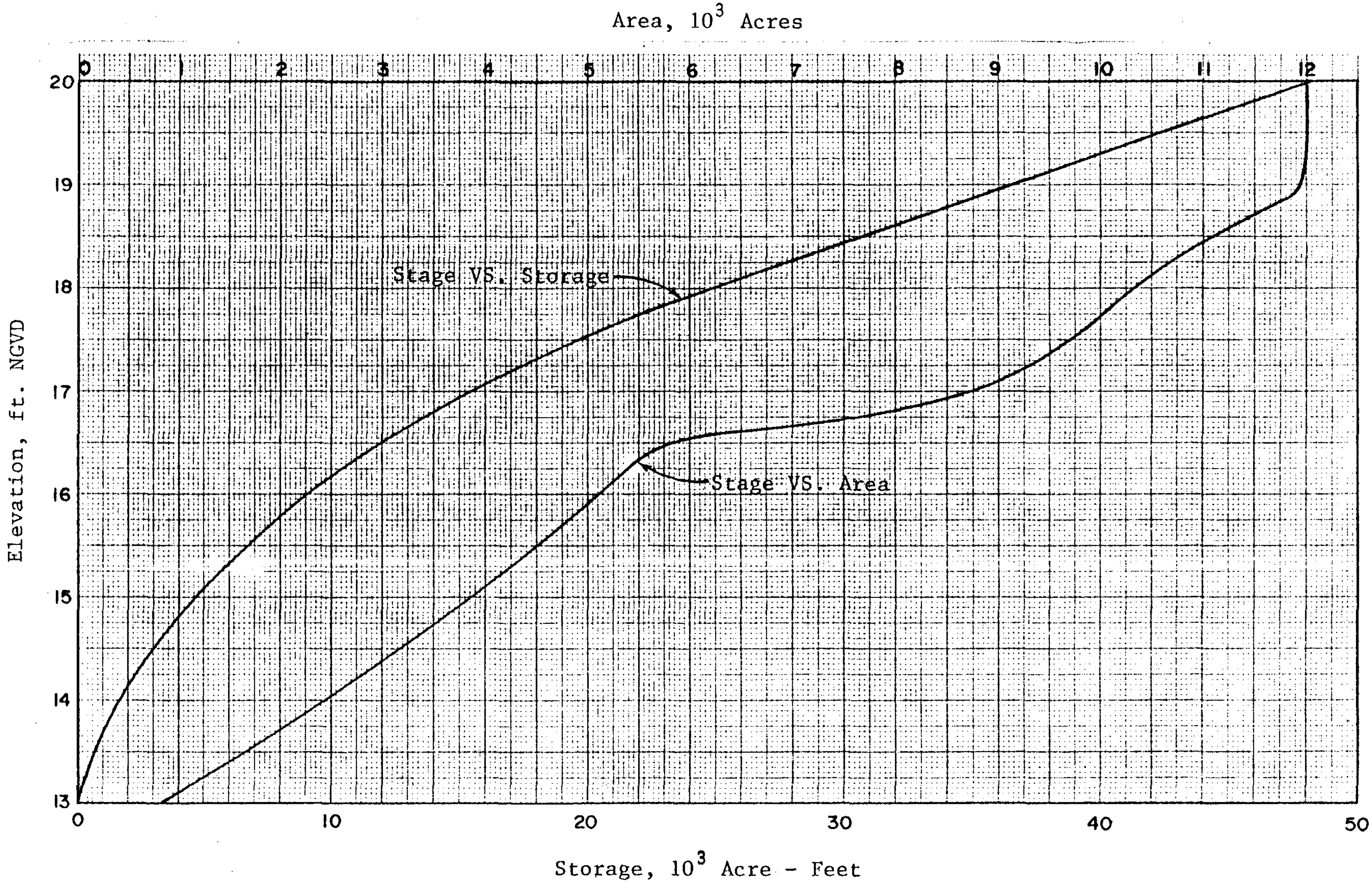


Fig. 5-5. Stage - Storage - Area Relationships for the St. Johns Marsh Conservation Area

Table 5-4 Annual Series of Low Stages for St. Johns Marsh Conservation Area

@@@@@ ELEVATION IN ST. JOHNS MARSH CONSERVATION AREA, FT NGVD

LOWEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING SEPT 30

YEAR	1	7	14	30	60	120	183	274	1 YEAR
1943	18.12	18.16	18.21	18.26	18.37	18.67	18.93	19.19	19.54
1944	18.98	19.00	19.04	19.13	19.23	19.36	19.48	19.74	20.06
1945	17.79	17.84	17.87	17.99	18.28	18.76	19.11	19.47	19.80
1946	18.82	18.85	18.89	18.94	19.06	19.29	19.44	19.62	19.86
1947	19.63	19.65	19.68	19.75	19.80	19.89	19.92	20.02	20.20
1948	19.33	19.35	19.37	19.42	19.53	19.64	19.69	19.78	20.15
1949	18.53	18.60	18.61	18.65	18.86	19.22	19.45	19.66	19.97
1950	17.88	17.91	17.94	17.97	18.01	18.19	18.45	18.87	19.17
1951	18.62	18.65	18.65	19.48	19.61	19.69	19.81	19.89	19.98
1952	19.42	19.45	19.51	19.62	19.77	19.90	19.90	19.94	20.03
1953	19.15	19.20	19.25	19.35	19.48	19.59	19.66	19.76	20.01
1954	19.34	19.36	19.37	19.39	19.44	19.60	19.76	19.90	20.17
1955	19.25	19.30	19.32	19.37	19.43	19.48	19.60	19.70	19.84
1956	17.85	17.89	17.91	17.98	18.16	18.44	18.74	19.10	19.42
1957	19.61	19.64	19.65	19.70	19.75	19.79	19.88	20.01	20.25
1958	19.29	19.32	19.33	19.38	19.49	19.69	19.84	19.89	19.92
1959	19.62	19.66	19.70	19.72	19.72	19.76	19.88	20.02	20.10
1960	19.71	19.72	19.73	19.77	19.84	19.94	20.05	20.15	20.26
1961	18.80	18.86	18.91	19.03	19.18	19.26	19.30	19.41	19.67
1962	17.10	17.14	17.17	17.24	17.32	17.50	17.73	18.22	18.71
1963	18.63	18.65	18.67	18.73	18.80	18.90	19.00	19.21	19.41
1964	18.88	18.92	18.92	18.96	19.03	19.16	19.35	19.58	19.80
1965	17.90	17.92	17.94	17.99	18.03	18.44	18.74	19.07	19.30
1966	19.35	19.38	19.43	19.49	19.59	19.81	19.83	19.95	20.06
1967	16.50	16.55	16.57	16.66	16.74	16.94	17.16	17.76	18.27
1968	15.61	15.68	15.75	15.81	15.94	16.28	16.50	17.00	17.85
1969	19.38	19.43	19.45	19.52	19.61	19.69	19.76	19.77	19.89
1970	18.75	18.78	18.81	18.87	18.93	19.12	19.32	19.57	19.76
1971	16.99	17.03	17.08	17.15	17.24	17.46	17.66	18.05	18.50
1972	19.16	19.22	19.27	19.31	19.39	19.53	19.62	19.83	19.91
1973	19.16	19.21	19.23	19.27	19.38	19.48	19.49	19.61	19.84
1974	17.80	17.83	17.86	17.88	18.03	18.51	18.89	19.24	19.58
1975	18.37	18.40	18.44	18.46	18.64	18.96	19.15	19.38	19.61
1976	17.72	17.76	17.80	17.88	18.08	18.55	18.92	19.27	19.53
1977	17.74	17.76	17.79	17.83	17.88	17.95	18.30	18.76	19.07
1978	19.36	19.39	19.43	19.47	19.51	19.71	19.80	19.84	19.94
1979	19.26	19.30	19.33	19.38	19.54	19.81	19.79	19.87	19.99
1980	18.74	18.81	18.85	18.94	19.04	19.20	19.35	19.52	19.68
1981	14.65	14.70	14.73	14.81	14.97	15.36	15.86	16.51	17.01
1982	15.22	15.26	15.30	15.41	15.52	15.59	15.64	16.17	17.24
1983	19.50	19.55	19.61	19.70	19.78	19.91	20.04	20.04	20.08
1984	18.72	18.74	18.76	18.83	18.89	19.02	19.14	19.36	19.54
1985	17.88	17.91	17.96	18.06	18.14	18.36	18.61	18.97	19.15
1986	17.85	17.89	17.90	17.95	18.06	18.57	19.01	19.32	19.68

Table 5-5 Annual Series of High Stages for St. Johns Marsh Conservation Area

@@@@@ ELEVATION IN ST. JOHNS MARSH CONSERVATION AREA, FT NGVD

HIGHEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING MAY 31

YEAR	1	7	14	30	60	120	183	274	1 YEAR
1943	21.13	21.12	21.08	20.99	20.80	20.45	20.22	19.99	19.73
1944	21.31	21.30	21.28	21.22	21.05	20.84	20.52	20.21	19.87
1945	21.24	21.20	21.15	21.06	20.98	20.92	20.64	20.33	19.97
1946	21.22	21.17	21.13	20.93	20.68	20.52	20.31	20.11	19.78
1947	20.87	20.87	20.84	20.72	20.61	20.39	20.23	20.15	20.02
1948	22.98	22.96	22.92	22.65	21.91	21.24	21.00	20.63	20.41
1949	21.77	21.72	21.62	21.45	21.03	20.52	20.30	20.08	19.88
1950	21.13	21.11	21.08	20.98	20.84	20.53	20.30	20.12	19.82
1951	21.26	21.25	21.20	20.93	20.51	20.14	19.97	19.75	19.34
1952	20.75	20.65	20.52	20.43	20.30	20.23	20.17	20.09	20.05
1953	21.14	21.09	20.94	20.65	20.41	20.35	20.21	20.05	19.93
1954	22.34	22.23	22.19	21.83	21.59	21.08	20.71	20.42	20.19
1955	20.91	20.88	20.80	20.65	20.46	20.25	20.25	20.14	20.05
1956	20.87	20.82	20.70	20.63	20.42	20.15	20.02	19.83	19.60
1957	23.08	22.82	22.37	21.77	21.25	20.76	20.42	20.26	19.84
1958	20.84	20.77	20.62	20.53	20.48	20.35	20.19	20.14	20.12
1959	20.66	20.61	20.57	20.46	20.26	20.03	19.93	19.95	19.86
1960	21.29	21.25	21.15	20.96	20.67	20.42	20.44	20.26	20.25
1961	22.21	22.12	22.04	21.76	21.16	20.82	20.56	20.26	20.01
1962	19.79	19.76	19.72	19.67	19.62	19.57	19.48	19.30	18.89
1963	21.02	20.95	20.87	20.83	20.64	20.27	20.07	19.84	19.35
1964	20.97	20.96	20.94	20.74	20.43	20.25	20.14	19.87	19.63
1965	20.84	20.79	20.70	20.65	20.43	20.15	19.95	19.69	19.48
1966	20.74	20.63	20.56	20.48	20.22	20.07	20.04	19.95	19.63
1967	21.09	21.07	20.99	20.72	20.46	20.33	20.18	19.89	19.39
1968	17.40	17.36	17.32	17.28	17.26	17.20	17.11	16.99	16.78
1969	21.18	21.15	21.09	21.05	20.83	20.44	20.35	20.12	19.99
1970	20.78	20.69	20.60	20.48	20.41	20.34	20.26	20.14	20.01
1971	19.57	19.55	19.52	19.46	19.31	19.12	19.15	18.88	18.56
1972	20.65	20.60	20.55	20.35	20.23	20.14	20.00	19.86	19.48
1973	21.10	21.08	21.03	20.75	20.44	20.24	20.03	19.87	19.76
1974	20.92	20.91	20.88	20.75	20.67	20.53	20.36	20.12	19.77
1975	21.00	20.99	20.97	20.81	20.74	20.47	20.22	19.95	19.57
1976	20.72	20.68	20.61	20.52	20.49	20.15	20.04	19.83	19.45
1977	20.74	20.68	20.62	20.49	20.40	20.32	20.15	20.00	19.68
1978	20.44	20.38	20.34	20.18	20.03	19.98	19.98	19.82	19.35
1979	21.04	21.01	20.91	20.73	20.43	20.19	20.06	20.03	19.95
1980	21.63	21.54	21.48	21.40	20.97	20.45	20.29	20.15	20.04
1981	19.62	19.57	19.53	19.46	19.37	19.20	19.02	18.68	18.29
1982	17.08	16.08	16.05	16.02	15.98	15.90	15.83	15.73	15.61
1983	20.88	20.85	20.74	20.68	20.54	20.43	20.27	20.25	20.13
1984	20.66	20.62	20.54	20.42	20.28	20.18	20.11	20.02	19.88
1985	19.92	19.90	19.87	19.83	19.77	19.59	19.46	19.32	19.14
1986	21.29	21.26	21.21	20.98	20.57	20.24	20.12	19.85	19.46

The mean discharge at U.S. 192 would increase by 13% (see 1-year values, Table 5-7), i.e., about 62,000 AF or 20,000 million gallons per year. This occurs primarily due to the curtailment of the diversion to the Indian River. The 1-day to 60-day low flows, which govern Lake Washington water supply potential will increase as a result of various water conservation measures implemented under the USJRB Project including specific operation schedules designated for the five water management/marsh conservation areas. The 60-day low flows will increase by 80%, with the improvement progressively rising to 190% for the 1-day low flows.

Three withdrawals, the current demand (14 mgd), and the projected demands (available at the commencement of this study) for the years 2000 and 2030 (25 mgd and 30 mgd, respectively), were considered for evaluating low stages in Lake Washington. Table 5-8 summarizes the results of low stage frequency analysis. For a 50-year drought, the 1-day and 60-day low stages are estimated as 13.4 ft. NGVD and 13.5 ft. NGVD, respectively, for the 14 mgd withdrawal. These stages will decrease to 12.6 ft. NGVD and 12.9 ft. NGVD, respectively, as the withdrawal is increased to 30 mgd. In general, these levels are quite satisfactory to provide good water quality in Lake Washington (see Fig. 5-3 and Eq. 5.1). Due to low flow augmentation by release of flows upstream, these low levels would stabilize and for a 200-year drought the estimated low stages at 30 mgd withdrawal are

Table 5-6: Estimates of Drought Stages, ft. NGVD, for the St. Johns Marsh Conservation Area

Duration Days	Mean Annual Low	Return Period, Years. 5	10	25	50	100	200
1	18.4	17.8	16.8	15.8	15.1	14.45	13.8
7	18.45	17.85	16.85	15.85	15.15	14.5	13.85
14	18.5	17.85	16.85	15.9	15.2	14.55	13.9
30	18.55	17.9	16.95	15.95	15.25	14.6	14.0
60	18.65	18.05	17.05	16.1	15.4	14.75	14.1

Table 5-7: Mean Low Flows for 1943-1985 for the St. Johns River at U.S. 192.

Duration	Recorded cfs	No-Plug Condition (simulated) cfs	With Project (simulated) cfs	Ratio, With-Project/No-Plug Condition
1-Day	39.8	38.5	111	2.9
7-Day	49.5	42.1	115	2.7
14-Day	55.2	47.6	120	2.5
30-Day	66.6	62.6	132	2.1
60-Day	87.5	89.8	158	1.8
120-Day	144	157	213	1.4
183-Day	225	213	278	1.3
274-Day	356	353	414	1.17
1-Year	671	659	745	1.13

12.0 ft. NGVD, and 12.3 ft. NGVD, respectively, for the 1-day and 60-day durations (Table 5-8). This shows that under the USJRB Project water depths in Lake Washington would be higher by about 4 feet during extreme droughts as compared to the existing conditions.

5.3.3 USJRB Project Conditions with Modified Weir Structures

Three lake withdrawals, i.e., 14 mgd, 25 mgd, and 30 mgd were considered for each of the four weir settings analyzed. Tables 5-9 through 5-12 summarize the results of low stage frequency analysis.

i) Modified weir with weir crest at 14.0 ft. NGVD

Low stages for return periods 5 yr to 200 yr will improve by 0.5 ft. or greater (see Tables 5-8 and 5-9). The 1-in-50 year drought stages will vary from 13.2 ft. NGVD at 30 mgd withdrawal to 13.95 ft. NGVD at 14 mgd withdrawal. The 200-yr low stages for the same withdrawals are estimated to vary from 12.6 ft. NGVD to 13.8 ft. NGVD. Water quality should not be a concern at these elevations (see Fig. 5-3).

ii) Modified weir with weir crest at 13.0 ft. NGVD

The low stages in the lake will drop by 0.3 ft. to 0.6 ft. if the existing weir height is reduced by 0.5 ft. (see Tables 5-8 and 5-10). At 30 mgd withdrawal the 1-day to 60-day low stages are estimated to vary from 12.1 ft. NGVD to 12.4 ft. NGVD during a 50-year drought and 11.4 ft. NGVD to 11.7 ft. NGVD during a 200-year drought. The chloride concentrations will be satisfactory at these levels (see Fig 5-3).

Table 5-8. Lake Washington: Estimated Low Stages (ft. NGVD) for Droughts of Different Return Periods (USJRB Project, Existing Weir)

Duration Days	Mean Annual Low	Recurrence interval, years 5	10	25	50	100	200
				Withdrawal = 14 mgd.			
1	13.75	13.65	13.55	13.5	13.4	13.35	13.3
7	13.75	13.65	13.55	13.5	13.4	13.35	13.3
14	13.8	13.65	13.6	13.5	13.45	13.4	13.35
30	13.8	13.65	13.6	13.5	13.5	13.45	13.4
60	13.9	13.7	13.65	13.55	13.5	13.45	13.4
				Withdrawal = 25 mgd.			
1	13.7	13.55	13.45	13.25	13.0	12.8	12.6
7	13.7	13.55	13.45	13.3	13.1	12.9	12.7
14	13.7	13.55	13.45	13.3	13.1	12.95	12.8
30	13.75	13.6	13.5	13.35	13.15	13.0	12.8
60	13.8	13.65	13.55	13.54	13.3	13.1	12.9
				Withdrawal = 30 mgd.			
1	13.65	13.5	13.3	13.0	12.6	12.3	12.0
7	13.65	13.5	13.35	13.05	12.7	12.4	12.1
14	13.65	13.55	13.35	13.1	12.75	12.45	12.15
30	13.7	13.55	13.4	13.1	12.8	12.5	12.2
60	13.8	13.6	13.45	13.25	12.9	12.6	12.3

Table 5-9. Lake Washington: Estimated Low Stages (ft. NGVD) for Droughts of Different Return Periods (USJRB Project, Modified Weir with Weir Crest at 14 ft. NGVD).

Duration Days	Mean Annual Low	Recurrence interval, years 5	10	25	50	100	200
				Withdrawal = 14 mgd.			
1	14.25	14.2	14.15	14.0	13.95	13.9	13.8
7	14.25	14.2	14.15	14.0	13.95	13.9	13.8
14	14.25	14.2	14.2	14.05	13.95	13.9	13.8
30	14.3	14.2	14.2	14.1	14.0	14.0	13.9
60	14.3	14.2	14.2	14.1	14.0	14.0	13.95
				Withdrawal = 25 mgd.			
1	14.2	14.15	14.1	13.8	13.6	13.3	13.1
7	14.2	14.15	14.15	13.85	13.6	13.4	13.2
14	14.2	14.15	14.15	13.85	13.65	13.45	13.25
30	14.25	14.2	14.15	13.85	13.65	13.5	13.3
60	14.3	14.2	14.15	13.95	13.75	13.6	13.4
				Withdrawal = 30 mgd.			
1	14.15	14.15	14.1	13.6	13.2	12.9	12.6
7	14.2	14.15	14.1	13.6	13.2	12.9	12.6
14	14.2	14.15	14.1	13.65	13.3	13.0	12.7
30	14.2	14.15	14.15	13.7	13.35	13.05	12.75
60	14.25	14.15	14.15	13.8	13.5	13.2	12.9

Table 5-10. Lake Washington: Estimated Low Stages (ft. NGVD) for Droughts of Different Return Periods (USJRB Project, Modified Weir with Weir Crest at 13 ft. NGVD)

Duration Days	Mean Annual Low	Recurrence interval, years 5	10	25	50	100	200
				Withdrawal = 14 mgd.			
1	13.4	13.20	13.15	13.05	12.95	12.9	12.8
7	13.4	13.2	13.15	13.05	12.95	12.9	12.8
14	13.45	13.25	13.15	13.05	12.95	12.9	12.8
30	13.45	13.25	13.2	13.1	13.0	12.95	12.9
60	13.55	13.25	13.25	13.15	13.05	13.0	12.95
				Withdrawal = 25 mgd.			
1	13.3	13.15	13.05	12.8	12.55	12.3	12.1
7	13.3	13.15	13.05	12.8	12.55	12.3	12.1
14	13.35	13.15	13.1	12.8	12.6	12.4	12.2
30	13.4	13.2	13.1	12.9	12.65	12.45	12.3
60	13.5	13.2	13.15	12.95	12.75	12.6	12.4
				Withdrawal = 30 mgd.			
1	13.25	13.1	13.0	12.5	12.1	11.75	11.4
7	13.25	13.15	13.05	12.5	12.1	11.75	11.4
14	13.3	13.15	13.05	12.6	12.2	11.8	11.5
30	13.35	13.15	13.1	12.65	12.3	11.9	11.6
60	13.45	13.15	13.15	12.8	12.4	12.0	11.7

iii) Modified weir with weir crest at 12.0 ft. NGVD:

At 30 mgd withdrawal the lake levels will drop to about 11.0 ft. NGVD during a 50-year drought and to about 10.0 ft. NGVD during a 200-year drought (Table 5-11). The chloride levels are likely to exceed 250 mg/l at these low elevations.

iv) Weir totally removed: This case has been analyzed to examine the impact of weir removal on minimum flow criteria as discussed in Chapter VII. Results for the 14 mgd withdrawal case (Table 5-12) indicate that if the weir is removed, the drought stages in the lake would be very low (about 9.0 ft. NGVD) and the lake would be very shallow giving rise to severe water quality problems. Thus, this case is considered infeasible and no further analyses were made for 25 mgd and 30 mgd withdrawals.

5.3.4 Summary and Discussion

Depending on the weir heights, during low water levels, drinking water quality standards will restrict the usefulness of Lake Washington as a source of water supply. The previous sections of this chapter presented the estimates of low (drought) stages for Lake Washington for return periods of 5-years to 200-years for various alternative basin and weir conditions. The lake withdrawals are varied from the current use (14 mgd) to the projected demand for 2030 A.D. (30 mgd).

The 1977-1986 chloride data available for Lake Washington were used to derive a regression equation relating annual low levels in the lake to chloride concentrations (Fig. 5-3; Eq. 5.1). The highest chloride value recorded during the 1981 drought (about 302 mg/l at 11.5 ft. NGVD) greatly influences the

Table 5-11. Lake Washington: Estimated Low Stages (ft. NGVD) for Droughts of Different Return Periods (USJRB Project, Modified Weir with Weir Crest at 12 ft. NGVD)

Duration Days	Mean Annual Low	Recurrence interval, years 5	10	25	50	100	200
				Withdrawal = 14 mgd.			
1	12.45	12.2	12.15	12.0	11.95	11.9	11.8
7	12.5	12.25	12.15	12.0	11.95	11.9	11.8
14	12.5	12.25	12.2	12.0	11.95	11.9	11.8
30	12.55	12.25	12.2	12.05	12.0	11.95	11.9
60	12.7	12.3	12.25	12.15	12.05	12.0	11.95
				Withdrawal = 25 mgd.			
1	12.35	12.15	12.05	11.8	11.5	11.25	11.05
7	12.35	12.15	12.1	11.8	11.5	11.25	11.05
14	12.4	12.15	12.1	11.8	11.55	11.3	11.1
30	12.45	12.2	12.15	11.85	11.65	11.4	11.2
60	12.6	12.2	12.2	11.95	11.7	11.5	11.3
				Withdrawal = 30 mgd.			
1	12.3	12.1	12.05	11.45	10.95	10.45	10.05
7	12.3	12.15	12.05	11.5	10.95	10.5	10.1
14	12.35	12.15	12.05	11.55	11.0	10.55	10.2
30	12.4	12.15	12.1	11.65	11.2	10.7	10.25
60	12.55	12.2	12.15	11.8	11.35	10.85	10.4

Table 5-12. Lake Washington: Estimated Low Stages (ft. NGVD) for Droughts of Different Return Periods (USJRB Project, No Weir)

Duration Days	Mean Annual Low	Recurrence interval, years 5	10	25	50	100	200
1	11.85	11.15	11.0	10.2	9.75	9.35	9.0
7	11.90	11.2	11.05	10.25	9.75	9.35	9.0
14	11.95	11.25	11.1	10.35	9.85	9.45	9.1
30	12.05	11.35	11.15	10.35	9.85	9.45	9.1
60	12.25	11.5	11.3	10.5	10.0	9.6	9.2

regression relation. The high chloride levels observed in the lake during this drought are attributed primarily to the mineralized seepage water induced and conveyed by the borrow canals in the upstream marsh. This condition is not expected to occur in the future because these canals are now plugged. Thus, the chloride value given by Eq. 5.1 would be an over-estimate and a conservative index for the general water quality of the lake at a given elevation. No detailed analyses of TDS are made. However, similar trends and conclusions are expected.

Table 5-13 summarizes the estimates of the 50-year and 200-year lowest elevations (1-day) in Lake Washington and the corresponding levels of chloride concentration for different alternatives evaluated. The following conclusions can be drawn with regard to Lake Washington water supply potential.

Existing conditions: The lake will, for all practical purposes, go dry during a 200-year drought at 30 mgd withdrawal. The levels of chloride concentration will exceed the Class I standard of 250 mg/l during a 50-year drought if the withdrawal is 20 mgd and above, and during a 200-year drought if the withdrawals is 14 mgd or above. Thus, the lake under the existing conditions would not be able to meet the projected (South Brevard County) water demands of either 2030 or 2000 (30 mgd and 25 mgd, respectively). Based on a 50-year low stage or drought frequency, the water supply potential of the lake is estimated as about 18 mgd.

The USJRB Project Conditions: For the four alternative weir settings considered (weir crest at 14.00 ft. NGVD, 13.50 ft.

Table 5-13 Summary of the 50-year and 200-year Low Elevation Estimates for Lake Washington and the Estimates of Chloride Concentration

Elevation of Weir Crest ft. NGVD	Lake Washington Withdrawal mgd	Drought Conditions in Lake Washington: 50- year Stage ft. NGVD	50- year Chlorides Concentation Mg/1	200-year Stage ft. NGVD	200-year Chlorides Concentration Mg/1
		Existing Conditions			
13.5	14	11.9	223	11.35	*
	16	11.7	242	11.05	*
	20	11.0	*	10.15	*
	22	10.65	*	9.7	*
	25	10.25	*	9.1	*
	30	8.9	*	(Lake goes dry)	
		The USJRB Project Conditions			
14.0	14	13.95	98	13.8	104
	25	13.6	113	13.1	138
	30	13.2	132	12.6	168
13.5	14	13.4	122	13.3	127
	25	13.0	143	12.6	168
	30	12.6	168	12.0	215
13.0	14	12.95	146	12.8	155
	25	12.55	172	12.1	206
	30	12.1	206	11.4	*
12.0	14	11.95	219	11.8	233
	25	11.5	*	11.05	*
	30	10.95	*	10.05	*
No Weir	14	9.75	*	9.00	*

* Chloride concentration exceeds 250 mg/1

NGVD, 13.00 ft. NGVD and 12.00 ft. NGVD) the 50-year and 200-year low stages in Lake Washington are estimated to be in the ranges of 10.95 ft. NGVD to 13.95 ft. NGVD, and 10.05 ft. NGVD to 13.80 ft. NGVD, respectively. The chloride concentrations are likely to exceed 250 mg/l if the weir crest is lowered to 12.00 ft. NGVD. From these results the water supply potential of Lake Washington under the USJRB Project conditions is estimated as 30 mgd or greater provided the redesigned weir has a crest elevation of 13.00 ft NGVD or greater.

CHAPTER VI

HYDROLOGIC CONSIDERATIONS AND CRITERIA FOR SURFACE WATER DEVELOPMENT

Chapter 17-40, FAC, Water Policy, contains Sections 17-40.07 and 17-40.08, FAC, which respectively are titled, Surface Water Management and Minimum Flows and Levels. The former prescribes considerations that should be included in regulatory programs implemented pursuant to Part IV of Chapter 373 F.S. The latter sets forth considerations that should be taken into account when setting a minimum flow or level.

Among those factors or considerations applicable to the evaluation of this Lake Washington weir study are:

a) The impacts on:

i) minimum flows and levels,

ii) reasonable beneficial use of water, and

iii) other factors relating to the public health, safety, and welfare;

b) The ability of the facilities and related improvements to avoid increased damage to offsite property or the public caused by:

i) floodplain development, encroachment or other alteration, and

ii) retardance, acceleration or diversion of flowing water.

Considerations for establishing minimum flows and levels applicable to this study include:

(a) Recreation in and on the water;

(b) Fish and wildlife habitats and the passage of fish;

(c) Transfer of detrital material;

(d) Maintenance of freshwater storage and supply;

(e) Sediment loads;

(f) Water quality in the lake and downstream; and

(g) Navigation.

6.1 Minimum Flow and Levels Requirements

6.1.1 Floodplain Vegetation, Soils and Wildlife Consideration

Satisfying vegetative and wildlife requirements of Lake Washington and the river downstream (i.e., north of the lake) is a prime consideration in this study. For examining downstream critical conditions, a location at RM 253.1 between Lakes Washington and Winder (Fig. 2-5) has been selected (Hall, 1987). The District chose the following general hydrologic criteria for meeting the minimum flow and level requirements in the USJRB (Brooks and Lowe, 1984).

1) The mean depth and frequency of inundation for the central critical marsh elevation should be such that there will be no net subsidence of organic soil.

   a. The minimum frequency of inundation on the central critical marsh elevation should be 60 percent. The central critical marsh elevation is the central elevation of the zone delimited by the upper and lower critical marsh elevations. The upper and lower critical marsh elevations are determined from the stage area curve and are defined as the upper and lower elevations of the marshflat. The critical zone thus contains the majority of the wetland acreage. Hydrologic constraints concerning long-term events (e.g., mean depth) will reference the central elevation.

b. The mean water elevation should be maintained approximately at 0.25 feet below the central critical marsh elevation to prevent subsidence.

2) The natural timing of fluctuation in water depth should be modified as little as possible.

3) Short-term (less than 60 days) and infrequent (return interval greater than 10 years) minima are not considered detrimental.

4) A minimum range of fluctuation in water depth should be maintained. Specifically, the lower and upper critical marsh elevations should experience both exposure and inundation in a typical year (i.e., once in two years or greater).

5) The duration and intensity of maximum water elevations should not significantly damage or alter the plant communities at the lower critical marsh elevation. Maximum 30 and 60 day depths of 4.8 ft. and 3.3 ft., respectively, are recommended to protect marsh vegetation.

The conditions stipulated under Criterion 1 above are regarded as primary criteria. The other criteria are desirable and are considered as secondary criteria.

The upper, central and lower critical marsh elevations for Lake Washington and the adjacent floodplain marsh have been determined as 15.00 ft. NGVD, 14.00 ft. NGVD, and 13.00 ft. NGVD respectively (Hall, 1987). For the river reach downstream of the weir, i.e., at RM 253.1 (a point about 1.3 miles from the weir), these values are 14.0 ft. NGVD, 12.7 ft. NGVD, and 11.4 ft. NGVD, respectively. From these elevations, the ecologic/hydrologic criteria specific to Lake Washington and RM 253.1 can be derived as follows:

Primary Criteria

1. The mean water elevation shall not be less than 13.75 ft. NGVD and 12.45 ft. NGVD for Lake Washington and RM 253.1, respectively.
2. The cumulative frequency of inundation for the central critical marsh elevation, 14.00 ft. NGVD and 12.70 ft. NGVD for Lake Washington and RM 253.1, respectively, shall not be less than 60 percent.

Secondary Criteria

3. The natural timing of fluctuation in water depth should be retained.
4. The lower and upper critical marsh elevations, 13.00 ft. NGVD and 15.00 ft. NGVD for Lake Washington and 11.40 ft. NGVD and 14.00 ft. NGVD for RM 253.1 should experience both exposure and inundation in a typical year.
5. Maximum 30 and 60 day water elevations should not exceed 17.80 ft. NGVD and 16.30 ft. NGVD, respectively, for Lake Washington, and 16.20 ft. NGVD and 14.70 ft. NGVD, respectively for RM 253.1.

Figure 6-1 shows the relative positions of various critical marsh elevations for RM 253.1 and a river cross section at Lake Washington. The following is a brief description of how these parameters are calculated from the daily stage data generated by hydrologic simulation.

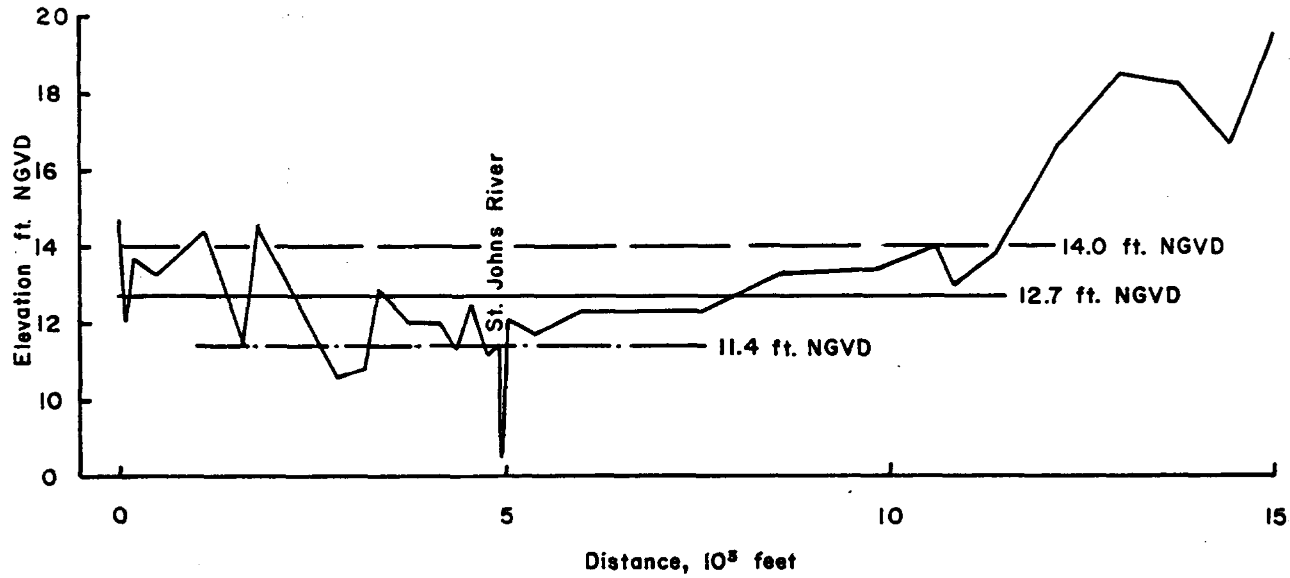
Primary Requirements

1) Mean water elevation shall not be less than 13.75 ft. NGVD at Lake Washington, and 12.45 ft. NGVD at RM 253.1. These are the mean elevation requirements over a long period. Mean stages for the period of simulation (45 yrs) were calculated for the two locations and compared with the required values.
2) The central critical marsh elevation (14.00 ft. NGVD for Lake Washington and 12.70 ft. NGVD for RM 253.1) should be exceeded for 60% of the time over a long period. These values were obtained from the depth-duration data for the simulation period.

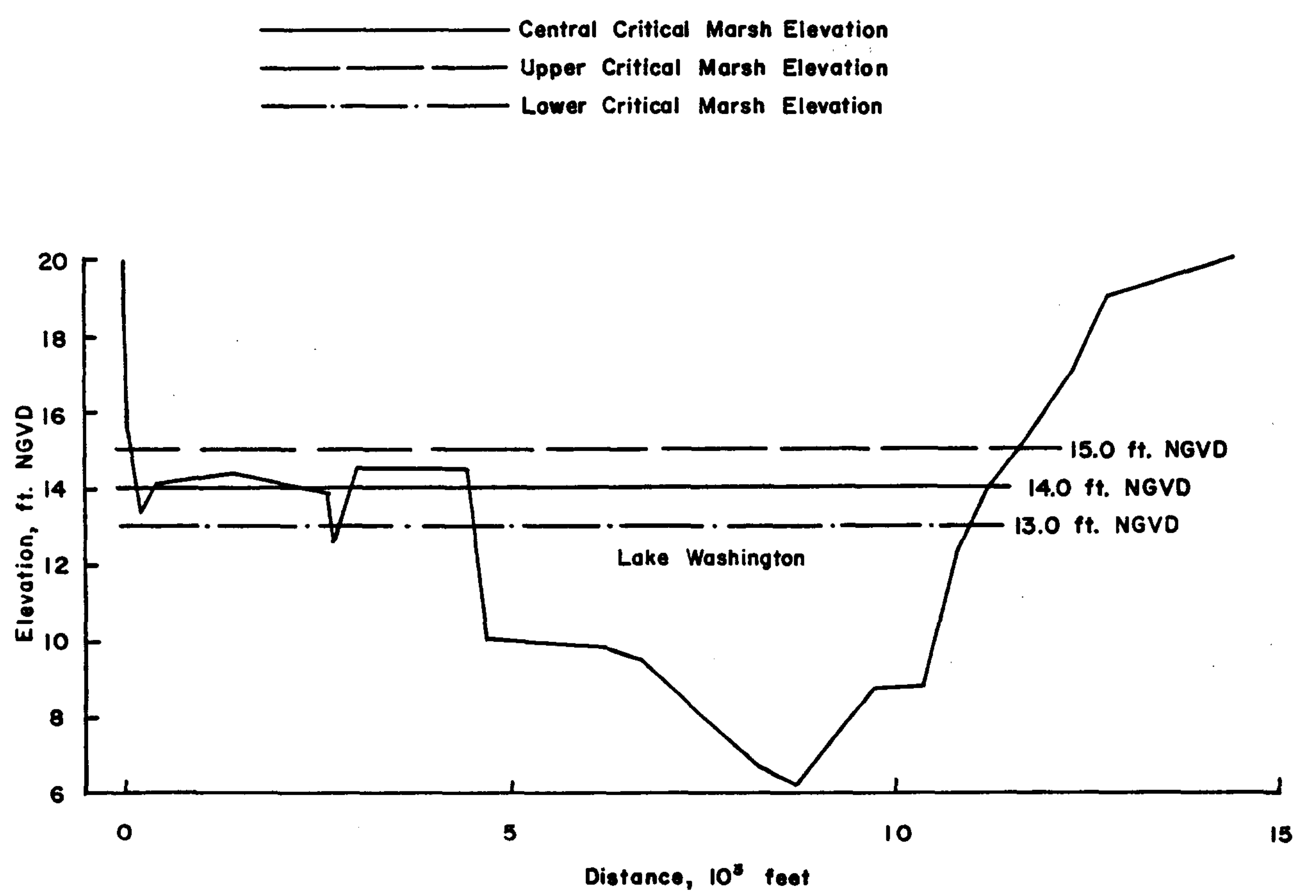
Secondary Requirements

The natural timing of fluctuation in water depth at Lake Washington and downstream is not affected by the presence of the existing or redesigned Lake Washington weir. The weir is only an overflow structure without control gates to alter the natural timing of the flow regime. Other parameters are calculated as follows:

1) The lower critical marsh elevation (13.00 ft. NGVD for Lake Washington and 11.40 ft. NGVD for RM 253.1) should be exceeded in a typical year. The number of years this



ST. JOHNS RIVER AT RIVER MILE 253.1



ST. JOHNS RIVER AT RIVER MILE 256.96

Figure 6-1 Critical Marsh Elevations at River Miles 253.1 and 256.96

elevation was exceeded (during the period of simulation) was evaluated and expressed as a percentage.

2) The marsh at its lower critical elevation should be exposed in a typical year. The number of years this elevation was not exceeded (during the period of simulation) was evaluated and expressed as a percentage.

3) The upper critical marsh elevation (15.00 ft. NGVD for Lake Washington and 14.0 ft. NGVD for RM 243.1) should be exceeded in a typical year. The number of years this elevation was exceeded (during the period of simulation) was evaluated and expressed as a percentage.

4) The marsh at its upper critical elevation should be exposed in a typical year. The number of years this elevation was not exceeded (during the period of simulation) was evaluated and expressed as a percentage.

5) Maximum 30-day water elevation should not exceed 17.8 ft. NGVD at Lake Washington (16.20 ft. NGVD at RM 253.1) - Number of years this elevation was exceeded (during the period of simulation) was evaluated and expressed as a percentage.

6) Maximum 60-day water elevation should not exceed 16.30 ft. NGVD at Lake Washington (14.70 ft. NGVD at RM 253.1) - Number of years this elevation was exceeded (during the period of simulation) was evaluated and expressed as a percentage.

Appendix IV presents the tables summarizing various parameters of minimum flow/stage criteria (as explained in this section) for Lake Washington and the St. Johns River at RM 253.1 for the existing and USJRB Project conditions.

6.1.2 Other Considerations

Fish and Wildlife Habitat-- The minimum level criteria prescribed for the protection of floodplain soils and vegetation also promote the maintenance of fish and wildlife habitat. However, to protect the fisheries during drought conditions the following specific recommendations were made for the study area (Hall, 1987).

a) Lake Washington: one-day one-in-50 year and one-day one-in 100 year minimum surface water levels should equal or exceed 10.00 ft NGVD and 9.50 ft NGVD, respectively.

b) St. Johns River at RM 253.1: one-day one-in-five year low stages should equal or exceed 9.50 ft NGVD.

Recreation and Navigation -- No specific hydrologic criteria for recreation and navigation have been established for the Lake Washington area. However, it is recognized that any new weir design must provide for navigational needs between Lake Washington and the river channel downstream of the lake.

Sediment loads and transfer of detrital material -- No specific hydrologic criteria for controlling sediment loads and transfer of detrital material have been established. However, it is recognized that any new weir design must provide for sediment control and transfer of detrital material. This can probably best be accomplished by use of a sluice gate.

6.2 Other Management and Storage Considerations

6.2.1 Impacts on Reasonable-Beneficial Use of Water

At present, the City of Melbourne is the only major user of Lake Washington water. The District, pursuant to its authority under Chapter 373. F.S. has issued a consumptive use permit for these withdrawals. Any design of a new weir should not adversely impact the City's ability to continue to withdraw water from the lake.

6.2.2 Impacts to Public Health, Safety and Welfare Including Increased Damage to Offsite Property and Public.

An increase in the crest elevations of the Lake Washington weir may increase the flooding potential and flood durations within the basin. These occurrences may cause property damage and/or affect the function of septic tanks. A change in weir design and increased lake withdrawal might affect the navigability of the river causing public inconvenience. Therefore, the effect of various alternative weir designs were evaluated with respect to flood damages near Lake Washington and navigability of the St. Johns River between Lakes Winder and Washington. Appendix V summarizes the estimates of flood stages for Lake Washington.

CHAPTER VII

MANAGEMENT ALTERNATIVES EVALUATION

Extensive hydrologic simulation studies were conducted to derive pertinent results for various alternative design conditions considered in this study. The results derived consisted of the estimates of low stages for Lake Washington and for a location in the downstream floodplain marsh (RM 253.1), the parameters of minimum flow criteria (see Chapter VI), the estimates of flood stages, and the information regarding socio-economic impacts. In Chapter V, the water supply potential of Lake Washington was estimated (for various alternative conditions) based on drought levels in the lake and water quality (chloride concentration) considerations. Before a given alternative is selected it is necessary to examine the degree to which the selected alternative also satisfies the other environmental and socio-economic criteria described in Chapter VI.

7.1 Selection of Management Alternatives Based on Primary Criteria and Considerations

The hydrologic criteria for minimum level requirements give rise to two primary criteria, i.e., 1) the mean water elevation over a long period shall not be less than an elevation determined with reference to the central critical marsh elevation of the stream at a given location; and 2) the central critical marsh elevation should be exceeded 60% of the time over a long period. These criteria are applied to two locations in the study area, i.e., Lake Washington (RM 258.8) and St. Johns River downstream of Lake Washington (RM 253.1). The results are summarized in Tables 7-1 and 7-2 (See Appendix IV for detailed results).

Lake Washington (RM 258.8): The mean elevation of the lake will exceed the minimum requirement of 13.75 ft. NGVD for both the existing conditions and the USJRB Project conditions under various alternative weir settings. However, the criteria with reference to the central critical marsh elevation will not be met if the weir height is reduced to 13.00 ft. NGVD or less under the USJRB Project conditions. Thus, the three alternatives shown with an asterisk in Table 7-1 are not acceptable and will be excluded from further evaluation.

St. Johns River at RM 253.1: The primary minimum level criteria are well satisfied for all the alternative conditions evaluated in this study (Table 7-2).

Table 7-3 summarizes the mean and range of annual low flows entering Lake Washington at U.S. 192 and leaving the lake at the weir. The mean 1-day to 30-day low flows at US 192 ranged from 40 cfs to 63 cfs under the existing conditions and about 110 cfs to 130 cfs under the USJRB Project conditions. Thus, the USJRB Project will provide substantial low flow augmentation benefits to Lake Washington. Likewise, the downstream low flows also will improve under the USJRB Project.

7.2 Evaluation of Selected Alternatives Based on Secondary Criteria and Considerations.

The existing conditions alternative, the USJRB Project with the existing weir, and the USJRB Project with weir crest at 14.00

Table 7-1 Selection of Alternatives Based on Primary Minimum Level Criteria for Lake Washington

Primary Minimum Level Criterion	Primary Minimum Level Criteria Requirement	Alternatives Evaluated	Consumptive Use Withdrawal Considered, Mgd 14	25	30
Mean Elevation for simulation period, ft. NGVD	13.75	Existing Conditions	14.59	14.50	14.44
		USJRB, project w/ Existing Weir	14.76	14.72	14.70
		USJRB, project w/ weir at 14.0 ft. NGVD	14.94	14.92	14.90
		USJRB project w/ weir at 13.0 ft. NGVD	14.53	14.48	14.46
		USJRB project w/ weir at 12.0 ft. NGVD	14.15	14.08	14.04
		USJRB project w/o weir	13.93	(not evaluated)	
Percent of time 14 ft. NGVD equaled or exceeded	60	Existing Conditions	63.6	61.0	59.9
		USJRB project w/ Existing weir	74.0	71.0	69.0
		USJRB project w/ weir at 14.0 ft. NGVD	100.0	99.2	98.8
		USJRB project w/ weir at 13.0 ft. NGVD	58.5	56.3	55.4 *
		USJRB project w/ weir at 12.0 ft. NGVD	48.9	47.0	46.4 *
		USJRB project w/o weir	48.6	(not evaluated)*	

* Deleted from further evaluation

Table 7-2 Selection of Alternatives Based on Primary Minimum Level Criteria for River Mile 253.1 (Downstream of Lake Washington)

Primary Minimum Level Criterion	Primary Minimum Level Criteria Requirement	Alternatives Evaluated	Consumptive Use Withdrawal from Lake Washington, Mgd 14	25	30
Mean Elevation for simulation period, ft. NGVD	12.40	Existing Conditions	13.48	13.38	13.34
		USJRB, project w/ Existing Weir	13.76	13.76	13.71
		USJRB, project w/ weir at 14.0 ft. NGVD	13.82	13.73	13.69
		USJRB project w/ weir at 13.0 ft. NGVD	13.84	13.75	13.71
		USJRB project w/ weir at 12.0 ft. NGVD	13.86	13.77	13.72
		USJRB project w/o weir	13.87	Not evaluated	
Percent of time 12.65 ft NGVD equaled or exceeded	60.0	Existing Conditions	64.3	63.1	62.4
		USJRB project w/ Existing weir	69.5	68.7	67.7
		USJRB project w/ weir at 14.0 ft. NGVD	69.7	67.9	66.8
		USJRB project w/ weir at 13.0 ft. NGVD	70.7	68.7	67.7
		USJRB project w/ weir at 12.0 ft. NGVD	71.8	69.6	68.4
		USJRB project w/o weir	72.4	Not evaluated	

Table 7-3: The Mean and Range of Annual Low Flows for St. Johns River at U.S. 192 and Lake Washington Weir (simulated)

Duration Days	US 192: Existing Conditions	US 192: USJRB Project Weir Crest Elevation 13.5 ft NGVD	US 192: USJRB Project Weir Crest Elevation 14.0 ft NGVD	Lake Washington: Existing Conditions, 14 mgd	Lake Washington: Existing Conditions, 25 mgd	Lake Washington: Existing Conditions, 30 mgd	Lake Washington: USJRB Project Weir Crest Elevation 13.5 ft NGVD, 14 mgd	Lake Washington: USJRB Project Weir Crest Elevation 13.5 ft NGVD, 25 mgd	Lake Washington: USJRB Project Weir Crest Elevation 13.5 ft NGVD, 30 mgd	Lake Washington: USJRB Project Weir Crest Elevation 14.00 ft NGVD, 14 mgd	Lake Washington: USJRB Project Weir Crest Elevation 14.00 ft NGVD, 25 mgd	Lake Washington: USJRB Project Weir Crest Elevation 14.00 ft NGVD, 30 mgd
Mean Low Flows for 1943-1986 Water Years, cfs												
1	40	110	108	31	20	17	96	78	70	70	74	67
7	44	114	111	35	24	20	101	84	76	94	78	71
14	49	119	116	41	29	24	105	89	81	99	82	75
30	63	131	129	53	40	35	116	101	93	111	94	87
60	89	156	154	81	68	63	142	126	118	137	120	113
120	154	211	210	143	129	123	199	182	174	196	179	171
183	209	275	274	199	184	177	263	247	239	260	244	236
274	350	410	410	341	323	315	398	383	375	399	383	375
1 year	661	740	740	660	636	628	737	724	716	741	724	716
Range of Annual Low Flows, cfs												
1	6-122	26-175	29-167	0-179	0-166	0-159	0-193	0-176	0-169	7-162	0-145	0-137
7	6-123	28-180	30-173	0-192	0-179	0-172	0-204	0-187	0-180	7-175	0-157	0-150
14	6-135	29-192	31-182	0-197	0-184	0-177	0-212	0-196	0-188	8-182	0-165	0-157
30	7-190	30-228	32-219	0-226	0-213	0-205	2-247	0-230	0-223	8-220	0-203	0-195
60	8-290	38-306	41-301	0-293	0-228	0-270	10-316	0-300	0-292	14-306	2-289	0-282
120	14-560	48-528	49-527	0-572	0-554	0-547	13-545	1-528	0-521	16-547	3-530	1-522
183	30-768	66-877	65-877	4-781	0-766	0-758	36-888	19-871	13-864	36-886	20-870	14-862
274	51-1128	93-1254	93-1254	31-1153	21-1136	18-1129	67-1278	50-1261	44-1253	67-1279	51-1262	45-1254
1 year	126-1550	157-1637	158-1637	83-1576	65-1560	58-1552	125-1665	107-1648	100-1640	130-1665	112-1648	105-1640

ft. NGVD are acceptable based on primary minimum level requirements criteria. In this section, these alternatives are further evaluated with reference to the secondary minimum level criteria and other considerations

7.2.1 Secondary Minimum Level Criteria.

The secondary criteria which are based on plant tolerance (and requirements) to exposure and inundation, are exceeded with respect to some parameters both at RM 258.8 and RM 253.1 (Tables 7-4 and 7-5). However, this violation may not bring undue damage to the marsh community since the secondary criteria developed are rather conservative (Hall, 1987). The exposure of Lake Washington and the surrounding marsh floodplain at an elevation of 13.00 ft. NGVD appears rather difficult to achieve under the USJRB Project conditions (Table 7-4) with the proposed operation schedules. If such an exposure is desirable periodically for proper marsh management, it may be achieved through curtailing or withholding low flow releases upstream for some period, and/or providing a drawdown structure as a part of the Lake Washington weir if it is redesigned. The recommended central critical marsh elevation will be exceeded almost 100% of the time rather than 60% of the time as recommended by Hall (1987) if the weir height is raised to 14 ft NGVD under the USJRB Project conditions (Table 7-1). This condition is not desirable since floodplain marshes should experience both inundation and exposure for the maintenance of populations of draw-down dependent plant species. In general, provision of a special drawdown or low flow structure appears essential under the USJRB Project conditions for proper

Table 7-4. Parameters of Secondary Minimum Level Requirements Criteria for Lake Washington for Selected Alternatives

Alternative	Consumptive Use Withdrawal mgd	Secondary Criteria: Number of years (in Percent): 13 ft. NGVD exceeded	13 ft. NGVD Not exceeded	15 ft. NGVD exceeded	15 ft. NGVD Not exceeded	30-day max elev exceeded 17.8 ft. NGVD	60-day max el exceed 16.3 ft NGVD
Existing Conditions	14	100	22.7	95.5	100	9.1	38.6
	25	100	29.5	95.5	100	9.1	38.6
	30	100	31.8	95.5	100	9.1	36.4
USJRB Plan with Existing Weir	14	100	0	97.7	100	15.9	36.4
	25	100	0	97.7	100	15.9	36.4
	30	100	2.3	97.7	100	15.9	36.4
USJRB Project with weir at 14 ft NGVD	14	100	0	97.7	100	15.9	34.1
	25	100	0	97.7	100	15.9	34.1
	30	100	0	97.7	100	15.9	34.1
Requirement		≥50	≥50	≥50	≥50	0	0

Table 7-5. Parameters of Secondary Minimum Level Requirements Criteria for St. Johns River at RM 253.1

Alternative	Lake Washington Consumptive Use Withdrawal mgd	Secondary Criteria Number of years (in Percent)					
		11.4 ft. NGVD exceeded	11.4 ft. NGVD Not exceeded	14.0 ft. NGVD exceeded	14.0 ft. NGVD Not exceeded	30-day max elev exceeded 16.2 ft. NGVD	60-day max el exceed 14.7 f NGVD
Existing Conditions	14	100	63.6	97.7	100	56.8	88.6
	25	100	70.5	97.7	100	56.8	88.6
	30	100	72.7	97.7	100	56.8	84.1
USJRB Plan with Existing Weir	14	100	36.4	97.7	100	53.1	84.1
	25	100	40.9	97.7	100	56.8	84.1
	30	100	43.2	97.7	100	56.8	81.8
USJRB Plan with weir at 14 ft NGVD	14	100	36.4	97.7	100	59.1	84.1
	25	100	40.9	97.7	100	56.8	81.8
	30	100	43.2	97.7	100	56.8	81.8
Requirement		≥50	≥50	≥50	≥50	0	0

marsh management near Lake Washington. Releases through a low flow structure could also benefit navigation and fisheries downstream. These considerations will be incorporated into the design of a new weir.

The 30-day and 60-day maximum water depths exceeded the desirable elevations for a large number of years, especially for the St. Johns River at R.M. 253.1 (Tables 7-4 and 7-5). These (desirable) elevations were established from a conservative approach (Brooks and Lowe, 1984, pg. 34). It is quite possible that the plant species in the marsh can tolerate greater depths than those established. Table 7-6 summarizes the extent of maximum excessive depths over the desirable 30-day and 60-day elevations for Lake Washington and St. Johns River at RM 253.1. At RM 253.1 the 60-day maximum depths exceed the desirable by 2 feet for about 18% to 27% of years. No data is available regarding the long-term effects of such inundation on plant species.

7.2.2 Fish and Wildlife Habitat Requirements

To protect fisheries during drought conditions the following criteria are recommended (Hall, 1987)

Lake Washington: The one-day one-in-50 year and one-day one-in-100 year minimum water levels should equal or exceed 10.00 ft. NGVD and 9.5 ft. NGVD, respectively. These criteria are satisfied for consumptive use withdrawals not exceeding 25 mgd for existing conditions (Table 5-2). For the USJRB Project conditions with weir crest elevation at 13.5 ft NGVD or 14.00 ft NGVD these criteria can be satisifed for withdrawals exceeding 30

Table 7-6. Extent of 30-day and 60-day Mean High Water Depths Above the Desirable Elevation, Percent of Years

Consumptive Use Withdrawal from Lake Washington MGD	Depth of Water Above the Desirable Elevation: 0.5 ft		1.0 ft		1.5 ft.		2.0 ft	
	30-Day	60-Day	30-Day	60-Day	30-Day	60-Day	30-Day	60-Day
Lake Washington: Existing Conditions								
14	4.5	13.6	2.3	9.1	0	2.3	0	0
25	4.5	13.6	2.3	9.1	0	2.3	0	0
30	4.5	13.6	2.3	9.1	0	2.3	0	0
Lake Washington: USJRB Project - Weir Crest at 13.5 ft. NGVD or 14.0 ft. NGVD								
14	6.8	27.2	2.3	15.9	0	9.1	0	4.5
25	6.8	27.2	2.3	15.9	0	9.1	0	4.5
30	6.8	27.2	2.3	13.6	0	9.1	0	2.3
St. Johns River at RM 253.1: Existing Conditions								
14	29.5	75.0	15.9	59.1	11.4	38.6	4.5	18.2
25	29.5	75.0	15.9	56.8	11.4	38.6	4.5	18.2
30	29.5	75.0	15.9	56.8	11.4	38.6	4.5	15.9
St. Johns River at RM 253.1: USJRB Project - Weir Crest at 13.5 ft. NGVD or 14.0 ft. NGVD								
14	36.4	75.0	25.0	65.9	15.9	40.9	6.8	27.3
25	36.4	75.0	25.0	65.9	15.9	40.9	6.8	25.0
30	36.4	75.0	25.0	63.6	15.9	40.9	6.8	25.0

mgd (Tables 5-8 and 5-9). The limiting withdrawal value is not determined in this study.

St. Johns River at River Mile 253.1: one-day one-in-5 year low stages should equal or exceed 9.5 ft NGVD. This criterion is not satisifed under the existing conditions (Table VI-1, Appendix VI), but is well satisfied under the USJRB Project conditions for the weir crest elevations ranging from 12.00 ft. NGVD to 14.00 ft NGVD (Tables VI-2 through VI-5, Appendix VI).

7.2.3 Navigability of St. Johns River Between Lakes Winder and Washington.

Figs. 7-1 and 7-2 show an approximate longitudinal section of St. Johns River between Lakes Winder and Washington and the low water profiles. Depending on the size and type of boat, about one to three feet depth of water is required in the channel for navigability. During low stages, the backwaters of Lake Winder extend upstream for some miles, but not all the way up to the Lake Washington weir. High ground exists between RM 250.0 and the Lake Washington weir.

The number of days in a year the river may have a depth less than, 1 foot, 2 feet, and 3 feet at RM 253.1 were evaluated and summarized in Table 7-7. These results indicate the USJRB Project, in general, will improve the navigational conditions in the St. Johns River between Lakes Washington and Winder. Increased lake withdrawals do not appear to have a major impact on navigability of the river. By dredging the channel between River Mile 250.0 and the weir (RM 254.4) the navigation conditions in the river can be greatly improved. Discharges released

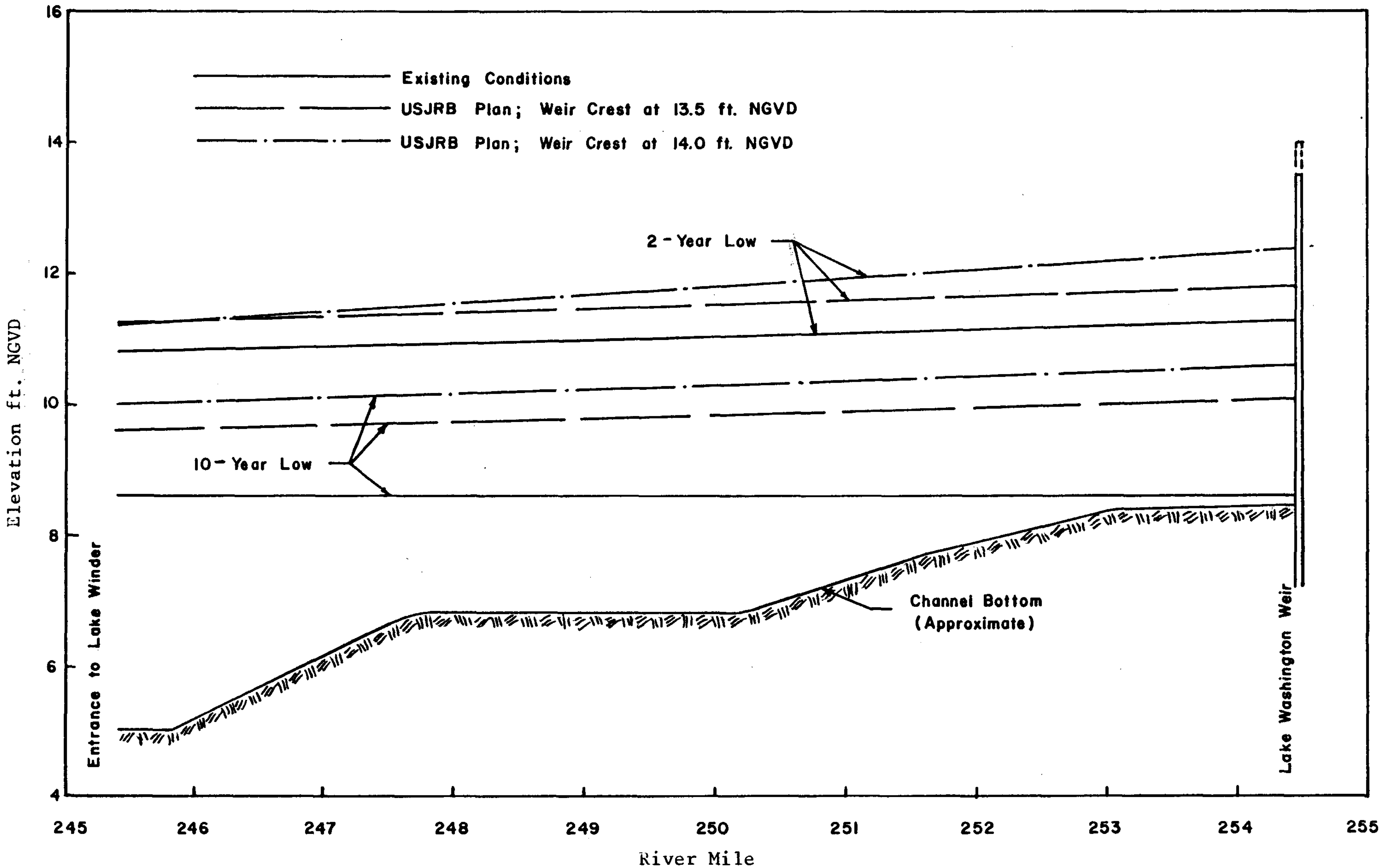


Figure 7-1 Low Surface Water Profiles for St. Johns River Between Lake Winder and Lake Washington (Lake Washington Consumptive Use Withdrawal = 14 mgd)

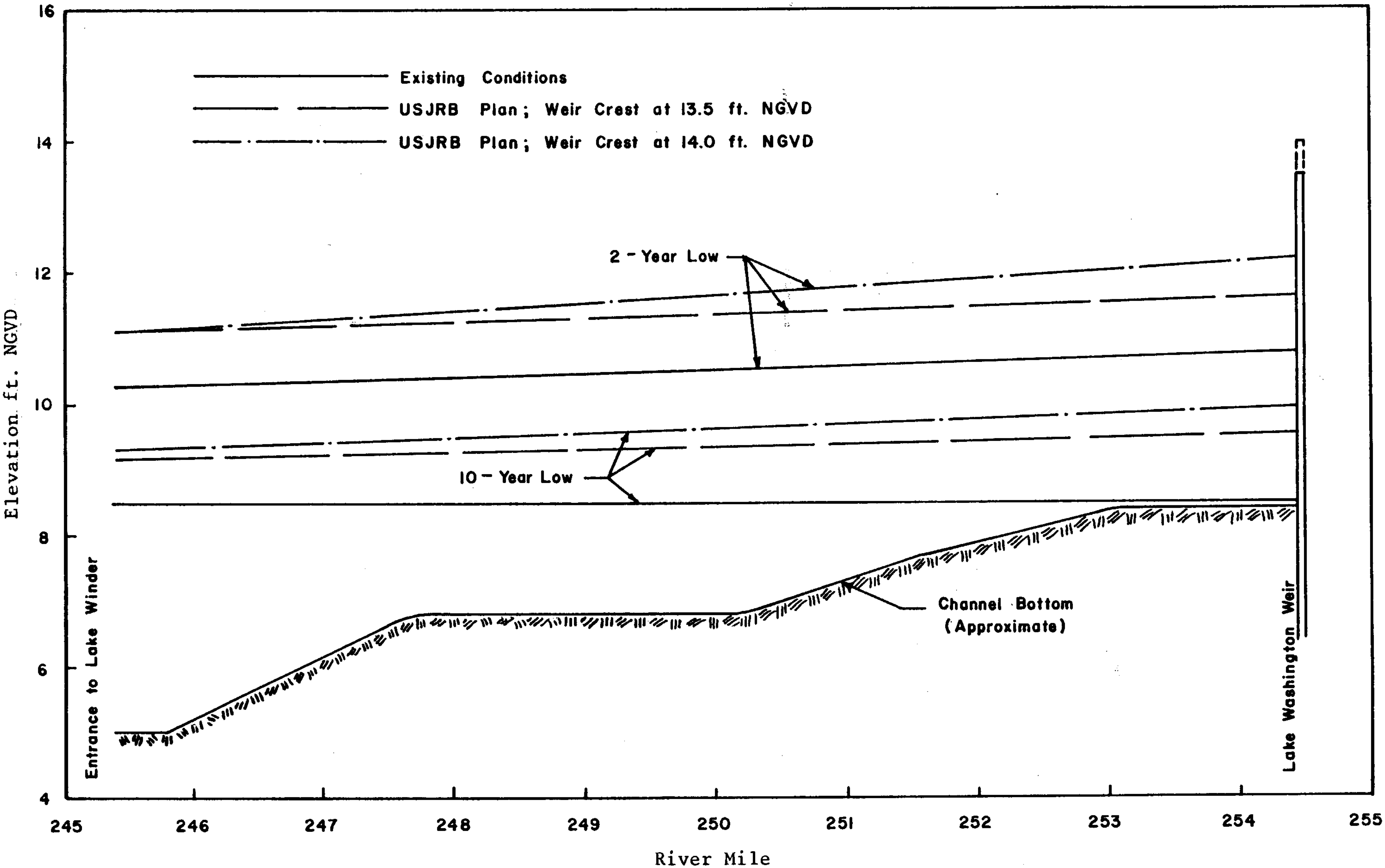


Figure 7-2 Low Surface Water Profiles for St. Johns River Between Lake Winder and Lake Washington (Lake Washington Consumptive Use Withdrawal = 30 mgd)

Table 7-7 Navigability of St. Johns River Between Lakes Winder and Washington: Estimates of Minimum Depths in the River.

(D= Depth of water in feet at RM253.1)

Recurrence Interval Years	Number of Days in a Year					
	D <1 ft	D <2 ft	D <3 ft	D <1 ft	D <2 ft	D <3 ft
	(Existing Conditions)			(USJRB Project)		
	Lake Washington Withdrawal = 14 Mgd (Existing Weir)					
2	0	0	4	0	0	0
5	36	73	116	0	0	52
10	58	95	130	0	0	75
25	80	135	200	0	50	135
	Lake Washington Withdrawal = 25 Mgd (Existing Weir)					
2	0	0	25	0	0	0
5	45	84	129	0	0	68
10	70	116	148	0	20	95
25	95	160	200	25	80	145
	Lake Washington Withdrawal = 30 Mgd (Existing Weir)					
2	0	0	29	0	0	0
5	48	86	136	0	9	74
10	80	116	163	0	34	102
25	95	160	210	35	95	173
	Weir Crest 14.00 ft. NGVD; Withdrawal = 14 Mgd					
2				0	0	0
5				0	0	55
10				0	0	80
25				2	50	135
				Withdrawal = 25 Mgd		
2				0	0	0
5				0	0	69
10				0	18	96
25				15	80	150
				Withdrawal = 30 Mgd		
2				0	0	0
5				0	7	75
10				0	32	103
25				25	98	173

through a low flow or a drawdown structure at the weir may also improve navigability within this reach.

7.2.4 Minimum Depths of Water in St. Johns River Between Lakes Winder and Washington

It is desirable to maintain a certain minimum depth of water in the river between Lakes Winder and Washington to ensure safe passage of fish over numerous sandbars that exist in the river and for maintenance of water quality. However, during extreme droughts the river practically goes dry. During low flow periods, this river segment receives discharge overflowing the Lake Washington weir and the runoff generated within the floodplain and the adjacent watershed areas. The channel bottom at RM 253.1 is at about 8.5 ft. NGVD and the overbanks are at about 11.4 ft. NGVD. Most of the marsh floodplain is at about 12.0 ft. NGVD. Low stage frequency analyses (Table 7-8) indicate low flows would be confined to the river proper for drought events with return periods of 2 years or above both under existing and the USJRB Project conditions. Studies have shown that the canal plugs upstream would not have any effect on low stages at this location. Under the existing conditions, Table 7-8 indicates that the river for some stretches could be very shallow or dry during droughts with return frequencies of 5 yrs or greater. However, the USJRB Project would greatly improve the conditions by providing one to two foot depths of water during the 5 year and 10-year drought events.

7.2.5 Flood Stages and Flood Damages Near Lake Washington

Table 7-8 Estimates of Minimum Stage (ft. NGVD) for the St. Johns River at RM 253.1

Lake Washington Consumptive Use Withdrawal	Return Period Years	Existing Conditions	USJRB Project Conditions: Existing Weir	USJRB Project Conditions: With Weir Crest at 14 ft. NGVD
	2	11.2	11.7	12.2
14	5	8.75	10.7	10.7
	10	8.6	10.0	10.5
	25	*	9.35	9.6
	2	10.85	11.6	12.1
25	5	8.7	10.3	10.35
	10	8.55	9.7	10.1
	25	*	8.9	9.15
30	2	10.7	11.55	12.05
	5	8.7	10.15	10.15
	10	*	9.5	9.85
	25	*	8.8	8.95

*The channel goes dry

Studies have shown that the rate of withdrawal (14 mgd to 30 mgd) would have an insignificant effect on annual peak flows in Lake Washington. This is expected because the amount of water withdrawn is only a small fraction of the annual peak flow passing at Lake Washington. The estimates of flood stages evaluated with 14 mgd withdrawal are summarized in Table 7-9 for the existing conditions and for the USJRB Project conditions with the weir crest at 13.5 ft. NGVD and 14.00 ft. NGVD.

1-day flood stages: The USJRB Project conditions will result in reduction of the 100 yr and 500 yr flood stages by about 0.1 ft. and 0.4 ft., respectively, from the existing. There will be a slight increase in high frequency flood stages (Mean annual, 5 yr, 10 yr, and 25 yr) under the project conditions. An explanation for this occurrence can be given as follows. Under the USJRB Project conditions, seaward diversion of drainage from the Fellsmere Water Control District (through Fellsmere Canal) would be completely eliminated (diversion of about 60% drainage from an estimated area of 22,400 acres currently occurs). In addition, discharge through Canal-54 to the Indian River would be made only in the event of large floods with a return frequency greater than one in ten years. In general, floodwaters would be temporarily stored in various water management/marsh conservation areas and releases downstream would be made in a "controlled" fashion. These releases, coinciding with downstream discharges could slightly increase the magnitude of more frequent floods (Note: the results presented in Table 7-9 differ somewhat from those given in the GDM of the USJRB

Table 7-9 Lake Washington: Estimates of High Stages (ft. NGVD) for Floods of Different Return Periods.

Duration Days	Mean Annual High	Recurrence interval, years 5	10	25	50	100	500
		Existing Conditions (Weir Crest at 13.5 ft. NGVD)					
1	16.83	17.63	18.39	18.98	19.41	19.86	20.86
7	16.80	17.59	18.33	18.93	19.35	19.79	20.76
14	16.72	17.48	18.17	18.80	19.19	19.58	20.53
30	16.46	17.14	17.71	18.42	18.72	19.01	19.66
60	16.08	16.70	17.14	17.67	18.04	18.39	18.84
		The USJRB Plan: Weir Crest at 13.5 ft. NGVD					
1	16.96	17.89	18.55	19.07	19.42	19.76	20.46
7	16.93	17.86	18.52	19.02	19.37	19.70	20.39
14	16.86	17.77	18.46	18.94	19.27	19.58	20.22
30	16.64	17.49	18.13	18.67	18.98	19.24	19.79
60	16.26	17.00	17.57	18.26	18.61	18.88	19.44
		The USJRB Plan: Weir Crest at 14 ft. NGVD					
1	16.96	17.88	18.54	19.06	19.43	19.77	20.52
7	16.93	17.84	18.52	19.02	19.38	19.71	20.44
14	16.86	17.75	18.45	18.93	19.27	19.59	20.27
30	16.65	17.47	18.12	18.67	18.98	19.25	19.83
60	16.27	16.99	17.57	18.26	18.61	18.88	19.45

Project because of the differing procedures used in the two studies).

Flood stages for other durations: Mean flood elevations for 7- to 60-day durations under USJRB Project conditions will be slightly higher than existing for recurrence intervals T= 50 yr or less. For T= 100 yr and 500 yr the increases would occur for 30- and 60-day durations. However, these large duration floods would be confined primarily to the marsh floodplain and would not affect residences because the house pads near Lake Washington are located generally above 21.0 ft. NGVD as indicated by field survey. As explained earlier, water conservation measures implemented upstream by way of reducing the diversions to the Indian River are responsible for the slight increase in duration and magnitude of more frequent high stages at Lake Washington.

The effect of weir height: The results (Table 7-9) show that increasing the weir height to 14.00 ft. NGVD has practically no influence on flood stages. This is possible because the entire lake and the weir would be under several feet of water during floods.

Flood damages: Field survey and aerial survey maps indicate that practically all houses near Lake Washington are located at least one foot above the the 100-year flood elevation, i.e., greater than 21.00 ft. NGVD. Two house pads have elevations close to 100-year flood; House #5200 on Aurora Road at 19.85 ft. NGVD and House #5725 on a side road south of Lake Washington Road close the the lake, at 19.73 ft. NGVD (Fig. 7-3). Three other houses are located less than one foot above the 100-yr flood

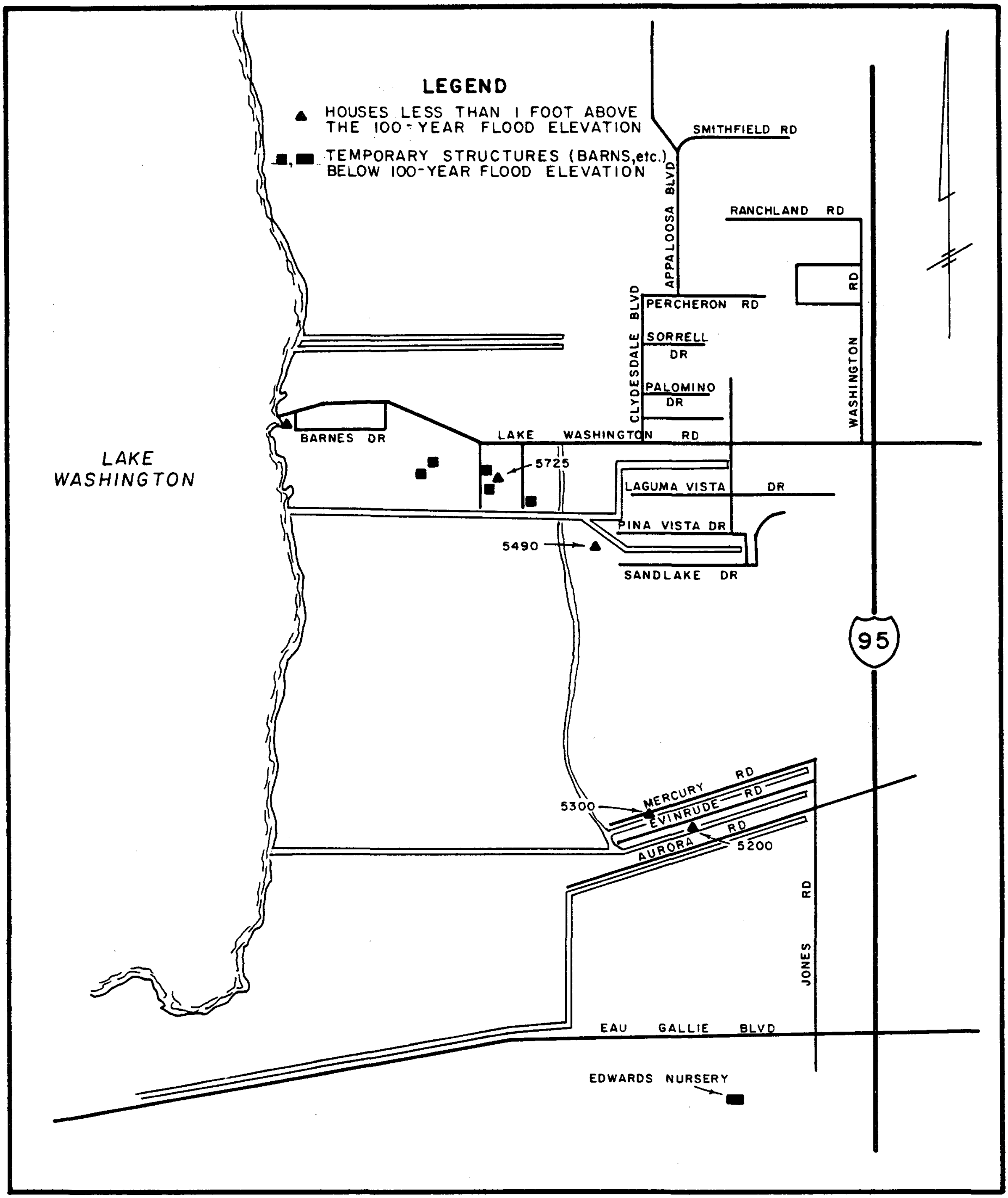


Figure 7-3. Properties Near Lake Washington Which May be Affected by Major Flood Events

elevation; 20.52 ft. NGVD (a house on Lake Washington Road, offshore), 20.55 ft. NGVD (House #5490, Sand Lake Road) and 20.72 ft. NGVD (House #5300, Evinrude Drive). Thus, flood damage potential near Lake Washington appears minimal. When flood waters reach a house pad, some minor damage may result to the carpet and other contents of the house due to seepage. Minor structural damage is also possible. This may be prevented by sand bag protection (flood proofing) which may cost a few hundred dollars or more depending on the size of the house. In general, the rise in flood stages would be slow near the lake.

Under existing conditions there are several horse barns and a nursery (Edwards Nursery near Sarno Road) which will be periodically flooded. Damages to these structures are expected to be none or insignificant. Occurrence of septic tank problems (during flooding season) have been reported by the residents living close to the lake. However, it appears the residents accept this as an inevitable inconvenience and a trade-off against the aesthetic value provided by the lake.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Lake Washington is the sole drinking water supply source for South Brevard County, one of the most rapidly growing population centers in the St. Johns River Water Management District. The current average annual water use is about 14 million gallons per day (mgd), but the projected demand is 30 mgd by the year 2000 and 44 mgd by the year 2030. The lake is dammed at its north-end by a temporary sheetpile weir, the Lake Washington weir, with crest elevation at 13.50 ft. NGVD. This weir was constructed to protect water supplies during low flow periods. However, during extended droughts the lake levels have receded below the weir crest resulting in concern regarding the ability of the lake to supply adequate amounts of water to meet the growing needs of South Brevard County. This study was undertaken to evaluate the water supply potential of Lake Washington and to develop an appropriate water management plan for Lake Washington and the river downstream.

Simulated hydrologic data (stage and discharge) was generated for different locations of interest for a period of 45 years (1942-1986). This period included several major drought and flood events. The simulated data provided the required data samples for different analyses. Various weir alternatives analyzed were: 1) the existing basin conditions with the existing weir (crest elevation = 13.5 ft. NGVD, length = 160 ft.), and

2) the USJRB Project conditions with, a) existing weir, b) weir crest at 14.00 ft. NGVD, c) weir crest at 13.00 ft. NGVD, d) weir crest at 12.00 ft. NGVD, and e) no weir. For cases b) through d) the length of the weir was kept the same as existing.

The criteria for determining the water supply potential of Lake Washington include, 1) the long-term low or drought stages expected in the lake at different rates of consumptive use withdrawal and the accompanying water quality concerns, 2) hydrologic considerations for minimum flow/stage requirements of the floodplain marsh around and downstream of Lake Washington and 3) requirements for recreation, navigation, and fish and wildlife. Other considerations for developing an optimal water management plan are those related to socio-economic impacts of various alternative weir designs, i.e., flood damages.

During low flow periods chloride concentration and TDS increase as lake stages decline due to reduced discharge contribution from upstream. The waters entering the lake carry greater mineral content due largely to the discharge from the agricultural area. The equation given below was developed to estimate chloride concentration in Lake Washington during low stages.

$$\log_{10} C = 4.4325 - 0.17508\ H \qquad \text{(Equation 5.1)}$$

in which C = chloride concentration in mg/l and H= annual low stage. This equation, derived from 1977-1986 data, however, would give rather a conservative estimate (over-prediction) for C. Before the spring of 1986, the borrow canals in the upstream marsh collected highly mineralized water and conveyed it directly to Lake Washington. These canals have been plugged at several places. This measure is expected to greatly reduce the mineral content of the lake during low flows. Thus, the future relation between annual low stage and chloride concentration would improve. Nevertheless, Eq. 5.1 is used in this study to estimate chloride concentration of the lake during drought events. As per Eq. 5.1, the chloride levels in the lake would exceed the drinking water standard of 250 mg/l if the lake recedes below 11.6 ft. NGVD.

Based on ecologic/hydrologic considerations, Hall (1987) has established elevations critical to the floodplain marsh in the Lake Washington area, and has developed criteria for minimum flow/stage requirements. Three elevations are identified as critical to the marsh and are designated as the central, upper, and lower critical marsh elevations (Fig. 6-1). The criteria for minimum flow/stage requirements are classified as primary and secondary. The primary criteria are: 1) the mean water elevation, over a long period of time, should equal or exceed the central critical marsh elevation less 0.25 ft, and 2) the central critical marsh elevation should be exceeded at least 60% of the time over a long period. The secondary criteria which are derived based on plant tolerance to both maximum and minimum water depths are, 1) the marsh at its upper and lower critical elevations should experience both exposure and inundation in a typical year (i.e., once in two years or greater), 2) maximum 30 day and 60 day depths of water may not exceed 4.8 ft. and 3.3 ft., respectively, over the lower critical marsh elevation,

3) the natural timing of fluctuation in water depth should be modified as little as possible, and 4) the short-term (less than 60 days) and infrequent minima (return interval greater than 10 years) are not considered detrimental. These guidelines (requirements) are used in this study in both determining Lake Washington water supply potential and developing a water management plan for the area.

Each weir alternative was evaluated first with respect to, 1) the long-term low (drought) stages and the accompanying water quality concerns based on chloride concentration, and 2) primary criteria for minimum flow/stage requirements at Lake Washington (RM 258.8) and the St. Johns River downstream of the lake at RM 253.1. These results are summarized in Table 8-1. Three alternatives failed to meet the primary criteria, i.e., the USJRB Project with weir crest at 13.0 ft. NGVD, 12.0 ft. NGVD, and no weir (alternative numbers 4, 5, and 6, Table 8-1). These three alternatives were excluded from further consideration. The remaining alternatives (alternative numbers 1, 2, and 3, Table 8-1) were then compared based on secondary criteria which include the marsh flow/stage requirements at Lake Washington and downstream, fish and wildlife portection, and other socio-economic considerations. This comparison is shown in Table 8-2.

8.1 Selection of Optimal Water Management Plan for Lake Washington

8.1.1 Existing Conditions

Although this condition is shown as an alternative in Tables 8-1 and 8-2, this is only an interim condition pending the

Table 8-1 Evaluation of Selected Alternatives Based on Primary Criteria

Alternatives	Description	Consumptive Use Withdrawal, mgd	Stage in Lake Washington, ft. NGVD: 50-yr Drought	Stage in Lake Washington, ft. NGVD: 200-yr Drought	Estimated Chloride Concentration, mg/1: 50-yr Drought	Estimated Chloride Concentration, mg/1: 200-yr Drought	Mean Elevation, ft NGVD: Lake Washington	Mean Elevation, ft NGVD: RM 253.1	% of Time Central Critical Marsh Elevation Exceeded: Lake Washington (14.0' NGVD)	% of Time Central Critical Marsh Elevation Exceeded: RM.253.1 (12.7' NGVD)
1	Existing Conditions	14	11.9	11.35	223	(*)	14.59	13.48	63.6	64.3
		25	10.25	9.1	(*)	(*)	14.50	13.38	61.0	63.1
		30	8.9	(Dry)	(*)	(–)	14.44	13.34	(59.9)	62.4
2	USJRB Project w/ Weir crest at 14.0 ft NGVD	14	13.95	13.8	98	104	14.94	13.82	100.0	69.7
		25	13.6	13.1	113	138	14.92	13.73	99.2	67.9
		30	13.2	12.6	132	168	14.90	13.69	98.8	66.8
3	USJRB Project w/ weir crest at 13.5 ft NGVD	14	13.4	13.3	122	127	14.76	13.76	74.0	69.5
		25	13.0	12.6	143	168	14.72	13.76	71.0	68.7
		30	12.6	12.0	168	215	14.70	13.71	69.0	67.7
4	USJRB Project w/ weir crest at 13.0 ft NGVD	14	12.95	12.8	146	155	14.53	13.84	(58.5)	70.7
		25	12.55	12.1	172	206	14.48	13.75	(56.3)	68.7
		30	12.1	11.4	206	(*)	14.46	13.71	(55.4)	67.7
5	USJRB Project w/ weir crest at 12.0 ft NGVD	14	11.95	11.8	219	233	14.15	13.86	(48.9)	71.8
		25	11.5	11.05	(*)	(*)	14.08	13.77	(47.0)	69.6
		30	10.95	10.05	(*)	(*)	14.04	13.72	(46.4)	68.4
6	USJRB Project w/ No Weir	14	9.75	9.00	(*)	(*)	13.93	13.87	(48.6)	72.4
Requirement					$\leq$ 250	$\leq$ 250	13.75	12.40	$\geq$ 60	$\geq$ 60

* exceeds 250 mg/1.

( ) does not meet requirement. Based on this evaluation cases 4, 5 and 6 are excluded from further consideration.

Table 8-2 Selection of Optimum Alternatives Based on Secondary Criteria.

Criterion		Existing Conditions			USJRB Project w/weir crest at 13.5' NGVD			USJRB Project w/weir crest at 14.0' NGVD			Requirement
		14 mgd	25 mgd	30 mgd	14 mgd	25 mgd	30 mgd	14 mgd	25 mgd	30 mgd	
A. Minimum Level & Flow Requirement											
Percent of years Lower Critical Marsh Elevation Inundated	Lake Washington	100	100	100	100	100	100	100	100	100	≥ 50
	RM253.1	100	100	100	100	100	100	100	100	100	≥ 50
Percent of years Lower Critical Marsh Elevation Exposed	Lake Washington	22.7	29.5	31.8	0	0	2.3	0	0	0	≥ 50
	RM253.1	63.6	70.5	72.7	36.4	40.9	43.2	36.4	40.9	43.2	≥ 50
Percent of years Upper Critical Marsh Elevation Inundated	Lake Washington	95.5	95.5	95.5	97.7	97.7	97.7	97.7	97.7	97.7	≥ 50
	RM253.1	97.7	97.7	97.7	97.7	97.7	97.7	97.7	97.7	97.7	≥ 50
Percent of years Upper Critical Marsh Elevation Exposed	Lake Washington	100	100	100	100	100	100	100	100	100	≥ 50
	RM253.1	100	100	100	100	100	100	100	100	100	≥ 50
Percent of years 30-day Max Elevation Exceeded	17.8 ft. NGVD at Lake Washington	9.1	9.1	9.1	15.9	15.9	15.9	15.9	15.9	15.9	0
	16.2 ft NGVD at Lake Washington	56.8	56.8	56.8	59.1	56.8	56.8	59.1	56.8	56.8	0
Percent of years 60-day Max Elevation Exceeded	16.3 ft NGVD at Lake Washington	38.6	38.6	36.4	36.4	36.4	36.4	34.1	34.1	34.1	0
	14.7 ft NGVD RM253.1	88.6	88.6	84.1	84.1	84.1	81.8	84.1	81.8	81.8	0
B. Recreation and Navigation (No. of days depth 2 ft during 1 out of 5 yrs)		73	84	86	0	0	9	0	0	7	
C. Fish Protection											
50 yr low stage Lk Washington		11.9	10.25	8.9	13.4	13.0	12.6	13.95	13.6	13.2	≥ 10.0
100 yr low stage Lk Washington		11.65	9.65	8.1	13.35	12.8	12.3	13.9	13.3	12.9	≥ 9.5
(5 yr low stage at RM 253.1-ft NGVD)		8.75	8.7	8.7	10.7	10.3	10.15	10.7	10.35	10.15	≥ 9.5
D. Sediment and Transfer & detrital materials											
E. Reasonable Beneficial Use of Water											
F. Flooding Damage Potential (100 yr flood elevation-ft NGVD)		19.86	19.86	19.86	19.76	19.76	19.76	19.77	19.77	19.77	

completion of the USJRB Project. Determining the water supply potential of Lake Washington is the major objective for this condition. Results have indicated that the primary minimum flow/stage requirements of the floodplain marsh near Lake Washington and downstream would not be violated for consumptive use withdrawals in the range of 14 mgd to 25 mgd (Table 8-1). However, the low flow conditions during extreme droughts would considerably lower the lake levels and the drinking water quality standards might not be met. Thus, although the ecologic/hydrologic requirements of the river do not restrict lake withdrawals up to 25 mgd, the water supply potential of the lake may be restricted because of water quality considerations. The future relationship between lake drought stages and water quality parameters can not be determined with certainty. The effects of some of the measures implemented recently to improve water quality of the lake, e.g., canal plugs upstream, have not been fully verified. A regression relationship developed from the past data (Eq. 5.1) indicates that during a 50-year drought the chloride concentration in the lake would exceed the drinking water standard of 250 mg/l if the withdrawal rate exceeds approximately 18 mgd. (Table 5-13).

8.1.2 The USJRB Project Conditions

Two alternatives, a weir with its crest elevation at 13.5 ft. NGVD and a weir with its crest elevation at 14.0 ft. NGVD are acceptable based on the consideration of primary criteria. (Table 8-1). For both alternatives conservative estimates of chloride concentration for the lake are well below the Class I standard of

250 mg/1 at 30 mgd withdrawal (see 200-yr drought event, Table 8-1). Based on this result, the water supply potential of Lake Washington for the two alternatives is estimated as greater than 30 mgd. No calculations were performed to establish the limiting potential.

In summary, the results based on the consideration of primary criteria (Table 8-1) and the consideration of secondary criteria (Table 8-2), indicate that the weir with crest elevation at 14.0 ft. NGVD is the optimal choice under the USJRB Project conditions. Compared to the weir with existing crest elevation of 13.5 ft. NGVD, the weir with crest elevation at 14.0 ft NGVD will produce the following benefits.

1. The drought elevations in Lake Washington will be higher.
2. Water quality of Lake Washington will be better.
3. Water supply potential of Lake Washington would be higher (this result follows from Result No. 2).
4. Conditions for fish protection at Lake Washington will be better.
5. Results with respect the secondary minimum level/flow requirements are similar for both alternatives.
6. Recreation and navigation benefits will be marginally better.
7. Low stages downstream of Lake Washington will be similar under both alternatives.
8. Flood damage potential at Lake Washington will be similar under both alternatives.

Based on the foregoing results, a weir with crest elevation of 14.00 ft. NGVD (length 160 feet) is recommended. Appurtenant structures for various water management purposes should include:

1. a drawdown or low flow structure for low flow and stage control, fish passage and transfer of detrital material and sediments and
2. navigation facilities.

Further studies should be conducted to determine the effects of the drawdown/low flow structure.

8.2 Conclusions

The following conclusions are made based on this study.

1. Existing Conditions: The ecologic/environmental requirements will not be violated by the consumptive use withdrawal from Lake Washington up to 25 mgd. However, the low flow conditions during extreme droughts would considerably lower the lake levels and the Class I drinking water standards might be exceeded. Future relationships between lake drought stages and water quality parameters can not be determined with certainty. The effects of some of the measures implemented recently to improve water quality of the lake, e.g., canal plugs upstream, are yet to be quantified. A regression relationship developed from the available data indicates that during a 50-year drought the chloride concentration in the lake might exceed the Class I standard of 250 mg/l if the withdrawal rate exceeds approximately 18 mgd.

2. Under the USJRB Project conditions the ecologic/environmental minimum flow/level requirements will not be satisfied if Lake Washington weir crest elevation is reduced to 13.0 ft. NGVD or below. This result applies also to the existing conditions (although not evaluated) since low flow/stage values are below those expected under the plan. Thus, restoration of St. Johns River to natural conditions by removing the Lake Washington weir is not acceptable both under the existing and the USJRB Project conditions.

3. The Upper St. Johns River Basin Project Conditions: Of the various alternative weir designs considered a weir with crest elevation at 14.00 ft. NGVD provides the maximum water supply and other socio-economic benefits and is acceptable from the ecologic/environmental considerations. Thus, the present temporary weir should be replaced by a permanent structure of similar dimensions (length 160 feet; crest elevation 14.0 ft. NGVD). With this structure, withdrawals greater than 30 mgd may be made with no adverse environmental impacts or deterioration in water quality (chloride levels). However, further studies should be conducted for withdrawals greater than 30 mgd.

The new weir structure should include a sluice gate to aid periodic lake drawdown and low flow releases downstream. Studies should be conducted to determine the operation schedule of this gate. Also other appurtenant structures to facilitate navigation should be included.

REFERENCES

1. Brooks, J.E., and Lowe, E.F. 1984. U.S. EPA Clean Lakes Program, Phase I, Diagnostic-Feasibility Study of the Upper St. Johns River Chain of Lakes, Vol II- Feasibility Study. Technical Publication No. SJ 84-15, St. Johns River Water Management District, Palatka, FL.

2. Cox, D.T., H.L. Moody, E.D. Vosatka, and L. Hartzog, 1976. D-J F-25 Stream Investigations Completion Report, Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

3. Gilman, C.S. 1964. Rainfall, Section 9 Handbook of Applied Hydrology, McGraw-Hill Book Co., New York.

4. Hall, G.B. 1987. Establishment of Minimum Surface Water Requirements for the Greater Lake Washington Basin. Technical Publication No. SJ 87-3, St. Johns River Water Management District, Palatka, Florida.

5. Lowe, E.F., Brooks, J.E., Fall, C.J., Gerry, L.R., and Hall, G.B. 1984, U.S. EPA Clean Lakes Program, Phase I, Diagnostic - Feasibility Study of the Upper St. Johns River Chain of Lakes, Vol. 1- Diagnostic Study, Technical Publication No. SJ 84-15, SJRWMD, Palatka, FL.

6. Rao, D.V. 1980a. Log Pearson Type 3 Distribution: A Generalized Evaluation, Journal of the Hydraulics Division, American Society of Civil Engineers, Vol. 106, HY5, pp. 853-872.

7. Rao, D.V. 1980b. Log Pearson Type 3 Distribution: Method of Mixed Moments, Journal of the Hydraulics Division, American Society of Civil Engineers, Vol. 106, HY6, pp. 999-1019.

8. Rao, D.V. 1983. Estimating Log Pearson Parameters by Mixed Moments, Journal of Hydraulic Engineering, American Society of Civil Engineers, Vol. 109, No. 8, pp. 1118-1132.

9. St. Johns River Water Management District, 1979 - 1980, Upper St. Johns River Basin Surface Water Management Plan, Phase 1 Report, Palatka, FL.

10. Suphunovorranop, T., and Tai, C.C, Upper St. Johns Hydrologic Model, Users Manual, Technical Publication No. SJ 82-4, SJRWMD, Palatka, FL

11. U.S. Army Corps of Engineers, 1982, HEC-2 Water Surface Profiles, Users Manual, The Hydrologic Engineering Center, Davis, California.

12. U.S. Army Corps of Engineers, 1985, Central and Southern Florida Project for Flood Control and Other Purposes, Part III, Upper St. Johns River Basin and Related Areas, Jacksonville District, Florida

13. U.S. Geological Survey, 1986, Water Resources Data, Florida, Water Year 1984, Volume 1A: Northeast Florida Surface Water, Tallahassee, Florida

APPENDIX I

Regional Water Resource Assistance Program Proposal Summary

REGIONAL WATER RESOURCE ASSISTANCE PROGRAM

PROPOSAL SUMMARY

FEB 21 1984

OEP & C

A

APPLICANT South Brevard Water Authority

ADDRESS P. O. Box 360382 CITY Melbourne

COUNTY Brevard STATE FL ZIP 32936 TELEPHONE 305 / 259-7126

B

TITLE OF PROPOSED PROGRAM

Evaluation of Lake Washington Temporary Weir DATE 2/15/84

C

PROGRAM DESCRIPTION

WHAT IS THE NATURE AND SCOPE OF THE PROPOSED PROGRAM?

The Nature of the proposal is a study of the temporary weir at the North end of Lake Washington.

The scope of the work is an engineering, hydrological, and environmental evaluation of what would be required to make that structure a permanent facility.

WHAT ARE THE PRINCIPAL OBJECTIVES TO BE ACCOMPLISHED?

The principal objectives are:

1. Improvement to the existing structure
2. Enhanced water supply
3. Improved downstream environmental protection
4. Navigation accomodations

HOW WILL THE RESULTS BE UTILIZED?

The results would be utilized by the SBWA and SJRWMD on improving the management of Lake Washington, downstream areas and the existing water supply for the South Brevard area.

D

PROPOSED SOURCES OF FUNDING

	INKIND*	CASH
LOCAL South Brevard Water Authority	$	$ 50,000.00
STATE (AGENCY) St.Johns River Water Management District	$	$ 50,000.00
FEDERAL (AGENCY)	$	$
OTHER (SPECIFY)	$	$
TOTAL	$	$ 100,000.00

* SPECIFY TYPES OF INKIND SERVICES PROPOSED

E

AUTHORIZING LOCAL UNIT South Brevard Water Authority

MAILING ADDRESS P. O. Box 360382 Melbourne FL 32936

AUTHORIZED BY Robert J. Massarelli, Exec.Dir.

TELEPHONE 305 / 259-7126

SIGNATURE [signature]

F

PERFORMING AGENCY	South Brevard Water Authority	MAILING ADDRESS	P. O. Box 360382 Melbourne, FL 32936
CONTACT	Robert J. Massarelli	TELEPHONE	305/ 254-7126
SIGNATURE	[signature]		

PROGRAM PERFORMANCE

SPECIFY THE METHODOLOGY THAT WILL BE EMPLOYED.

The methodology used will be an engineering evaluation of the temporary weir to determine its existing condition and projected life. In addition, engineering evaluations will be done on the feasibility of raising the crest elevation of that weir to improve water management and increase water storage. Downstream flow requirements will be considered.

Use of the Upper Basin Model is necessary to evaluate the effects of raising the weir on flood elevations and downstream flows.

Environmental evaluation of the impacts of the weir will be conducted.

G

WHAT WILL BE THE PROPOSED TIME FRAMES FOR EACH SEGMENT, BY WHOM COMPLETED, INCLUDING THE FINAL COMPLETION DATE?

October	Engineering Evaluation
Oct.-Nov.	Alternative Weir Elevation Developed
Dec.-Jan.	Complete Evaluation
Feb.-April	Environmental Evaluation
May-June	Draft Report Preparation
July	Review
August	Final Report

FOR DISTRICT USE ONLY

RECOMMENDATION SUMMARY (details attached)

H

		RECOMMENDED	NOT RECOMMENDED
EXECUTIVE DIRECTOR	DATE		
EXECUTIVE PLANNING AND COORDINATION	DATE		

EVALUATION OF LAKE WASHINGTON TEMPORARY WEIR

PROBLEM

The South Brevard area uses Lake Washington as a drinking water supply. Most of the time there is enough water in Lake Washington to meet the needs of South brevard, as well as, the other users of the St. Johns River. During the 1960's and 70's, drought conditions in the St. Johns River severely limited the amount of water which could be withdrawn from the Lake.

During 1962, a sandbag dam was constructed to protect the Lake Washington water supply. This dam, however, was destroyed and rebuilt several times. In 1975 the Brevard County Board of Commissioners constructed a temporary sheet piling weir at the North end of Lake Washington. Upon completion of the weir, the ownership was transferred to the Central and Southern Florida Flood Control district.

The South Brevard Water Authority was created in the summer of 1983 to insure a safe, reliable water supply for the South Brevard area. All of the alternatives that are being considered by the SBWA involve the continued use of Lake Washington. Therefore, the temporary weir must be evaluated to determine what modifications, if any, must be made.

The weir also acts as a barrier to downstream flows when the stage of the lake drops below 13.5 feet. Under current projections, this will occur for more than 30 days in a 1 in 5 year, low-stage frequency. If the weir is to become a more permanent structure, then it should be modified to provide for minimum downstream flows.

The weir also acts as a barrier to navigation. This problem was addressed by the construction of a small boat lift and an airboat map. These facilities are difficult to use and often are inoperable. Again, if the structure is to become a more permanent facility, small boat navigation needs must be addressed.

The SJRWMD is authorized to provide such dams as the Board deems necessary to establish, maintain and regulate water levels in lakes (373.086 F.S.). The District is also required to establish minimum flows and lake levels (373.042 F.S.). In addition, the State Water Policy states that water management programs, rules and plans shall seek to establish minimum flows and levels to protect water resources and environmental values [17-40.03(7)] . The State Water Policy also states that in considering surface water management, consideration should be given to, amoung other things, navigation, fish and wildlife, minimum flows and levels, and retardance, acceleration, and diversion of flowing water [17-40.07(2)].

PROPOSAL TO ADDRESS THE PROBLEM

The proposal is an evaluation of the existing temporary weir to determine what improvements, if any, are necessary for water management needs. There are several issues which should be addressed in this evaluation. One is what improvements are necessary to make this a permanent structure.

The second issue is that of water supply. The original purpose of the facility was for drinking water supply protection. What is the potential of raising the weir for increased water storage?

The third issue is environmental. What modifications are needed to the weir for minimum downstream flow? If the weir was raised, what modifications would be necessary for downstream flows? What affect would raising the weir be on the environment of and around Lake Washington?

Navigation is the fourth issue which should be addressed. The current weir restricts navigation at certain stages. Are the existing navigation features adequate? What improvements should made?

This study will require a multi-disciplinary approach. The use of the Upper St. Johns River Model is critical in determining the effect of modifying the crest elevation of the weir. Hydrologists will be very useful in that work.

Engineers will be required to evaluate different designs of modified facilities. Cost projections will also be required.

Biologists and water chemistry professionals will be required to evaluate the environmental impacts of the alternatives. In addition, their imput is required for the minimum flow calculations.

RESULTS

The result of the proposal would be an evaluation of the district owned, temporary weir at the North end of Lake Washington. This report would:

1. Identify what improvements are needed, if any, to make this facility a permanent facility.

2. Evaluate the potential of modifying the weir to increase water supply potential.

3. Determine the environmental impacts and mitigation measures, including downstream flow requirements.

4. Evaluate what navigation improvements are needed, if any.

This work should be conducted by the District since this is a District facility.

APPENDIX II

Agreement between SJRWMD and South Brevard Water Authority

AGREEMENT

BETWEEN THE

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

AND THE

SOUTH BREVARD WATER AUTHORITY

THIS AGREEMENT is entered into on the 6th day of May, 1985, by and between the ST. JOHNS RIVER WATER MANAGEMENT DISTRICT, hereinafter the "DISTRICT", and the SOUTH BREVARD WATER AUTHORITY, hereinafter the "AUTHORITY."

WHEREAS, the DISTRICT is requested by the AUTHORITY to perform technical studies in order to develop a best water management plan to improve water availability from Lake Washington, and

WHEREAS, the DISTRICT has been established and authorized, pursuant to Chapter 373, F.S., to manage water resources within its geographical area, and

WHEREAS, the AUTHORITY and the DISTRICT desire to jointly fund this study entitled "EVALUATION OF LAKE WASHINGTON TEMPORARY WEIR, PHASE I - HYDROLOGICAL EVALUATION" in the sum of Fifty-six Thousand Three Hundred Eighty Dollars ($56,380) by each party hereto committing Twenty-eight Thousand One Hundred Ninety ($28,190); and

NOW THEREFORE, in consideration of the foregoing premises, which are part of the consideration herein, the parties hereto do mutually agree as follows:

1. The DISTRICT will:

   A. Obligate for the purposes of this Agreement monies in the sum of Twenty-eight Thousand One Hundred Ninety Dollars ($28,190) for the completion of the said Phase I study. Said funds are budgeted in Fiscal Year 1984/1985 in Project Nos. 20 200 25 and 20 200 75.

B. Secure the services of a qualified mapping contractor for the DISTRICT to prepare photogrammetric maps for the floodplain areas east of Lake Washington as shown in Exhibit A according to the specifications in Exhibit B.

C. Complete a hydrologic evaluation and develop a recommended modification to existing temporary weir as follows: (Detailed study outlines are shown in Exhibit C.)

1. develop complete hydraulic data for the existing weir; and
2. adapt and calibrate a hydrological simulation model for the basin above the said temporary weir; and
3. delineate floodplain of the Lake Washington and areas upstream; and
4. assess flooding damage potential associated with various alternative evaluated for the proposed modification to the temporary weir.

2. AUTHORITY will:

A. Obligate for the purposes of this Agreement in the sum of Twenty-eight Thousand One Hundred Ninety Dollars ($28,190) for services relating to the photogrammetric mapping and the said Phase I Study.

B. Pay the DISTRICT for work invoiced it by the DISTRICT a sum not to exceed Twenty-eight Thousand One Hundred Ninety Dollars ($28,190) for work and services described in paragraphs 1.B and 1.C above.

IN WITNESS WHEREOF, the parties hereto have duly executed this Agreement on the date and year ascribed above.

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

By: ______________________________
IDWAL H. OWEN, JR., Chairman

ATTEST:

____
LYNNE C. CAPEHART, Secretary

____
Legal Form Content Approved

SOUTH BREVARD WATER AUTHORITY

BY: ______________________________
O. W. HUDSON, Chairman

ATTEST:

____
R. C. WINSTEAD, Clerk

____
Legal Form Content Approved

APPENDIX III

Historic Sequence of Annual, Warm Season and Cold Season Rainfall at Selected Stations

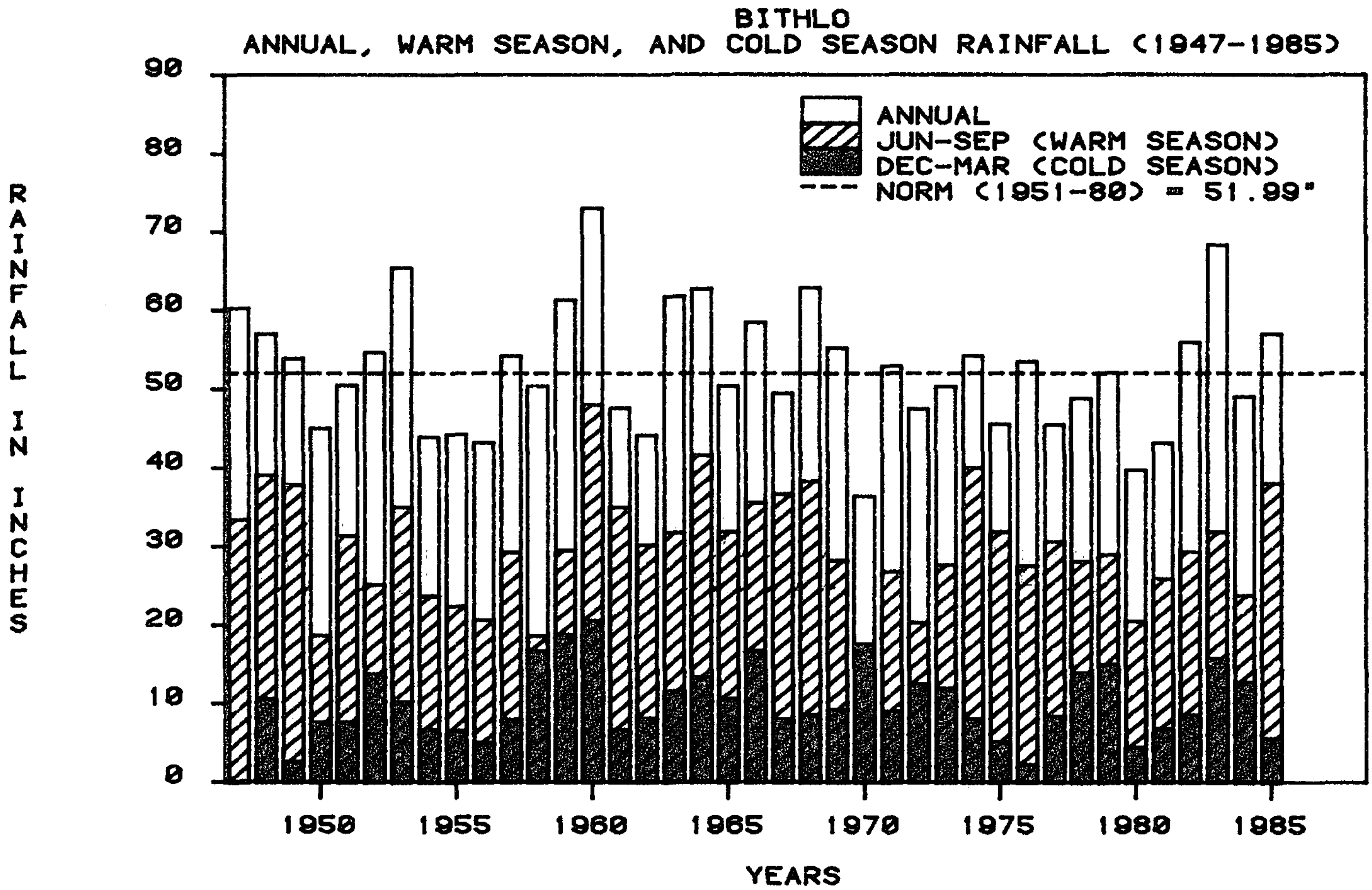
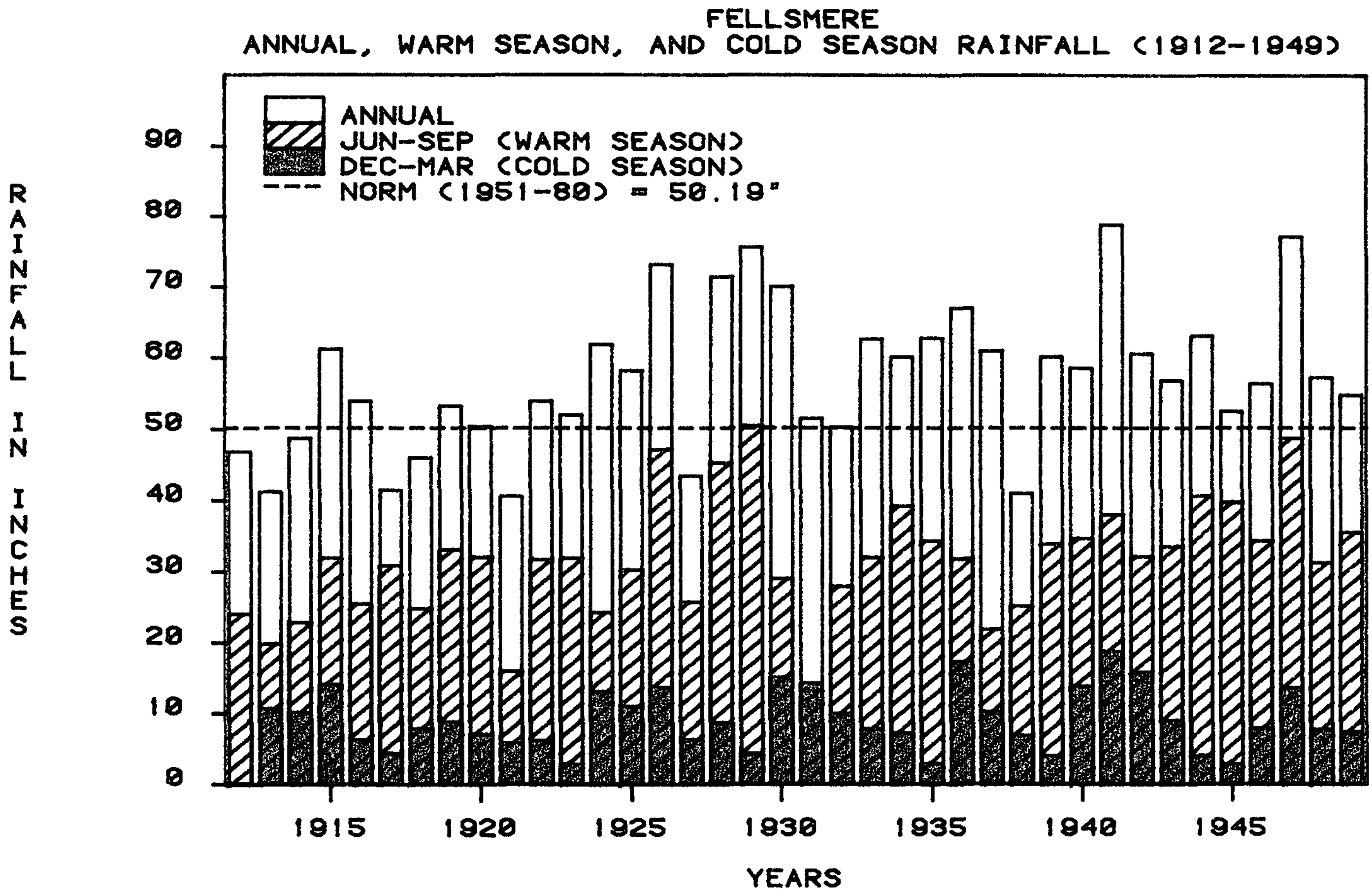


Figure III-1. Historic Rainfall Variation at Bithlo



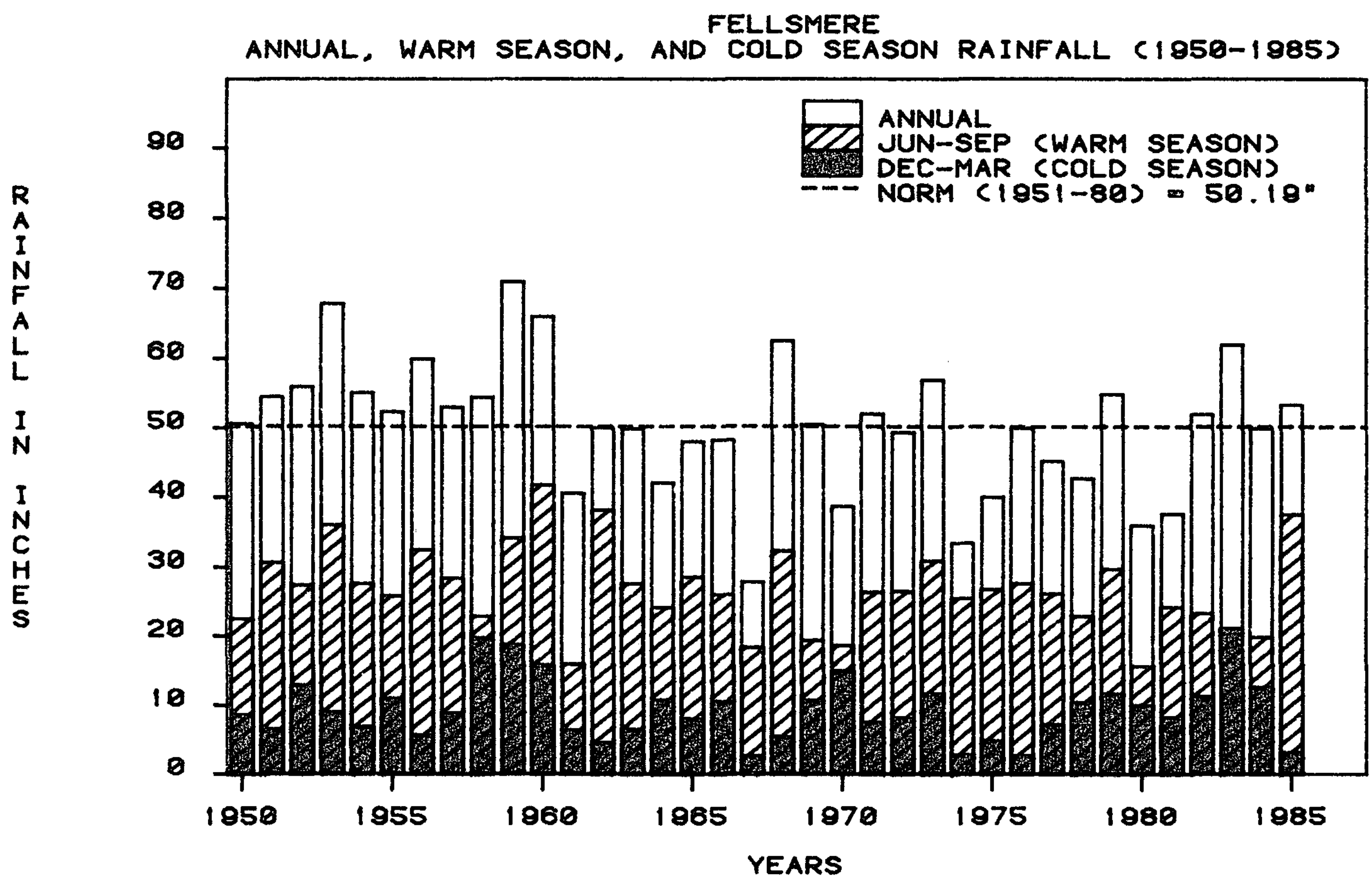


Figure III-2. Historic Rainfall Variation at Fellsmere

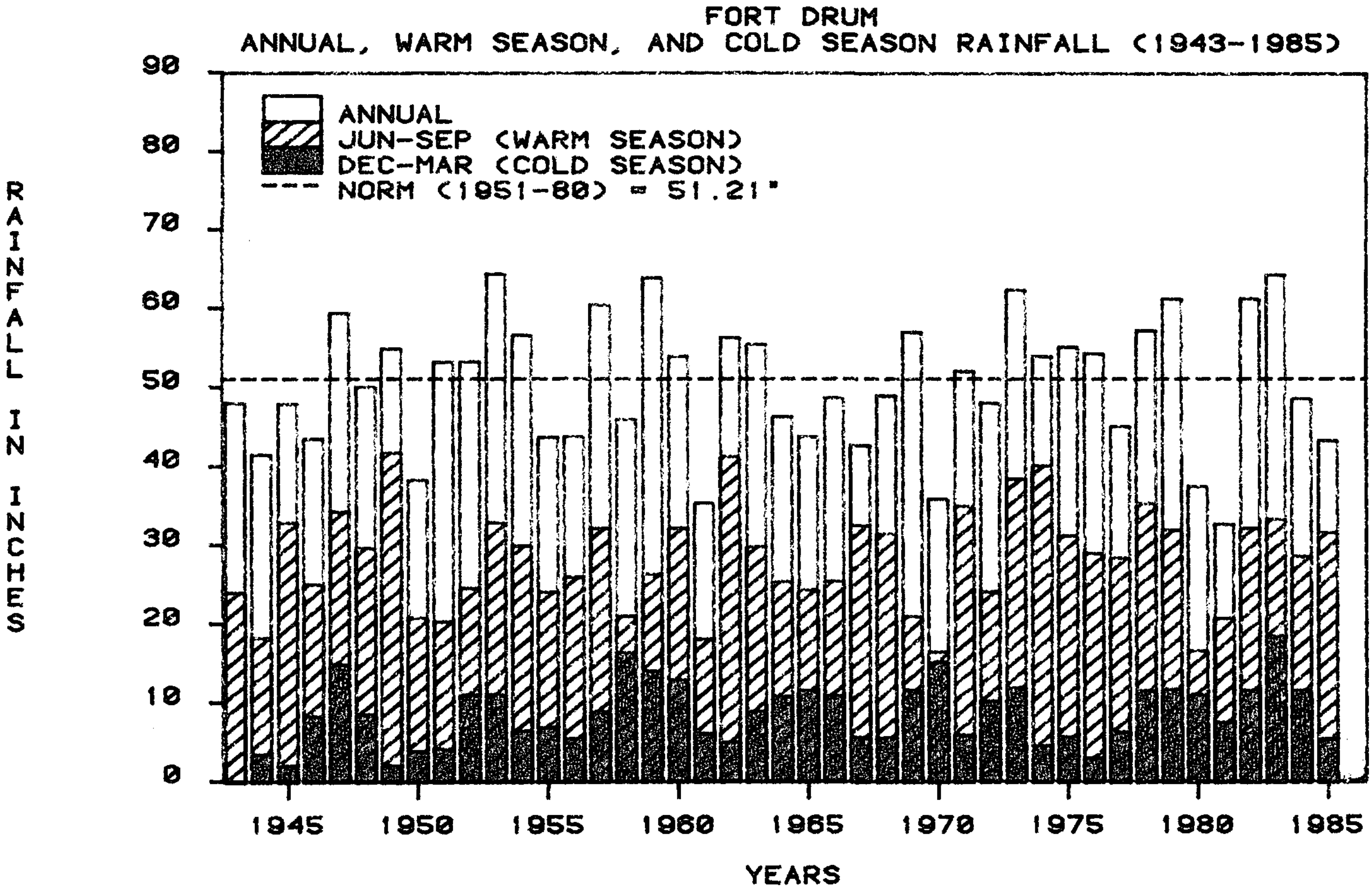
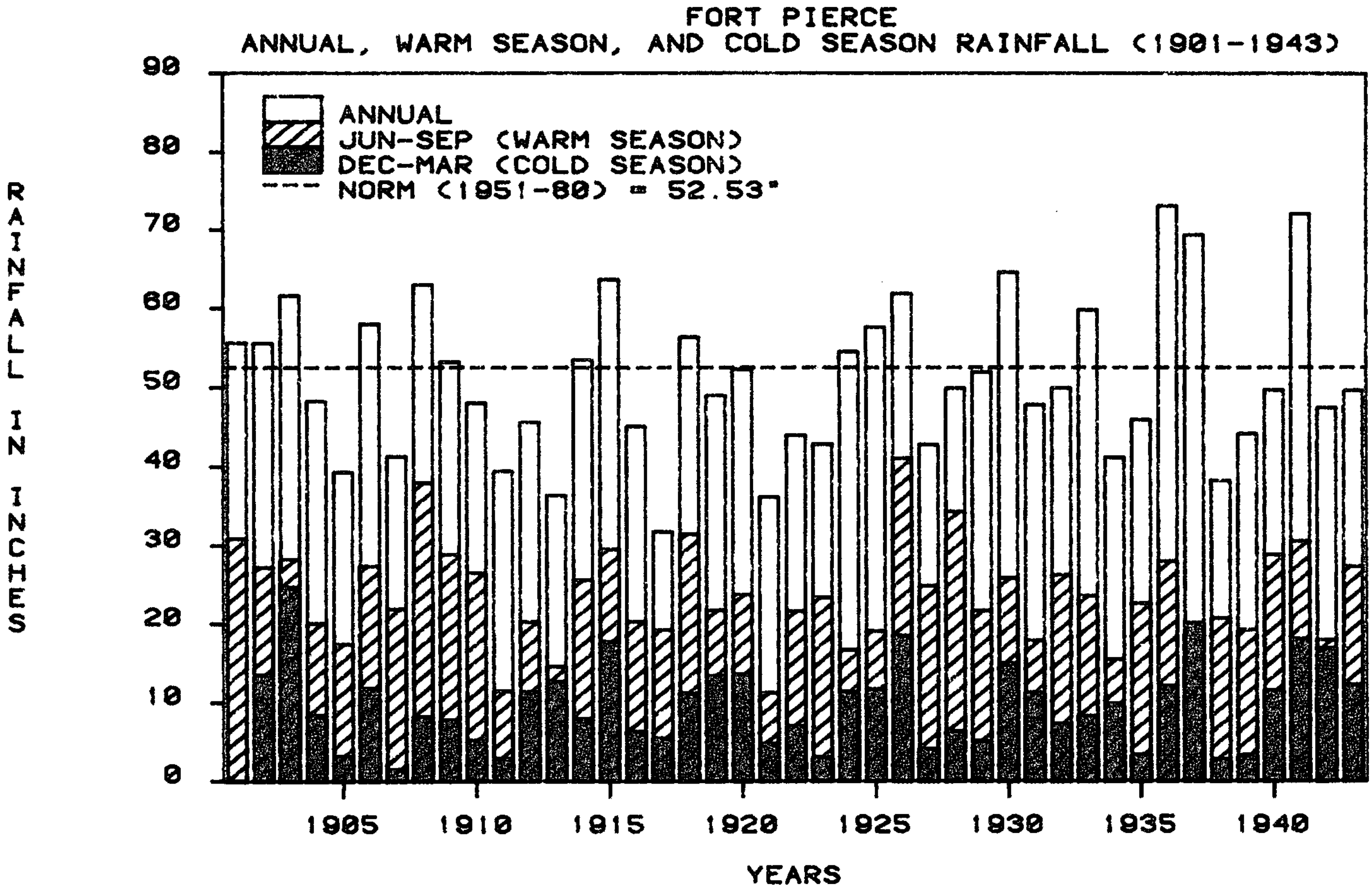


Figure III-3. Historic Rainfall Variation at Fort Drum



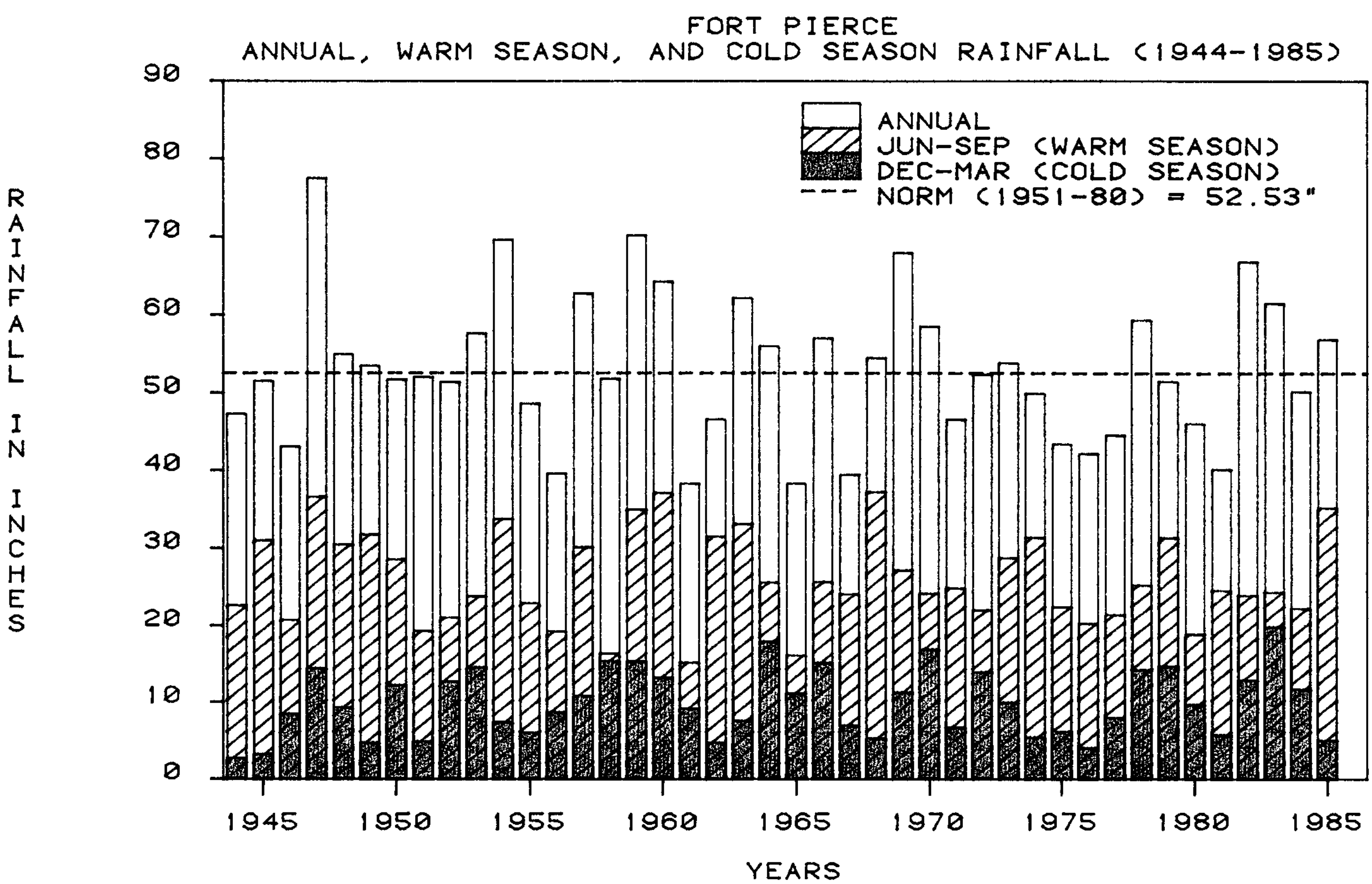


Figure III-4. Historic Rainfall Variation at Fort Pierce

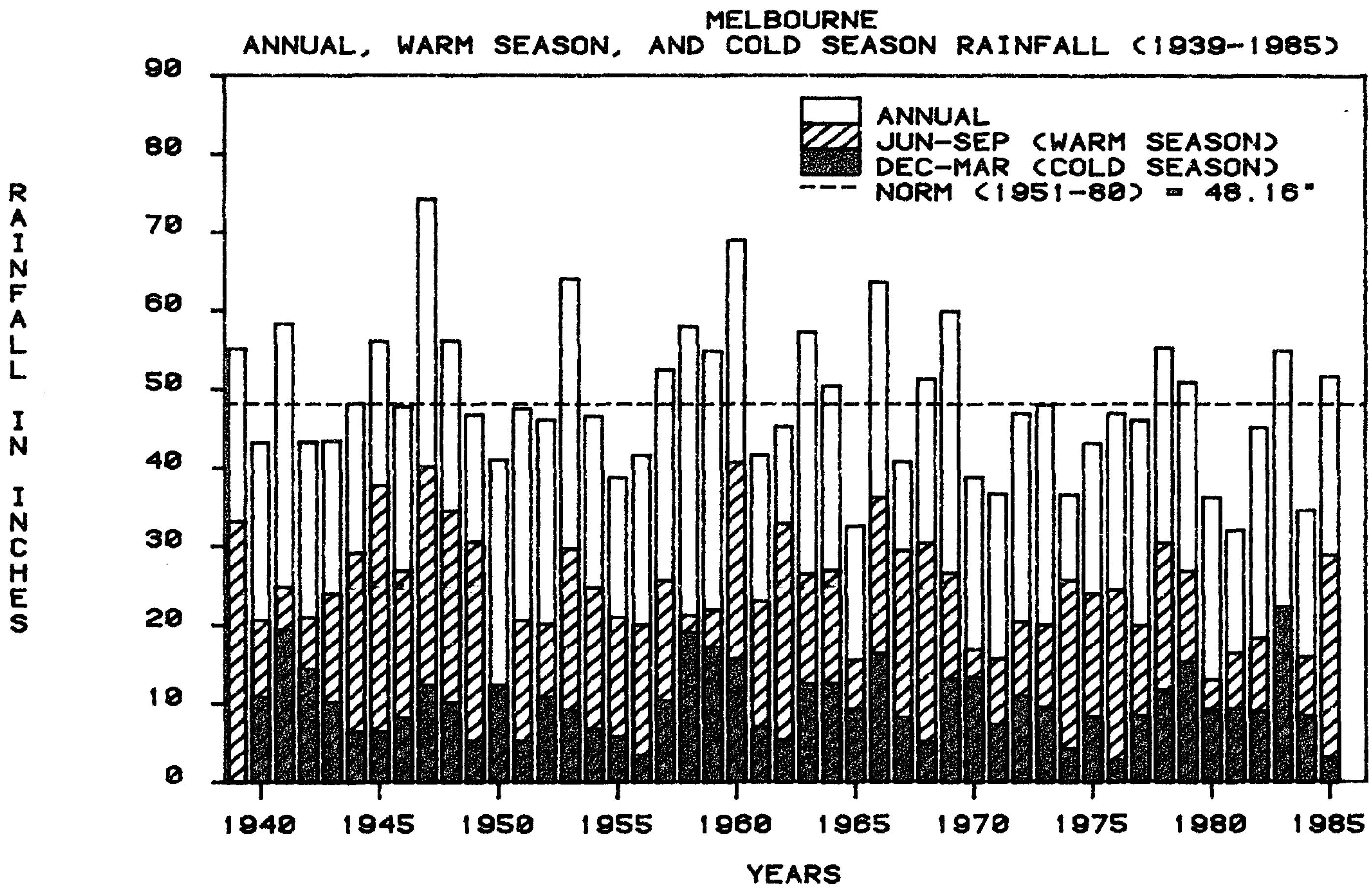


Figure III-5. Historic Rainfall Variation at Melbourne

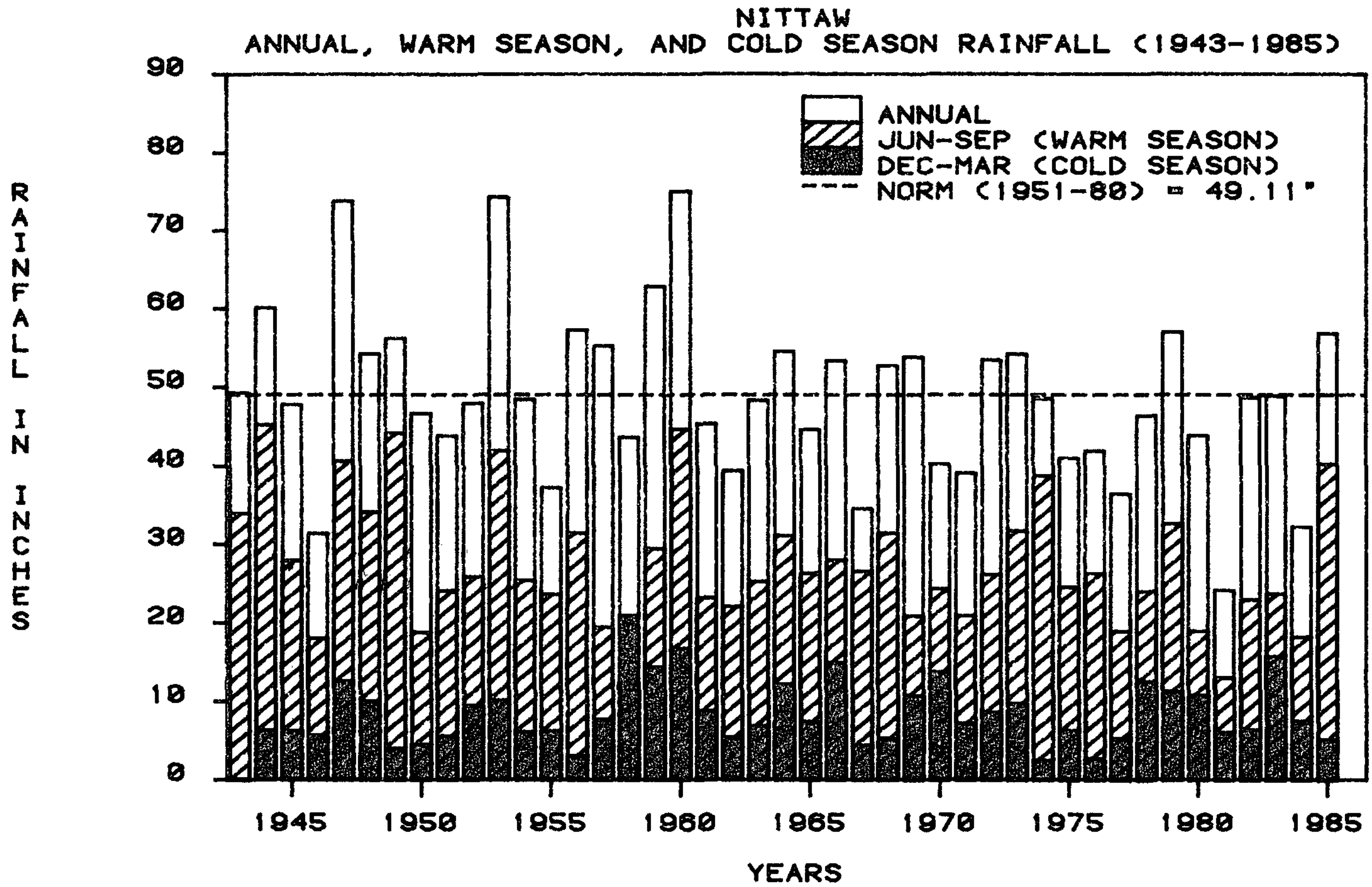
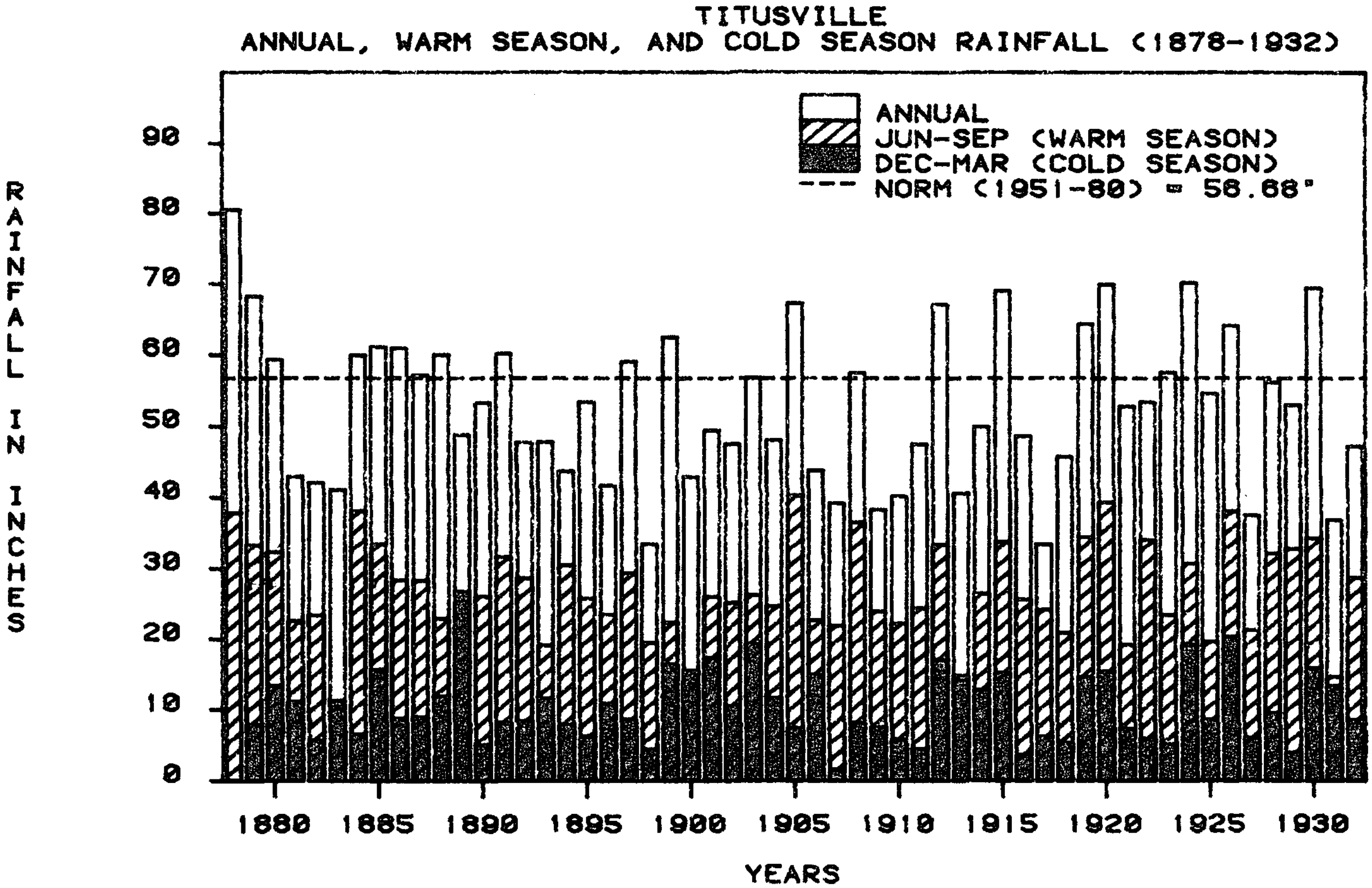


Figure III-6. Historic Rainfall Variation at Nittaw



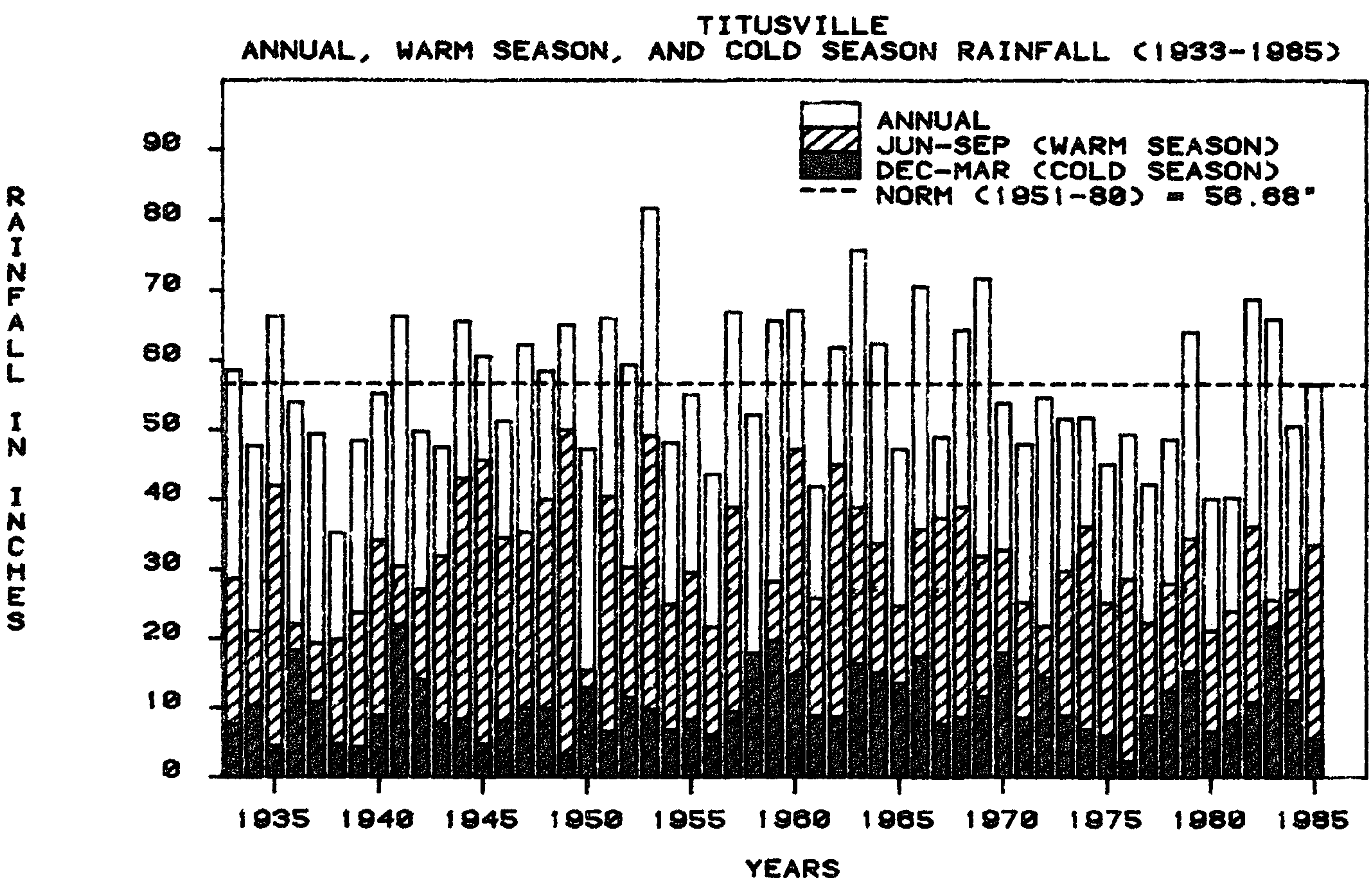


Figure III-7. Historic Rainfall Variation at Titusville

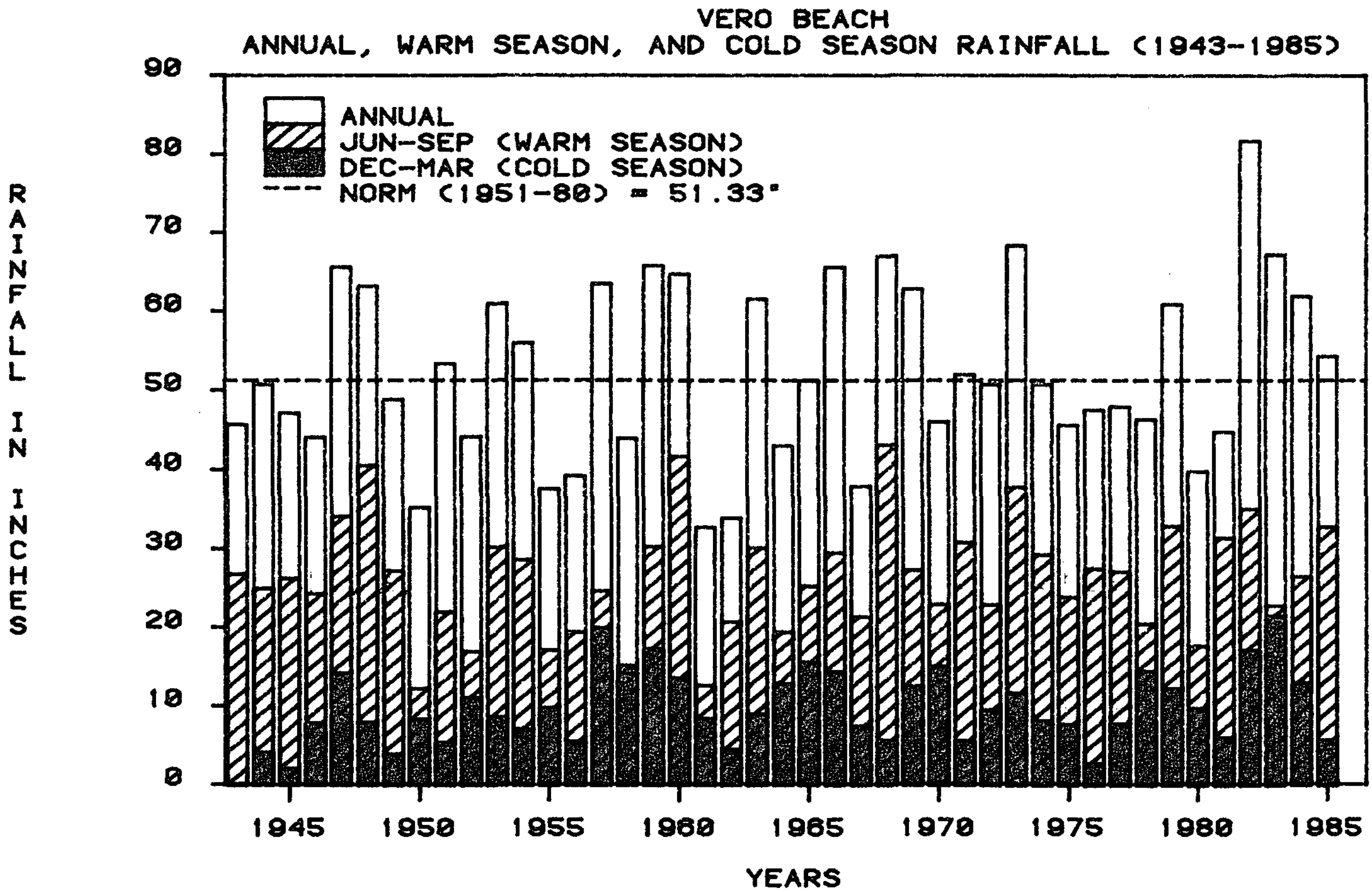


Figure III-8. Historic Rainfall Variation at Vero Beach

APPENDIX IV

Parameters of Minimum Flow Criteria For Various Alternative Weir Conditions Evaluated

Table IV-1a. Lake Washington: Parameters of Minimum Flow Criteria - Existing Conditions

Rate of Withdrawal mgd	Primary Criteria: Mean Elev. for simulation period ft. NGVD	Primary Criteria: Percent time 14 ft. NGVD equaled or exceeded	Secondary Criteria, Number of years (in Percent): 13 ft. NGVD exceeded	13 ft. NGVD Not exceeded	15 ft. NGVD exceeded	15 ft. NGVD Not exceeded	30-day max elev exceeded 17.8 ft. NGVD	60-day max elev exceeded 16.3 ft. NGVD
14	14.59	63.55	100	22.7	95.5	100	9.1	38.6
25	14.50	61.03	100	29.5	95.5	100	9.1	38.6
30	14.44	59.91	100	31.8	95.5	100	9.1	36.4
Requirement	≥13.75	≥ 60.00	≥50	≥ 50	≥50	≥50	0	0

Table IV-1b. St. Johns River at River Mile 253.1: Parameters of Minimum Flow Criteria - Existing Conditions

Rate of Withdrawal mgd	Primary Criteria: Mean Elev. for simulation period ft. NGVD	Primary Criteria: Percent time 12.7 ft. NGVD equaled or exceeded	Secondary Criteria, Number of years (in Percent): 11.4 ft. NGVD exceeded	11.4 ft NGVD Not exceeded	14.0 ft. NGVD exceeded	14.0 ft NGVD Not exceeded	30-day max elev exceeded 16.2 ft. NGVD	60-day max elev exceeded 14.7 ft. NGVD
14	13.48	64.34	100	63.6	97.7	100	56.8	88.6
25	13.38	63.05	100	70.5	97.7	100	56.8	88.6
30	13.34	62.39	100	72.7	97.7	100	56.8	84.1
Requirement	>12.40	≥60.00	≥50	≥ 50	≥ 50	≥50	0	0

Table IV-2a. Lake Washington: Parameters of Minimum Flow Criteria - USJRB Plan, Existing Weir.

Rate of Withdrawal mgd	Primary Criteria: Mean Elev. for simulation period ft. NGVD	Primary Criteria: Percent time 14 ft. NGVD equaled or exceeded	Secondary Criteria – Number of years (in Percent): 13 ft. NGVD inundated	13 ft. NGVD exposed	15 ft. NGVD inundated	15 ft. NGVD exposed	30-day max elev exceeded 17.8 ft. NGVD	60-day max elev exceeded 16.3 ft. NGVD
14	14.76	73.98	100	0	97.7	100	15.9	36.4
25	14.72	70.97	100	0	97.7	100	15.9	36.4
30	14.70	69.04	100	2.3	97.7	100	15.9	36.4
Requirement	≥13.75	≥60.00	≥50	≥50	≥50	≥50	0	0

Table IV-2b. St. Johns River at River Mile 253.1: Parameters of Minimum Flow Criteria - USJRB Plan, Existing Weir on Lake Washington

Rate of Withdrawal mgd	Primary Criteria: Mean Elev. for simulation period ft. NGVD	Primary Criteria: Percent time 12.7 ft. NGVD equaled or exceeded	Secondary Criteria – Number of years (in Percent): 11.4 ft. NGVD exceeded	11.4 ft NGVD Not exceeded	14.0 ft. NGVD exceeded	14.0 ft NGVD Not exceeded	30-day max elev exceeded 16.2 ft. NGVD	60-day max elev exceeded 14.7 ft. NGVD
14	13.76	69.51	100	36.4	97.7	100	59.1	84.1
25	13.76	68.67	100	40.9	97.7	100	56.8	84.2
30	13.71	67.69	100	43.2	97.7	100	56.8	81.8
Requirement	≥12.40	≥60.00	≥50	≥50	≥50	≥50	0	0

Table 1V-3a. Lake Washington: Parameters of Minimum Flow Criteria - USJRB Plan, Modified Weir with Weir Crest at 14.0 ft. NGVD.

Rate of Withdrawal mgd	Primary Criteria: Mean Elev. for simulation period ft.NGVD	Primary Criteria: Percent time 14 ft. NGVD equaled or exceeded	Secondary Criteria, Number of years (in Percent): 13 ft. NGVD exceeded	13 ft. NGVD Not exceeded	15 ft. NGVD exceeded	15 ft. NGVD Not exceeded	30-day max elev exceeded 17.8 ft. NGVD	60-day max elev exceeded 16.3 ft. NGVD
14	14.94	100.00	100	0	97.7	100	15.9	34.1
25	14.92	99.17	100	0	97.7	100	15.9	34.1
30	14.90	98.83	100	0	97.7	100	15.9	34.1
Requirement	≥13.75	≥60.00	≥50	≥50	≥50	≥50	0	0

Table IV-3b. St. Johns River at River Mile 253.1: Parameters of Minimum Flow Criteria - USJRB Plan, Modified Weir on Lake Washington(Weir Crest at 14 ft. NGVD).

Rate of Withdrawal mgd	Primary Criteria: Mean Elev. for simulation period ft.NGVD	Primary Criteria: Percent time 12.7 ft. NGVD equaled or exceeded	Secondary Criteria, Number of years (in Percent): 11.4 ft. NGVD exceeded	11.4 ft NGVD Not exceeded	14.0 ft. NGVD exceeded	14.0 ft NGVD Not exceeded	30-day max elev exceeded 16.2 ft. NGVD	60-day max elev exceeded 14.7 ft. NGVD
14	13.82	69.73	100	36.4	97.7	100	59.1	84.1
25	13.73	67.85	100	40.9	97.7	100	56.8	81.8
30	13.69	66.79	100	43.2	97.7	100	56.8	81.8
Requirement	≥12.40	≥60.00	≥50	≥50	≥50	≥ 50	0	0

Table IV-4a. Lake Washington: Parameters of Minimum Flow Criteria - USJRB Plan, Modified Weir with Weir Crest at 13.0 ft NGVD.

Rate of Withdrawal mgd	Primary Criteria: Mean Elev. for simulation period ft. NGVD	Primary Criteria: Percent time 14 ft. NGVD equaled or exceeded	Secondary Criteria, Number of years (in Percent): 13 ft. NGVD exceeded	13 ft. NGVD Not exceeded	15 ft. NGVD exceeded	15 ft. NGVD Not exceeded	30-day max elev exceeded 17.8 ft. NGVD	60-day max elev exceeded 16.3 ft. NGVD
14	14.53	58.53	100	2.3	95.5	100	15.9	36.4
25	14.48	56.28	100	9.9	93.2	100	15.9	34.1
30	14.46	55.44	100	9.9	93.2	100	15.9	34.1
Requirement	≥13.75	≥60.00	≥50	≥50	≥50	≥50	0	0

Table IV-4b. St. Johns River at River Mile 253.1: Parameters of Minimum Flow Criteria - USJRB Plan, Modified Weir on Lake Washington (Weir Crest at 13.0 ft. NGVD).

Rate of Withdrawal mgd	Primary Criteria: Mean Elev. for simulation period ft. NGVD	Primary Criteria: Percent time 12.7 ft. NGVD equaled or exceeded	Secondary Criteria, Number of years (in Percent): 11.4 ft. NGVD exceeded	11.4 ft NGVD Not exceeded	14.0 ft. NGVD exceeded	14.0 ft NGVD Not exceeded	30-day max elev exceeded 16.2 ft. NGVD	60-day max elev exceeded 14.7 ft. NGVD
14	13.84	70.68	100	36.4	97.7	100	59.1	84.1
25	13.75	68.65	100	40.9	97.7	100	56.8	84.1
30	13.71	67.67	100	43.2	97.7	100	56.8	81.8
Requirement	≥12.40	≥ 60.00	≥50	≥50	≥50	≥50	0	0

Table IV-5a. Lake Washington: Parameters of Minimum Flow Criteria - USJRB Plan, Modified Weir with Weir Crest at 12.0 ft. NGVD.

	Primary Criteria		Secondary Criteria					
			Number of years (in Percent)					
Rate of Withdrawal mgd	Mean Elev. for simula-tion period ft. NGVD	Percent time 14 ft. NGVD equaled or exceeded	13 ft. NGVD exceeded	13 ft. NGVD Not exceeded	15 ft. NGVD exceeded	15 ft. NGVD Not exceeded	30-day max elev exceeded 17.8 ft. NGVD	60-day max elev exceeded 16.3 ft. NGVD
14	14.15	48.92	100	97.7	93.2	100	15.9	36.4
25	14.08	47.02	100	100.0	93.2	100	15.9	34.1
30	14.04	46.36	100	100.0	93.2	100	15.9	34.1
Requirement	≥13.75	≥60.00	≥50	≥50	≥50	≥50	0	0

Table IV-5b. St. Johns River at River Mile 253.1: Parameters of Minimum Flow Criteria - USJRB Plan, Modified Weir on Lake Washington(Weir Crest at 12.0 ft. NGVD).

	Primary Criteria		Secondary Criteria					
			Number of years (in Percent)					
Rate of Withdrawal mgd	Mean Elev. for simula-tion period ft. NGVD	Percent time 12.7 ft. NGVD equaled or exceeded	11.4 ft. NGVD exceeded	11.4 ft NGVD Not exceeded	14.0 ft. NGVD exceeded	14.0 ft NGVD Not exceeded	30-day max elev exceeded 16.2 ft. NGVD	60-day max elev exceeded 14.7 ft. NGVD
14	13.86	71.77	100	36.4	97.7	100	59.1	84.1
25	13.77	69.63	100	38.6	97.7	100	56.8	81.8
30	13.72	68.43	100	40.9	97.7	100	56.9	81.8
Requirement	≥12.40	≥60.00	≥ 50	≥ 50	≥50	≥50	0	0

APPENDIX V

Estimates of Flood Stages for Lake Washington

Table V-1: Estimates of Flood Stages for Lake Washington

Duration Days	Mean Annual High	Recurrence interval, years 5	10	25	50	100	500
		Existing Conditions (Weir Crest at 13.5 ft. NGVD)					
1	16.83	17.63	18.39	18.98	19.41	19.86	20.86
7	16.80	17.59	18.33	18.93	19.35	19.79	20.76
14	16.72	17.48	18.17	18.80	19.19	19.58	20.53
30	16.46	17.14	17.71	18.42	18.72	19.01	19.66
60	16.08	16.70	17.14	17.67	18.04	18.39	18.84
		The USJRB Plan: Weir Crest at 13.5 ft. NGVD					
1	16.96	17.89	18.55	19.07	19.42	19.76	20.46
7	16.93	17.86	18.52	19.02	19.37	19.70	20.39
14	16.86	17.77	18.46	18.94	19.27	19.58	20.22
30	16.64	17.49	18.13	18.67	18.98	19.24	19.79
60	16.26	17.00	17.57	18.26	18.61	18.88	19.44
		The USJRB Plan: Weir Crest at 14 ft. NGVD					
1	16.96	17.88	18.54	19.06	19.43	19.77	20.52
7	16.93	17.84	18.52	19.02	19.38	19.71	20.44
14	16.86	17.75	18.45	18.93	19.27	19.59	20.27
30	16.65	17.47	18.12	18.67	18.98	19.25	19.83
60	16.27	16.99	17.57	18.26	18.61	18.88	19.45
		The USJRB Plan: Weir Crest at 12 ft. NGVD					
1	16.93	17.91	18.56	19.07	19.41	19.73	20.38
7	16.91	17.87	18.53	19.03	19.36	19.67	20.30
14	16.85	17.78	18.46	18.94	19.26	19.55	20.15
30	16.44	17.49	18.13	18.67	18.98	19.24	19.77
60	16.25	16.97	17.57	18.26	18.61	18.88	19.45

APPENDIX VI

Estimates of Low Stages for St. Johns River at River Mile 253.1

Table VI-1. St. Johns River at River Mile 253.1: Estimated Low Stages (ft. NGVD) for Droughts of Different Return Periods (No-Plug and Existing Conditions)

Duration Days	Mean Annual Low	5	10	25	50	100	200
		Recurrence intervals, years					
No-Plug and Existing Conditions: Lake Washington Withdrawal = 14 mgd.							
1	10.65	8.75	8.6	*	*	*	*
7	10.7	8.8	8.65	8.5	*	*	*
14	10.75	8.85	8.65	8.55	*	*	*
30	10.9	9.0	8.75	8.6	8.55	*	*
60	11.15	9.3	8.95	8.75	8.7	8.6	*
Existing Conditions: Lake Washington Withdrawal = 25 mgd.							
1	10.45	8.7	8.55	*	*	*	*
7	10.5	8.75	8.55	*	*	*	*
14	10.6	8.75	8.6	*	*	*	*
30	10.7	8.9	8.65	8.55	*	*	*
60	11.0	9.1	8.85	8.7	8.6	8.6	*
Existing Conditions: Lake Washington Withdrawal = 30 mgd.							
1	10.4	8.7	*	*	*	*	*
7	10.45	8.7	8.55	*	*	*	*
14	10.5	8.75	8.55	*	*	*	*
30	10.65	8.85	8.6	8.55	*	*	*
60	10.9	9.05	8.8	8.7	8.6	8.6	*

* The channel goes dry.

Table VI-2 St. Johns River at River Mile 253.1: Estimated Low Stages (ft. NGVD) for Droughts of Different Return Periods (USJRB Plan, Existing Weir on Lake Washington)

Duration Days	Mean Annual Low	Recurrence interval, years 5	10	25	50	100	200
			Lake Washington Withdrawal = 14 mgd.				
1	11.55	10.7	10.0	9.35	9.0	8.6	*
7	11.6	10.75	10.1	9.4	9.0	8.6	*
14	11.65	10.8	10.2	9.55	9.1	8.6	*
30	11.75	10.95	10.4	9.65	9.1	8.6	*
60	11.95	11.1	10.8	9.95	9.35	8.8	*
			Lake Washington Withdrawal = 25 mgd.				
1	11.35	10.3	9.7	8.9	8.6	*	*
7	11.4	10.4	9.75	8.95	8.65	*	*
14	11.45	10.45	9.8	9.1	8.75	*	*
30	11.55	10.55	10.1	9.2	8.8	*	*
60	11.75	10.75	10.3	9.5	9.0	8.6	*
			Lake Washington Withdrawal = 30 mgd.				
1	11.25	10.15	9.5	8.8	8.55	*	*
7	11.3	10.2	9.6	8.85	8.6	*	*
14	11.35	10.25	9.65	8.95	8.6	*	*
30	11.45	10.4	10.0	9.1	8.7	*	*
60	11.7	10.6	10.2	9.3	8.9	8.6	*

* The channel goes dry.

Table VI-3 St. Johns River at River Mile 253.1: Estimated Low Stages (ft. NGVD) for Droughts of Different Return Periods (USJRB Plan, Modified Weir on Lake Washington with Weir Crest at 14 ft. NGVD)

Duration Days	Mean Annual Low	Recurrence interval, years 5	10	25	50	100	200
		Lake Washington Withdrawal = 14 mgd.					
1	11.5	10.7	10.5	9.6	9.2	8.7	*
7	11.55	10.75	10.5	9.7	9.2	8.7	*
14	11.6	10.85	10.55	9.8	9.2	8.7	*
30	11.7	10.9	10.65	9.8	9.2	8.7	*
60	11.9	11.05	10.85	10.05	9.5	8.9	*
		Lake Washington Withdrawal = 25 mgd.					
1	11.3	10.35	10.1	9.15	8.7	*	*
7	11.35	10.4	10.1	9.2	8.7	*	*
14	11.4	10.45	10.15	9.25	8.75	*	*
30	11.5	10.55	10.25	9.35	8.8	*	*
60	11.75	10.75	10.45	9.6	9.05	8.6	*
		Lake Washington Withdrawal = 30 mgd.					
1	11.2	10.15	9.85	8.95	8.55	*	*
7	11.25	10.2	9.85	9.05	8.6	*	*
14	11.3	10.3	9.95	9.1	8.65	*	*
30	11.4	10.4	10.05	9.25	8.8	*	*
60	11.65	10.6	10.25	9.4	8.9	8.6	*

* The channel goes dry.

Table VI-4 St. Johns River at River Mile 253.1: Estimated Low Stages (ft. NGVD) for Droughts of Different Return Periods (USJRB Plan, Modified Weir on Lake Washington with Weir Crest at 13 ft. NGVD)

Duration Days	Mean Annual Low	Recurrence interval, years 5	10	25	50	100	200
		Lake Washington Withdrawal = 14 mgd.					
1	11.55	10.7	10.45	9.4	9.05	8.6	*
7	11.6	10.75	10.5	9.5	9.05	8.6	*
14	11.65	10.8	10.55	9.6	9.1	8.6	*
30	11.75	10.95	10.6	9.7	9.1	8.6	*
60	11.95	11.1	10.85	10.0	9.35	8.8	*
		Lake Washington Withdrawal = 25 mgd.					
1	11.35	10.3	10.05	8.95	8.6	*	*
7	11.4	10.4	10.1	9.0	8.65	*	*
14	11.45	10.45	10.15	9.1	8.75	*	*
30	11.55	10.55	10.25	9.2	8.8	*	*
60	11.75	10.75	10.45	9.5	9.0	8.6	*
		Lake Washington Withdrawal = 30 mgd.					
1	11.25	10.15	9.75	8.85	8.55	*	*
7	11.3	10.2	9.8	8.9	8.6	*	*
14	11.35	10.3	9.9	8.95	8.6	*	*
30	11.45	10.4	10.05	9.1	8.7	*	*
60	11.7	10.6	10.25	9.4	8.9	8.6	*

* The channel goes dry.

Table VI-5. St. Johns River at River Mile 253.1: Estimated Low Stages (ft. NGVD) for Droughts of Different Return Periods (USJRB Plan, Modified Weir on Lake Washington with Weir Crest at 12 ft. NGVD)

Duration Days	Mean Annual Low	Recurrence interval, years 5	10	25	50	100	200
		Lake Washington Withdrawal = 14 mgd.					
1	11.6	10.75	10.45	9.45	9.05	8.6	*
7	11.65	10.8	10.5	9.5	9.05	8.6	*
14	11.7	10.85	10.55	9.6	9.05	8.6	*
30	11.8	11.0	10.65	9.7	9.15	8.6	*
60	12.0	11.1	10.85	10.0	9.4	8.8	*
		Lake Washington Withdrawal = 25 mgd.					
1	11.4	10.35	10.05	8.95	8.65	*	*
7	11.45	10.4	10.1	9.05	8.65	*	*
14	11.5	10.5	10.15	9.2	8.75	*	*
30	11.6	10.6	10.25	9.2	8.8	*	*
60	11.8	10.8	10.45	9.5	9.0	8.6	*
		Lake Washington Withdrawal = 30 mgd.					
1	11.3	10.2	9.8	8.9	8.6	*	*
7	11.35	10.25	9.85	8.9	8.6	*	*
14	11.4	10.3	9.9	9.0	8.6	*	*
30	11.5	10.45	10.05	9.1	8.7	*	*
60	11.7	10.6	10.3	9.4	8.9	8.6	*

* The channel goes dry.