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SELECTION OF AN OPTIMAL SITE FOR THE LAKE WASHINGTON WEIR BREVARD COUNTY, FLORIDA

by

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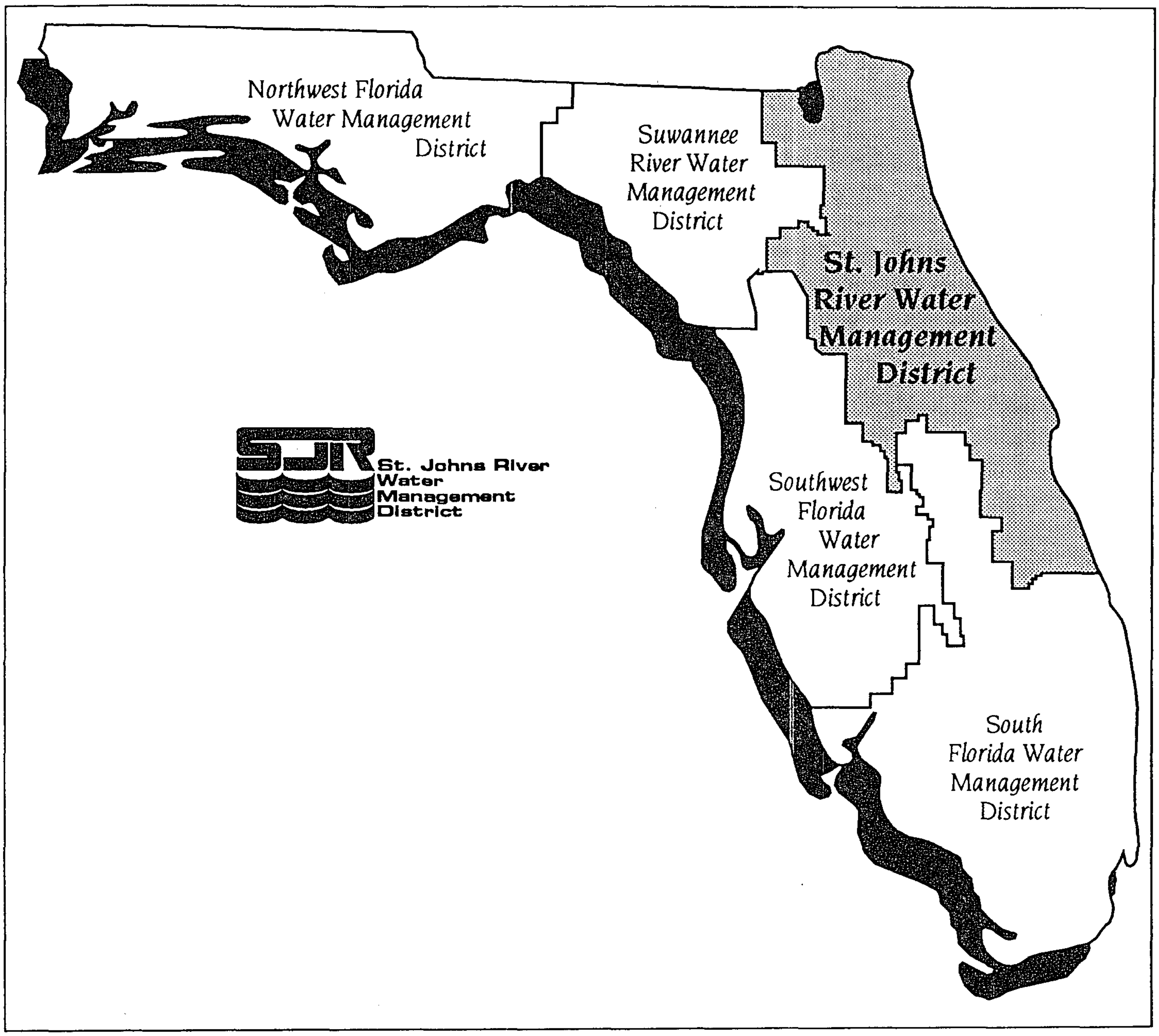

The **St. Johns River Water Management District** (SJRWMD) was created by the Florida Legislature in 1972 to be one of five water management districts in Florida. It includes all or part of 19 counties in northeast Florida. The mission of SJRWMD is to manage water resources to ensure their continued availability while maximizing environmental and economic benefits. It accomplishes its mission through regulation; applied research; assistance to federal, state, and local governments; operation and maintenance of water control works; and land acquisition and management.

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EXECUTIVE SUMMARY

Lake Washington, located on the St. Johns River in east central Florida, is the major drinking water supply source for south Brevard County. The 1990 average annual water use was about 16.24 million gallons per day (mgd). The projected water use 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 sheet-pile weir, the Lake Washington weir, with crest elevation at 13.5 feet, National Geodetic Vertical Datum (ft NGVD). This weir, 165 ft in length, was constructed in 1976 to protect water supplies during low-flow periods. Lake levels have receded below the weir crest during extended droughts, resulting in concern regarding the ability of the lake to supply adequate amounts of water to meet the growing needs of south Brevard County.

The St. Johns River Water Management District evaluated the water supply potential of Lake Washington by doing a study from 1985 to 1987 and developed an appropriate water management plan for Lake Washington and the river downstream. The study recommendations included replacement of the temporary weir with a permanent weir of length 165 ft and crest elevation 14.00 ft NGVD. The study determined that, with this structure, withdrawals of up to 30 mgd could be made with no adverse environmental impacts or deterioration in water quality (chloride levels). The study recommendations also included further analyses for withdrawals greater than 30 mgd.

After the 1985–87 study was completed, questions were raised regarding whether the existing weir location would be the best for constructing a permanent facility or if moving the weir to a downstream location would offer greater benefits, especially environmental benefits. The current report identifies other potential weir sites and provides a hydrologic and environmental evaluation. The present study identified two alternative weir sites: Site 1, at the mouth of Lake Winder, and Site 2, upstream of Lake Winder.

A continuous hydrologic simulation model generated daily stage and discharge data for a period of 48 years (1942–89) for various locations in the study area. The daily stage data and the annual extreme stages for various durations determined from the daily data formed a basis for evaluating Lake Washington water supply potential and for conducting environmental analyses. The data were generated for the eight alternatives derived from the varying combinations of the following factors: two weir heights (crest elevations of 13.5 and 14.00 ft NGVD); two consumptive use withdrawals (14.5 and 30.0 mgd); and two weir locations, the current location and Site 1, at the mouth of Lake Winder (river mile 240.1). Site 2 evaluations were deferred until the analyses for Site 1 were completed.

Drought stages for different return periods estimated for the eight alternatives indicated that a new weir at Site 1 would create a greater water supply potential than does the present weir. Withdrawals greater than 30 mgd would be possible with the weir at Site 1, while a withdrawal of 30 mgd at the present weir location would lead to very low stages (less than 11.50 ft NGVD) and water quality problems for drought return periods greater than 25 years. The weir at Site 1, however, would increase the flood levels by about 1.6 ft at Lake Winder to 0.1 ft at Lake Washington. The total cost of the weir at Site 1 and the other improvements undoubtedly would far exceed the cost of replacing the present temporary weir with a permanent structure (no cost estimates were made in this study).

Environmental evaluations consisted of comparing the hydrologic conditions that would prevail at various study area locations, under each water management alternative, to a set of environmental criteria for each location. The environmental criteria were formulated based on historic hydrologic conditions. A no-weir scenario (weir completely removed) was also simulated for testing environmental criteria.

Using simulated hydrologic data, the potential environmental impacts of relocating the Lake Washington weir downstream to the mouth of Lake Winder were evaluated. The evaluations indicated that moving the weir would dramatically alter the current hydrologic regime over 14 miles of river channel and 14,000 acres of floodplain by increasing mean annual stages over 1 ft and decreasing the annual range of fluctuation as much as 54 percent. These changes in hydrology would have a detrimental impact on wetland resources within the area.

A weir located at Site 2, upstream of Lake Winder, would impact the wetlands in much the same way as a weir would at Site 1. Weirs located at Sites 1 or 2 can alter the hydrologic regime of extensive areas of marshlands in an undesirable fashion. Therefore, building a weir at Site 2 cannot be justified, and no detailed hydrologic evaluations were performed. The recommendation, therefore, is to keep the weir in its current location.

A detailed study will be conducted in the future to establish minimum flow criteria for the Lake Washington reach of the river and to determine the water supply potential of Lake Washington, considering various plan elements of the Upper St. Johns River Basin Project and the low-flow augmentation downstream. A permanent weir structure will be designed to meet various environmental and water supply goals after that detailed study is completed.

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INTRODUCTION

Lake Washington is located on the St. Johns River in east central Florida (Figure 1). It is the primary drinking water supply source for south Brevard County, in the St. Johns River Water Management District (SJRWMD). The service area for the City of Melbourne public water supply includes areas in south Brevard County, outside the city limits. This public water supply serves a population in excess of 136,000. The average annual water use was about 16.24 million gallons per day (mgd) as of 1990 (Florence 1992); the projected demand is 30 mgd by the year 2000 and 44 mgd by the year 2030, as estimated by the South Brevard Water Authority in 1985. For the year 2010, the projected use is 31.25 mgd (Cynthia Moore, SJRWMD, pers. com. 1992). The lake is dammed at its north end by a temporary sheet-pile weir, the Lake Washington weir. The crest elevation of the weir is 13.5 feet, National Geodetic Vertical Datum (ft NGVD). This weir, 165 ft in length, was constructed in 1976 to protect water supplies for the City of Melbourne during low-flow periods. Lake levels have receded below the weir crest during extended droughts (e.g., 1981 and 1986) (Rao and Tai 1987), resulting in concern regarding the ability of this source to provide adequate amounts of water to meet the growing needs of south Brevard County.

The South Brevard Water Authority (SBWA), which was created by the Legislature in 1983 and disbanded by the Legislature in 1994, was vested with the responsibility of providing a safe and reliable water supply for the south Brevard area, including the City of Melbourne. At the request of SBWA, SJRWMD evaluated the water supply potential of Lake Washington by conducting a study performed from 1985 to 1987 (Hall 1987; Rao and Tai 1987).

The findings of the 1985–87 study (hereinafter denoted as the "previous study") were published in two reports. One report (Hall 1987) described and analyzed the ecology of the floodplain marsh in the Lake Washington area. Based on ecologic/ hydrologic considerations, Hall established elevations critical to a

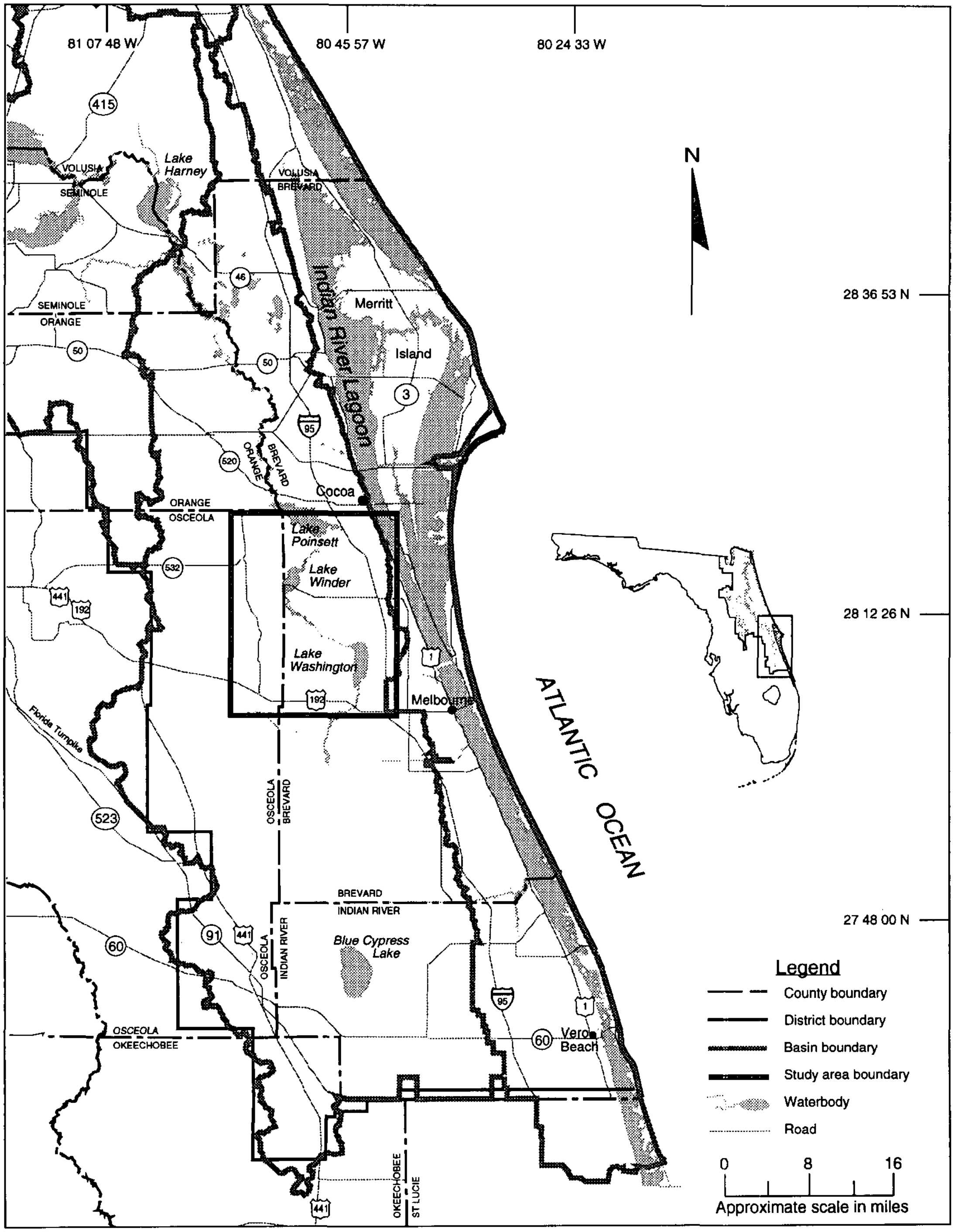

Figure 1. The Upper St. Johns River Basin

healthy marsh regime at and downstream of Lake Washington and developed criteria for determining minimum flow/stage requirements. The other report (Rao and Tai 1987) presented the results of detailed hydrologic evaluations concerning the potential of Lake Washington as a water supply source. Applying various environmental criteria, Rao and Tai determined the water supply potential under existing conditions (1985) and for the flow conditions that would occur after the completion of the Upper St. Johns River Basin Project (USJRBP) in 1997. The USJRBP is a $177 million flood control and river restoration effort, co-sponsored by SJRWMD and the U.S. Army Corps of Engineers (USACE). The data required for the preceding analyses were generated by watershed hydrologic simulations.

Rao and Tai (1987) evaluated five alternative weir configurations relative to the USJRBP. These configurations were (1) weir crest at 13.50 ft NGVD (existing height and length), (2) weir crest at 14.00 ft NGVD, (3) weir crest at 13.00 ft NGVD, (4) weir crest at 12.00 ft NGVD, and (5) removal of the weir. For alternatives 2–4, the length of the weir was kept the same as the existing weir—165 ft. Simulated hydrologic data (stage and discharge) were generated for different locations of interest for a period of 45 years (1942–86). This period included several major drought and flood events.

The criteria for determining the water supply potential of Lake Washington included (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 related to socio-economic impacts of various alternative weir designs, that is, potential flood damage.

Rao and Tai (1987) determined that the second alternative (weir crest elevation of 14.00 ft NGVD) was the best elevation choice. Alternatives 3–5 (i.e., a weir with crest elevation at 13.00 ft NGVD or 12.00 ft NGVD or no weir) were not acceptable based on environmental considerations. Compared to the existing weir (crest elevation of 13.50 ft NGVD), the weir with crest elevation at 14.00 ft NGVD would lead to higher water levels during drought conditions and improved water quality with respect to chlorides.

Rao and Tai (1987) recommended replacement of the temporary weir (13.50 ft NGVD) with a permanent weir with a length of 165 ft and a crest elevation of 14.00 ft NGVD. Rao and Tai (1987) also determined that, with this structure, withdrawals of up to 30 mgd (projected water use by the year 2000) could be made with no adverse environmental impacts or deterioration in water quality (chloride levels). They recommended further analyses for withdrawals greater than 30 mgd, however.

After the 1985-87 study, questions were raised regarding the location of the existing weir. Is the existing location of the weir the best for constructing a permanent facility, or should the weir be moved to a downstream location? Would one location offer greater benefits than the other, especially with reference to environmental benefits?

The current report identifies other potential weir sites and provides a hydrologic and environmental evaluation of different weirs constructed at the current and at other sites. The study identified two alternative weir sites: Site 1, at the mouth of Lake Winder at river mile (RM) 240.1, and Site 2, upstream of Lake Winder at RM 249.5 (Figure 2).

A detailed re-evaluation of the water supply potential of Lake Washington was not an objective of the study presented in this report. It will be done under a wider study (currently in progress) that will also address the issues of minimum flows and levels at Lake Washington and its vicinity and optimization of operation of certain components of the USJRBP, such as the Three Forks Marsh Conservation Area.

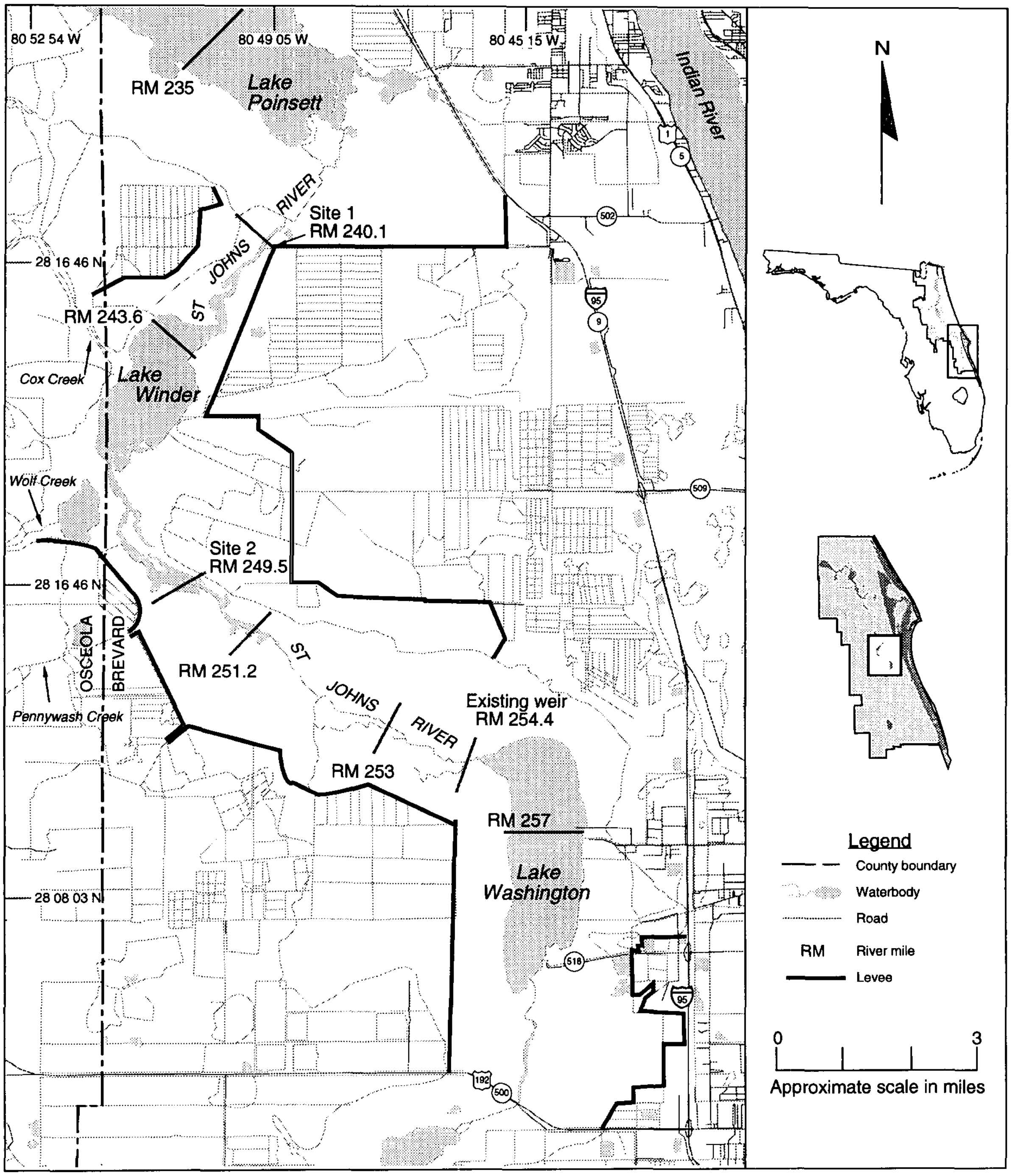

Figure 2. Alternative weir sites

HYDROLOGIC SIMULATIONS

Long-term streamflow (stage and discharge) data are necessary for evaluating the environmental hydrologic criteria (described in the next section) and for determining the water supply potential of Lake Washington. Although discharge records are available for a period of over 50 years in the vicinity of Lake Washington (the St. Johns River at U.S. Highway 192/State Road 500), use of these data in various analyses will not provide satisfactory results because watershed conditions changed continuously during the period. Also, projected stage and discharge data are required for several locations for conditions that would prevail after the completion of the USJRBP in 1997. For these reasons, SJRWMD uses hydrologic modeling procedures to simulate stage and discharge data under different watershed conditions.

HYDROLOGIC MODEL

SJRWMD developed a continuous watershed simulation model (Upper St. Johns Hydrologic Model), which generates daily streamflow and stage/storage data at desired locations in the Upper St. Johns River Basin under any given (assumed) watershed condition (Suphunvorranop and Tai 1982). This model is periodically updated to simulate various features of the USJRBP (Rao and Tai 1987) and used to generate long-term streamflow and stage data needed for this study. The simulations were performed under the assumption that the USJRBP was complete and fully functional.

The simulations used in this study include all of the elements of the completed Environmental Water Management Plan (EWMP) (Miller et al. 1994). When Rao and Tai (1987) completed their study, EWMP for the USJRBP was not fully developed.

The previous study and this study differ with respect to the operation of the Three Forks Marsh Conservation Area (TFMCA) (Figure 3), which was called the St. Johns Marsh Conservation

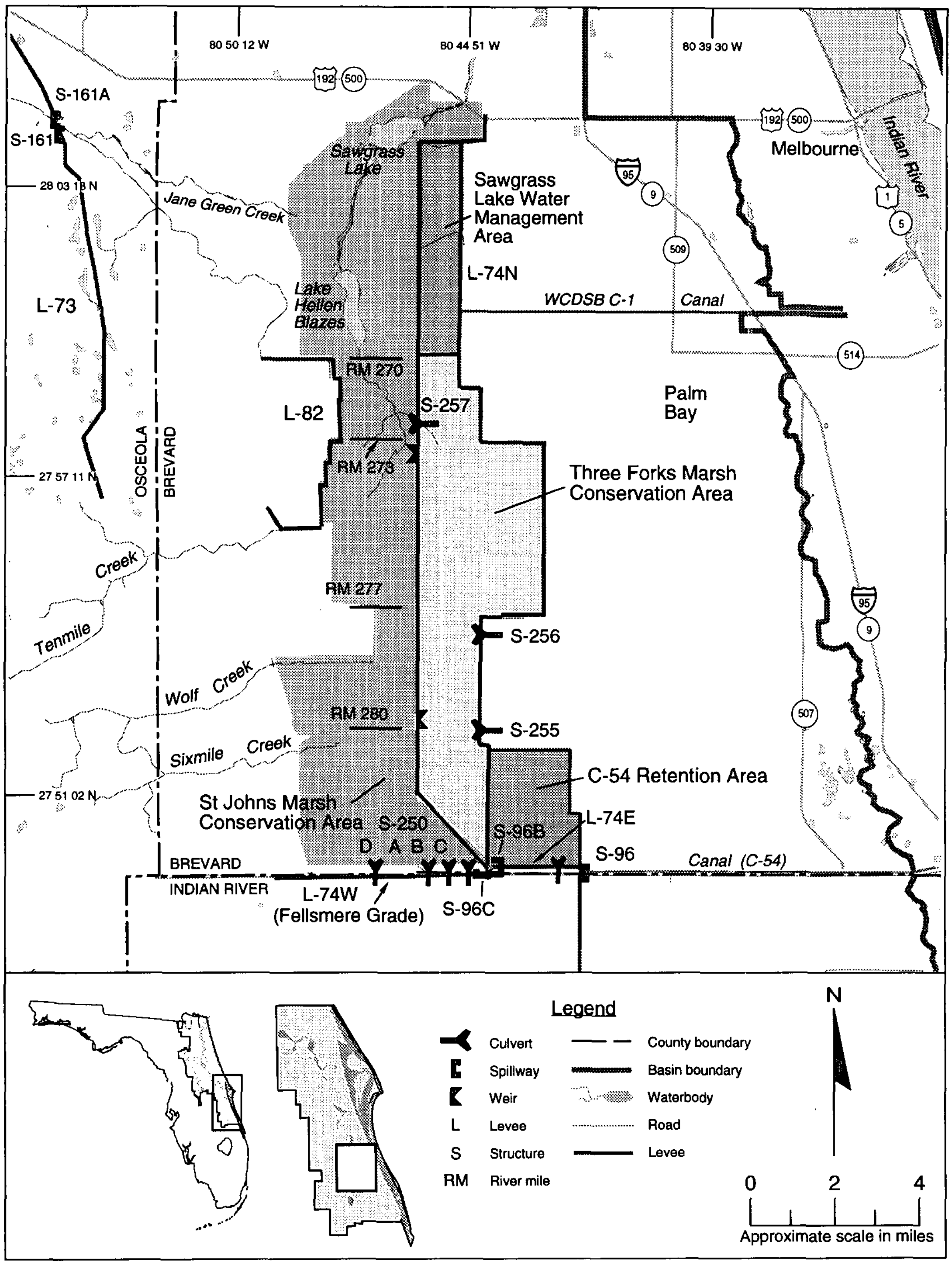

Figure 3. **The proposed Upper St. Johns River Basin Project: U.S. Highway 192 to Fellsmere Grade**

Area in the previous study. In the previous study, Rao and Tai (1987) assumed that TFMCA, with a storage capacity equal to about 3.5 times that of Lake Washington, would be operated primarily to augment flows into Lake Washington. The area west of TFMCA, about 33,000 acres of existing marsh, is now denoted as the St. Johns Marsh Conservation Area (SJMCA). The environmental criteria for TFMCA and several other marsh conservation and water management areas of the USJRBP, however, have been revised since 1987. TFMCA will be regulated to meet the revised environmental criteria (Miller et al. 1994) and to assure minimum flows and levels. This regulation might result in somewhat different water supply benefits from Lake Washington (i.e., Lake Washington water supply potential) than those determined by Rao and Tai (1987). Whichever way TFMCA is operated, the benefits still are expected to be substantially greater than those obtained under the pre-project conditions.

TFMCA encompasses approximately 14,000 acres of former agricultural lands located on the east side of the St. Johns River immediately north of the Fellsmere Grade (Figure 3). Nearly all of TFMCA was diked and drained previously for agricultural purposes. As a result, soil subsidence has caused ground elevations to be 2–3 ft lower in TFMCA than in adjacent areas of SJMCA. Because of this subsidence, the existing levee separating TFMCA from SJMCA will be retained and improved where necessary. The levee system will prevent over-drainage of SJMCA during dry periods and maintain an acceptable hydrologic regime within both SJMCA and TFMCA. Proposed restoration plans for TFMCA will result in the establishment of an open water area in the northern portion (7,000 acres) and approximately 7,000 acres of freshwater marsh in the southern portion of the area.

The design and operation of TFMCA are still being finalized by SJRWMD and USACE; however, the following conditions were tentatively assumed in the simulations for this study.

- Inflows to TFMCA will occur from SJMCA over a 500-ft-wide weir with a crest elevation of 20.00 ft NGVD near RM 280.

This weir would allow about 50 percent of the flow to enter TFMCA when the water level is above 20.00 ft NGVD at this location.

- Inflows to TFMCA from agricultural lands to the east and the C-54 Retention Area will occur through two culvert structures (S-255 and S-256; see Figure 3).

- Outflows from TFMCA to SJMCA, near RM 273, will occur over a 2,500-ft-wide weir having a crest elevation of 19.00 ft NGVD.

- Outflows from TFMCA to SJMCA can also occur through a culvert structure (S-257) having a discharge capacity of 200 cubic feet per second (cfs). S-257 will provide low-flow augmentation and allow for a smooth transition to low-flow conditions immediately after flows over the weir cease. Flow released through S-257 would be determined as follows.

1. If $H_{TFMCA} > 17.5$ ft, then $Q_{S\text{-}257} = 120$ cfs
   If $H_{TFMCA} < 17.5$ ft, then $Q_{S\text{-}257} = 0$ cfs

2. If flow in River Reach 4 (RM 270 to 277) < 30 cfs and $H_{TFMCA} > 14.0$ ft, then $Q_{S\text{-}257} = 30$ cfs

where H = water level, Q = discharge, and cfs = cubic feet per second.

Alternatives for Hydrologic Simulation

Two potential weir sites were identified initially from the engineering and economic considerations (Figure 2). Modeling and detailed evaluations of model results were performed for Site 1 (mouth of Lake Winder). Modeling and these evaluations are very time consuming; therefore, Site 2 (upstream of Lake Winder) would be evaluated only if the results for Site 1 indicated the necessity of such evaluation. Hydrologic simulations were performed for a total of eight cases (Table 1), four for the weir at the present location (RM 254.4) and four for a new weir located downstream of Lake Winder at RM 240.1 (Site 1). Two weir heights and two water supply withdrawal rates were considered for each location—weir crest elevations of 13.50 ft and 14.00 ft NGVD and withdrawal rates of 14.5 and 30.0 mgd. The crest elevation of the present weir is 13.50 ft NGVD; 14.00 ft NGVD was considered because of the increased storage capacity of Lake Washington (Rao and Tai 1987). The permitted average withdrawal rate from Lake Washington will be approximately 14.5 mgd during the 1990s, and 30.0 mgd is the projected water use for the City of Melbourne by the year 2000. The average permitted withdrawal from Lake Washington by the City of Melbourne varied from about 16 mgd in 1984 to 20.53 mgd in 1992. This surface water withdrawal, however, was reduced to 13.7 mgd in 1993, and a ground water withdrawal of 8.1 mgd was permitted. An increase in surface water withdrawal from Lake Washington from 13.7 mgd in 1993 to 15.6 mgd in 1998 has also been permitted (SJRWMD Consumptive Use Permit No. 2-009-0068-NGRM).

Figures 4 and 5 show the stage-area and the stage-storage relationships, respectively, for the two weir locations. The areas of Lake Washington and Lake Winder are about 2,930 and 1,670 acres, respectively. Note that on Figure 4, the area for a given elevation is the total marsh and lake area. If the current weir is removed and a new weir is installed at a downstream location, the new weir would impound water in Lakes Washington and Winder. Because the combined area of the two lakes is only about 4,600 acres, most of the impounded area at higher elevations lies outside the lakes and would have a shallow water depth. For example, between elevations 12.00 ft NGVD and 14.00 ft NGVD, the difference in water area for the new weir location is about 19,000 acres (Figure 4). Thus, when the water level is at 14.00 ft NGVD, this area, about 70 percent of the total water area, would have a depth of less than 2 ft. This area, however, would contribute enormously to evapotranspiration loss. Therefore, most of the impounded water likely would be lost as evapotranspiration instead of contributing to the water supply potential.

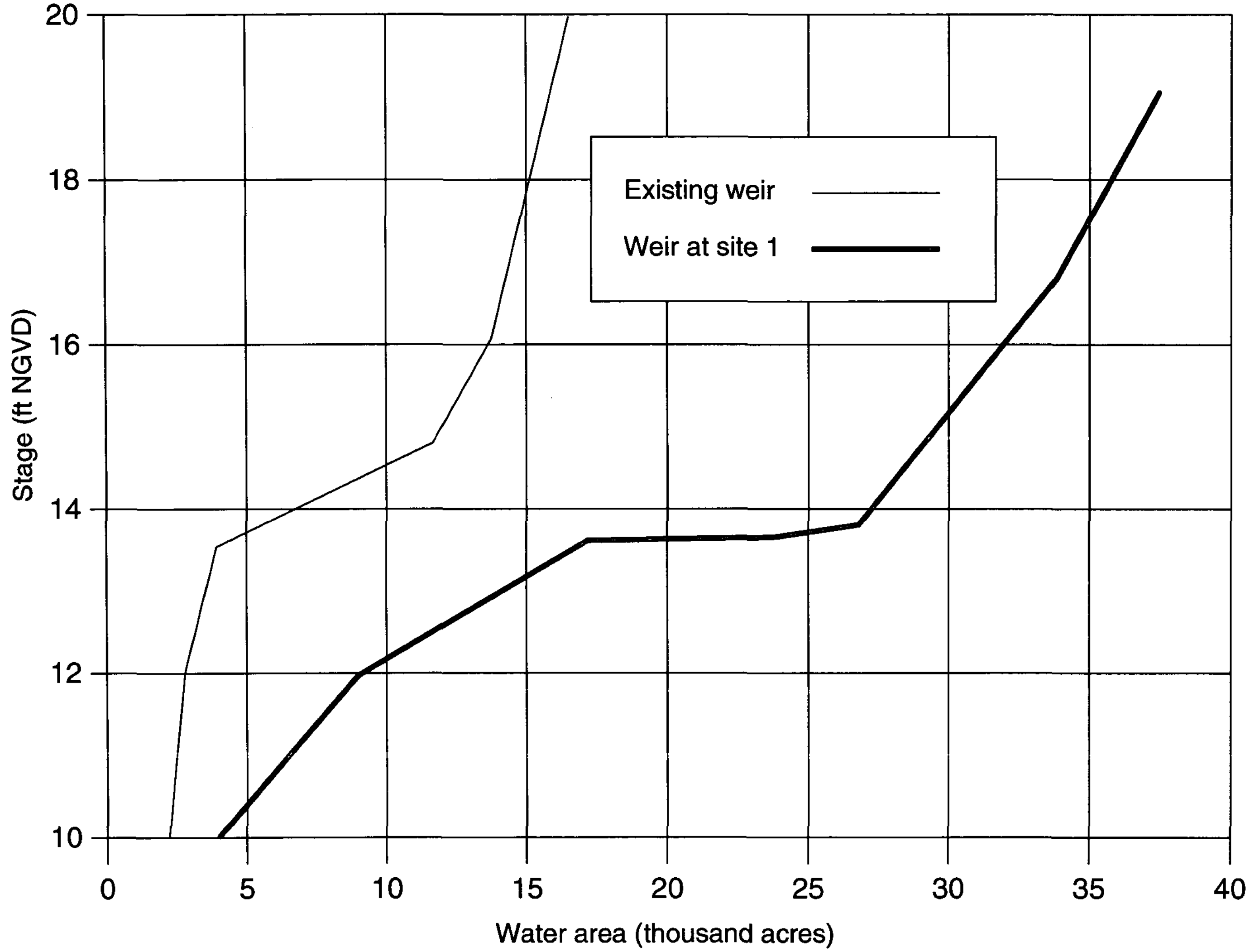

Figure 4. Stage-area relationships for the existing and new weirs. *Weir crest elevation = 13.50 feet, National Geodetic Vertical Datum (ft NGVD).*

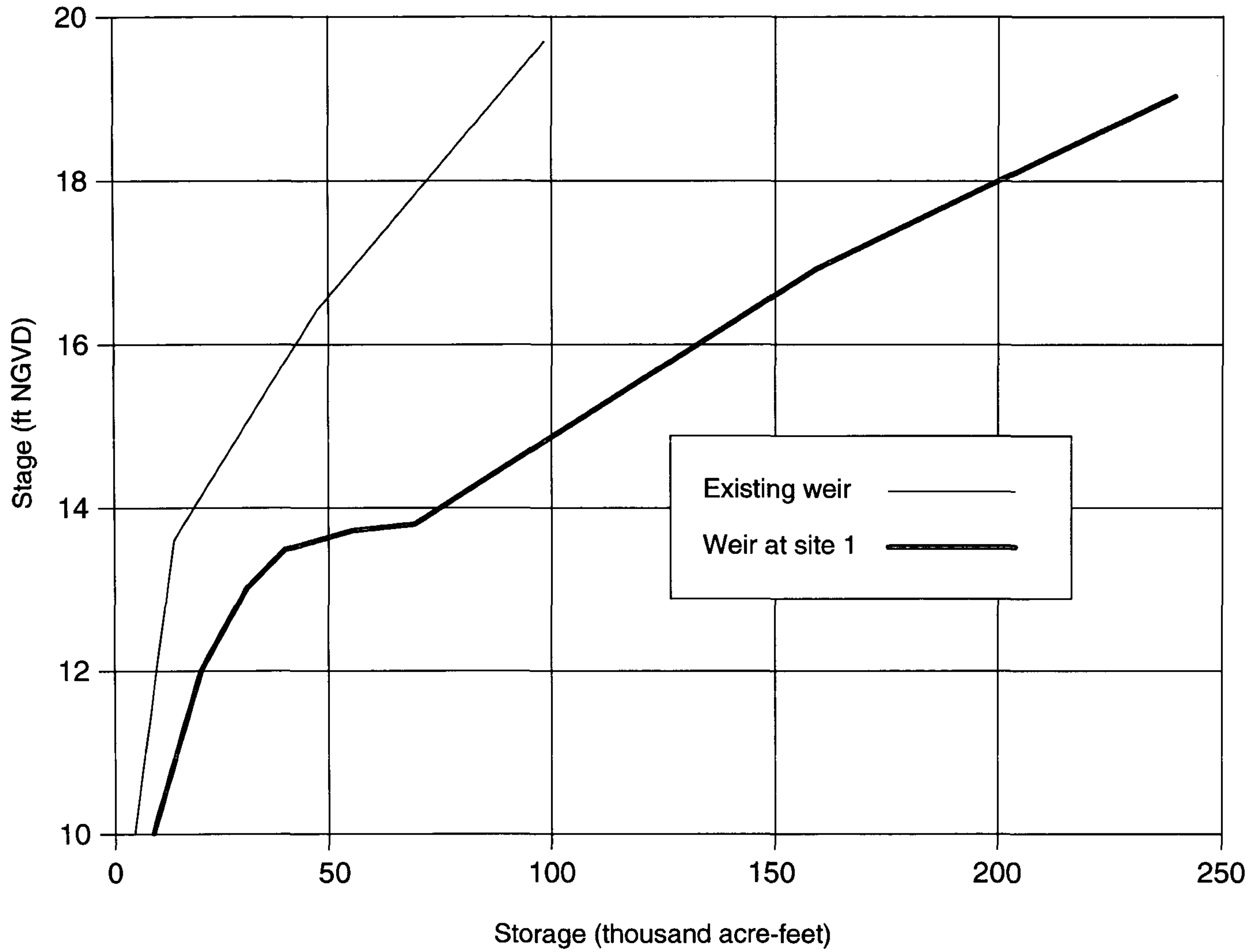

Figure 5. Stage-storage relationships for the existing and new weirs. *Weir crest elevation = 13.50 feet, National Geodetic Vertical Datum (ft NGVD). One acre-foot equals 0.326 million gallons per day.*

SIMULATION RESULTS

The simulations produced daily stage and discharge data for the desired locations for a period of 48 years (1942–89), for each case described (Tables 1 and 2). Annual extreme (high/low) stages for

Table 1. Assumed conditions for various hydrologic simulations

Weir Location	River Mile	Simulation Run Designation	Weir Crest Elevation (ft NGVD)	Water Supply Withdrawal (mgd)
Current	254.4	V3A	13.50	14.5
		V3B	13.50	30.0
		V4A	14.00	14.5
		V4B	14.00	30.0
Site 1	240.1	V5A	13.50	14.5
		V5B	13.50	30.0
		V6A	14.00	14.5
		V6B	14.00	30.0

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day

different durations constitute the basic input data for a number of environmental and hydrologic analyses performed in this study. These input data are as follows.

- **Highest mean values for different durations** (Tables 3–4). A reference year starting on June 1 and ending on May 31 is chosen to evaluate annual high stages because water levels gradually rise, reach a peak (or several peaks), and then recede during this period. The values computed are the highest average values for each duration (1-, 7-, 14-day, etc.).

Table 2. Example of daily simulated data: Stages in Lake Washington (RM 257), ft NGVD (Year 1942, Run V3A—13.5-ft weir, 14.5 mgd). *Consecutive readings begin first day of each month.*

1942 1 1	14.54	14.55	14.54	14.57	14.55	14.53	14.51	14.48
1942 1 2	14.49	14.55	14.53	14.50	14.47	14.45	14.42	14.39
1942 1 3	14.37	14.36	14.34	14.32	14.29	14.27	14.24	14.22
1942 1 4	14.19	14.17	14.14	14.12	14.10	14.07	14.05	
1942 2 1	14.02	14.00	13.97	13.95	13.93	13.90	13.88	13.85
1942 2 2	13.83	13.81	13.79	13.76	13.70	13.65	13.61	13.58
1942 2 3	13.56	13.66	13.74	13.73	13.71	13.69	13.80	13.85
1942 2 4	13.85	13.86	13.86	13.87				
1942 3 1	13.88	13.92	13.93	13.95	13.99	14.01	14.02	14.06
1942 3 2	14.09	14.10	14.10	14.11	14.12	14.12	14.12	14.11
1942 3 3	14.14	14.32	14.33	14.35	14.36	14.36	14.36	14.36
1942 3 4	14.35	14.35	14.35	14.34	14.33	14.32	14.39	
1942 4 1	14.37	14.36	14.34	14.32	14.30	14.28	14.27	14.25
1942 4 2	14.23	14.21	14.19	14.17	14.15	14.13	14.14	14.12
1942 4 3	14.32	14.31	14.31	14.31	14.31	14.31	14.31	14.32
1942 4 4	14.34	14.35	14.36	14.37	14.38	14.38		
1942 5 1	14.38	14.38	14.37	14.36	14.35	14.33	14.32	14.33
1942 5 2	14.31	14.29	14.27	14.25	14.23	14.28	14.27	14.24
1942 5 3	14.22	14.19	14.16	14.14	14.12	14.10	14.08	14.07
1942 5 4	14.06	14.05	14.04	14.06	14.07	14.08	14.13	
1942 6 1	14.12	14.14	14.28	14.37	14.39	14.42	14.44	14.52
1942 6 2	14.59	14.64	14.69	14.76	14.82	14.87	14.91	14.95
1942 6 3	14.98	15.01	15.11	15.12	15.21	15.36	15.46	15.57
1942 6 4	15.67	15.76	15.86	15.96	16.06	16.16		
1942 7 1	16.35	16.46	16.57	16.65	16.72	16.77	16.79	16.80
1942 7 2	16.79	16.77	16.73	16.68	16.62	16.55	16.50	16.43
1942 7 3	16.36	16.29	16.22	16.16	16.09	16.03	16.07	16.11
1942 7 4	16.06	16.03	15.98	15.93	15.88	15.84	15.80	
1942 8 1	15.78	15.76	15.74	15.72	15.71	15.71	15.72	15.72
1942 8 2	15.73	15.86	15.97	16.02	16.04	16.04	16.03	16.00
1942 8 3	15.98	15.94	15.91	15.87	15.83	15.79	15.74	15.69
1942 8 4	15.66	15.63	15.59	15.59	15.55	15.50	15.51	
1942 9 1	15.47	15.44	15.43	15.47	15.43	15.39	15.35	15.31
1942 9 2	15.26	15.22	15.17	15.14	15.11	15.07	15.04	15.00
1942 9 3	14.96	14.93	14.89	14.86	14.87	14.84	14.80	14.80

Table 2—*Continued*

1942 9 4	14.79	14.78	14.77	14.78	14.79	14.81		
1942 10 1	14.84	14.87	14.89	14.91	14.92	14.92	14.92	14.91
1942 10 2	14.90	14.88	14.86	14.84	14.82	14.79	14.76	14.73
1942 10 3	14.70	14.66	14.63	14.59	14.55	14.51	14.49	14.45
1942 10 4	14.42	14.38	14.34	14.33	14.31	14.28	14.29	
1942 11 1	14.27	14.25	14.24	14.23	14.22	14.22	14.20	14.19
1942 11 2	14.18	14.16	14.15	14.13	14.12	14.10	14.09	14.07
1942 11 3	14.06	14.04	14.03	14.01	14.00	13.98	13.97	13.96
1942 11 4	13.94	13.93	13.91	13.90	13.89	13.88		
1942 12 1	13.87	13.86	13.85	13.84	13.83	13.82	13.90	13.91
1942 12 2	13.91	13.92	13.92	13.93	13.93	13.93	13.93	13.93
1942 12 3	13.94	13.94	13.94	13.94	13.93	13.93	13.93	13.92
1942 12 4	13.92	13.91	13.91	13.90	13.92	13.91	13.90	

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day
RM = river mile

Table 3. Simulated highest mean stages at RM 257 (Run V3A—13.5-ft weir, 14.5 mgd), ft NGVD. *Values represent consecutive-day intervals for a year. A reference year begins on June 1 of the preceding year and ends on May 31.*

Year	1	7	14	30	60	120	183	274	1 Year
1943	16.80	16.77	16.67	16.39	16.12	15.62	15.17	14.71	14.45
1944	16.82	16.75	16.68	16.46	16.16	15.97	15.48	14.93	14.63
1945	17.45	17.43	17.35	17.21	17.04	16.57	15.93	15.36	14.92
1946	16.61	16.57	16.56	16.34	15.93	15.74	15.44	14.93	14.60
1947	15.52	15.50	15.43	15.42	15.31	15.09	14.81	14.59	14.49
1948	18.41	18.36	18.28	17.95	17.37	16.54	16.35	15.73	15.28
1949	17.85	17.81	17.71	17.28	16.46	15.65	15.15	14.74	14.44
1950	16.96	16.93	16.86	16.65	16.56	16.12	15.55	14.99	14.66
1951	17.82	17.76	17.60	17.05	16.15	15.20	14.78	14.59	14.38
1952	15.71	15.68	15.63	15.47	15.25	15.14	14.94	14.68	14.52
1953	16.19	16.18	16.14	15.89	15.58	15.37	15.06	14.70	14.54
1954	18.58	18.52	18.40	18.13	17.95	16.97	16.21	15.49	15.06
1955	16.38	16.36	16.31	16.17	15.78	15.23	15.15	14.80	14.54
1956	15.68	15.65	15.59	15.49	15.23	14.67	14.45	14.23	14.05
1957	19.69	19.63	19.44	18.79	17.47	16.22	15.63	15.08	14.84
1958	16.13	16.09	15.98	15.70	15.47	15.45	15.20	15.08	15.03
1959	15.28	15.27	15.23	15.13	14.89	14.52	14.40	14.39	14.29
1960	17.26	17.21	17.10	16.72	16.28	15.66	15.59	15.16	15.16
1961	17.91	17.86	17.76	17.46	16.81	16.74	16.16	15.49	15.09
1962	15.52	15.47	15.35	15.23	14.90	14.71	14.48	14.18	14.03
1963	16.13	16.10	16.01	15.74	15.59	15.20	14.84	14.57	14.34
1964	15.82	15.79	15.75	15.65	15.39	15.16	15.09	14.89	14.66
1965	16.80	16.76	16.64	16.32	16.01	15.38	14.94	14.58	14.34
1966	15.73	15.70	15.60	15.34	14.95	14.70	14.62	14.58	14.38
1967	16.40	16.38	16.34	16.12	15.74	15.53	15.25	14.77	14.40
1968	14.72	14.71	14.68	14.60	14.59	14.49	14.20	13.99	13.83

Table 3—*Continued*

Year	1	7	14	30	60	120	183	274	1 Year
1969	16.79	16.77	16.70	16.50	16.28	15.73	15.58	15.03	14.93
1970	15.53	15.50	15.45	15.35	15.32	15.31	15.18	14.93	14.71
1971	15.19	15.15	15.09	15.03	14.88	14.49	14.29	14.10	13.98
1972	15.11	15.10	15.05	14.91	14.82	14.77	14.63	14.41	14.26
1973	16.55	16.51	16.43	16.16	15.58	15.21	14.83	14.73	14.57
1974	15.99	15.96	15.90	15.79	15.70	15.57	15.24	14.77	14.40
1975	17.17	17.13	17.09	16.91	16.42	15.80	15.20	14.74	14.45
1976	15.30	15.30	15.28	15.23	15.20	14.99	14.75	14.41	14.15
1977	16.48	16.42	16.25	15.91	15.48	15.27	14.97	14.60	14.27
1978	15.21	15.18	15.12	14.97	14.84	14.71	14.51	14.32	14.16
1979	16.54	16.50	16.44	16.21	15.67	15.13	14.75	14.67	14.52
1980	17.96	17.91	17.83	17.44	16.61	15.73	15.39	14.92	14.64
1981	14.08	14.08	14.06	14.01	13.87	13.84	13.78	13.77	13.64
1982	15.37	15.35	15.31	15.12	14.78	14.37	14.09	14.01	13.78
1983	16.20	16.15	16.13	16.12	15.97	15.63	15.25	14.97	14.91
1984	15.19	15.18	15.14	15.03	14.93	14.86	14.73	14.56	14.37
1985	15.21	15.19	15.17	15.08	14.93	14.62	14.51	14.29	14.13
1986	16.70	16.68	16.61	16.31	15.76	15.22	14.84	14.51	14.23
1987	15.37	15.35	15.30	15.12	14.92	14.81	14.57	14.35	14.18
1988	15.43	15.35	15.31	15.20	15.06	14.84	14.60	14.48	14.29
1989	14.71	14.68	14.65	14.63	14.50	14.18	13.98	13.87	13.78
Mean	16.30	16.27	16.20	15.99	15.67	15.29	14.99	14.67	14.45
Max	19.69	19.63	19.44	18.79	17.95	16.97	16.35	15.73	15.28
Min	14.08	14.08	14.06	14.01	13.87	13.84	13.78	13.77	13.64

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day
RM = river mile

Table 4. Simulated highest mean stages at RM 257 (Run V3B—13.5-ft weir, 30.0 mgd), ft NGVD. *Values represent consecutive-day intervals for a year. A reference year begins on June 1 of the preceding year and ends on May 31.*

Year	1	7	14	30	60	120	183	274	1 Year
1943	16.78	16.75	16.65	16.37	16.09	15.59	15.13	14.65	14.39
1944	16.80	16.73	16.66	16.44	16.14	15.94	15.45	14.89	14.57
1945	17.43	17.41	17.33	17.19	17.02	16.54	15.90	15.31	14.85
1946	16.58	16.55	16.54	16.32	15.91	15.71	15.40	14.88	14.50
1947	15.49	15.48	15.41	15.40	15.29	15.06	14.77	14.54	14.44
1948	18.39	18.34	18.26	17.93	17.34	16.51	16.32	15.69	15.24
1949	17.83	17.79	17.69	17.26	16.44	15.62	15.11	14.68	14.36
1950	16.94	16.91	16.84	16.63	16.54	16.10	15.51	14.94	14.56
1951	17.80	17.74	17.58	17.02	16.12	15.16	14.72	14.53	14.32
1952	15.68	15.66	15.61	15.45	15.23	15.11	14.90	14.63	14.46
1953	16.17	16.16	16.11	15.87	15.55	15.35	15.03	14.65	14.49
1954	18.56	18.51	18.39	18.11	17.93	16.95	16.18	15.45	15.01
1955	16.35	16.33	16.28	16.15	15.75	15.19	15.11	14.76	14.49
1956	15.66	15.62	15.56	15.46	15.20	14.63	14.40	14.16	13.92
1957	19.68	19.61	19.43	18.78	17.45	16.19	15.59	15.03	14.75
1958	16.11	16.07	15.96	15.68	15.45	15.43	15.17	15.04	15.00
1959	15.26	15.24	15.20	15.10	14.85	14.47	14.34	14.33	14.23
1960	17.24	17.19	17.08	16.70	16.25	15.63	15.56	15.12	15.12
1961	17.88	17.84	17.74	17.44	16.78	16.72	16.13	15.45	15.04
1962	15.50	15.44	15.33	15.20	14.86	14.66	14.43	14.03	13.82
1963	16.10	16.08	15.98	15.72	15.57	15.17	14.79	14.51	14.26
1964	15.79	15.76	15.73	15.62	15.37	15.13	15.06	14.85	14.61
1965	16.78	16.73	16.62	16.30	15.99	15.35	14.90	14.52	14.25
1966	15.70	15.67	15.57	15.31	14.91	14.65	14.56	14.53	14.28
1967	16.37	16.36	16.32	16.09	15.72	15.51	15.22	14.72	14.23
1968	14.61	14.59	14.57	14.53	14.47	14.38	14.05	13.82	13.52

Table 4—*Continued*

Year	1	7	14	30	60	120	183	274	1 Year
1969	16.77	16.75	16.67	16.47	16.25	15.70	15.55	14.98	14.88
1970	15.50	15.48	15.43	15.33	15.30	15.28	15.15	14.89	14.67
1971	15.16	15.12	15.06	14.99	14.84	14.44	14.24	13.97	13.84
1972	15.08	15.06	15.02	14.86	14.77	14.72	14.58	14.35	14.19
1973	16.52	16.49	16.41	16.13	15.55	15.17	14.78	14.68	14.52
1974	15.96	15.94	15.88	15.77	15.67	15.55	15.21	14.73	14.25
1975	17.14	17.10	17.07	16.88	16.39	15.77	15.15	14.68	14.31
1976	15.28	15.27	15.25	15.20	15.17	14.95	14.70	14.35	13.96
1977	16.45	16.40	16.23	15.89	15.46	15.24	14.92	14.55	14.14
1978	15.17	15.15	15.08	14.93	14.79	14.65	14.45	14.25	14.00
1979	16.52	16.48	16.42	16.18	15.64	15.08	14.70	14.61	14.46
1980	17.94	17.89	17.81	17.42	16.59	15.70	15.35	14.87	14.59
1981	14.03	14.02	14.01	13.96	13.81	13.77	13.68	13.68	13.45
1982	15.32	15.31	15.27	15.07	14.69	14.24	13.94	13.90	13.34
1983	16.18	16.13	16.10	16.09	15.95	15.60	15.21	14.93	14.87
1984	15.16	15.15	15.11	15.00	14.90	14.82	14.68	14.50	14.30
1985	15.18	15.16	15.14	15.05	14.89	14.57	14.46	14.22	14.06
1986	16.68	16.66	16.59	16.29	15.74	15.18	14.79	14.45	14.10
1987	15.35	15.33	15.27	15.09	14.87	14.76	14.50	14.28	14.06
1988	15.41	15.32	15.28	15.17	15.03	14.79	14.54	14.43	14.21
1989	14.64	14.60	14.58	14.56	14.43	14.10	13.89	13.76	13.63
Mean	16.27	16.24	16.17	15.97	15.64	15.25	14.94	14.61	14.35
Max	19.68	19.61	19.43	18.78	17.93	16.95	16.32	15.69	15.24
Min	14.03	14.02	14.01	13.96	13.81	13.77	13.68	13.68	13.34

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day
RM = river mile

- **Highest values exceeded continuously for different durations** (Tables 5–6). For a given duration, using the same reference period as above, the water levels are higher than the indicated value for all days.

- **Lowest mean values for different durations** (Tables 7–8). A reference year starting on October 1 and ending on September 30 is chosen to evaluate annual low stages because water levels start declining by about October, reach a minimum, and then recover during this period. This is also the U.S. Geological Survey water year. The values computed are the lowest average values for each duration.

- **Lowest values not exceeded continuously for different durations** (Tables 9–10). For a given duration, using the same reference period as in the previous paragraph, the water levels are lower than the indicated value for all days.

Tables 3–10 illustrate the data for a location on Lake Washington (RM 257, Figure 2) for two simulation runs (V3A and V3B, Table 1). Several statistics of hydrologic and environmental significance can be generated based on these tables (see next section). Similar tables for other runs and other locations are not furnished in this report.

Stage duration relationships (Figures 6–9) and annual ranges of stage fluctuations (Table 11) describe general inundation characteristics for a location. For example, over a long period (30 years or more), Lake Winder would be inundated to an elevation of 13.50 ft NGVD only for about 23 percent of the time with the current weir, but for about 90 percent of the time if the weir were moved to Site 1 (Figure 6). Daily stage data were used in developing Figures 6–9. Water level fluctuations are necessary on an annual basis for the preservation and enhancement of riverine ecology and quality of waterbodies. Table 11 shows that the annual water level fluctuations can range from 0.67 to 6.38 ft for Lake Washington for the conditions of the V3A simulation run. Similar tables are generated for several locations to obtain

Table 5. Simulated stages at RM 257 (Run V3A—13.5-ft weir, 14.5 mgd), ft NGVD. *Values represent the highest water levels exceeded continuously for the indicated number of days in year. A reference year begins on June 1 of the preceding year and ends on May 31.*

Year	1	7	14	30	60	120	183	274	1 Year
1943	16.80	16.72	16.46	15.96	15.69	14.77	13.88	13.51	13.49
1944	16.82	16.67	16.52	16.06	15.58	15.11	13.98	13.64	13.32
1945	17.45	17.40	17.20	16.97	16.68	15.44	14.20	13.72	13.26
1946	16.61	16.55	16.50	15.86	15.19	14.91	14.24	13.73	13.24
1947	15.52	15.48	15.34	15.29	15.03	14.51	14.09	13.69	13.69
1948	18.41	18.33	18.03	17.44	16.02	15.26	14.95	14.18	13.71
1949	17.85	17.74	17.50	16.34	15.12	14.45	13.99	13.78	13.06
1950	16.96	16.90	16.68	16.24	16.16	15.17	13.89	13.69	13.27
1951	17.82	17.68	17.26	16.01	14.70	14.09	13.78	13.67	13.53
1952	15.71	15.65	15.54	15.11	14.81	14.61	14.08	13.86	13.86
1953	16.19	16.17	16.03	15.32	15.04	14.89	13.97	13.84	13.79
1954	18.58	18.44	18.16	17.67	17.03	15.44	14.31	13.83	13.61
1955	16.38	16.33	16.21	15.86	14.99	14.38	14.38	13.85	13.59
1956	15.68	15.58	15.50	15.33	14.59	13.85	13.79	13.64	13.31
1957	19.69	19.53	19.02	17.33	15.56	14.47	14.21	13.77	13.44
1958	16.13	16.03	15.77	15.30	15.12	15.07	13.97	13.90	13.90
1959	15.28	15.26	15.15	14.94	14.37	14.16	13.85	13.85	13.80
1960	17.26	17.14	16.85	16.03	15.26	14.46	14.46	13.84	13.84
1961	17.91	17.77	17.57	16.80	15.87	15.27	14.52	13.81	13.49
1962	15.52	15.38	15.20	14.95	14.34	14.18	13.87	13.46	13.32
1963	16.13	16.05	15.81	15.33	15.30	14.39	13.85	13.72	13.38
1964	15.82	15.75	15.68	15.44	14.86	14.64	14.47	14.10	13.66
1965	16.80	16.70	16.38	15.90	15.35	14.14	13.87	13.71	13.15
1966	15.73	15.65	15.38	14.89	14.27	14.18	13.98	13.98	13.04
1967	16.40	16.36	16.22	15.60	15.18	14.91	14.02	13.61	12.85
1968	14.72	14.69	14.60	14.53	14.41	14.07	13.38	13.38	12.94

Table 5—*Continued*

Year	1	7	14	30	60	120	183	274	1 Year
1969	16.79	16.73	16.51	16.20	15.81	14.83	14.58	13.68	13.68
1970	15.53	15.46	15.42	15.18	15.09	15.06	14.51	14.07	13.60
1971	15.19	15.11	14.96	14.76	14.42	13.99	13.81	13.43	13.26
1972	15.11	15.08	14.93	14.74	14.57	14.37	14.11	13.83	13.51
1973	16.55	16.47	16.24	15.63	14.57	14.48	13.82	13.82	13.56
1974	15.99	15.92	15.79	15.57	15.42	15.07	14.07	13.68	12.89
1975	17.17	17.09	17.01	16.46	15.62	14.58	13.75	13.70	13.42
1976	15.30	15.29	15.24	15.16	15.09	14.50	13.97	13.50	12.85
1977	16.48	16.34	15.87	15.39	14.85	14.84	13.86	13.79	12.69
1978	15.21	15.13	14.96	14.71	14.55	14.16	13.97	13.79	12.91
1979	16.54	16.43	16.35	15.57	14.86	14.31	13.79	13.70	13.60
1980	17.96	17.83	17.65	16.56	15.19	14.49	14.29	13.79	13.48
1981	14.08	14.07	14.03	13.90	13.72	13.56	13.44	13.44	12.79
1982	15.37	15.33	15.21	14.74	14.18	13.55	13.49	13.49	12.75
1983	16.20	16.12	16.09	16.03	15.54	15.05	14.01	13.79	13.79
1984	15.19	15.16	15.03	14.91	14.70	14.39	14.20	13.88	13.38
1985	15.21	15.17	15.11	14.88	14.61	13.98	13.86	13.68	13.49
1986	16.70	16.65	16.44	15.75	14.98	14.43	13.91	13.67	12.94
1987	15.37	15.33	15.16	14.80	14.58	14.33	13.78	13.77	12.83
1988	15.43	15.24	15.19	15.04	14.80	14.23	13.96	13.83	13.36
1989	14.71	14.65	14.58	14.53	14.30	13.47	13.46	13.43	13.37
Mean	16.30	16.22	16.05	15.60	15.06	14.52	14.01	13.73	13.36
Max	19.69	19.53	19.02	17.67	17.03	15.44	14.95	14.18	13.90
Min	14.08	14.07	14.03	13.90	13.72	13.47	13.38	13.38	12.69

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day
RM = river mile

Table 6. Simulated stages at RM 257 (Run V3B—13.5-ft weir, 30.0 mgd), ft NGVD. *Values represent the highest water levels exceeded continuously for the indicated number of days in year. A reference year begins on June 1 of the preceding year and ends on May 31.*

Year	1	7	14	30	60	120	183	274	1 Year
1943	16.78	16.70	16.44	15.93	15.67	14.73	13.82	13.39	13.37
1944	16.80	16.65	16.49	16.03	15.55	15.09	13.91	13.57	13.04
1945	17.43	17.38	17.17	16.95	16.66	15.42	14.14	13.58	12.89
1946	16.58	16.52	16.48	15.83	15.17	14.89	14.16	13.64	12.77
1947	15.49	15.46	15.32	15.27	15.01	14.44	14.01	13.62	13.62
1948	18.39	18.31	18.00	17.42	15.99	15.23	14.92	14.11	13.64
1949	17.83	17.72	17.48	16.32	15.10	14.40	13.92	13.66	12.61
1950	16.94	16.88	16.66	16.22	16.14	15.14	13.81	13.60	12.69
1951	17.80	17.66	17.23	15.99	14.66	14.03	13.64	13.61	13.44
1952	15.68	15.63	15.52	15.08	14.78	14.56	14.02	13.80	13.79
1953	16.17	16.14	16.01	15.30	15.02	14.86	13.91	13.78	13.65
1954	18.56	18.43	18.14	17.65	17.01	15.41	14.24	13.75	13.54
1955	16.35	16.31	16.18	15.83	14.97	14.32	14.32	13.79	13.52
1956	15.66	15.56	15.47	15.30	14.53	13.79	13.65	13.57	12.87
1957	19.68	19.51	19.01	17.31	15.54	14.41	14.15	13.63	12.81
1958	16.11	16.01	15.75	15.27	15.09	15.05	13.91	13.83	13.83
1959	15.26	15.23	15.13	14.92	14.31	14.09	13.78	13.78	13.68
1960	17.24	17.12	16.83	16.01	15.23	14.41	14.41	13.78	13.78
1961	17.88	17.75	17.55	16.77	15.85	15.24	14.46	13.69	13.40
1962	15.50	15.35	15.17	14.90	14.29	14.12	13.81	12.85	12.52
1963	16.10	16.03	15.79	15.30	15.28	14.34	13.79	13.63	13.00
1964	15.79	15.72	15.65	15.41	14.83	14.58	14.41	14.04	13.58
1965	16.78	16.67	16.36	15.88	15.32	14.07	13.80	13.64	12.59
1966	15.70	15.62	15.35	14.87	14.21	14.11	13.91	13.91	12.38
1967	16.37	16.33	16.20	15.58	15.15	14.88	13.96	13.54	11.76
1968	14.61	14.58	14.53	14.45	14.30	13.93	13.00	12.99	11.71

Table 6—*Continued*

Year	1	7	14	30	60	120	183	274	1 Year
1969	16.77	16.71	16.48	16.17	15.79	14.80	14.53	13.61	13.34
1970	15.50	15.43	15.40	15.15	15.06	15.04	14.45	14.01	13.53
1971	15.16	15.07	14.93	14.72	14.35	13.92	13.70	12.80	12.80
1972	15.08	15.03	14.90	14.70	14.50	14.31	14.04	13.74	13.27
1973	16.52	16.45	16.22	15.61	14.51	14.42	13.72	13.72	13.48
1974	15.96	15.90	15.76	15.54	15.40	15.05	14.01	13.61	12.09
1975	17.14	17.06	16.99	16.44	15.60	14.52	13.63	13.60	12.44
1976	15.28	15.27	15.21	15.13	15.05	14.43	13.90	13.38	11.94
1977	16.45	16.31	15.84	15.37	14.81	14.81	13.79	13.66	11.83
1978	15.17	15.10	14.94	14.66	14.48	14.09	13.90	13.60	12.02
1979	16.52	16.40	16.33	15.55	14.83	14.24	13.65	13.62	13.54
1980	17.94	17.81	17.63	16.54	15.16	14.43	14.23	13.66	13.40
1981	14.03	14.02	13.97	13.85	13.60	13.49	13.14	13.14	11.93
1982	15.32	15.30	15.16	14.70	14.04	13.38	13.25	13.25	10.98
1983	16.18	16.09	16.06	16.00	15.51	15.03	13.94	13.67	13.67
1984	15.16	15.13	15.01	14.86	14.64	14.33	14.13	13.81	13.15
1985	15.18	15.14	15.07	14.83	14.57	13.91	13.79	13.61	13.41
1986	16.68	16.63	16.41	15.72	14.95	14.36	13.85	13.59	12.16
1987	15.35	15.30	15.13	14.75	14.50	14.27	13.64	13.64	11.91
1988	15.41	15.22	15.17	15.02	14.76	14.15	13.89	13.75	13.10
1989	14.64	14.58	14.52	14.46	14.24	13.28	13.26	13.04	12.98
Mean	16.27	16.20	16.02	15.57	15.02	14.46	13.92	13.60	12.92
Max	19.68	19.51	19.01	17.65	17.01	15.42	14.92	14.11	13.83
Min	14.03	14.02	13.97	13.85	13.60	13.28	13.00	12.80	10.98

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day
RM = river mile

Table 7. Simulated lowest mean stages at RM 257 (Run V3A—13.5-ft weir, 14.5 mgd), ft NGVD. *Values represent consecutive-day intervals for a year. A reference year begins on October 1 of the preceding year and ends on September 30.*

Year	1	7	14	30	60	120	183	274	1 Year
1943	13.49	13.52	13.53	13.56	13.61	13.65	13.70	13.82	14.29
1944	13.26	13.28	13.31	13.40	13.63	13.74	13.81	14.19	14.85
1945	13.24	13.25	13.26	13.33	13.48	13.59	13.85	14.32	14.72
1946	13.36	13.39	13.41	13.47	13.64	13.75	13.85	14.13	14.46
1947	13.69	13.70	13.71	13.73	13.78	14.05	14.18	14.44	14.83
1948	13.71	13.73	13.75	13.77	13.87	13.95	14.07	14.26	14.85
1949	13.06	13.09	13.13	13.22	13.35	13.54	13.67	14.12	14.72
1950	13.37	13.39	13.41	13.48	13.54	13.66	13.73	13.79	14.16
1951	13.67	13.70	13.70	13.75	13.88	13.97	14.11	14.28	14.62
1952	13.84	13.86	13.86	13.87	13.89	14.11	14.06	14.32	14.56
1953	13.79	13.80	13.81	13.86	13.95	14.00	14.02	14.18	14.72
1954	13.61	13.62	13.65	13.72	13.75	13.84	14.20	14.53	15.06
1955	13.59	13.62	13.65	13.69	13.72	13.76	13.83	13.91	14.18
1956	13.31	13.35	13.39	13.40	13.46	13.54	13.63	13.85	14.15
1957	13.77	13.79	13.80	13.84	13.90	14.02	14.23	14.62	15.17
1958	13.80	13.81	13.82	13.85	13.91	14.08	14.31	14.57	14.59
1959	13.85	13.88	13.92	13.99	14.02	14.11	14.28	14.48	14.67
1960	13.84	13.85	13.89	13.97	14.13	14.47	14.73	15.08	15.44
1961	13.49	13.54	13.64	13.78	13.90	13.91	13.98	14.13	14.60
1962	13.32	13.36	13.39	13.44	13.48	13.53	13.56	13.70	14.07
1963	13.38	13.41	13.44	13.48	13.64	13.86	13.87	14.04	14.25
1964	13.66	13.69	13.74	13.82	13.95	14.05	14.28	14.50	14.80
1965	13.04	13.06	13.11	13.22	13.36	13.59	13.66	13.81	14.12
1966	13.68	13.71	13.76	13.83	14.05	14.40	14.37	14.55	14.80
1967	12.83	12.88	12.90	12.93	13.05	13.28	13.45	13.72	13.99
1968	13.07	13.12	13.17	13.28	13.39	13.48	13.50	13.83	14.31

Table 7—*Continued*

Year	1	7	14	30	60	120	183	274	1 Year
1969	13.68	13.68	13.70	13.75	13.79	14.10	14.28	14.36	14.56
1970	13.60	13.61	13.64	13.76	13.83	13.90	14.00	14.34	14.58
1971	13.26	13.30	13.35	13.42	13.49	13.68	13.65	13.83	14.07
1972	13.66	13.71	13.72	13.75	13.78	13.87	13.96	14.25	14.50
1973	13.56	13.61	13.67	13.78	14.05	14.10	14.25	14.27	14.59
1974	12.89	12.93	12.96	13.04	13.16	13.38	13.53	13.95	14.48
1975	13.42	13.44	13.44	13.48	13.53	13.66	13.72	13.97	14.26
1976	12.85	12.90	12.94	13.03	13.19	13.40	13.54	13.91	14.26
1977	12.69	12.72	12.76	12.84	13.01	13.31	13.48	13.62	13.84
1978	13.65	13.66	13.67	13.74	13.81	13.92	14.03	14.23	14.52
1979	13.60	13.61	13.62	13.68	13.82	14.22	14.17	14.33	14.63
1980	13.48	13.53	13.59	13.64	13.73	13.76	13.78	13.84	14.13
1981	12.75	12.77	12.79	12.81	12.89	12.97	13.17	13.36	13.55
1982	13.49	13.50	13.51	13.53	13.55	13.62	13.73	14.04	14.44
1983	13.79	13.80	13.81	13.84	13.91	14.16	14.57	14.49	14.60
1984	13.38	13.42	13.46	13.58	13.75	13.82	13.91	14.15	14.33
1985	13.36	13.40	13.44	13.53	13.61	13.64	13.71	13.89	14.13
1986	12.83	12.85	12.88	12.96	13.08	13.37	13.55	13.85	14.21
1987	13.36	13.38	13.41	13.51	13.65	13.77	13.81	13.88	14.05
1988	13.39	13.41	13.44	13.54	13.55	13.85	13.97	14.10	14.30
1989	13.37	13.39	13.40	13.46	13.49	13.55	13.58	13.60	13.74
Mean	13.42	13.45	13.48	13.54	13.64	13.79	13.90	14.12	14.44
Max	13.85	13.88	13.92	13.99	14.13	14.47	14.73	15.08	15.44
Min	12.69	12.72	12.76	12.81	12.89	12.97	13.17	13.36	13.55

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day
RM = river mile

Table 8. Simulated lowest mean stages at RM 257 (Run V3B—13.5-ft weir, 30.0 mgd), ft NGVD. *Values represent consecutive-day intervals for a year. A reference year begins on October 1 of the preceding year and ends on September 30.*

Year	1	7	14	30	60	120	183	274	1 Year
1943	13.37	13.41	13.42	13.45	13.52	13.56	13.61	13.74	14.23
1944	12.89	12.92	12.99	13.16	13.46	13.63	13.71	14.10	14.78
1945	12.77	12.79	12.82	12.97	13.25	13.43	13.72	14.21	14.64
1946	13.05	13.11	13.13	13.25	13.47	13.63	13.74	14.05	14.39
1947	13.62	13.63	13.64	13.64	13.70	13.98	14.11	14.38	14.78
1948	13.64	13.64	13.65	13.67	13.79	13.87	13.99	14.19	14.79
1949	12.61	12.64	12.68	12.73	13.00	13.32	13.49	13.99	14.62
1950	13.09	13.15	13.19	13.28	13.39	13.54	13.62	13.70	14.08
1951	13.61	13.63	13.63	13.65	13.80	13.90	14.04	14.22	14.56
1952	13.78	13.79	13.79	13.80	13.82	14.04	13.99	14.26	14.51
1953	13.65	13.68	13.70	13.78	13.88	13.93	13.95	14.12	14.67
1954	13.54	13.55	13.58	13.63	13.66	13.76	14.13	14.47	15.01
1955	13.52	13.54	13.56	13.61	13.64	13.68	13.76	13.84	14.12
1956	12.81	12.83	12.86	12.94	12.97	13.19	13.36	13.65	14.00
1957	13.63	13.66	13.70	13.76	13.83	13.95	14.17	14.57	15.13
1958	13.68	13.71	13.73	13.77	13.84	14.01	14.25	14.52	14.54
1959	13.78	13.81	13.85	13.92	13.95	14.04	14.22	14.42	14.61
1960	13.78	13.79	13.82	13.90	14.06	14.42	14.68	15.04	15.40
1961	13.40	13.46	13.53	13.70	13.82	13.84	13.91	14.07	14.55
1962	12.52	12.54	12.57	12.68	12.81	13.04	13.20	13.44	13.87
1963	13.00	13.07	13.15	13.26	13.47	13.74	13.76	13.95	14.17
1964	13.58	13.59	13.63	13.74	13.88	13.98	14.22	14.45	14.75
1965	12.38	12.42	12.50	12.67	12.96	13.33	13.46	13.66	13.99
1966	13.59	13.60	13.65	13.75	13.98	14.34	14.31	14.49	14.75
1967	11.71	11.76	11.77	11.83	12.06	12.59	12.96	13.36	13.70
1968	12.49	12.58	12.65	12.76	12.90	13.11	13.19	13.58	14.12

Table 8—*Continued*

Year	1	7	14	30	60	120	183	274	1 Year
1969	13.61	13.61	13.62	13.66	13.71	14.03	14.22	14.30	14.51
1970	13.53	13.53	13.55	13.68	13.77	13.83	13.93	14.29	14.53
1971	12.80	12.85	12.90	13.01	13.17	13.49	13.42	13.65	13.93
1972	13.58	13.61	13.63	13.66	13.70	13.80	13.88	14.18	14.45
1973	13.48	13.51	13.57	13.69	13.98	14.03	14.19	14.20	14.53
1974	12.09	12.16	12.21	12.29	12.42	12.87	13.15	13.68	14.28
1975	13.12	13.15	13.17	13.18	13.27	13.49	13.58	13.86	14.17
1976	11.94	12.02	12.06	12.20	12.47	12.96	13.22	13.67	14.07
1977	11.83	11.89	11.95	12.08	12.30	12.73	13.07	13.32	13.61
1978	13.58	13.58	13.59	13.65	13.74	13.85	13.96	14.16	14.46
1979	13.54	13.54	13.55	13.59	13.75	14.16	14.11	14.27	14.57
1980	13.40	13.45	13.50	13.55	13.63	13.69	13.71	13.77	14.07
1981	10.98	11.02	11.05	11.12	11.29	11.70	12.21	12.70	13.01
1982	13.25	13.28	13.30	13.32	13.37	13.48	13.61	13.95	14.37
1983	13.67	13.69	13.71	13.76	13.83	14.09	14.51	14.43	14.55
1984	13.15	13.22	13.30	13.45	13.65	13.73	13.83	14.07	14.26
1985	13.15	13.21	13.29	13.41	13.50	13.55	13.62	13.81	14.06
1986	11.91	11.94	11.99	12.14	12.41	12.95	13.25	13.62	14.03
1987	13.10	13.12	13.19	13.32	13.51	13.66	13.71	13.80	13.96
1988	13.07	13.13	13.21	13.34	13.38	13.73	13.87	14.01	14.23
1989	12.89	12.93	12.99	13.05	13.11	13.23	13.32	13.39	13.56
Mean	13.09	13.12	13.16	13.24	13.38	13.59	13.74	13.99	14.34
Max	13.78	13.81	13.85	13.92	14.06	14.42	14.68	15.04	15.40
Min	10.98	11.02	11.05	11.12	11.29	11.70	12.21	12.70	13.01

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day
RM = river mile

Table 9. Simulated stages at RM 257 (Run V3A—13.5-ft weir, 14.5 mgd), ft NGVD. *Values represent the lowest water levels not exceeded continuously for the indicated number of days in year. A reference year begins on October 1 of the preceding year and ends on September 30.*

Year	1	7	14	30	60	120	183	274	1 Year
1943	13.49	13.55	13.56	13.60	13.77	13.83	13.87	14.66	16.65
1944	13.26	13.29	13.40	13.57	13.88	14.16	14.19	15.93	17.45
1945	13.24	13.26	13.29	13.45	13.78	13.95	14.74	16.10	16.64
1946	13.36	13.42	13.45	13.61	13.91	14.00	14.18	15.18	16.55
1947	13.69	13.72	13.74	13.78	13.97	14.57	14.92	16.82	17.43
1948	13.71	13.75	13.78	13.82	14.08	14.09	14.58	15.09	18.41
1949	13.06	13.12	13.22	13.34	13.68	13.82	14.20	15.88	17.85
1950	13.37	13.42	13.46	13.62	13.72	13.86	14.02	14.10	16.96
1951	13.67	13.73	13.74	13.86	14.08	14.52	14.85	15.02	17.82
1952	13.84	13.86	13.87	13.91	13.95	14.82	14.82	15.36	15.71
1953	13.79	13.80	13.83	13.95	14.11	14.40	14.46	15.15	18.58
1954	13.61	13.63	13.77	13.85	13.86	14.19	15.75	16.38	18.22
1955	13.59	13.64	13.72	13.78	13.85	13.90	14.12	14.47	15.55
1956	13.31	13.39	13.45	13.50	13.58	13.74	13.84	14.79	15.68
1957	13.77	13.81	13.82	13.92	14.01	14.27	15.20	16.13	19.69
1958	13.80	13.82	13.83	13.95	14.04	14.41	15.06	15.91	15.91
1959	13.85	13.91	13.99	14.08	14.11	14.58	15.18	15.97	16.30
1960	13.84	13.87	13.96	14.12	14.46	15.84	16.57	17.26	17.35
1961	13.49	13.61	13.82	13.88	14.09	14.14	14.38	14.97	17.91
1962	13.32	13.40	13.42	13.54	13.57	13.77	13.77	14.42	16.13
1963	13.38	13.44	13.49	13.57	13.88	14.37	14.38	14.88	16.01
1964	13.66	13.72	13.83	13.94	14.22	14.43	15.28	15.38	16.80
1965	13.04	13.09	13.20	13.42	13.73	13.89	13.89	14.80	16.71
1966	13.68	13.77	13.83	13.96	14.32	15.30	15.73	15.74	16.40
1967	12.83	12.92	12.94	13.01	13.34	13.79	13.83	14.72	15.37
1968	13.07	13.17	13.28	13.45	13.58	13.77	13.77	16.15	16.79

Table 9—*Continued*

Year	1	7	14	30	60	120	183	274	1 Year
1969	13.68	13.69	13.76	13.80	13.93	14.84	15.38	15.50	15.98
1970	13.60	13.61	13.75	13.92	13.97	14.07	14.34	15.43	15.53
1971	13.26	13.34	13.43	13.52	13.62	14.20	14.32	14.77	15.19
1972	13.66	13.75	13.77	13.82	13.88	14.13	14.41	16.22	16.55
1973	13.56	13.67	13.76	13.98	14.45	14.64	14.79	14.97	15.99
1974	12.89	12.97	13.02	13.18	13.39	13.76	14.00	15.59	17.17
1975	13.42	13.45	13.46	13.62	13.63	13.87	13.89	15.28	15.44
1976	12.85	12.94	13.02	13.20	13.47	13.73	14.09	15.27	16.48
1977	12.69	12.75	12.84	12.97	13.35	13.78	13.88	13.95	15.39
1978	13.65	13.67	13.72	13.90	13.95	14.14	14.59	14.82	16.54
1979	13.60	13.61	13.65	13.81	14.14	15.02	15.05	15.28	17.96
1980	13.48	13.58	13.68	13.78	13.82	13.89	14.00	14.11	17.56
1981	12.75	12.80	12.82	12.87	13.06	13.34	13.86	13.98	15.37
1982	13.49	13.51	13.54	13.58	13.63	13.87	14.08	16.03	16.20
1983	13.79	13.82	13.83	13.92	14.06	14.95	15.30	15.79	15.79
1984	13.38	13.46	13.56	13.84	14.05	14.08	14.43	15.11	15.21
1985	13.36	13.43	13.53	13.71	13.73	13.88	14.05	14.75	16.61
1986	12.83	12.89	12.93	13.10	13.36	13.81	14.02	14.99	16.70
1987	13.36	13.40	13.47	13.74	13.95	14.07	14.07	14.34	15.11
1988	13.39	13.43	13.48	13.69	13.77	14.42	15.02	15.04	15.43
1989	13.37	13.42	13.45	13.53	13.73	13.83	13.92	13.92	14.43
Mean	13.42	13.47	13.54	13.66	13.84	14.19	14.49	15.24	16.54
Max	13.85	13.91	13.99	14.12	14.46	15.84	16.57	17.26	19.69
Min	12.69	12.75	12.82	12.87	13.06	13.34	13.77	13.92	14.43

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day
RM = river mile

Table 10. Simulated stages at RM 257 (Run V3B—13.5-ft weir, 30.0 mgd), ft NGVD. *Values represent the lowest water levels not exceeded continuously for the indicated number of days in year. A reference year begins on October 1 of the preceding year and ends on September 30.*

Year	1	7	14	30	60	120	183	274	1 Year
1943	13.37	13.43	13.46	13.51	13.71	13.80	13.82	14.62	16.63
1944	12.89	12.98	13.12	13.46	13.83	14.09	14.13	15.90	17.43
1945	12.77	12.81	12.90	13.28	13.71	13.88	14.65	16.07	16.62
1946	13.05	13.15	13.19	13.51	13.82	13.94	14.11	15.15	16.53
1947	13.62	13.64	13.65	13.67	13.91	14.50	14.88	16.80	17.41
1948	13.64	13.65	13.69	13.77	14.03	14.04	14.51	15.07	18.39
1949	12.61	12.68	12.75	12.89	13.57	13.77	14.11	15.85	17.83
1950	13.09	13.18	13.29	13.47	13.57	13.82	13.97	14.04	16.94
1951	13.61	13.65	13.67	13.79	14.02	14.47	14.80	14.99	17.80
1952	13.78	13.79	13.80	13.84	13.89	14.75	14.75	15.33	15.68
1953	13.65	13.70	13.75	13.88	14.04	14.34	14.40	15.13	18.56
1954	13.54	13.56	13.67	13.80	13.82	14.14	15.73	16.35	18.20
1955	13.52	13.56	13.61	13.71	13.80	13.84	14.06	14.41	15.52
1956	12.81	12.86	12.93	13.04	13.10	13.63	13.78	14.72	15.66
1957	13.63	13.68	13.77	13.86	13.95	14.20	15.18	16.11	19.68
1958	13.68	13.75	13.77	13.88	13.97	14.34	15.04	15.89	15.89
1959	13.78	13.84	13.92	14.01	14.04	14.51	15.15	15.95	16.27
1960	13.78	13.81	13.90	14.05	14.39	15.81	16.54	17.24	17.33
1961	13.40	13.51	13.71	13.82	14.03	14.08	14.31	14.92	17.88
1962	12.52	12.58	12.66	12.88	13.04	13.51	13.60	14.37	16.10
1963	13.00	13.15	13.26	13.45	13.80	14.29	14.29	14.82	15.99
1964	13.58	13.61	13.74	13.88	14.17	14.37	15.25	15.36	16.78
1965	12.38	12.48	12.65	12.99	13.46	13.83	13.83	14.75	16.69
1966	13.59	13.62	13.77	13.91	14.25	15.27	15.70	15.72	16.37
1967	11.71	11.79	11.80	12.00	12.58	13.60	13.79	14.51	15.35
1968	12.49	12.66	12.79	12.90	13.19	13.59	13.59	16.13	16.77

Table 10—*Continued*

Year	1	7	14	30	60	120	183	274	1 Year
1969	13.61	13.61	13.63	13.77	13.86	14.78	15.36	15.47	15.95
1970	13.53	13.54	13.59	13.85	13.92	14.00	14.29	15.41	15.50
1971	12.80	12.91	13.00	13.20	13.49	14.12	14.22	14.70	15.16
1972	13.58	13.63	13.71	13.78	13.83	14.06	14.35	16.19	16.52
1973	13.48	13.53	13.67	13.91	14.38	14.58	14.74	14.92	15.96
1974	12.09	12.23	12.28	12.44	12.76	13.69	13.92	15.56	17.14
1975	13.12	13.17	13.22	13.22	13.53	13.81	13.84	15.25	15.41
1976	11.94	12.06	12.17	12.47	13.05	13.66	13.96	15.24	16.45
1977	11.83	11.94	12.04	12.32	12.67	13.65	13.82	13.88	15.37
1978	13.58	13.59	13.62	13.83	13.91	14.07	14.52	14.75	16.52
1979	13.54	13.54	13.56	13.70	14.08	14.99	15.03	15.25	17.94
1980	13.40	13.51	13.57	13.66	13.78	13.84	13.94	14.05	17.54
1981	10.98	11.04	11.10	11.27	11.73	12.63	13.64	13.94	15.32
1982	13.25	13.30	13.33	13.40	13.44	13.82	14.01	16.01	16.18
1983	13.67	13.73	13.77	13.85	14.00	14.93	15.28	15.76	15.76
1984	13.15	13.30	13.45	13.77	13.97	14.04	14.36	15.08	15.18
1985	13.15	13.28	13.43	13.62	13.65	13.85	13.99	14.68	16.59
1986	11.91	11.96	12.10	12.43	12.99	13.76	13.95	14.94	16.68
1987	13.10	13.16	13.32	13.52	13.88	14.00	14.00	14.27	15.08
1988	13.07	13.20	13.34	13.55	13.61	14.37	14.99	15.01	15.41
1989	12.89	12.98	13.07	13.15	13.32	13.74	13.79	13.85	14.36
Mean	13.09	13.16	13.24	13.40	13.65	14.10	14.42	15.20	16.52
Max	13.78	13.84	13.92	14.05	14.39	15.81	16.54	17.24	19.68
Min	10.98	11.04	11.10	11.27	11.73	12.63	13.59	13.85	14.36

Note: ft NGVD = feet; National Geodetic Vertical Datum
mgd = million gallons per day
RM = river mile

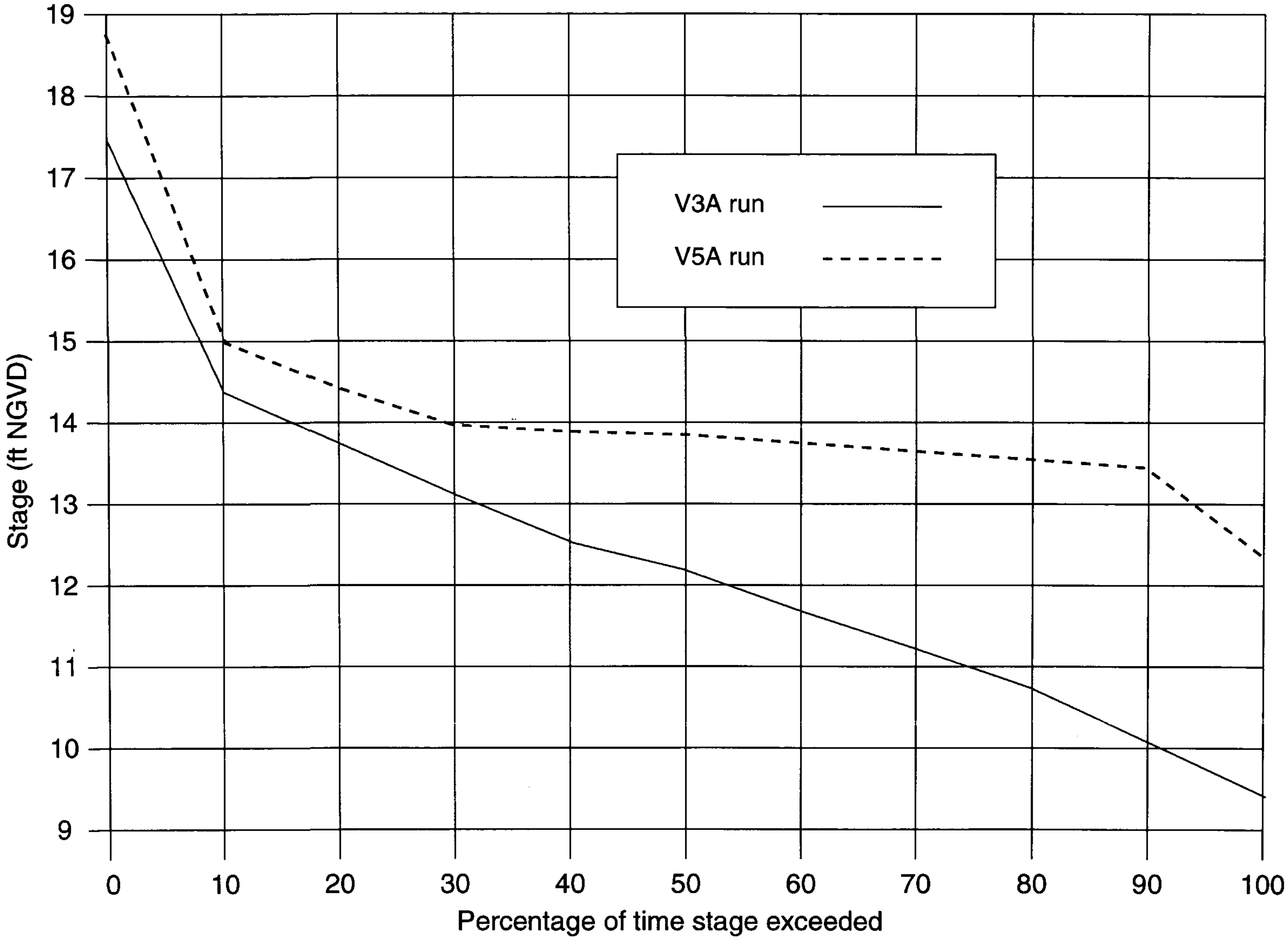

Figure 6. Stage-duration curves for Lake Winder (river mile 243.6). *Weir crest elevation = 13.50 feet, National Geodetic Vertical Datum (ft NGVD).*

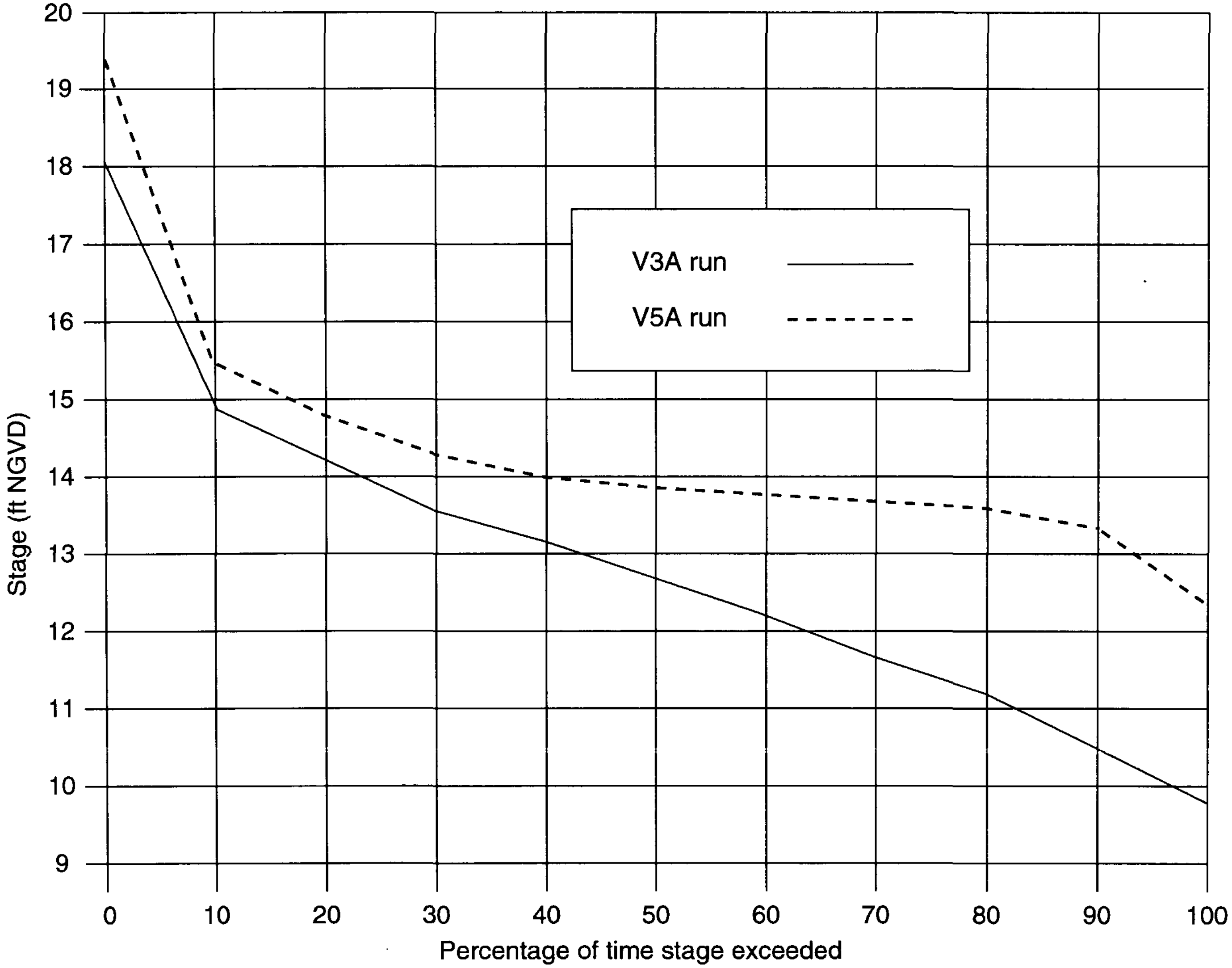

Figure 7. Stage-duration curves for river mile 251.2. *Weir crest elevation = 13.50 feet, National Geodetic Vertical Datum (ft NGVD).*

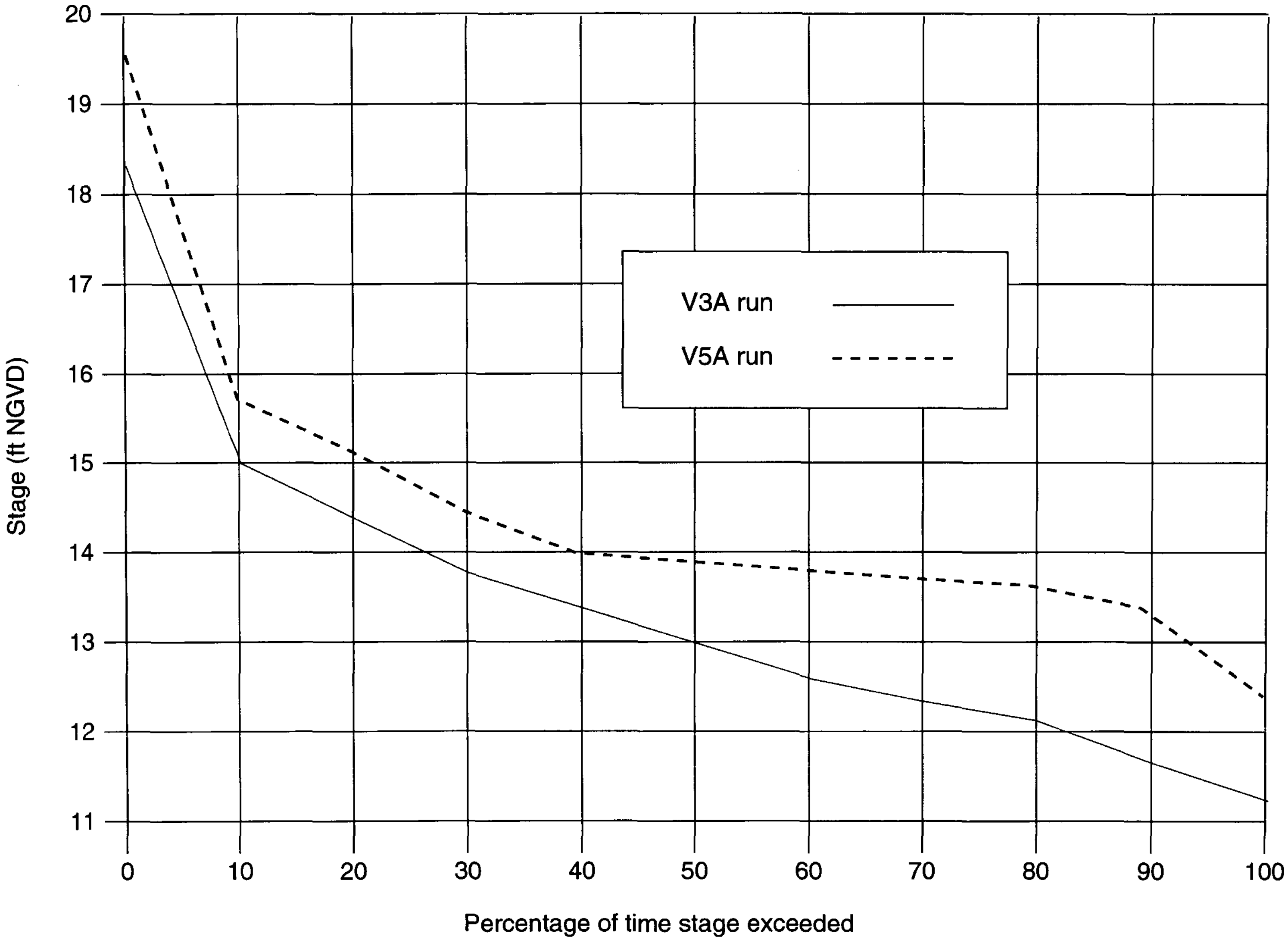

Figure 8. Stage-duration curves for river mile 253. *Weir crest elevation = 13.50 feet, National Geodetic Vertical Datum (ft NGVD).*

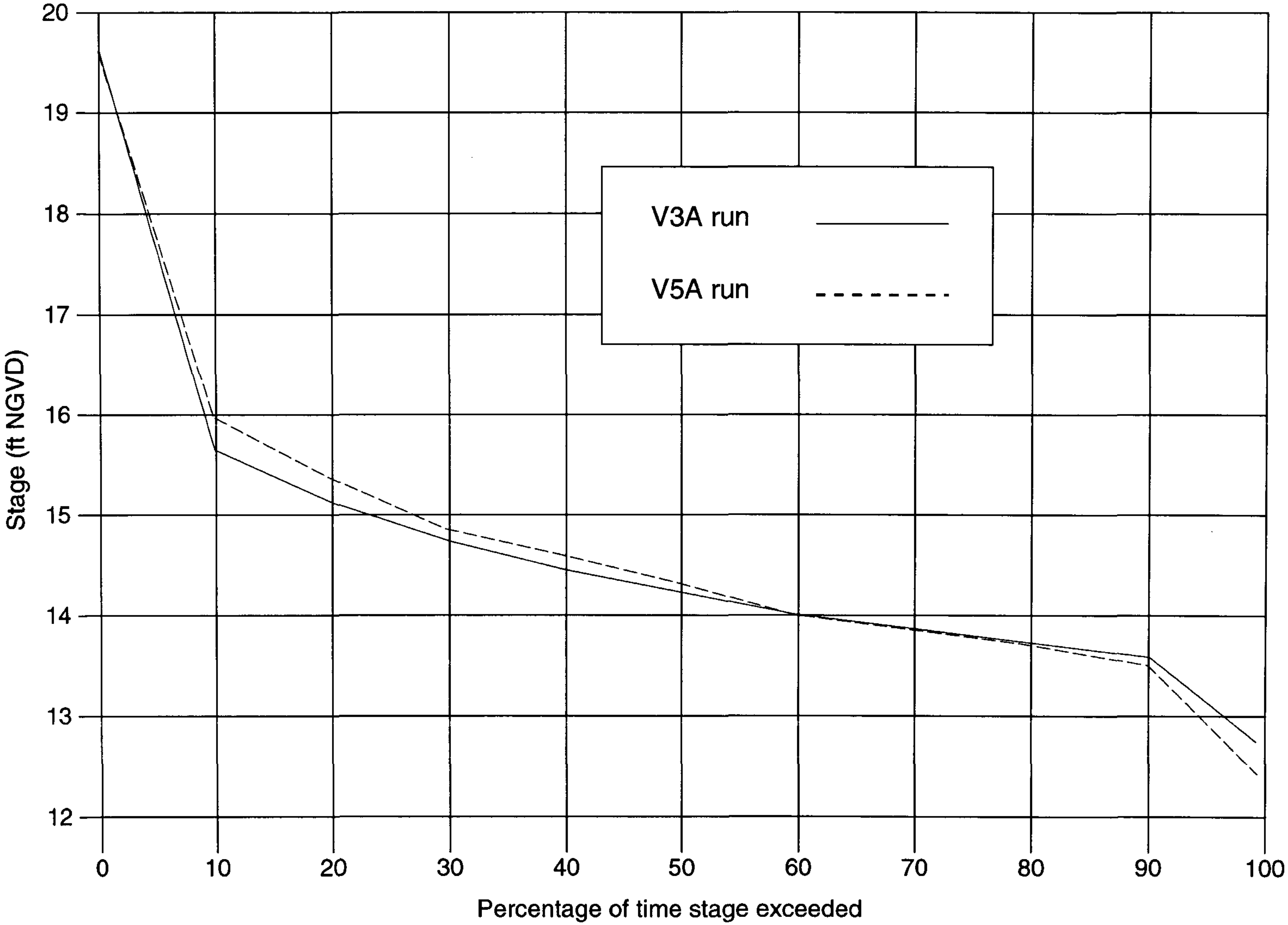

Figure 9. Stage-duration curves for Lake Washington (river mile 257). *Weir crest elevation = 13.50 feet, National Geodetic Vertical Datum (ft NGVD).*

Table 11. Simulated yearly stage data at RM 257 (V3A—13.5-ft weir, 14.5 mgd)

Year	Maximum 1-Day Value (ft NGVD)	Minimum 1-Day Value (ft NGVD)	Annual Water Level Range (ft)	Mean Water Level (ft NGVD)
1942	16.80	13.56	3.24	14.65
1943	16.82	13.49	3.33	14.59
1944	17.45	13.26	4.19	14.87
1945	16.61	13.24	3.37	14.65
1946	15.52	13.36	2.16	14.32
1947	18.41	13.69	4.72	15.31
1948	17.85	13.71	4.14	14.64
1949	16.96	13.06	3.90	14.61
1950	17.82	13.37	4.45	14.24
1951	15.71	13.67	2.04	14.52
1952	16.19	13.84	2.35	14.57
1953	18.58	13.79	4.79	15.09
1954	16.38	13.61	2.77	14.61
1955	15.68	13.59	2.09	14.14
1956	19.69	13.31	6.38	14.62
1957	16.13	13.77	2.36	14.65
1958	15.91	13.80	2.11	14.55
1959	17.26	13.98	3.28	15.02
1960	17.91	13.84	4.07	15.42
1961	15.52	13.48	2.04	14.20
1962	16.13	13.32	2.81	14.21
1963	15.82	13.38	2.44	14.41
1964	16.80	13.66	3.14	14.67
1965	15.30	13.04	2.26	14.08
1966	16.40	13.68	2.72	14.78
1967	14.72	12.83	1.89	13.82
1968	16.79	13.07	3.72	14.59

Table 11—*Continued*

Year	Maximum 1-Day Value (ft NGVD)	Minimum 1-Day Value (ft NGVD)	Annual Water Level Range (ft)	Mean Water Level (ft NGVD)
1969	15.53	13.68	1.85	14.64
1970	15.43	13.48	1.95	14.31
1971	15.11	13.26	1.85	14.17
1972	16.55	13.66	2.89	14.42
1973	15.99	13.56	2.43	14.73
1974	17.17	12.89	4.28	14.36
1975	15.30	13.42	1.88	14.23
1976	16.48	12.85	3.63	14.26
1977	15.21	12.69	2.52	13.95
1978	16.54	13.65	2.89	14.36
1979	17.96	13.60	4.36	14.86
1980	14.11	13.44	0.67	13.81
1981	15.37	12.75	2.62	13.65
1982	16.20	13.52	2.68	14.52
1983	15.79	13.79	2.00	14.67
1984	15.21	13.38	1.83	14.24
1985	16.70	13.36	3.34	14.27
1986	15.37	12.83	2.54	14.06
1987	15.43	13.36	2.07	14.21
1988	15.04	13.39	1.65	13.99
1989	15.55	13.37	2.18	13.99
Mean Annual Stage		14.45		
Mean Annual Range		2.89		

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day
RM = river mile

the necessary results, but the tables are not presented in this report.

WATER SUPPLY POTENTIAL

Drought stages determine the water supply potential of an impoundment, for example, the reservoirs formed behind the weirs proposed in this study. As water is drawn for consumptive use during low-flow periods, the stages will decline. With declining stages, water quality of Lake Washington deteriorates, giving rise to increased chloride concentration and total dissolved solids. Rao and Tai (1987) determined the critical drought elevation for Lake Washington as about 11.50 ft NGVD, below which chlorides exceed the Class I potable water supply standard of 250 milligrams per liter (mg/L) (Chapter 17-302, *Florida Administrative Code*). If water is withdrawn when chlorides exceed 250 mg/L, the water treatment costs can be higher.

A low-stage frequency analysis performed on annual low mean stages (e.g., Tables 7–8) would provide drought stages for different return periods (T) (Tables 12–13). Durations of up to 60 days are significant in water supply analyses. The results of frequency analysis show that for a consumptive use withdrawal rate of 14.5 mgd, the estimated drought stages are well above the critical stage of 11.50 ft NGVD for the impoundments formed by the weirs at both existing and alternative sites (Table 12). (The critical drought elevation for the alternative site can be less than 11.50 ft NGVD because of larger impounded volume [Figure 5] and the consequent greater dilution of chlorides.) For a withdrawal rate of 30.0 mgd, however, water levels can drop below 11.50 ft NGVD for the existing site for T > 25 years (if the weir crest is at 13.50 ft NGVD) or T > 50 years (if the weir crest is at 14.00 ft NGVD) (Table 13). In the case of the alternative weir (at Site 1), it appears that, because of the large volume of water impounded at lower elevations (Figure 5), a withdrawal rate of 30.0 mgd does not unduly lower the drought stages relative to a 14.5-mgd withdrawal rate. For T = 100 years, the 1-day drought stage is about 12.40 ft NGVD for both impoundments (if the weir

Table 12. Estimated mean low stages for droughts of different return periods (Upper St. Johns River Basin Project, consumptive use withdrawal rate at 14.5 mgd)

Duration (days)	Mean Annual Low (ft NGVD)	Return Period (years)					
		5	10	25	50	100	200
Existing Site, Weir Crest Elevation = 13.50 ft NGVD (V3A)							
1	13.39	13.13	12.93	12.71	12.55	12.40	12.25
7	13.42	13.16	12.97	12.74	12.59	12.44	12.30
14	13.45	13.19	13.00	12.78	12.63	12.48	12.34
30	13.52	13.27	13.08	12.86	12.70	12.55	12.41
60	13.63	13.37	13.20	12.99	12.85	12.71	12.58
Alternative Site, Weir Crest Elevation = 13.50 ft NGVD (V5A)							
1	13.31	13.11	12.94	12.72	12.56	12.41	12.26
7	13.33	13.14	12.97	12.75	12.59	12.44	12.29
14	13.35	13.17	13.00	12.78	12.62	12.47	12.31
30	13.38	13.22	13.05	12.83	12.67	12.51	12.36
60	13.43	13.30	13.14	12.93	12.78	12.62	12.47
Existing Site, Weir Crest Elevation = 14.00 ft NGVD (V4A)							
1	13.87	13.61	13.33	12.98	12.72	12.47	12.23
7	13.90	13.65	13.38	13.04	12.79	12.54	12.29
14	13.93	13.70	13.44	13.10	12.85	12.60	12.36
30	13.99	13.79	13.54	13.21	12.96	12.71	12.46
60	14.07	13.90	13.68	13.38	13.15	12.92	12.70
Alternative Site, Weir Crest Elevation = 14.00 ft NGVD (V6A)							
1	13.73	13.50	13.32	134.09	12.93	12.78	12.63
7	13.75	13.53	13.35	13.13	12.97	12.81	12.66
14	13.77	13.57	13.38	13.16	13.00	12.84	12.68
30	13.82	13.63	13.45	13.22	13.06	12.90	12.74
60	13.88	13.72	13.55	13.34	13.19	13.03	12.88

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day

Table 13. Estimated mean low stages for droughts of different return periods (Upper St. Johns River Basin Project, consumptive use withdrawal rate at 30.0 mgd)

Duration (days)	Mean Annual Low (ft NGVD)	Return Period (years)					
		5	10	25	50	100	200
Existing Site, Weir Crest Elevation = 13.50 ft NGVD (V3B)							
1	13.01	12.42	11.97	11.46	11.10	10.77	10.45
7	13.05	12.47	12.03	11.52	11.16	10.83	10.51
14	13.09	12.52	12.09	11.57	11.21	10.87	10.55
30	13.18	12.64	12.20	11.68	11.31	10.96	10.63
60	13.33	12.82	12.40	11.89	11.53	11.19	10.86
Alternative Site, Weir Crest Elevation = 13.50 ft NGVD (V5B)							
1	13.19	12.92	12.68	12.39	12.18	11.98	11.78
7	13.22	12.96	12.72	12.43	12.22	12.02	11.82
14	13.24	12.99	12.76	12.47	12.25	12.05	11.85
30	13.29	13.05	12.82	12.53	12.32	12.11	11.90
60	13.35	13.15	12.93	12.65	12.44	12.23	12.03
Existing Site, Weir Crest Elevation = 14.00 ft NGVD (V4B)							
1	13.55	12.79	12.43	11.77	11.29	10.84	10.42
7	13.60	13.05	12.52	11.87	11.40	10.95	10.52
14	13.64	13.13	12.60	11.94	11.46	11.00	10.56
30	13.72	13.27	12.75	12.08	11.59	11.11	10.65
60	13.85	13.50	13.00	12.34	11.85	11.37	10.90
Alternative Site, Weir Crest Elevation = 14.00 ft NGVD (V6B)							
1	13.63	13.35	13.11	12.83	12.62	12.43	12.24
7	13.66	13.38	13.14	12.86	12.65	12.46	12.26
14	13.68	13.42	13.18	12.89	12.68	12.48	12.29
30	13.73	13.48	13.25	12.95	12.74	12.54	12.34
60	13.80	13.59	13.37	13.09	12.88	12.68	12.48

Note: ft NGVD = feet, National Geodetic Vertical Datum
mgd = million gallons per day

crest elevation is 13.50 ft NGVD) with a 14.5-mgd withdrawal rate. At a 30.0-mgd withdrawal rate, however, this stage falls to about 10.80 and 12.00 ft NGVD, respectively, for the existing and new impoundments (Tables 12 and 13). The weir at Site 1 impounds a volume of about 20,500 and 74,000 acre-feet of water at 12.00 and 14.00 ft NGVD, respectively, while the existing weir impounds about 10,000 and 18,000 acre-feet at the two elevations, respectively (Figure 5) (1 mgd = 3.07 acre-feet). Thus, the additional volume impounded by the alternative weir easily meets a 30.0-mgd demand without significantly lowering the stages. If the critical drought elevation for the alternative impoundment also is assumed as 11.50 ft NGVD, withdrawals greater than 30.0 mgd can be made without causing water levels to fall below this level.

HIGH WATER LEVELS

This study considered alternatives to the present situation. These alternatives included raising the weir crest elevation from the present 13.50 ft NGVD to 14.00 ft NGVD and relocating the weir downstream from the present site to Site 1. These alternatives may cause an increase in high water (flood) levels in the area. Simulated data show that the peak stages generally are not affected by a choice between 13.5- and 14.0-ft crest elevations (Table 14). Likewise, increased withdrawals would not affect high water levels. Relocating the weir to Site 1, however (i.e., to the mouth of Lake Winder), would increase the high water levels by about 1.6 ft at Lake Winder to about 0.1 ft at Lake Washington. Therefore, the levees and other protective works that exist along the St. Johns River from Lake Washington to Lake Winder need to be strengthened suitably if the weir is built at Site 1. Also, building a weir at Site 1 will be more expensive than replacing the present temporary weir with a permanent structure. At Site 1, the total length of the weir, or a combination of weir and levee to be built across the St. Johns River, would be about 3,000 ft. The present weir has a length of only 165 ft. No cost estimates, however, have been made in this study.

Table 14. Summary of annual 1-day high elevations (ft NGVD) for the simulation period (1942–89)

Weir Location	Weir Crest Elevation (ft NGVD)	Simulation Run	RM 243.6 (Lake Winder)			RM 257 (Lake Washington)		
			Maximum	Minimum	Mean	Maximum	Minimum	Mean
			Consumptive Use Withdrawal = 14.5 mgd					
Current	13.50 14.00	V3A V4A	17.34 17.34	11.27 11.20	14.72 14.74	19.69 19.69	14.08 14.49	16.30 16.32
Site 1	13.50 14.00	V5A V6A	18.93 18.98	13.73 14.23	15.58 15.77	19.74 19.80	14.18 14.55	16.46 16.64
			Consumptive Use Withdrawal = 30.0 mgd					
Current	13.50 14.00	V3B V4B	17.33 17.33	11.08 11.03	14.68 14.70	19.68 19.68	14.03 14.42	16.27 16.30
Site 1	13.50 14.00	V5B V6B	18.91 18.97	13.72 14.21	15.56 15.75	19.73 19.79	14.13 14.52	16.44 16.62

Note: ft NGVD = feet, National Geodetic Vertical Datum

FUTURE STUDIES

Stages in Lake Washington under drought conditions (Tables 12 and 13) may be regarded as tentative because a detailed study addressing the following issues is currently in progress and may affect results.

- Optimization of the TFMCA operation to maximize environmental and water supply benefits
- Establishment of minimum flows and levels for Lake Washington and the immediate downstream river reach
- Choice between weir crest elevation of 13.50 and 14.00 ft NGVD
- Lake Washington water supply potential

HYDROLOGIC CRITERIA AND CONSIDERATIONS

The hydrologic model simulated water stages for the Upper St. Johns River Basin using different weir locations and weir heights for the period 1942–89. Simulated stage data were then evaluated against the environmental hydrologic criteria that are based on the historic hydrologic characteristics of the basin. In addition, other hydrologic issues were considered, such as fish passage, recreation and navigation, and sediment loading. These criteria and considerations were the basis of the recommendation to leave the weir at its current location. The final weir elevation (13.50 ft versus 14.00 ft NGVD) will be determined after a later study that will set minimum flows and levels for Lake Washington and its vicinity.

ENVIRONMENTAL HYDROLOGIC CRITERIA

Five stations along the river from Lake Washington to Lake Poinsett were selected for the environmental hydrologic evaluation. Stations were located near the center of Lake Washington (RM 257), downstream of the current weir (RM 253), upstream of Lake Winder (RM 251.2), in the northern portion of Lake Winder (RM 243.6), and near the center of Lake Poinsett (RM 235) (Figure 2). Proposed weir site alternatives were evaluated with regard to impacts of the weir on hydrology at each of the stations.

Hydrologic Characteristics

Several hydrologic characteristics have been identified as being critical to maintaining the ecological integrity of the marsh ecosystem in the Upper St. Johns River Basin (Brooks and Lowe 1984; Hall 1987; Miller et al. 1994). These general hydrologic characteristics include average water depths, marsh inundation frequencies, magnitude and duration of flood events, minimum ranges of annual fluctuations, seasonal timing of water level fluctuation, water level recession rates, and minimum levels for natural lakes. To establish and maintain the St. Johns marsh ecosystem, each of these hydrologic characteristics should reflect historical conditions.

Ideally, these historical hydrologic conditions could be enumerated from historical hydrologic records. However, because a limited historical hydrologic data base exists, criteria were developed from historical data as well as from earlier studies conducted in the basin. These studies quantified relationships between spatial vegetation patterns and hydrologic conditions. (For a more complete discussion of the development of environmental hydrologic criteria, see Lowe 1983, Brooks and Lowe 1984, and Miller et al. 1994.)

Critical Land Elevations

The range of elevations and marsh types in the basin makes the development of a single set of numerical operational criteria for the entire project area unrealistic. Therefore, criteria were developed relative to a suite of critical elevations determined specifically for each river mile. Minimum and maximum critical elevations are those elevations that encompass the majority of wetland acreage present within an area as determined from stage-area curves (Brooks and Lowe 1984). The central critical elevation corresponds to the midpoint between these two values.

In the Upper St. Johns River Basin where elevational gradients are more extreme, using overall stage-area curves was discovered to be inappropriate for determining critical elevations. Here, critical elevations were determined for individual river miles using wetted perimeter curves derived from cross-sectional data.

Critical elevations at RMs 257, 253, 251.2, 243.6, and 235 (Table 15) were determined using a combination of stage-area curves, wetted perimeter curves, field observations, interpretation of aerial photographs, and historical water level data. In this report, critical elevations for RM 253 are higher than those recommended by Hall (1987), which were used in the previous Lake Washington weir hydraulic and hydrologic analysis (Rao

Table 15. Critical marsh elevations at selected river miles along the St. Johns River between Lake Washington and Lake Poinsett

River Mile	Minimum Elevation	Central Elevation	Maximum Elevation
257	13.00	14.00	15.00
253	12.70	13.60	14.50
251.2	12.50	13.20	14.00
243.6	11.50	12.70	14.00
235	10.00	12.00	14.00

Note: Elevations are in feet, National Geodetic Vertical Datum.

and Tai 1987). In previous studies, maximum and minimum critical elevations were determined primarily from stage-area curves (Brooks and Lowe 1984; Hall 1987).

Hydrologic Criteria

Meeting environmental hydrologic criteria both within the Lake Washington area and downstream of the lake (up to Lake Poinsett) is a major consideration of this study. Exceeding these criteria can harm the environment.

A description follows of the hydrologic criteria that form the boundaries of an acceptable hydrologic regime and that are considered for each station. (The appendix contains a more detailed excerpt from Miller et al. 1994.)

- Mean water level
- Frequency of inundation
- Maximum water elevations
- Minimum range of yearly water fluctuation
- Timing of water fluctuation
- Stage recession rates

- Minimum water levels

Mean Water Level. The long-term (30 years or more) average water level should be no less than the central critical marsh elevation. This hydrologic statistic is calculated from the daily stage data (e.g., Table 2).

Frequency of Inundation. The long-term (30 years or more) frequency of inundation for the central critical elevation should be at least 60 percent (i.e., over a long period, at least 60 percent of the time the marsh is inundated with water to or above the level of central critical elevation). This criterion can be checked from the stage-duration curves (Figures 6–9).

Maximum Water Elevations for 14-, 30-, and 60-Day Periods. For a continuous period of 14, 30, or 60 days, the water elevation should not exceed 4 ft, 3.5 ft, or 2.5 ft above the minimum critical elevation, respectively. Should the minimum critical elevation be exceeded in any of these instances, it should not occur more frequently than 1 year out of 10. (See Table 5 for an example of the data used in evaluating these criteria.)

Minimum Range of Yearly Water Fluctuation. There are two conditions to be met under this criterion:

1. The minimum range of water level fluctuation during at least 25 percent of the years (over a long period) should allow for both inundation of the marsh to the maximum critical elevation for at least 30 days and exposure of the marsh to the minimum critical elevation for at least 30 days in the same year. (See Tables 5 and 9 for examples of data used in these evaluations.) For RM 257, the maximum and minimum critical elevations are 15.00 and 13.00 ft NGVD, respectively. For the same year, the value in Table 5 should equal or exceed 15.00 ft NGVD, the value in Table 9 should equal or not exceed 13.00 ft NGVD, and there should be 25 percent such years (see data under 30-day columns in Tables 5 and 9). This condition was satisfied only for 1 year,

1977. Therefore, this criterion would not be met for the conditions of the V3A simulation run.

2. The long-term (30 years or more) average annual water level fluctuation should be at least the distance between 0.5 ft below the minimum critical elevation and 0.5 ft above the maximum critical elevation. Table 11 is an example of data used to evaluate this condition. For RM 257, the long-term average annual water level fluctuation is 2.89 ft. The value of the distance against which the 2.89 ft compares is 3 ft ([15.0 + 0.5] – [13.0 – 0.5]). Therefore, this criterion is not met for the conditions of the V3A simulation run.

Timing of Water Fluctuation. Timing of fluctuations should be such that minimum water levels occur between April 1 and June 30 in more than 50 percent of the years and that maximum water levels occur between September 1 and November 30 in more than 50 percent of the years over a long period (i.e., 30 years or more).

Stage Recession Rates. When stage levels are less than or equal to 1 ft above the maximum critical elevation, the rate at which stage levels recede should not exceed 1.2 ft during any 30-day period or 0.5 ft during any 7-day period for at least 95 percent of the recession periods. For example, at RM 257, the maximum critical elevation is 15.00 ft NGVD (Table 15). When beginning water level was in the 15.00–16.00 ft NGVD range at this river mile, water level recession rates were less than or equal to 0.5 ft for 99.07 percent (23.35 + 75.72) of all the 7-day recession periods (Table 16). Table 16 is an example of stage-recession rates data.

Minimum Water Levels for Lake Washington. Minimum water levels should not be too low to exclude fish from the littoral zone for more than 1 day in every 5 years. To protect fisheries during drought conditions, the following criteria are recommended: minimum lake depths should be 3 ft for no more than 1 day in every 50 years and 2.5 ft for no more than 1 day in every 100 years.

Table 16. Examples of stage recession rates data

7-Day Water Level Recession Periods (percentage)						
Simulated Stages at RM 257 (V3A, 13.5-ft weir, 14.5 mgd), ft NGVD						
Recession Rate (ft)	Initial Stage					
	> 16.00	15.00–16.00	14.00–15.00	13.00–14.00	12.00–13.00	< 12.00
> 2.0	0.00	0.00	0.00	0.00	0.00	0.00
1.8–2.0	0.00	0.00	0.00	0.00	0.00	0.00
1.6–1.8	0.00	0.00	0.00	0.00	0.00	0.00
1.4–1.6	0.00	0.06	0.00	0.00	0.00	0.00
1.2–1.4	0.00	0.06	0.00	0.00	0.00	0.00
1.0–1.2	0.00	0.00	0.03	0.00	0.00	0.00
0.75–1.0	2.55	0.00	0.13	0.00	0.00	0.00
0.50–0.75	19.12	0.81	0.16	0.00	0.00	0.00
0.25–0.50	42.35	23.35	0.69	0.23	0.00	0.00
0.00–0.25	35.98	75.72	98.99	99.77	100.00	0.00
30-Day Water Level Recession Periods (percentage)						
Simulated Stages at RM 257 (V3A, 13.5-ft weir, 14.5 mgd), ft NGVD						
Recession Rate (ft)	Initial Stage					
	> 16.00	15.00–16.00	14.00–15.00	13.00–14.00	12.00–13.00	< 12.00
> 2.0	12.96	0.00	0.00	0.00	0.00	0.00
1.8–2.0	4.47	0.00	0.00	0.00	0.00	0.00
1.6–1.8	10.35	0.05	0.00	0.00	0.00	0.00
1.4–1.6	9.15	0.55	0.00	0.00	0.00	0.00
1.2–1.4	10.46	3.68	0.00	0.00	0.00	0.00
1.0–1.2	14.71	9.08	0.05	0.00	0.00	0.00
0.75–1.0	10.68	22.96	6.33	0.00	0.00	0.00
0.50–0.75	9.48	23.31	27.82	1.33	0.00	0.00
0.25–0.50	10.46	20.33	36.89	24.80	0.00	0.00
0.00–0.25	7.30	20.03	28.90	73.87	100.00	0.00

Hydrologic Requirements

Although the seven characteristics listed above constitute the hydrologic requirements needed to maintain a wetland system, these characteristics do not constitute the entire legal minimum flows and levels requirements mandated by Chapter 373 of *Florida Statutes.* Chapter 373 requires that minimum flows and levels be maintained in a riverine system. Minimum flow requirements downstream of the Lake Washington weir, however, need to be determined. Minimum lake discharge requirements will be determined by SJRWMD staff by 1996; therefore, minimum base flows were not available for this analysis.

Fish and Wildlife Habitats and Passage of Fish Downstream

Meeting the environmental hydrologic criteria prescribed also will maintain fish and wildlife habitats.

Any new weir design must provide for passage of fish upstream or downstream during the majority of the year. The new weir should contain an appurtenant structure that allows for low-flow augmentation downstream when water levels upstream of the weir are below the weir crest.

Fish passage and minimum discharge through the weir will be determined from future investigations of minimum flows and levels.

Recreation and Navigation

No specific hydrologic criteria for recreation or navigation have been established for the Lake Washington area. Any new weir design must provide for navigational needs along the river.

SEDIMENT LOAD AND TRANSFER OF DETRITAL MATERIAL

No specific hydrologic criteria for controlling sediment loads and transfer of detrital material have been established. Any new weir design must provide for sediment control and transfer of detrital material. This probably can be accomplished best by including a sluice gate in the design of the new weir.

EVALUATION OF ENVIRONMENTAL CRITERIA

An ecological evaluation was conducted for the river stations by comparing the environmental impacts of each of the water management alternatives. These alternatives were as follows:

- Maintaining the weir in its current location (RM 254.4)
- Relocating the weir downstream to Site 1 (RM 240.1)
- Removing the weir entirely
- Relocating the weir downstream to Site 2 (RM 249.5)
- Withdrawing 14.5 mgd versus 30.0 mgd with a weir located at its current location

These management alternatives were evaluated by calculating various hydrologic statistics using the data generated from the continuous watershed simulation model for the period 1942–89 and then comparing these statistics with the environmental hydrologic criteria. All analyses assumed that the USJRBP was completed and operational.

HYDROLOGIC ANALYSIS OF THE WEIR—CURRENT LOCATION

The current weir location is just downstream of Lake Washington, at RM 254.4. The data for a weir at this location were generated for two weir heights: crest elevations of 13.50 and 14.00 ft NGVD. For a weir crest elevation of 14.00 ft NGVD, the data, however, were not analyzed. The data were not analyzed because another study addresses minimum flows and levels for this area; this study will generate new hydrologic data.

An evaluation of the simulated hydrologic conditions resulting from keeping the weir at its current location and crest height (13.50 ft NGVD) indicated that all hydrologic criteria at RM 257 (Lake Washington) were met except for the maximum elevation and the minimum range of fluctuation criteria (Table 17). Maximum elevation criteria were exceeded during 11–23 percent of the years instead of the desired 10 percent. In addition, exposure of the minimum critical elevation and inundation of the maximum critical elevation for at least 30 days (in the same year) occurred in only 2 percent of the years modeled, instead of the desired 25 percent.

Hydrologic simulations indicated that mean depth criteria would be met at two of the four river miles examined downstream of Lake Washington and that the frequency of inundation criteria would not be met at all four locations (Table 17). Frequency of inundation of the central critical elevation at downstream stations ranged from 35 to 52 percent. Maximum elevation criteria were exceeded at all river miles except RM 253, and stage recession rates were excessive. Water level recession rates were most notably rapid at all downstream stations when water levels in Lake Washington fell below 13.50 ft NGVD and flows over the weir ceased. The range of fluctuation criteria were met at all river miles except RM 235.

HYDROLOGIC ANALYSIS OF THE WEIR—SITE 1

Site 1 location is at the mouth of Lake Winder, RM 240.1. The data for a weir at this location were generated for two weir heights: crest elevations of 13.50 and 14.00 ft NGVD.

Weir Crest Elevation of 13.50 ft NGVD

Relocating the weir to RM 240.1 would significantly alter the surface water hydrology at all river miles from Lake Poinsett to Lake Washington (Table 17); however, relocating the weir would have minimal impact on the hydrology of Lake Washington (Table 17). The overall effect of relocating the weir would be to raise mean water levels and reduce annual water level fluctuations at RMs 253, 251.6, and 243.6. At these river miles, the mean depth would increase by 1.07 to 1.77 ft and the frequency of inundation of the central critical elevation would increase from approximately 35 percent to greater than 80 percent. The annual range of fluctuation would decrease by about 0.9 to 2.6 ft (23–53 percent) at these stations and both the inundation of the maximum critical elevation and exposure of the

Table 17. Summary of hydrologic modeling results comparing environmental impacts of moving the Lake Washington weir downstream from its current location to river mile (RM) 240.1 (Site 1)

Weir Location	Mean Water Level	Frequency of Inundation	Maximum Water Elevations	Range of Fluctuation		Timing of Water Fluctuation	Stage Recession Rates
				A	B		
RM 257							
Current	14.45 ft Criteria met	61% Criteria met	14-, 30-, and 60-day critical elevations were exceeded 19%, 11%, and 23% of years, respectively	2% Criteria not met	2.83 ft Criteria not met	Criteria met	Criteria met
Site 1	14.50 ft Criteria met	60% Criteria met	14-, 30-, and 60-day critical elevations were exceeded 21%, 21%, and 40% of years, respectively	0% Criteria not met	3.15 ft Criteria met	Criteria met	Criteria met
RM 253							
Current	13.17 ft Criteria met	35% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 6%, 6%, and 9% of years, respectively	66% Criteria met	3.83 ft Criteria met	Criteria met	Criteria not met
Site 1	14.24 ft Criteria met	81% Criteria met	14-, 30-, and 60-day critical elevations were exceeded 23%, 28%, and 47% of years, respectively	0% Criteria not met	2.94 ft Criteria met	Criteria met	Criteria not met
RM 251.2							
Current	12.65 ft Criteria not met	38% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 11%, 11%, and 11% of years, respectively	72% Criteria met	4.89 ft Criteria met	Criteria met	Criteria not met
Site 1	14.18 ft Criteria met	97.3% Criteria met	14-, 30-, and 60-day critical elevations were exceeded 26%, 30%, and 47% of years, respectively	0% Criteria not met	2.77 ft Criteria met	Criteria met	Criteria met

See Table 14 for various critical marsh elevations. For both weirs, crest elevation is 13.5 feet, National Geodetic Vertical Datum and the water withdrawal rate is 14.5 million gallons per day. The data analyzed are from simulation runs V3A for current weir location and V5A for Site 1.

Table 17—*Continued*

Weir Location	Mean Water Level	Frequency of Inundation	Maximum Water Elevations	Range of Fluctuation		Timing of Water Fluctuation	Stage Recession Rates
				A	B		
RM 243.6							
Current	12.23 ft Criteria not met	38% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 19%, 24%, and 38% of years, respectively	51% Criteria met	4.91 ft Criteria met	Criteria met	Criteria not met
Site 1	14.00 ft Criteria met	99.6% Criteria met	14-, 30-, and 60-day critical elevations were exceeded 49%, 45%, and 68% of years, respectively	0% Criteria not met	2.28 ft Criteria not met	Criteria met	Criteria met
RM 235							
Current	12.15 ft Criteria met	52% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 66%, 74%, and 89% of years, respectively	15% Criteria not met	4.74 ft Criteria not met	Criteria met	Criteria not met
Site 1	12.02 ft Criteria met	49.6% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 66%, 70%, and 83% of years, respectively	28% Criteria met	5.50 ft Criteria met	Criteria met	Criteria not met

See Table 14 for various critical marsh elevations. For both weirs, crest elevation is 13.5 feet, National Geodetic Vertical Datum and the water withdrawal rate is 14.5 million gallons per day. The data analyzed are from simulation runs V3A for current weir location and V5A for Site 1.

minimum critical elevation would never occur during the same year.

Relocating the weir would have minimal impacts on hydrology at RM 257 and RM 235 (i.e., at Lakes Washington and Poinsett). Hydrologic conditions for Lake Washington (RM 257) actually would improve slightly because the annual range of fluctuation would increase (Table 17). At RM 235 (Lake Poinsett), the mean depth and frequency of inundation of the central critical elevation would decline slightly (Table 17).

Moving the weir from its current location would dramatically alter the hydrology of approximately 14 contiguous miles of river (from Lake Washington to Lake Winder). Reductions in the annual range of fluctuation and subsequent stabilization of water levels would undoubtedly have a detrimental impact on wetland resources in these areas. Relocating the weir would greatly impact the hydrology at elevations less than 13.50 ft NGVD (approximately 14,000 acres; Figure 4). Areas below 13.50 ft NGVD would be inundated for about 90 percent of the time instead of 25–35 percent under the current weir scenario (Figures 6–9). Because of the potential detrimental environmental impacts of relocating the weir, this alternative was deleted from further evaluations, and it was concluded that the current location of the weir is the most desirable from an environmental perspective.

Weir Crest Elevation of 14.00 ft NGVD

The results for the weir with crest elevation at 13.50 ft NGVD clearly indicated that moving the weir to Site 1 would have significant undesirable environmental impacts. The impacts of a weir with crest elevation of 14.00 ft NGVD would be even more detrimental (i.e., more area would be inundated for longer periods). For this reason, the data generated for 14.00 ft NGVD weir were not analyzed.

Hydrologic Analysis of the Weir—Removal

Removing the Lake Washington weir would decrease the mean depth at RM 257 by approximately 0.6 ft (Tables 17 and 18). In addition, the frequency of inundation of the central critical elevation would decline from 61 percent under the current weir scenario to 36.5 percent. Removing the weir would have little impact on the hydrology at stations located downstream of the current weir location (Table 18).

Because of the dramatic decrease in Lake Washington water levels that would occur if the weir were removed, this scenario was not evaluated further.

Hydrologic Analysis of the Weir—Site 2

A weir located at Site 2, upstream of Lake Winder (Figure 2), would impact the wetlands in much the same way as a weir would at Site 1. A weir located at either Site 1 or Site 2 can alter the hydrologic regime of extensive areas of marshlands in an undesirable fashion. Therefore, building a weir at either site cannot be justified.

Analysis of Consumptive Use Withdrawals

An analysis of different consumptive uses of water (14.5 mgd or 30.0 mgd) was performed for the scenario of leaving the weir at its current location (RM 254.4) and at the current height, that is, at a weir crest elevation of 13.50 ft NGVD.

Increased consumptive use withdrawals would benefit the hydrology of Lake Washington by increasing the range of annual fluctuation (Table 19). Under a 30.0-mgd withdrawal, exposure of the minimum critical elevation for 30 days and inundation of the maximum critical elevation for 30 days would occur within the same year during 15 percent of the years. This condition would only occur during 2 percent of the years modeled under the 14.5-mgd withdrawal rate.

Table 18. Summary of hydrologic modeling results for removing the Lake Washington weir.
Consumptive use withdrawal is 14.5 million gallons per day.

Weir Location	Mean Water Level	Frequency of Inundation	Maximum Water Elevations	Range of Fluctuation		Timing of Water Fluctuation	Stage Recession Rates
				A	B		
River mile 257	13.81 ft Criteria not met	36.5% Criteria not met	14-, 30-, and 60-day criteria exceeded 23%, 23%, and 26% of years, respectively	62% Criteria met	4.3 ft Criteria met	Criteria met	Criteria not met
River mile 253	13.86 ft Criteria met	51.7% Criteria not met	14-, 30-, and 60-day criteria exceeded 36%, 36%, and 49% of years, respectively	38% Criteria not met	4.80 ft Criteria met	Criteria met	Criteria not met
River mile 251.2	12.81 ft Criteria not met	50.4% Criteria not met	14-, 30-, and 60-day criteria exceeded 38%, 38%, and 49% of years, respectively	79% Criteria met	5.20 ft Criteria met	Criteria met	Criteria met
River mile 243.6	12.62 ft Criteria not met	47% Criteria not met	14-, 30-, and 60-day criteria exceeded 53%, 55%, and 60% of years, respectively	45% Criteria met	5.44 ft Criteria met	Criteria met	Criteria not met
River mile 235	12.32 ft Criteria met	55% Criteria not met	14-, 30-, and 60-day criteria exceeded 68%, 70%, and 89% of years, respectively	13% Criteria not met	4.97 ft Criteria met	Criteria met	Criteria met

Table 19. Summary of hydrologic modeling results comparing environmental impacts of increasing consumptive use withdrawals from Lake Washington from 14.5 million gallons per day (mgd) to 30 mgd. *(Weir at current location at a crest elevation of 13.50 ft NGVD)*

Withdrawal	Mean Water Level	Frequency of Inundation	Maximum Water Elevations	Range of Fluctuation		Timing of Water Fluctuation	Stage Recession Rates
				A	B		
River Mile 257							
14.5 mgd	14.45 ft Criteria met	61% Criteria met	14-, 30-, and 60-day critical elevations were exceeded 19%, 11%, and 23% of years, respectively	2% Criteria not met	2.89 ft Criteria not met	Criteria met	Criteria met
30.0 mgd	14.35 ft Criteria met	57% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 15%, 13%, and 23% of years, respectively	15% Criteria not met	3.2 ft Criteria met	Criteria met	Criteria not met
River Mile 253							
14.5 mgd	13.17 ft Criteria not met	35% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 6%, 6%, and 9% of years, respectively	66% Criteria met	3.83 ft Criteria met	Criteria met	Criteria not met
30.0 mgd	13.09 ft Criteria not met	33% Criteria met	14-, 30-, and 60-day critical elevations were exceeded 6%, 6%, and 9% of years, respectively	66% Criteria met	3.88 ft Criteria met	Criteria met	Criteria not met
River Mile 251.2							
14.5 mgd	12.65 ft Criteria not met	38% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 11%, 11%, and 11% of years, respectively	72% Criteria met	4.89 ft Criteria met	Criteria met	Criteria not met
30.0 mgd	12.54 ft Criteria not met	36% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 6%, 9%, and 9% of years, respectively	72% Criteria met	4.99 ft Criteria met	Criteria met	Criteria not met

Table 19—*Continued*

Withdrawal	Mean Water Level	Frequency of Inundation	Maximum Water Elevations	Range of Fluctuation		Timing of Water Fluctuation	Stage Recession Rates
				A	B		
River Mile 243.6							
14.5 mgd	12.23 ft Criteria not met	38% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 19%, 24%, and 38% of years, respectively	51% Criteria met	4.91 ft Criteria met	Criteria met	Criteria not met
30.0 mgd	12.13 ft Criteria met	36% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 19%, 21%, and 40% of years, respectively	62% Criteria met	5.00 ft Criteria not met	Criteria met	Criteria not met
River Mile 235							
14.5 mgd	12.15 ft Criteria met	52% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 66%, 74%, and 89% of years, respectively	15% Criteria not met	4.74 ft Criteria not met	Criteria met	Criteria not met
30.0 mgd	12.07 ft Criteria not met	50.0% Criteria not met	14-, 30-, and 60-day critical elevations were exceeded 66%, 68%, and 87% of years, respectively	17% Criteria not met	4.84 ft Criteria met	Criteria met	Criteria not met

Increased withdrawal rates would *slightly* increase annual water level fluctuations at stations downstream of the current weir location, but the increases would not be sufficient to lower water levels enough to meet maximum water elevation criteria (Table 19). At all downstream stations, increased withdrawal rates would cause mean depths to decline approximately 0.1 ft and inundation frequencies of the central critical elevation to decline slightly (2–4 percent). The major downstream impact of the increased withdrawal rates was reflected in the number of days water would overtop the weir. This would be a decline from 340 days per year under a 14.5-mgd withdrawal rate to 321 days per year under a 30.0-mgd withdrawal rate, as determined from stage-duration curves (not presented).

Increased withdrawals from Lake Washington from 14.5 mgd to 30.0 mgd may be beneficial to the lake and might have little impact on the downstream reaches, provided water under low-flow conditions is released through the weir when water levels in Lake Washington fall below the weir crest height.

SUMMARY AND RECOMMENDATIONS

SUMMARY

A continuous hydrologic simulation model generated daily stage and discharge data for a period of 48 years (1942–89) for various locations in the study area. The daily stage data and the annual extreme stages for various durations determined from the daily data formed a basis for evaluating Lake Washington water supply potential and for conducting environmental analyses. The data were generated for the eight alternatives that are derived from the varying combinations of the following factors: two weir heights (crest elevations of 13.50 and 14.00 ft NGVD); two consumptive use withdrawals (14.5 and 30.0 mgd); and two weir locations, the current location and Site 1, at the mouth of Lake Winder (RM 240.1).

Drought stages for different return periods estimated for the eight alternatives indicated that a new weir at Site 1 would create a greater water supply potential than does the present weir. Withdrawals greater than 30 mgd would be possible with the weir at Site 1, while a withdrawal of 30 mgd at the present weir location would lead to very low stages (less than 11.50 ft NGVD) and water quality problems for drought return periods greater than 25 years. The weir at Site 1, however, would increase the flood levels by about 1.6 ft at Lake Winder to 0.1 ft at Lake Washington. The total cost of the weir at Site 1 and the other improvements undoubtedly would far exceed the cost of replacing the present temporary weir with a permanent structure (no cost estimates were made in this study).

Environmental evaluations consisted of comparing the hydrologic conditions that would prevail at various study area locations, under each water management alternative, to a set of environmental criteria for each location. The environmental criteria were formulated based on historic hydrologic conditions. A no-weir scenario (weir completely removed) was also simulated for testing environmental criteria.

Using simulated hydrologic data, the potential environmental impacts of relocating the Lake Washington weir downstream to the mouth of Lake Winder (RM 240.1, Site 1) were evaluated. The evaluations indicated that moving the Lake Washington weir would dramatically alter the current hydrologic regime over 14 miles of river channel and 14,000 acres of floodplain by increasing mean annual stages over 1 ft and decreasing the annual range of fluctuation by as much as 53 percent. These changes in hydrology would have a detrimental impact on wetland resources within the area. Because Site 2 (RM 249.5) is upstream of Site 1, the impact of moving the weir to Site 2 would be similar to that of moving the weir to Site 1.

The impact of removing the weir also was examined. Removing the weir would have little impact on the river reaches downstream of its current location but would cause a significant decline in stage durations in Lake Washington.

The potential effects of increasing the consumptive use withdrawal of water from Lake Washington from 14.5 to 30.0 mgd were examined. Under the current withdrawal rate (14.5 mgd), water levels in Lake Washington exceed those considered desirable from an environmental perspective. Increased daily withdrawals (30.0 mgd) would allow the lower critical elevations established for this area to be exposed more frequently.

RECOMMENDATIONS

The following recommendations result from the analyses relative to the environment and the water supply potential of Lake Washington.

- The weir should be kept in its current location, RM 254.4.
- Future studies should establish minimum flows and levels for Lake Washington (RM 257) and downstream of the current weir location (RM 254.4).

- Future studies should determine the water supply potential of Lake Washington, considering various plan elements of the USJRBP and the augmentation of low flows downstream of the weir.

- A permanent weir structure should be designed to meet various environmental and water supply goals.

- Before a plan is endorsed that will increase daily consumptive use withdrawal, the environmental analysis should be re-conducted, to take into consideration low-flow needs as determined by the minimum flows and levels evaluations.

- Future studies should determine the optimal weir height (crest elevation of 13.50 versus 14.00 ft NGVD) and the details of various appurtenant structures.

REFERENCES

Brooks, J.E., and E.F. Lowe. 1984. *U.S. EPA clean lakes program, Phase I diagnostic-feasibility study of the upper St. Johns River chain of lakes. Volume II: feasibility study.* Technical Publication SJ84-15. Palatka, Fla.: St. Johns River Water Management District.

Florence, Bruce. 1992. *Annual water use survey: 1990.* Technical Publication SJ92-4. Palatka, Fla.: St. Johns River Water Management District.

Hall, G.B. 1987. *Establishment of minimum surface water requirements for the Greater Lake Washington Basin.* Technical Publication SJ87-3. Palatka, Fla.: St. Johns River Water Management District.

Lowe, E.F. 1983. *Distribution and structure of floodplain plant communities in the upper basin of the St. Johns River, Florida.* Technical Publication SJ83-8. Palatka Fla.: St. Johns River Water Management District.

Miller, S.J., M.A. Lee, A.K. Borah, D.V. Rao, and E.F. Lowe. 1994 (Draft). *Environmental water management plan for the Upper St. Johns River Basin Project.* St. Johns River Water Management District. Palatka, Fla.

Rao, D.V., and C.C. Tai. 1987. *An evaluation of Lake Washington temporary weir for surface water management phase I: Hydraulic/hydrologic analyses.* Technical Publication SJ87-4. Palatka, Fla.: St. Johns River Water Management District.

Suphunvorranop, T., and C.C. Tai. 1982. *Upper St. Johns Hydrologic Model, users manual.* Technical Publication SJ82-4. Palatka, Fla.: St. Johns River Water Management District.

APPENDIX—GENERAL ENVIRONMENTAL HYDROLOGIC CRITERIA

The following criteria are taken from Miller et al. 1994.

The environmental hydrologic criteria and the basis for their selection as ecologically important components of the natural hydrologic regime are as follows.

1. ***Mean Depth.*** *The long-term (30-year) average water depth should be no less than the central critical marsh elevation.*

One of the ecological consequences of draining and developing Upper Basin wetlands is a shift from deposition to oxidation of peat soils. The oxidation of exposed peat soils has caused ground elevations to subside over 2 feet (ft) in some areas (Brooks and Lowe 1984).

Studies conducted in the Everglades have demonstrated that to prevent soil subsidence, a mean water table depth of not less than -0.25 ft must be maintained (Stephens 1974).

2. ***Frequency of Inundation.*** *The long-term frequency of inundation for the central critical marsh elevation should be at least 60 percent.*

The mean depth criterion by itself may not be sufficient to prevent soil subsidence because the soil must be saturated for some minimum length of time within a typical year. In the work conducted in the Everglades, water depth was held constant. Where water level fluctuates, a frequency distribution of depths skewed toward the maxima could cause soil subsidence even though the mean depth was no lower than -0.25 ft. Soils have not subsided in the Blue Cypress Marsh Conservation Area (BCMCA, Figure A-1) where, based on historical stage data, the average inundation frequency of the central critical elevation is 60 percent (Lowe 1983; Brooks and Lowe 1984).

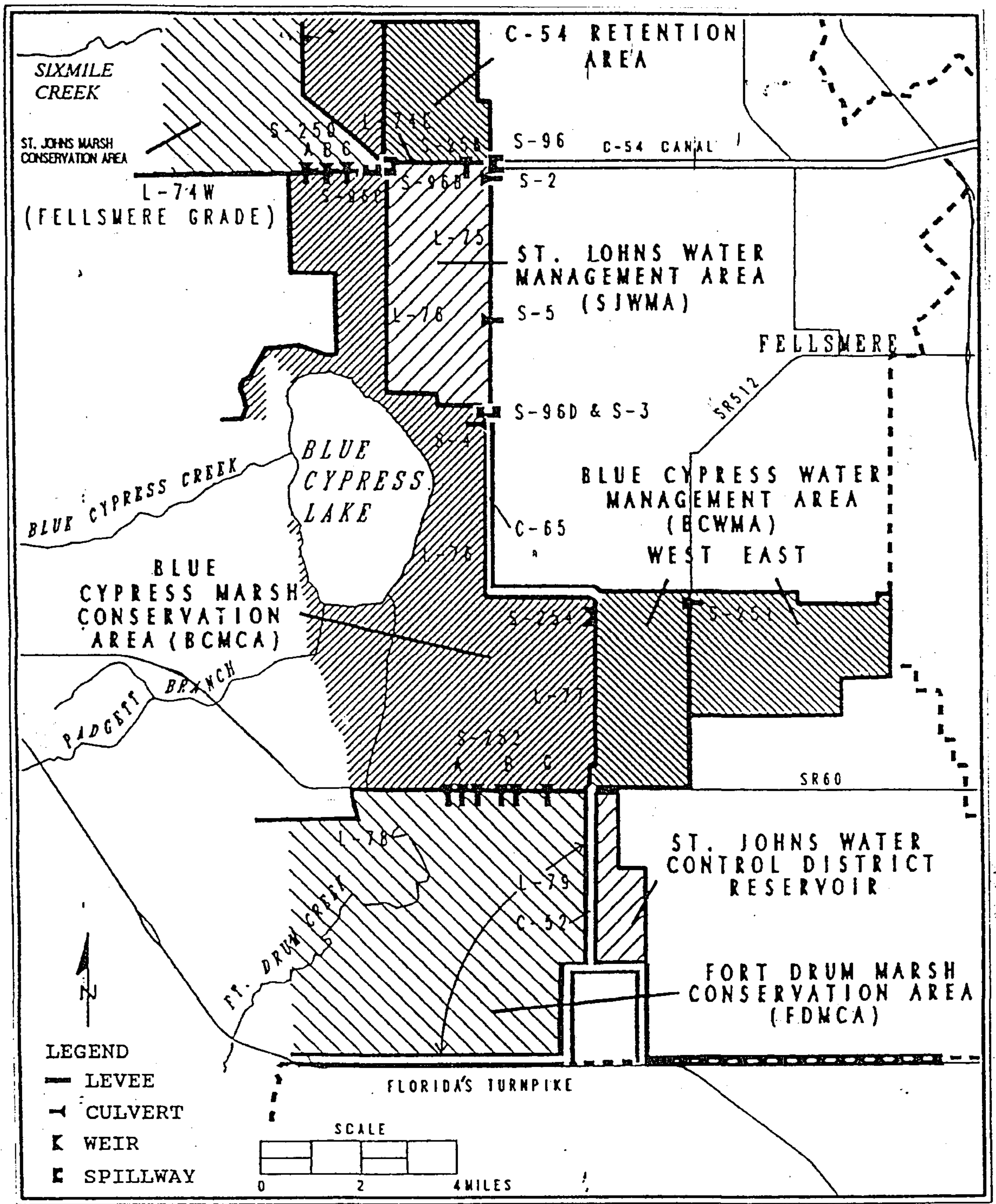

Figure A-1. **The Upper St. Johns River Basin Project—Fellsmere Grade to the Florida Turnpike**

3. ***Maximum Elevations (14-, 30-, and 60-day)***

14-Day*. The water elevation should not exceed 4 ft above the minimum critical marsh elevation for more than 14 continuous days more frequently than 1 year out of 10.*

30-Day*. The water elevation should not exceed 3.5 ft above the minimum critical marsh elevation for more than 30 continuous days more frequently than 1 year out of 10.*

60-Day*. The water elevation should not exceed 2.5 ft above the minimum critical marsh elevation for more than 60 continuous days more frequently than 1 year out of 10.*

These criteria were established to prevent extreme water depths from being maintained for sufficient durations to cause significant damage and alteration to marsh plant communities occupying the lower critical elevations (Brooks and Lowe 1984). Plant tolerances to extreme water depths were established by analysis of historic stages relative to the distribution of the dominant plant species along an elevation gradient in the BCMCA (Lowe 1983).

4. ***Minimum Range of Yearly Fluctuation***

(a) The minimum range of fluctuation during at least 25 percent of the years should allow for both inundation of the maximum critical marsh elevation for at least 30 days and exposure of the minimum critical marsh elevation for at least 30 days.

(b) The long-term (30-year) average annual water level fluctuation should be at least the distance between 0.5 ft below the minimum critical marsh elevation and 0.5 ft above the maximum critical marsh elevation.

Fluctuations in water level are critical to establishing and maintaining both spatial and temporal aspects of habitat heterogeneity in marsh ecosystems. Based on historical stage data, the average annual water level fluctuation in the BCMCA was 3.7 ft (Brooks and Lowe 1984). Water level fluctuations and their duration affect physical and chemical properties of wetlands such as nutrient availability, degree of substrate anoxia, sediment properties, and pH (Mitsch and Gosselink 1986). These in turn directly impact the biotic components of the wetlands, such as plant species composition, diversity, and productivity. Even slight alterations in the hydrologic regimes of wetlands can cause massive changes in plant community dynamics. In addition, reproductive strategies of many wetland animals are dependent upon water fluctuation cycles. Nesting success of most species of wading birds is linked to dry season drawdowns which concentrate fish and invertebrate food organisms (Kushlan et al. 1975; Kushlan 1976; De Sotell et al. 1982; Bancroft et al. 1990).

5. ***Timing of Fluctuation***

(a) *Timing of fluctuation should be such that minimum water levels occur between April 1 and June 30 in more than 50 percent of the years and maximum water levels occur between September 1 and November 30 in more than 50 percent of the years.*

(b) *Minimum yearly water levels should not occur between September 1 and October 31 and/or maximum yearly water levels should not occur between April 1 and May 31 with an average frequency greater than once in 30 years.*

Temporal aspects of water level fluctuations are as important as the magnitude of the fluctuations themselves. For example, breeding cycles of many wading birds are timed to occur between the middle and the end of the dry season to coincide with the concentration of prey (Kushlan et al. 1975; Kushlan 1976; Frederick and Collopy 1989; Bancroft et al. 1990). Breeding cycles of alligators are timed so hatching generally occurs during the middle of the wet season, when food is most abundant and growth rates are highest (Fogarty 1974). The dry season is a major factor determining the species composition and abundance of fish communities in the Everglades (Loftus and Kushlan 1987).

6. ***Water Level Recession Rates.*** *Water level recession rates should not exceed 1.2 ft during any 30-day period or 0.5 ft during any 7-day period when stage levels are less than or equal to 1 ft above the maximum critical marsh elevation.*

Water level recession rates can have a dramatic impact on wetland animal communities. Studies in the Everglades have documented a correlation between rate of recession during the spring and the number of wading birds nesting, and their overall nesting success (Kushlan et al. 1975; Frederick and Collopy 1989). Rapid recession rates also apparently initiated earlier nesting. Rapid recession rates can have potentially detrimental impacts on aquatic biota by degrading water quality. Rapid recession rates which occurred during the late summer caused massive fish kills in the Kissimmee River Restoration Demonstration Project, when nearly 60 percent of the floodplain was drained over a period of 3 days (Toth et al. 1990).

7. ***Minimum Water Levels for Natural Lakes.*** *One-day minimum water levels which*

   (a) *exclude fish from the littoral zone (zone of rooted vegetation) and should not occur more frequently than once every 5 years*

   (b) *cause mean lake depth to be less than 3 ft and should not occur more frequently than once every 50 years*

   (c) *cause mean lake depth to be less than 2.5 ft and should not occur more frequently than once every 100 years.*

These criteria are necessary to prevent extreme drawdowns from occurring too frequently. Drawdowns can beneficially impact lake ecosystems by causing consolidation of organic sediments, increased sportfish production, increased invertebrate production, littoral zone habitat enhancement, and short-term control of nuisance vegetation (Greening and Doyon 1990). However, if drawdowns are extreme enough, oxygen depletion can occur and cause massive fish kills. Fish kills caused by low dissolved oxygen levels reduce species diversity and favor rough fish such as bowfin and gar, which are adapted to survive these conditions (Kushlan 1974; Loftus and Kushlan 1987). If fish kills occur frequently enough, these species will become dominant in those lakes. Several studies have documented that aquatic vegetation provides important cover, spawning, and nursery habitats for a number of gamefish species (for a review see Janacek 1988). If lake levels fall below the vegetated littoral zone too frequently, declines in reproductive success and increased predation could lead to long-term declines in game fish populations in these lakes (Durocher et al. 1984).

Literature cited in material taken from Miller et al. 1994

Bancroft, G.T., S.D. Jewell, and A.M. Strong. 1990. *Foraging and nesting ecology of herons in the lower Everglades relative to water conditions.* Final report to the South Florida Water Management District. West Palm Beach, Fla.

Brooks, J.E., and E.F. Lowe. 1984. *U.S. EPA clean lakes program, Phase I diagnostic-feasibility study of the upper St. Johns River chain of lakes. Volume II: feasibility study.* Technical Publication SJ84-15. Palatka, Fla.: St. Johns River Water Management District.

De Sotell, R.J., S.W. Fletcher, and A.M. Arcari. 1982. "Patterns of wading bird utilization of natural and altered fresh water marshes: Causes and management implications." In *Progress in wetlands utilization and management,* eds. P.T. McCaffrey, P.T. Beeman, and S.E. Gatewood. Tallahassee, Fla.: Coordinating Council on the Restoration of the Kissimmee River.

Durocher, P.P., W.C. Provine, and J.E. Kraii. 1984. Relationship between abundance of largemouth bass and submerged vegetation in Texas reservoirs. *North American Journal of Fisheries Management* 4:84–88.

Fogarty, M.J. 1974. "The ecology of the Everglades alligator." In *Environments of South Florida: Present and Past,* ed. P.J. Gleason. Memoir 2. Miami, Fla.: Miami Geological Society.

Frederick, P.C., and M.W. Collopy. 1989. Nesting success of five Ciconiiform species in relation to water conditions in the Florida Everglades. *Auk* 106:625–634.

Greening, H., and S. Doyon. 1990. *Environmental and ecological effects on drawdown and enhanced fluctuation for Lake Apopka, Florida.* Special Publication SJ90-SP9. Palatka, Fla.: St. Johns River Water Management District.

Janacek, J.A. 1988 (unpublished report). *Literature review on fisheries interactions with aquatic macrophytes with special reference to the upper Mississippi River system.* Upper Mississippi Conservation Committee. Rock Island, Ill.

Kushlan, J.A. 1974. Effects of a natural fish kill on the water quality, plankton, and fish population of a pond in the Big Cypress Swamp, Florida. *Transactions of the American Fisheries Society* 103(2):235–243.

———. 1976. Wading bird predation in a seasonally fluctuating pond. *Auk* 93:464–476.

Kushlan, J.A., J.C. Ogden, and L.A. Higer. 1975. *Relation of water level and food availability to wood stork reproduction in the southern Everglades, Florida.* Open File Report 75-434. Tallahassee, Fla.: U.S. Geological Survey.

Loftus, W.F., and J.A. Kushlan. 1987. Freshwater fishes of southern Florida. Bulletin Florida State Museum, *Biological Sciences* 31(4):147–344.

Lowe, E.F. 1983. *Distribution and structure of floodplain plant communities in the upper basin of the St. Johns River, Florida.* Technical Publication SJ83-8. Palatka Fla.: St. Johns River Water Management District.

Mitsch, W.J., and J.G. Gosselink. 1986. *Wetlands.* New York: Van Nostrand Reinhold Co.

Stephens, J.C. 1974. "Subsidence of organic soils in the Florida Everglades - A review and update." In *Environments of South Florida: Present and Past,* ed. P.J. Gleason. Memoir 2. Miami, Fla.: Miami Geological Society.

Toth, L.A., S.J. Miller, and M.K. Loftin. 1990. "September 1988 Kissimmee River fish kill." In *Proceedings Kissimmee River Restoration Symposium,* eds. M.K. Loftin, L.A. Toth, and J.T.B.

Obeysekera. West Palm Beach, Fla.: South Florida Water Management District.