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ESTABLISHMENT OF MINIMUM FLOWS AND LEVELS FOR THE WEKIVA RIVER SYSTEM

by

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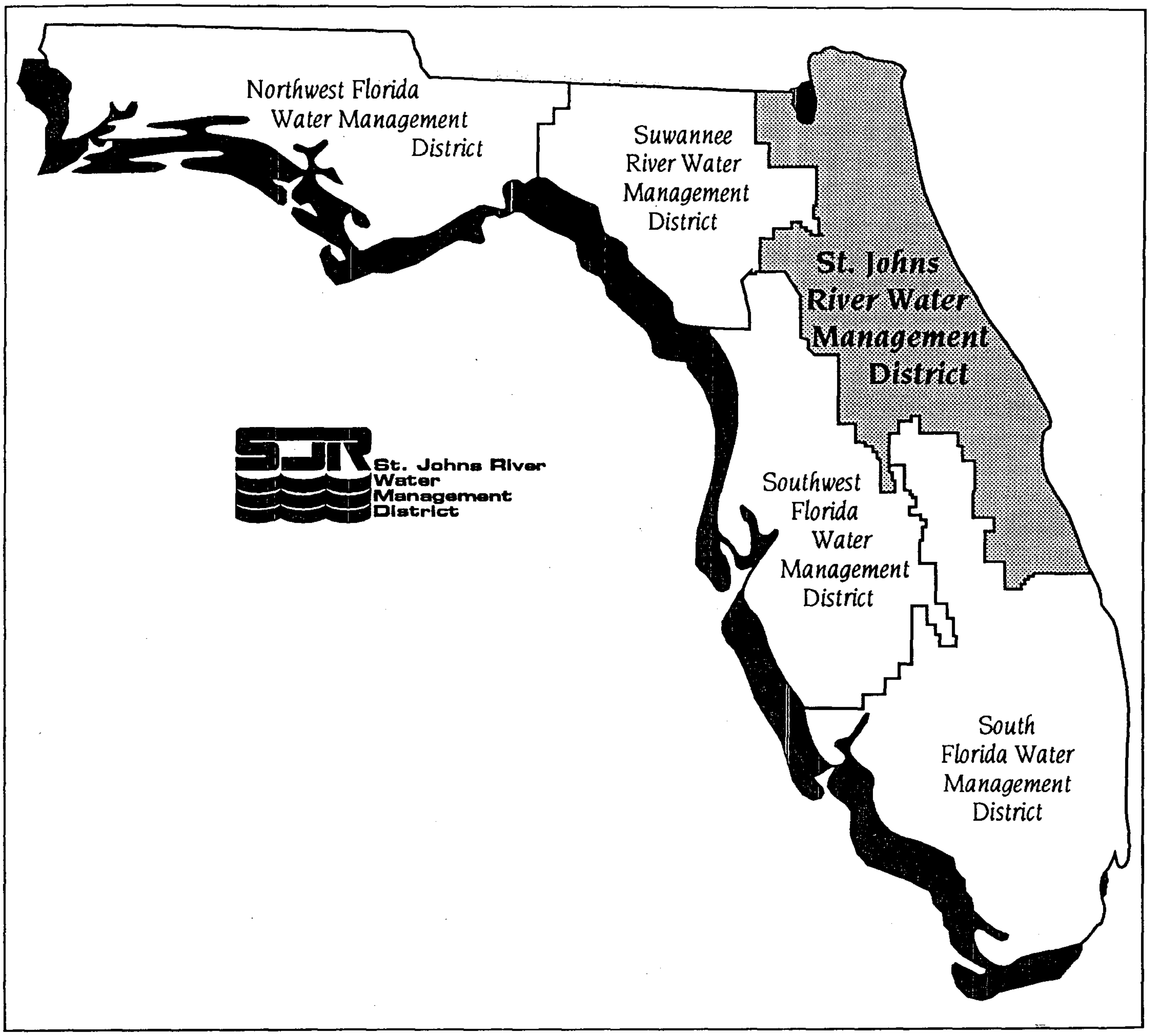

The **St. Johns River Water Management District** (SJRWMD) was created by the Florida Legislature in 1972 to be one of five water management districts in Florida. It includes all or part of 19 counties in northeast Florida. The mission of SJRWMD is to manage water resources to ensure their continued 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

The St. Johns River Water Management District is required by law to establish minimum surface water flows and levels for the Wekiva River System and to establish minimum ground water levels for the Floridan aquifer system within the Wekiva Basin (Paragraph 373.415[3], *Florida Statutes* [*FS*]). The Wekiva River System encompasses six watercourses: the Wekiva River, Little Wekiva River, Black Water Creek, Rock Springs Run, Sulphur Run, and Seminole Creek. Much of the river system is designated as an Outstanding Florida Water and an Aquatic Preserve. The Floridan aquifer system is the primary source of water supply in the Wekiva River surface water basin. The principal reason for establishing minimum levels and flows in the Wekiva Basin was to ensure that flow from artesian springs emanating from the Floridan aquifer system and the base flow of each stream would be adequate to prevent significant harm to aquatic and wetland resources.

Section 373.042, *FS*, directs the Florida water management districts to use best available information to calculate minimum levels, reflecting seasonal variation if appropriate. The State Water Policy gives consideration to environmental values associated with aquatic and wetland habitats, as well as to water quality, recreation, navigation, and the maintenance of freshwater supply. Additionally, minimum flows and levels are to be a consideration for the declaration of a water shortage.

Ecological and hydrological assessments led to the formulation of a surface water minimum flow regime that is monitored at two locations, on the Wekiva River at State Road (SR) 46 and on Black Water Creek at SR 44. A series of four water levels and flows for implementing water use restrictions during droughts was also developed for these locations. The minimum surface water flows were used to determine minimum spring flows needed from eight springs in the basin. Each minimum spring flow was associated with a ground water level (potentiometric surface) necessary to maintain the flow, thereby defining minimum ground water levels at the springs.

The minimum surface water flow regime encompasses five regulatory levels and flows. These define the minimum range within which the streams must fluctuate to conserve the current ecological nature of the system. In practice, this requires that a suitable duration and recurrence interval be associated with each minimum level and flow. Each minimum flow or minimum level and the associated recurrence interval and duration become a hydrologic statistic, a standard, that must not be violated by consumptive uses from an aquifer or the surface water system. Ecological harm likely would result if any minimum level or flow statistic would be violated. Currently, withdrawals are exclusively from the Floridan aquifer system; these withdrawals are most likely to affect base flow characteristics of the streams. However, a minimum flow regime covering a range of flow conditions, from base flows through flood flows, is necessary to test this assumption and to provide guidance should surface water withdrawals be proposed.

The series of minimum levels and minimum flows is referred to as the minimum flow regime and includes the Minimum Infrequent High, Minimum Frequent High, Minimum Average, Minimum Frequent Low, and Minimum Infrequent Low. The minimum flow regime covers a range of flow conditions, from flood flows through base flows. The Minimum Frequent Low flow and Minimum Average flow are necessary for maintaining a desirable level of stream base flow; these flows mark the lower limit of normal base flow. The Minimum Infrequent High and Minimum Frequent High flows and levels should be attained when there is moderately high rainfall over the basin. The Minimum Infrequent Low level and flow should not be exceeded (i.e., should not go below the specified values) even during periods of severe drought. Four additional levels and flows (phased water shortage restrictions) were placed between the Minimum Frequent Low and Minimum Infrequent Low to implement water conservation measures during periods of drought. Water conservation measures should help avoid the occurrence of a Minimum Infrequent Low flow or level and accelerate the recovery of stream flows.

The minimum flows were used with surface water modeling to determine minimum spring flows needed to maintain river base flow. These spring flows were used to calculate a minimum potentiometric surface elevation at each spring location. A regional ground water flow model will be used to assess the effects on spring flow of existing and potential consumptive uses from the Floridan aquifer system. Another surface water model is under development that will predict surface water levels over an extensive portion of the Wekiva River System. The model will be used to determine if minimum levels protect water resources upstream and downstream of the monitoring sites; it should also be valuable for review of permits.

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ACKNOWLEDGMENTS

We wish to thank the individuals and organizations that aided us during this study. The United States Geological Survey contributed the hydrologic data that were analyzed for this report. Barry Birch, Al Kinlaw, and Rosie Mulholland of the Florida Department of Natural Resources provided helpful information about the Wekiva River System and assisted the St. Johns River Water Management District (SJRWMD) in establishing a surface water level observer program at Wekiva Springs. Wekiva Haven Marina and Katies Landing kindly allowed use of their launching facilities on the Wekiva River. Drs. Donthamsetti Rao, Greenville B. Hall, Andrew Lieuwen, Larry Battoe, and Price Robison, P.E., contributed useful suggestions when reviewing drafts of the report. Surface water hydrologic modeling and springflow analysis were performed by Price Robison. Kim Ponzio provided superb GIS map support, and John Hendrickson compiled and summarized water quality data for the Wekiva River System stream reaches as part of the SJRWMD Permanent Monitoring Network. Doug Durden contributed the explanation of how minimum ground water levels for the Floridan aquifer system were derived.

INTRODUCTION

Paragraph 373.415(3), *Florida Statutes* (*FS*) requires the St. Johns River Water Management District (SJRWMD) to establish minimum flows and minimum water levels for surface watercourses in the Wekiva River System. The Wekiva River System is a network of six watercourses: the Wekiva River, Little Wekiva River, Black Water Creek, Rock Springs Run, Sulphur Run, and Seminole Creek (Paragraph 369.303[10], *FS*) (Figure 1). The minimum flow for a watercourse is defined in Paragraph 373.042(1), *FS*, as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." The minimum water level (elevation) is defined as "the level of ground water in an aquifer and the level of a surface water at which further withdrawals would be significantly harmful to the water resources of the area" (Paragraph 373.042[2], *FS*). This technical report describes the procedure used to determine minimum flows and levels at two sites in the Wekiva River System.

SJRWMD is directed to use the best available information to calculate a minimum flow and minimum water level, reflecting seasonal variations when appropriate (Section 373.042, *FS*). The State Water Policy (Section 17-40.405, *Florida Administrative Code* [*F.A.C.*]) addresses minimum flows and levels and requires consideration to be given to the protection of the water resources and ecology, including natural seasonal fluctuations in water flows or levels and environmental values associated with aquatic and wetland ecology. Consideration is to be given to the following:

- Recreation in and on the water
- Fish and wildlife habitats and the passage of fish
- Estuarine resources
- Transfer of detrital material
- Maintenance of freshwater storage and supply
- Aesthetic and scenic attributes
- Filtration and absorption of nutrients and pollutants

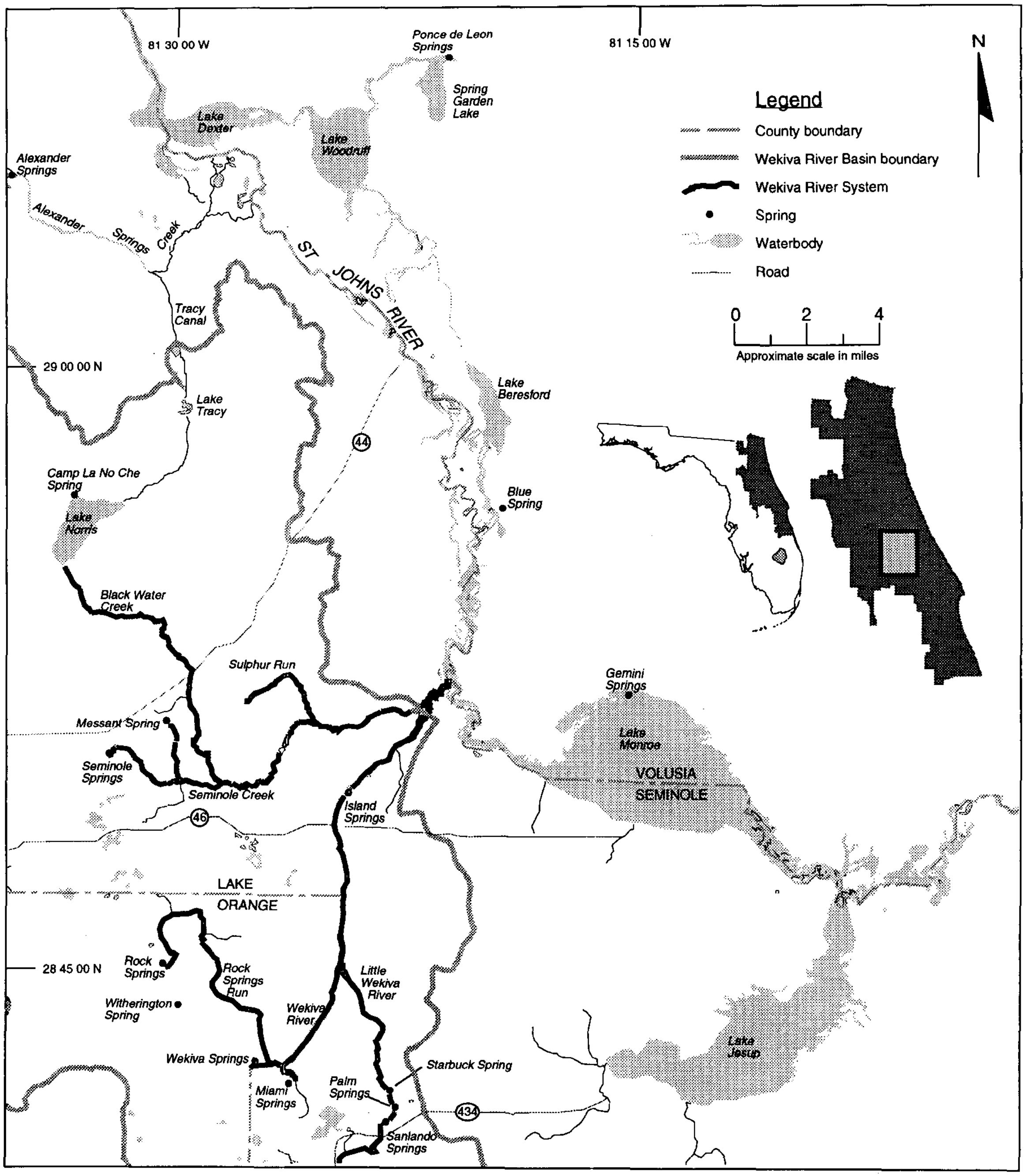

Figure 1. **Wekiva River Basin.** *The Wekiva River System watercourses are the Wekiva and Little Wekiva rivers, Black Water and Seminole creeks, and Sulphur and Rock Springs runs.*

- Sediment loads
- Water quality
- Navigation

This report documents the criteria and methods used to determine minimum flows and levels for the Wekiva River System and a phased series of water use restrictions for the Wekiva River Basin. An important reason for establishing minimum flows and levels was to ensure that flow from the artesian springs emanating from the Floridan aquifer system and the base flow of each stream would be adequate to prevent significant harm to the aquatic and wetland resources. Water is withdrawn from the Floridan aquifer system in the Wekiva River Basin for agricultural and public water supplies; the Floridan aquifer system is the primary source of water supply.

This study had three objectives.

1. To develop a conceptual model for determining minimum flows and levels based on ecological criteria—a model that can be applied to other surface waters in SJRWMD

2. To set minimum flows and levels for the Wekiva River System

3. To recommend a phased series of water levels for the purpose of implementing water use restrictions during drought periods.

WEKIVA RIVER BASIN

The Wekiva River Basin includes the Wekiva River System and other watercourses that ultimately flow to the St. Johns River. This discussion of the study area will include the following:

- Surface water hydrology and classification
- Water quality
- Soils
- Aquatic and wetland vegetation
- Sensitive endemic species

SURFACE WATER HYDROLOGY AND CLASSIFICATION

The Wekiva River Basin occupies approximately 396 square miles (mi^2) in Lake, Seminole, and Orange counties. Surface waters of the Wekiva River and its tributaries are not regulated by locks, dams, or other control structures, nor do they sustain any permitted consumptive use of surface waters. However, the spring flows that maintain stream base flow emanate from the Floridan aquifer system, which is used consumptively.

The Wekiva River Basin contains both spring-fed and blackwater streams. Blackwater streams receive most of their flow from precipitation, which often results in annual over-bank flows during the rainy season. Life on the floodplain and in the river is adapted to, and dependent on, these natural fluctuations (Wharton and Brinson 1978). The waters of blackwater streams are generally soft, acidic, and colored a tea-brown due to dissolved organic matter (Wharton and Brinson 1978). Blackwater streams sometimes stop flowing and may become a series of intermittent pools having depressed oxygen concentrations (0.2–1 milligrams per liter [mg/L]) during periods of low flow (Wharton and Brinson 1978).

Spring runs are perennial watercourses sustained by springs supplied from a deep aquifer—in SJRWMD, the Floridan aquifer.

They are characterized by clear water and a circum-neutral pH (Muller 1990). Flooding is less extensive and hydroperiods are shorter adjacent to spring runs than on floodplains associated with blackwater streams. Rock Springs Run, Sulphur Run, Seminole Creek, the Wekiva River, and the lower reaches of Black Water Creek and the Little Wekiva River are sustained by significant spring flow. Spring-run communities are rated G2 by the Nature Conservancy, meaning that the Conservancy ranks the community globally imperiled. Blackwater communities are rated G4, meaning that they are apparently secure globally (Muller 1990).

Upstream of the confluence with Seminole Creek, the base flow of Black Water Creek is maintained by ground water seepage and a small spring (Camp La No Che Spring) that discharges to Lake Norris. The headwater of Black Water Creek is Lake Dorr, in the Ocala National Forest. Black Water Creek is the longest stream in the Wekiva River System, falling an average of 1.9 feet per mile over 16 miles (mi) between Lake Norris and the Wekiva River. Black Water Creek has an expansive floodplain and a sinuous and braided channel with an abundance of deadwood snags. Springs contribute a considerable portion of the base flow in Black Water Creek downstream of the confluence with Seminole Creek.

Two stream reaches were chosen for study in the vicinities of State Road (SR) 44 on Blackwater Creek and SR 46 on the Wekiva River (Figure 1). These reaches had long-term hydrologic data and physical conditions representative of other stream reaches in the basin. The longest periods of stage and flow records in the basin are from U.S. Geological Survey (USGS) gaging stations. The gaging stations (02235200 and 02235000) are located at the intersections of SR 44 with Black Water Creek and SR 46 with the Wekiva River. These stations have 12-year and 54-year periods of record, respectively. The SR 44 gaging station has a drainage area of 126 mi^2, and the SR 46 station has a drainage area of 189 mi^2. Black Water Creek is a first-order (small sized) stream at the SR 44 gaging location, and the Wekiva River is a third-order (intermediate sized) stream at the SR 46 gaging location. The study areas were in the vicinities of these two gaging stations so that features of the lotic (flowing water) and riparian communities could be compared with hydrologic records. Stage-discharge rating curves for these two locations were obtained from USGS.

A third study reach on Black Water Creek, near Sulphur Run, was selected for future analysis; topographic and vegetational data collection has been initiated and a stage and flow gaging station installed.

WATER QUALITY

The Florida Stream Water Quality Index (WQI) provides a measure of how a stream reach compares with other stream reaches in Florida in terms of water clarity, dissolved oxygen, oxygen-demanding substances, nutrients, bacteria, and macroinvertebrate diversity. WQI scores are good (0–44), fair (45–59), and poor (60–90). The Wekiva River contributes good quality water to the St. Johns River (Hand et al. 1990) (Table 1).

Table 1. Stream reaches and indices of water quality. *See text for explanation of index.*

Reach Location	WQI Value	WQI Rating
Little Wekiva River above Wekiva River	49	Fair
Wekiva Run above Wekiva River	36	Good
Wekiva River above Black Water Creek	40	Good
Black Water Creek above Wekiva River	43	Good
Wekiva River above St. Johns River	42	Good
St. Johns River above Wekiva River	48	Fair

Note: WQI = Water Quality Index
Source: Hand et al. 1990

Lake Norris, Lake Dorr, and the watercourses of the Wekiva River System (excluding the upper Little Wekiva River) have been designated by the state as Outstanding Florida Waters (OFWs).

The lakes and the upper reach of Black Water Creek have less mineralized, more highly colored, and more acidic waters than the Wekiva River due to seepage from an extensive swamp (Table 2). Specific conductance (a measure of the concentration of total dissolved solids [TDS]) and total chlorides (TCl) are elevated compared with Lake Dorr. The difference is likely due to the artesian flow from Camp La No Che Spring into Lake Norris. Nutrient concentrations, especially total phosphorus, are markedly lower in the blackwater lakes and stream reaches compared with the Wekiva River or Wekiva and Rock springs. These data and the accounts provided by Rosenau et al. (1977) indicate that many central Florida springs have inherently high concentrations of nutrients.

The Little Wekiva River has relatively high levels of nutrients (Table 2). A relatively high concentration of TCl and a high specific conductivity are found in the vicinities of the Wekiva Falls Canal (1.4 mi upstream of SR 46) and in the lower Wekiva River downstream of Wekiva Falls Canal. Wekiva Falls Canal contains two flowing wells that contribute to the high chloride concentration in this reach of the Wekiva River. Water quality data from area wells indicated that the Upper Floridan aquifer underlying the portion of the Wekiva River Basin downstream of the Little Wekiva River contains a zone of connate water with chloride concentrations greater than 250 mg/L (Toth et al. 1989). Connate water (water trapped in the rocks during deposition) typically has high concentrations of chlorides and TDS and is generally located in discharge areas (Toth et al. 1989). Therefore, ground water flow entering the Wekiva River downstream of the Little Wekiva River contains higher concentrations of minerals than upstream ground water sources.

Springs do not contribute appreciably to the flow of the Little Wekiva River until approximately 3 mi upstream from its

Table 2. Water quality data from springs and stream reaches within the Wekiva River System. *The table compares the average of seasonal medians to typical water quality values of Florida streams and lakes.*

Locations in the Wekiva River System	Water Quality Parameter Values								
	DO (mg/L)	pH	Color (PTU)	Sp Cond (µmhos/cm)	TCl (mg/L)	TP (mg/L)	NO_x (mg/L)	TKN (mg/L)	Chlα (µg/L)
Lake Dorr	7.6 (6)	5.3 (7)	111 (6)	57 (6)	10.9 (5)	0.008 (4)	--	0.666 (4)	2.6 (4)
Lake Norris	7.1 (2)	6.9 (2)	275 (2)	250 (2)	18.5 (2)	0.019 (2)	0.143 (1)	1.065 (2)	5.3 (2)
Black Water Creek near SR 44	5.7 (8)	6.6 (10)	--	126 (10)	15.0 (10)	0.102 (10)	0.065 (10)	0.850 (10)	--
Wekiva Springs near Apopka	0.5 (11)	7.3 (17)	5 (1)	265 (30)	12.5 (19)	0.117 (13)	1.433 (21)	0.207 (14)	--
Rock Springs	0.4 (1)	7.5 (10)	--	248 (14)	10.3 (13)	--	1.617 (7)	--	--
Wekiva River: Wekiva Springs to Sweetwater Canal	5.1 (13)	7.0 (10)	--	253 (11)	9.8 (5)	0.107 (10)	1.085 (11)	0.410 (11)	--
Wekiva River: Sweetwater Canal to Little Wekiva River	5.3 (25)	7.2 (20)	--	263 (22)	12.3 (11)	0.121 (20)	0.942 (22)	0.432 (22)	--
Little Wekiva River upstream of Sanlando Springs	6.3 (66)	7.3 (68)	31 (39)	274 (77)	23.8 (40)	0.440 (71)	1.358 (75)	0.983 (75)	2.3 (26)
Little Wekiva River downstream of Sanlando Springs	5.7 (35)	7.3 (32)	--	279 (38)	16.7 (17)	0.294 (31)	0.748 (36)	0.663 (36)	--
Wekiva Falls Canal	6.4 (9)	7.4 (8)	--	1259 (9)	300.2 (3)	0.077 (8)	0.263 (9)	0.233 (9)	--
Wekiva River: Little Wekiva River to St. Johns River	6.5 (72)	7.5 (55)	52 (11)	629 (64)	124.7 (49)	0.156 (65)	0.613 (68)	0.470 (68)	1.2 (10)
Median value for Florida streams†	5.8	7.2	70	366	*	0.11	**	**	5.5
Median value for Florida lakes†	8.0	7.4	60	188	*	0.07	**	**	18.5

Note:
DO = dissolved oxygen
Sp Cond = specific conductivity
TP = total phosphorus
TKN = total Kjeldahl nitrogen
mg/L = milligrams per liter
µg/L = micrograms per liter
PTU = platinum-color unit
TCl = total chloride
NO_x = nitrite + nitrate
Chlα = chlorophyll α
µmhos/cm = micro-ohms per centimeter
-- = not applicable

The raw data were compiled by Hendrickson and Howe from the STORET data base and unpublished data collected by SJRWMD. Numbers in parentheses indicate sample size.

†From Friedemann and Hand 1989. Values are the 50th percentile of annual median values from 2,700 stream and 1,000 lake sample sites in Florida, 1970-87.
*Not computed
**The 50th percentile for TN was 1.2 mg/L in streams and 1.4 mg/L in lakes. TN is equal to TKN+NO_x.

confluence with the Wekiva River. The Little Wekiva River receives the flow from Sanlando, Palm, and Starbuck springs in this reach (downstream of SR 434). Upstream of these springs, ground water contributes much less to flow than do stormwater runoff and discharges from the Altamonte Springs Regional Wastewater Treatment Facility (ASRWTF) and the Weatherfield sewage treatment plant (Canfield and Hoyer 1988). These wastewater facilities discharge approximately 4.2 million gallons per day (mgd) and 0.5 mgd, respectively, to the Little Wekiva River (Jessica Phillips, Florida Department of Environmental Regulation [FDER], pers. com. 1990). The Little Wekiva River upstream of SR 434 was not designated an OFW because the Wekiva River Basin is highly urbanized, stormwater treatment systems do not exist for some developments, and sections of the river have been channelized.

The largest point source on the Little Wekiva River is ASRWTF. The plant began operation in the mid-seventies and replaced several smaller, obsolete treatment facilities. This greatly improved the dissolved oxygen concentration in the river by reducing the biological oxygen demand loading from previous levels (Hand et al. 1990). Nutrient and bacteria concentrations remain high but are diluted downstream by Starbuck, Palm, and Sanlando springs and are then diluted again by the Wekiva River.

The City of Altamonte Springs initiated a reuse program in October 1989. Currently, the average daily waste load processed at ASRWTF is approximately 6.2 mgd, of which 4.0–4.5 mgd is directed to the Little Wekiva River and the remainder is reused in the city (Rick Hosier, ASRWTF, pers. com. 1991). Ultimately, the waste load from this plant is expected to be 12.5 mgd, of which 10 mgd will be reused within the city and 2.5 mgd will be discharged to the Little Wekiva River (Jessica Phillips, FDER, pers. com. 1990).

Studies by McClelland (1982a, 1982b) pertaining to the wasteload allocation for the Little Wekiva River did not substantiate that the nutrients were causing an imbalance in natural populations of flora or fauna in the river. McClelland (1982b) concluded that no technically defensible relationship between point sources and the abundance of aquatic weeds was discernible. Canfield and Hoyer (1988) found that anthropogenic discharges were responsible for a significant nutrient enrichment and changes to the general stream chemistry of the Little Wekiva River, but they found no evidence that the distribution or abundance of aquatic plants was related to nutrient enrichment. Their study suggested, however, that a cumulative impact of anthropogenic-based nutrients may occur downstream of the Wekiva River in the St. Johns River, where current velocities slow considerably and light is not a limiting factor. Canfield and Hoyer (1988) found that the distribution and abundance of aquatic macrophytes in small Florida streams are controlled by physical factors such as substrate quality, current velocity, and shading.

SJRWMD performed linear regression analyses on water quality data to determine if water level or stream flow could be used as a predictor of nutrient concentrations at times of low flow. Identifying a strong relationship between nutrient concentrations and low flows would be useful if numerical loading or concentration criteria were developed. Data were collected during low-flow conditions from the Wekiva River at SR 46 during the period 1973–90; data were available for 17 samples taken when the water level was less than the median level of the 54-year period of record. Neither water level nor flow proved to be a good predictor of concentrations of total phosphorus (r^2 = 0.02 and 0.01, respectively, where r^2 is the coefficient of determination). Water level was a better predictor ($r^2 = 0.3$) of NO_x (nitrite [NO_2] + nitrate [NO_3]) than was flow ($r^2 = 0.03$). Although the relationship between NO_x and water level was significant ($p = 0.019$, where p is the observed significance level for a hypothesis test), it is not sufficient to determine minimum levels. The preceding information leads us to conclude that water quality is not affected sufficiently by flow rates to influence our determination of minimum flows.

SOILS

Floodplain soils in the study area are defined as hydric in Section 16.1.2 (Soils Index) of the SJRWMD Management and Storage of Surface Waters Applicant's Handbook. These soils typically develop on sites that are saturated or inundated for 30 or more consecutive days a year. Adjacent to Black Water Creek are Anclote and Myakka (Am) soils, which are very poorly drained, hydric, sandy soils usually found in low, large depressions and poorly defined drainage ways (SCS 1975). The Am soil complex had an organic surface layer.

In the study area, the west bank of the Wekiva River is within Lake County and the east bank is within Seminole County. In Lake County, the floodplain is composed of an Iberia and Manatee (Im) soil, a very poorly drained sandy clay soil with a high shrink-swell potential (SCS 1975). In Seminole County, the floodplain is composed of Sandy Alluvial Land (Sn), which varies in texture but is subject to frequent overflow (SCS 1990). Some areas overlie a non-hydric soil, Myakka and Placid (MpC) sands, with 2–8 percent slopes. This soil occurred at the highest areas of a hydric hammock plant community. The MpC soil is described as a gently sloping to sloping, poorly or very poorly drained soil in seep areas that slope toward natural drains (SCS 1975).

AQUATIC AND WETLAND VEGETATION

Brown and Schaefer (1987) classified forested riparian wetland habitats in the Wekiva River Basin into two major types: mixed hardwood swamp and hydric hammock communities. Evergreen-dominated bayheads and cypress swamps also occur in some areas. Mixed swamps are typically composed of a combination of pop ash (*Fraxinus caroliniana*), red maple (*Acer rubrum*), swamp gum (*Nyssa sylvatica* var. *biflora*), sweet gum (*Liquidambar styraciflua*), bald cypress (*Taxodium distichum*), and cabbage palm (*Sabal palmetto*) (Monk 1966). Florida elm (*Ulmus americana* var. *floridana*), water oak (*Quercus nigra*), swamp laurel oak (*Quercus laurifolia*), water hickory (*Carya aquatica*), and sweet bay (*Magnolia virginiana*) may be locally important in some stands (Monk 1966).

The term "hydric hammock" describes a diverse assemblage of forested communities, ranging from nearly monospecific stands of cabbage palms to species-rich hardwood forests (Vince et al. 1989). The following information regarding hydric hammocks is from an extensive compilation of data by Vince et al. (1989). The Wekiva Springs hydric hammock community has fewer live oak (*Quercus virginiana*) trees and more cabbage palm, swamp laurel oak, red maple, and sweet bay trees than other hydric hammock sites in Florida. The numerous bay trees, needle palms (*Rhapidophyllum hystrix*), and cinnamon ferns (*Osmunda cinnamomea*) at the Wekiva Springs hydric hammock suggest a relatively constant moisture regime. Hydric hammocks differ from bayheads and mixed swamps in that the water table is generally below the ground surface. Mixed swamp communities experience river overflow; bayhead communities occur where seepage is constant.

Submersed beds of aquatic plants in the Wekiva and Little Wekiva rivers, Rock Springs Run, and Seminole Creek form a productive community of considerable importance to the stream biota. In the Wekiva River, eelgrass (*Vallisneria americana*) is the dominant aquatic vascular plant species. In 1990, there were approximately 23 acres of eelgrass in the Wekiva River and approximately 6.3 acres of eelgrass in Rock Springs Run and the Little Wekiva River (Robert Kipker, Department of Natural Resources [DNR], Bureau of Aquatic Plant Management, pers. com. 1991). These values are for comparative purposes, based upon 100 percent plant coverage of the acreage. The actual coverage of eelgrass in a stream is often less than 100 percent and, therefore, is dispersed over many more acres of stream bottom.

SENSITIVE ENDEMIC SPECIES

There are 60 designated plant and animal species believed to frequent or occur within the Wekiva River Basin (Brown and

Schaefer 1987, Table A-6). The term "designated species" means a species is designated by one or more conservation agencies to a specific category of biological vulnerability. Brown and Schaefer (1987) was consulted to determine the aquatic species that potentially occur in the river system that are considered rare, as defined below.

Rabinowitz et al. (1986) classified biological rarity based on geographic distribution, habitat specificity, and local population size. The most sensitive species occur over a small geographic area and have narrow habitat requirements and small local populations. For these reasons, we considered the spring pool vicinities as the habitat for a biologically rare group of aquatic species.

Snails of the family Hydrobiidae are endemic to the immediate vicinities of several spring pools in the Wekiva River Basin (Thompson 1982). Maintaining spring flows for these species as well as for downstream aquatic communities was a consideration in this study. Several aquatic species of snails endemic to Wekiva River Basin springs have narrow habitat requirements, and they are relatively immobile. These snails are *Cincinnatia wekiwae* (Wekiwa silt snail), which is found at Wekiva Springs; *C. petriphons* (Rock Springs silt snail); *C. ponderosa* (ponderous silt snail), which occurs at Sanlando Springs; and *C. vanhyningi* (Seminole silt snail), found at Seminole Springs (Fred Thompson, Florida Museum of Natural History, pers. com. 1991). The Wekiwa Springs hydrobe snail (*Aphaostracon monas*) occurs in mats of aquatic plants and on submerged rocks in the upper spring run no farther than about 1 mi downstream of Wekiva Springs (Thompson 1982). The Rock Springs silt snail does not have a designated status with conservation agencies. The other snails are currently listed by the U.S. Fish and Wildlife Service as C2, a designation for candidates that show some evidence of vulnerability but lack sufficient data to support listing under the Endangered Species Act (Wood 1991).

Two other designated aquatic species also should be mentioned. The Orlando cave crayfish (*Procambarus acherontis*, designated C2), an endemic subterranean crayfish, has been observed on the pool bottom of Palm Spring (Little Wekiva River) and in several wells around Lakes Long and Brantley in the Orlando area, but only rarely (Franz 1982). The bluenose shiner (*Notropis welaka*) has been collected from the Wekiva and Ocklawaha rivers (Gilbert 1978) and occurs in the St. Johns River Basin. This population is disjunct from the panhandle population, where the fish is considered common. The bluenose shiner occurs in the deeper pools and holes of streams, often in quiet, weedy waters (Gilbert 1978). The Florida Game and Fresh Water Fish Commission lists the bluenose shiner as a Species of Special Concern.

There are no published studies defining the physical or chemical habitat requirements of the seven invertebrate species mentioned above. Consideration was given to whether a minimum stream flow resulted in minimal flow, no flow, or a dry spring at the locations whhere the Hydrobiid snails occur.

MINIMUM FLOWS AND LEVELS CRITERIA DEVELOPMENT

Setting multiple minimum levels and flows, rather than a single minimum level and flow, recognizes that lotic systems are inherently dynamic. Stalnaker (1981) advocated the abandonment of the "minimum flow" in favor of sound biological habitat criteria and a multiple flow regime. A single minimum level or flow allows consumptive users to withdraw or withhold the volume of water above the minimum without violating the standard. Experiences in the western United States have shown that as water becomes fully appropriated by upstream users or allocated to storage, frequently the minimum flow is violated or tends to become the average flow condition (Stalnaker 1990). At Lake Washington (Florida), a lentic system used as a public water supply, Hall (1987) recommended that a lake-level fluctuation range was necessary to conserve lake and wetland resources. Techniques were employed in the present study to define a minimum typical (average) flow and water level and a fluctuation range that conserves the water resource. Statistics were associated with the minimum flows and levels to define the minimum flow regime spatially and temporally.

The following subsections provide a conceptual basis for developing a minimum flow and level fluctuation regime. The conceptual basis focuses on the ecology of the water resource.

NEED FOR MINIMUM FLOOD LEVELS AND FLOWS

Conservation of riparian wetlands requires that a minimum level and flow regime include a range of flows resulting in inundation of the floodplain. Flood flows are necessary to deposit the sediment that allows the floodplain-forming process to occur (Hill et al. 1991). Lotic and wetland biota rely upon inundation of the floodplain for habitat and for the exchange of nutrients and organic matter (McArthur 1989).

Floodplains are a significant source of particulate organic matter for low-gradient blackwater rivers. Annual particulate organic matter imported from riparian floodplains supports a major portion of the bacterial biomass that is an important food source for instream invertebrate collector-gathering and collector-filtering guilds (Cuffney 1988). Alterations to the stream that restrict the quantity or change the quality of this material will affect the diversity and stability of the stream biota (McArthur 1989).

The life cycles of many fishes are related to seasonal water level fluctuations, particularly the annual flood pattern (Guillory 1979). The floodplain provides feeding and spawning habitat (Guillory 1979; Ross and Baker 1983) and a refugium for juveniles (Finger and Stewart 1987). Stabilization of water levels was implicated as the reason for low densities or absences of flood-exploitative fish species in an altered stream reach (Finger and Stewart 1987). At least 22 of the 48 species of fish (46 percent) occurring in the Wekiva River Basin are species that exploit inundated floodplains.

The species composition and structural development of floodplain forest communities are influenced by the timing and duration of floods occurring during the growing season (Huffman 1980). Floods affect reproductive success as well as plant growth. Schneider and Sharitz (1986) reported that short-term floods of relatively high discharge, occurring after seed-fall, scoured the seeds of mixed hardwood bottomland shrubs and trees from the soil surface and dispersed them downstream. Black Water Creek has a high-energy type floodplain that is, in this respect, similar to the floodplain studied by Schneider and Sharitz.

NEED FOR AN INTERMEDIATE LEVEL AND FLOW

An intermediate, typical, water level and flow is needed to maintain the water table, on average, near the surface of the floodplain. Topographic gradients result in a complex continuum of hydrologic and soil (edaphic) factors across the stream and the associated floodplain. A critical point on the topographic gradient occurs at the elevation where anoxic soil conditions prevail for sufficient periods to exclude upland plant species. Plants and soils at or below this elevation require saturation of the upper soil horizon for a significant portion of each year. However, constant flooding of wetlands is inappropriate. The seeds of many species of wetland plants require an unflooded soil surface for germination (Van der Valk 1981).

Studies in the Everglades demonstrated that the oxidation of peat soils occurred when the water table was more than 0.25 feet (ft) below the wetland surface for extended periods (Stephens 1974). Management-related studies in marshes of the upper basin of the St. Johns River determined that this water table depth corresponded to approximately the water level exceeded 60 percent of the time over a long period, that is, the 60th percentile of a long-term stage-duration curve (Brooks and Lowe 1984; Hall 1987).

In the Corkscrew Swamp region of the Everglades, wetland plant communities occur where the average annual hydroperiod is greater than 219 days per year, which is approximately 60 percent of each year (Duever et al. 1978). The term "average annual hydroperiod" refers to the average number of days per year that the average elevation of a plant community was inundated by surface water flooding. Twenty wetland sites, including marshes, cypress swamps, and willow swamps, had hydroperiods averaging between 224 and 296 days per year during a 14-year period (Duever et al. 1978). Wet-prairie species occupied several sites, with hydroperiods averaging between 45 and 155 days per year; however, these areas were dominated by wax myrtle (*Myrica cerifera*), a facultative plant species (Duever et al. 1978). Duever et al. did not note whether rainfall amounts were typical during the 14-year period that hydrologic data were collected compared with longer periods of record.

SIGNIFICANCE OF LOW LEVELS AND FLOWS

Aquatic Habitat Degradation

Low flows result in water levels that may degrade the aquatic habitat in portions of the river system. The most susceptible habitat occurs in the shallowest reaches of the stream, particularly where eelgrass is abundant. The stream flora and fauna are affected by the extremeness of the low flow, the duration of the event, and the frequency at which it occurs.

Eelgrass occurs in many of the riffle areas, shallow pools, and on the sides of deeper pools in the Wekiva River, Little Wekiva River, Rock Springs Run, and Seminole Creek. Beds of eelgrass serve as foraging areas for fish, turtles, and ducks (Korschgen and Green 1988). The roots and stolens reduce erosion and facilitate colonization by benthic algae and invertebrates; the foliage offers shelter and support and enriches the oxygen content of the water during the day (Korschgen and Green 1988).

In the Silver River of Florida (a spring run), spring-tape (*Sagittaria lorata*) forms beds similar in structure to those of eelgrass beds occurring in the Wekiva River. A variety of encrusting algae, diatoms, bacteria, and minute herbivorous and carnivorous animals, known collectively as the aufwuchs, grow on the leaves of spring-tape (Odum 1957). Odum found that the algal component of the aufwuchs accounted for about 23 percent of the entire instream, autotrophic, dry-weight biomass of the Silver River. Although not quantified, observations suggested that the eelgrass aufwuchs communities in the Wekiva River was as important to the food chain as that of the Silver River. Very low water levels might result in desiccation of the aufwuchs, eelgrass, and other aquatic plants or, in some areas, the replacement of grass beds by cattails (*Typha* spp.).

Frequent canoeing or motorboating during low flows in shallow areas having eelgrass beds may damage the plants. Canoes are the predominant recreational craft on the Wekiva River and Rock Springs Run.

A preliminary study conducted in the Wekiva River in 1990 by DNR indicated that damage to eelgrass beds from canoes was not extensive, occurring over less than 5 percent of the river (see appendix). Kinlaw reasoned that paddle-gouging of the grass beds is most likely to happen when three conditions occur simultaneously: (1) the water depth is about 20 inches (in.) or less, (2) the substrate is muck or silt, and (3) canoe traffic is heavy. During the preliminary study, boat propeller damage was observed in several shallow areas.

Fish Passage

Few studies have documented the minimum water depths necessary to maintain passage for fish. The term "passage depth" refers to the minimum water depth an organism requires to navigate safely a stream channel. As a result of several studies (discussed below), scientists have suggested guidelines for fish passage based on body dimension measurements of several species of adult fishes. However, no studies have determined the number of shallow obstructions that may be negotiated by fish before a serious reduction of health occurs.

Thompson (1972) (as cited by Mosley 1982 and Stalnaker and Arnette 1976) reported on passage flows for adult salmonoid fishes. Passage flows in coldwater streams are often based upon minimum passage depths and maximum allowable velocities. Passage depths of 0.8 ft for Chinook salmon and 0.6 ft for large trout were calculated by Thompson based upon body dimensions. Thompson (1972) recommended that the passage depth criterion be met over at least 25 percent of the stream width and that the critical depth occur over a continuous portion occupying at least 10 percent of the overall stream width. Stalnaker and Arnette (1976) stated that this method was adequate, but believed that more verification studies were necessary, especially in warmwater streams.

Recovery Mechanisms

Although spring-fed and blackwater stream reaches differ, the biota of both stream types are expected to recover from severe low-flow conditions, provided minimum habitat requirements remain available. Biological refugia, dispersal mechanisms, and physiological adaptations have been implicated as determinants of stream recolonization rates following pulsed disturbances such as droughts. These characteristics confer ecological resilience to the stream ecosystems.

Important site characteristics affecting recovery rates are the presence of barriers to migration and biological refugia. Direct access to unchannelized receiving streams, unchannelized tributary streams of equal stream order or equivalent size, or unmodified stream sections within sizable channelization projects are examples of refugia (Griswold et al. 1982). Organism-specific factors affecting fish population recovery rates depend on family (e.g., Centrarchidae), reproductive guild, and size at first reproduction (Detenbeck et al. 1992). These three factors have a bearing on how frequently a population of organisms can endure a low-flow period for a given duration. Benthic invertebrate species occupying riffle substrates in permanent and intermittent streams have generalized adaptations to dry-down conditions such as high rates of migration, drought-resistant eggs, and the ability to take refuge below the surface of the stream substrate (Delucchi 1988). Recovery times following pulse disturbances cannot be predicted accurately because they are a complex function of disturbance-, site-, and organism-specific factors (Detenbeck et al. 1992).

CRITERIA FOR MULTIPLE MINIMUM LEVELS

A series of five minimum flows and levels was selected to comprise a surface water minimum flow regime (Figure 2). These criteria are as follows.

- Minimum Infrequent High
- Minimum Frequent High

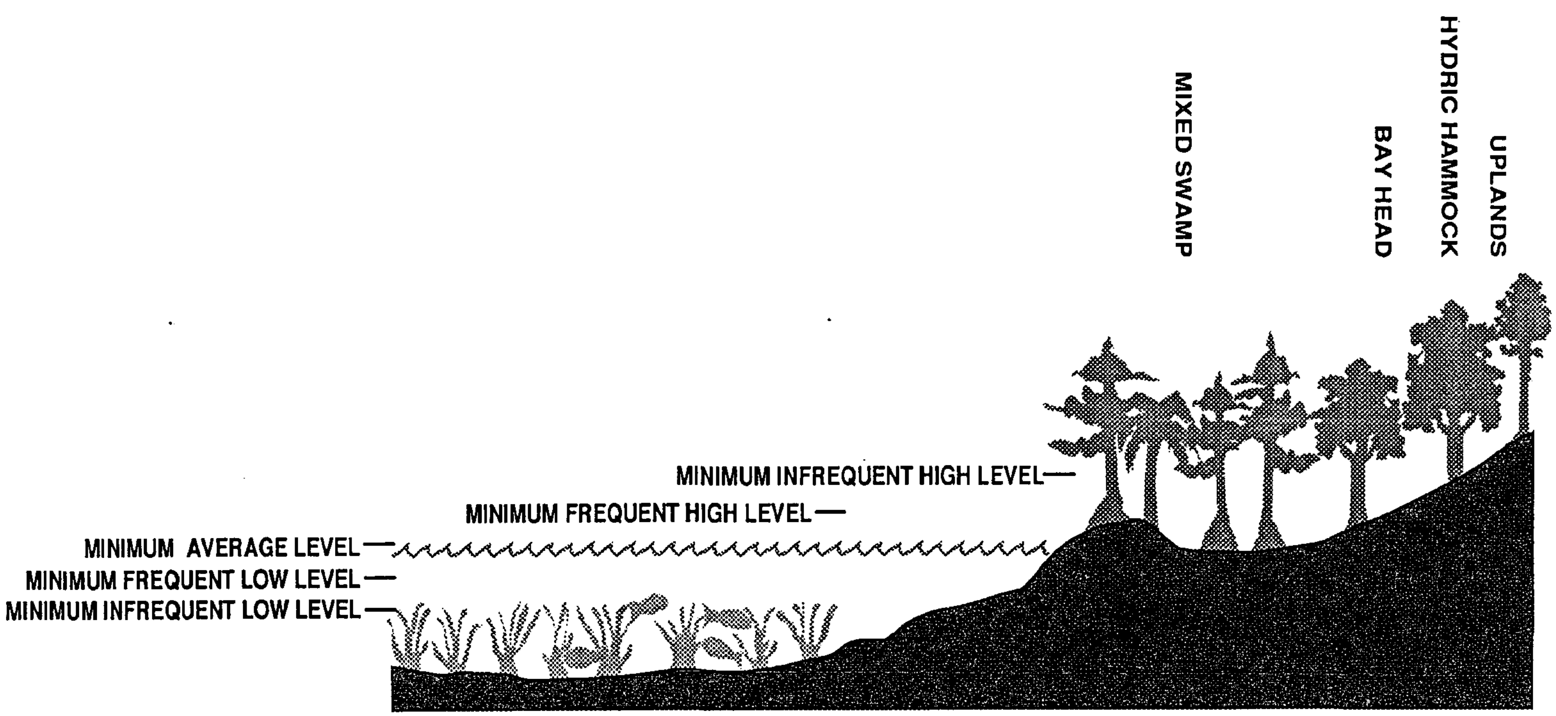

Figure 2. Schematic of a surface water ecosystem outlining the multiple minimum levels approach

- Minimum Average
- Minimum Frequent Low
- Minimum Infrequent Low

A minimum flow regime defines the range within which the stream must fluctuate to conserve the ecological attributes of the stream system. In practice, this requires that a suitable duration and recurrence interval be associated with each level or flow. Each minimum flow or minimum level and the associated recurrence interval and duration become a hydrologic statistic, a standard, that must not be violated by consumptive uses. Currently, withdrawals are exclusively from the Floridan aquifer system; these withdrawals are most likely to affect base flow characteristics of the streams. A minimum flow regime covering a range of flow conditions, from base flows through flood flows, is necessary to test this assumption and to provide guidance should surface water withdrawals be proposed.

A minimum level, minimum flow, and two associated temporal statistics are recommended to meet each of the criteria. The minimum high flows and levels (Minimum Infrequent High and Minimum Frequent High), must be equalled or exceeded no less frequently than stated, for a minimum period of consecutive days. In contrast, the low flows and levels (Minimum Average, Minimum Frequent Low, and Minimum Infrequent Low) should not occur more frequently or for longer durations than stated.

Minimum Infrequent High

The Minimum Infrequent High level and flow must inundate the riparian wetlands and recur at a frequency that is sufficient to support important ecological processes such as the transport of sediment, detritus, nutrients, and propagules. This does not require flooding upland plant communities.

Minimum Frequent High

The Minimum Frequent High level and flow must serve the needs of stream biota that utilize the floodplain habitat for feeding, reproduction, and refugia. Flooding should be of sufficient magnitude and frequency to maintain the floodplain plant community structure and composition adapted to periodic inundation. This level and flow should occur annually or biannually for a duration of several weeks.

Minimum Average

The Minimum Average level and flow is considered the minimum that must be sustained for extended periods to maintain riparian hydric soils and to impede the encroachment of upland plant species into the wetland plant community. Typical recreational uses of the stream should be unimpaired at this level and flow.

Minimum Frequent Low

The Minimum Frequent Low level and flow is the minimum that can occur during mild droughts. When this water level and flow does not occur too frequently, there is no significant harm to lotic and floodplain communities and the drawdown condition required for regeneration by many floodplain plant species is provided. This level may impair some recreational potential of the stream.

Minimum Infrequent Low

The Minimum Infrequent Low level and flow is a very low and infrequent level and flow that may occur during an extreme drought. Significant ecological impacts may occur rapidly if the water level and flow fall below the specified values or occur more frequently or for durations longer than specified. This level and flow must not be so frequent or of so long a duration (as a result of man's activities) that the system is not expected to readily recover.

METHODS

Physical features of the instream and wetland biotic communities were examined to determine the minimum levels required to fulfill each of the criteria. Mean floodplain elevation, eelgrass bed elevations, and hydraulic control elevations within the channel are some examples of important physical features. Next, consideration was given to the duration and recurrence interval most relevant to the biological events a criterion was intended to protect. These were formulated by consensus among the project biologists. The biological literature and frequency analysis of the stage and flow data were considered to formulate an acceptable recurrence interval for each level of a given duration.

For example, a flood flow and level that occurs for a minimum of 30 consecutive days on an average of every 2 years was chosen as a temporal statistic for the Minimum Frequent High level and flow. Flood flows occurring frequently for extended periods were considered important to the population biology of floodplain-exploitative fish. Many southeastern stream fishes have short life spans of 2–7 years, except centrarchids (bass and sunfishes), which may live for more than 10 years (Ross 1990). Floodplain-exploitative species must be given numerous opportunities during their lives to access the floodplain. The timing and duration of flooding is not always at an optimum from year to year for reproductive success. Knight et al. (1991) recommended that an extended period of flooding (2–3 months) provides sufficient time for stream fish to access the floodplain. In wet years, this period may be exceeded, and in dry years it may not occur; fish are adapted to year-to-year variation of the natural hydrologic regime. We chose a flood flow frequency that takes into account the short lifetimes of forage fish and a duration that is greater than a month, when the flood duration and the flood recession rates are both considered. Floods of lesser and greater magnitude also will occur as rainfall dictates, since the Wekiva River System is unregulated.

DETERMINATION OF MINIMUM LEVELS: THRESHOLD TRANSECTS

There is no singular best way to perform an analysis of instream flow requirements; consideration must be given to management objectives, available data, and economic and time constraints (Lamb 1989). Instream flow refers to the flow regime required in a stream for all of the individual and collective instream uses of water, including boating, hydroelectric production, recreation, aesthetics, fish and wildlife requirements, and maintenance of water quality (Stalnaker and Arnette 1976). Determining minimum flows and levels is one use of instream flow analysis.

Threshold methods are a form of instream flow analysis that examines key habitat variables along stream cross sections at locations that are first affected by declining stage or flow (Cuplin and Haveren 1979). The threshold transect method is considered an intermediate-level instream flow analysis method, in terms of biological and physical data requirements (Cuplin and Haveren 1979). Annear and Conder (1984), in a comparative study of instream flow methods, concluded that the threshold transect method can produce unbiased results by using data from either the most restrictive transect or an average of the transects located in riffle habitats (shallow stream segments).

An assumption of the threshold transect method is that a defined flow is as adequate for the rest of the stream as it is for the study reach (Annear and Conder 1984). To verify this assumption, a HEC-2 hydraulic model will be developed in the future for Black Water Creek, Seminole Creek, the Wekiva River, Rock Springs Run, and the lower Little Wekiva River (Figure 3). Sulphur Run does not contribute enough flow (approximately 1 cubic foot per second [cfs]) to warrant inclusion in the model. The model was designed by the U.S. Army Corps of Engineers (USACE) to calculate water surface profiles for steady, gradually varied flows in channels.

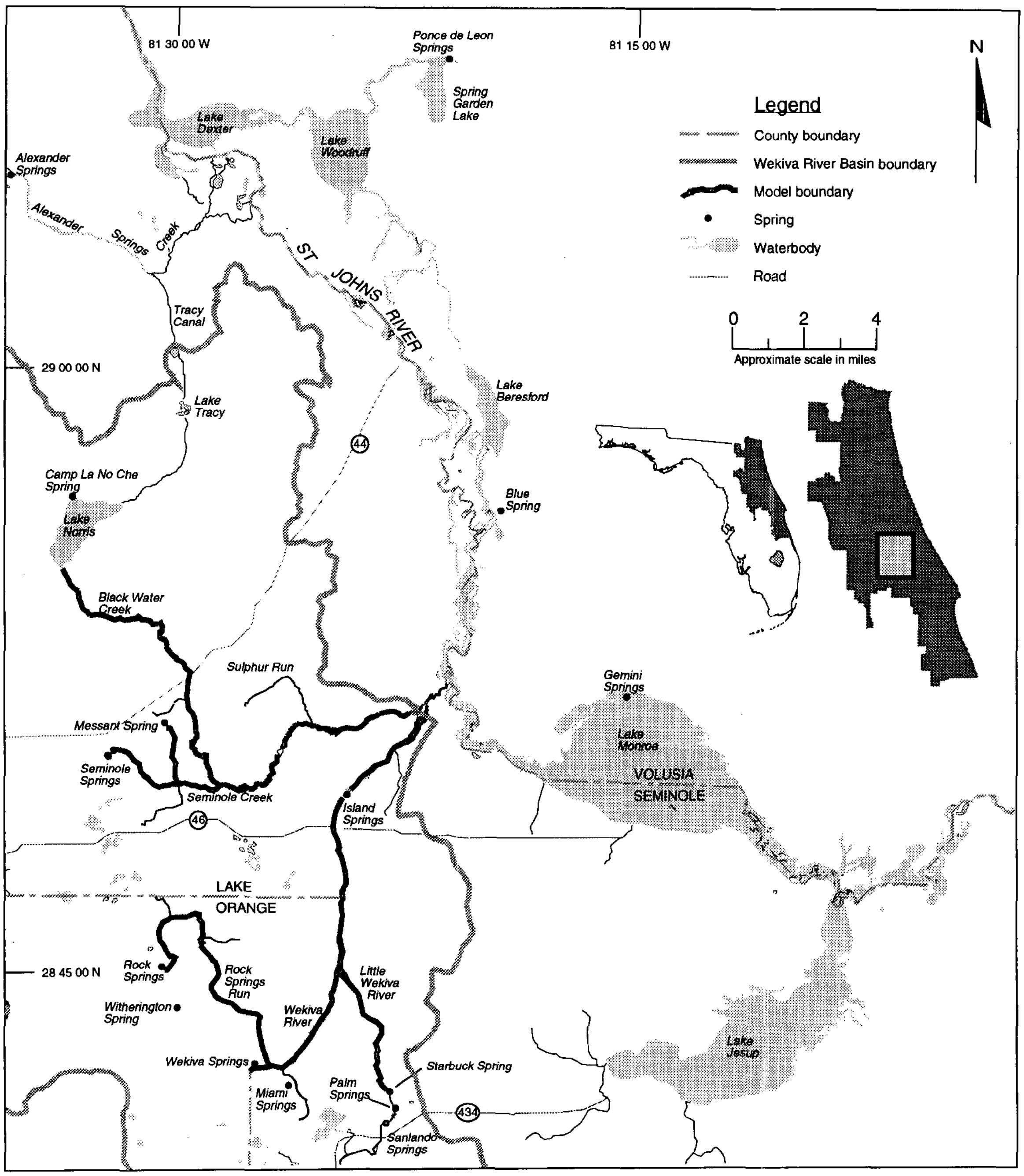

Figure 3. Surface water hydraulic model (HEC-2) boundaries for the Wekiva River System

Eight threshold transects were chosen at strategic locations within the Wekiva River System (Figure 4). Surveyors determined elevations on two threshold transects ("transects") across the Wekiva River, one downstream (#4) and one upstream (#5) of the SR 46 bridge and USGS gaging station. Three transects (#1–3) were surveyed on Black Water Creek downstream of the SR 44 gaging station. All transects were located within 0.3 miles of a gaging station location. Data were collected also at three transects (#6–8) on the lower part of Black Water Creek in the vicinity of a proposed gaging station but were not used for the current study (see page 6). All transects were considered strategic sampling sites because they were located in riffles judged the most restrictive in terms of water depth and eelgrass coverage. Riparian floodplain plant communities at the transect locations were representative of the major types found elsewhere in the system. Reconnaissance for potential transect sites and most of the data collection occurred in the fall of 1990 during a drought when stream levels had receded to a 1-in-25-year low level.

The difference in water surface elevation between a transect location and a hydrologic reference (gaging station) location was used to correct for the bed slope of the watercourse, that is, a normalizing factor to allow the water level at the gaging station to be compared with the elevation of features of the channel or floodplain at upstream or downstream locations. The following information was usually obtained from each transect: the upper (landward) and lower (waterward) boundary elevation of the riparian wetland; the density and basal area of the upper plant stratum; the mean elevation of each plant sampling plot; elevations of waterline stains on several tree trunks; cross-section profile of the stream channel; presence of submerged grass beds; and the mean, standard deviation, and elevation range of the substrate associated with the grass beds.

The transects were positioned perpendicular to the direction of stream flow and extended landward to the upland edge of the riparian wetland. The interval at which instream elevations were taken at each transect varied according to the stream width. For

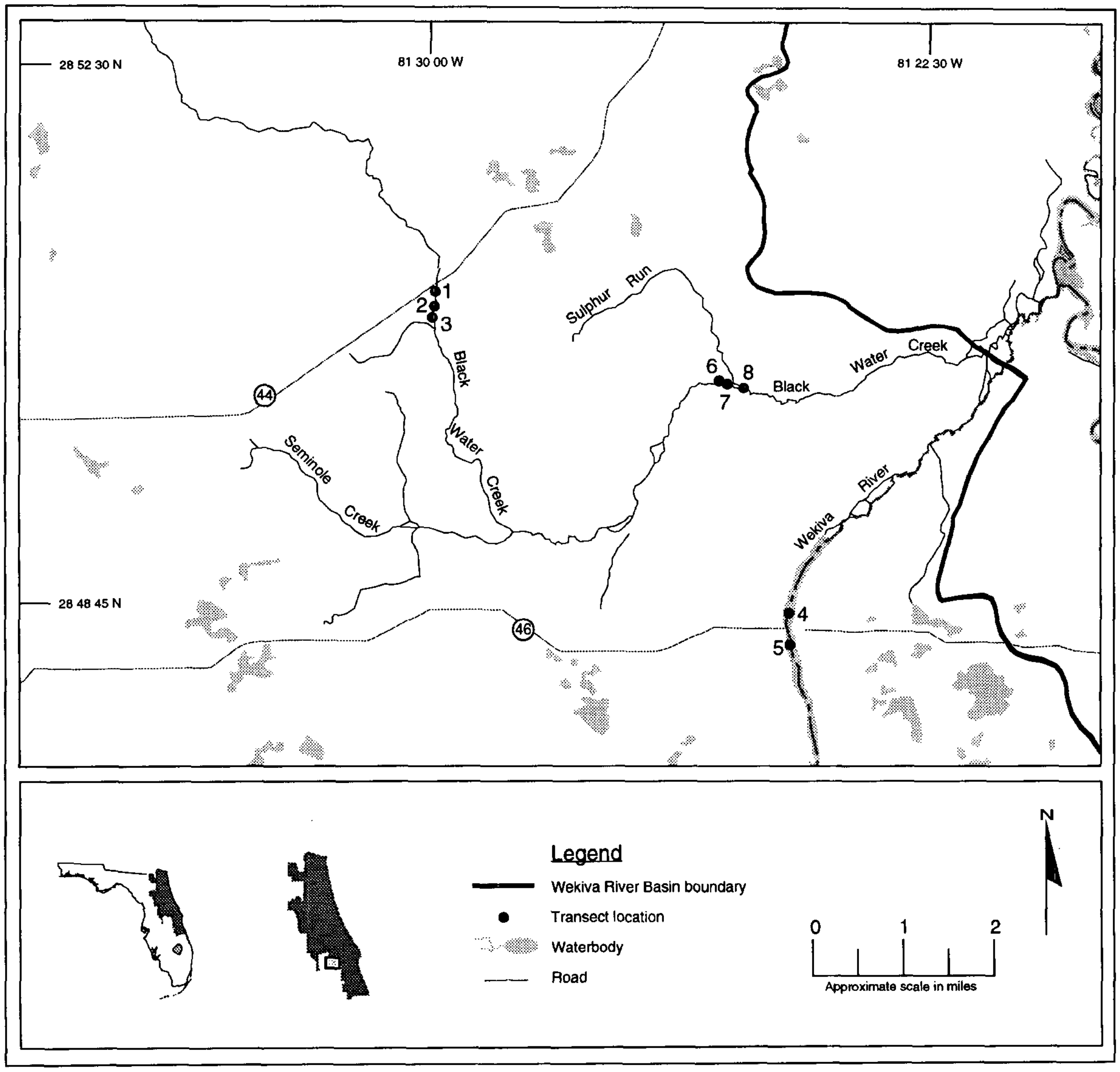

Figure 4. Locations of the threshold transects in the Wekiva River System

example, on Black Water Creek, the stream channel was approximately 25 ft wide; instream elevations were measured at 1-ft intervals. The Wekiva River was 400–500 ft wide, and instream elevations were measured at 10-ft intervals. Aquatic plants encountered were noted and identified at every elevation point. Elevations were measured at 10-ft intervals for a distance of 100 ft landward of the water's edge. Subsequent elevations were recorded at 100-ft intervals to the visual ecotone of upland and wetland plant communities.

A 16.4-ft x 65.6-ft (5-meter x 20-meter) sampling plot was located on the floodplain near (landward of) the tree line of each stream bank. The plots were intended to characterize the immediate area where the transects intercepted the floodplain. The elevation of the water table of the surficial aquifer system and the degree of flooding in this portion of the floodplain are heavily influenced by the stage of the watercourse (Leitman et al. 1983). Wetlands nearer the uplands may be more influenced by lateral ground water seepage from higher elevations. The plots were positioned so the long axis was perpendicular to the stream, parallelling the transect line, which also formed one side of the sample plot. All woody species having a diameter at breast height greater than 1 in. was recorded for each plot. Importance values were calculated based upon relative basal area and relative density of each species (Brower and Zar 1984, 80–84). Importance values give an overall estimate of influence or importance of a plant species in the community.

After the cross-section elevation data were plotted, stream width and selected wetted perimeters were measured from the graphs at incremental depths from the bankfull condition. Stream width is defined as the width of the water surface in the stream channel at any given elevation, measured at right angles to the direction of flow. Wetted perimeter is defined as the length of the wetted contact between the water and the containing channel, measured at right angles to the direction of flow (Stalnaker and Arnette 1976). Wetted perimeter is often used to calculate suitable water depths to allow fish passage in the stream channel. Stream width was a more expedient measure for calculating fish passage than wetted perimeter. Both variables (stream width and wetted perimeter) were plotted against elevation for several transects, and the correlation between wetted perimeter and stream width (as measured by the coefficient of determination, r^2) was 0.99.

The minimum requirements for maintaining fish passage were defined from criteria for transects of the stream cross section developed by Thompson (1972) and discussed by Stalnaker and Arnette (1976). For these criteria, the passage depth must be met over 25 percent of the stream width and occur over at least a 10 percent continuous segment of the cross section. The passage depths selected were 0.6 ft for transects occurring over bare substrate and 1.0 ft for transects occurring over substrate having eelgrass. The 0.6-ft passage depth criterion as recommended by Thompson (1972) was based on the body dimensions of large trout species. The 1-ft passage depth criterion for riffle sections with eelgrass was not based upon empirical measurements; rather, consideration was given to field observations of how eelgrass modified the physical habitat in shallow water.

Stream width was measured and plotted against water depth (from bankfull to zero depth) for each cross section. The elevation with 25 percent of the maximum within-bank stream width was determined from these graphs. Adult fish passage was provided by adding either 0.6 ft (without eelgrass cover) or 1.0 ft (with eelgrass cover) to the elevation where the stream width was 25 percent of the bankfull condition. More than 10 percent of the determined width was in contiguity at all of the transects (Figure 5). The average elevation calculated from all the transects in a stream reach or the value from the most restrictive transect was used to determine passage depth, depending on sample size.

HYDROLOGIC ANALYSES

Hydrologic and hydraulic analyses and surface water modeling were performed for the Wekiva River System. The flow of data and other information through the analyses used for this project is summarized in a flow chart (Figure 6).

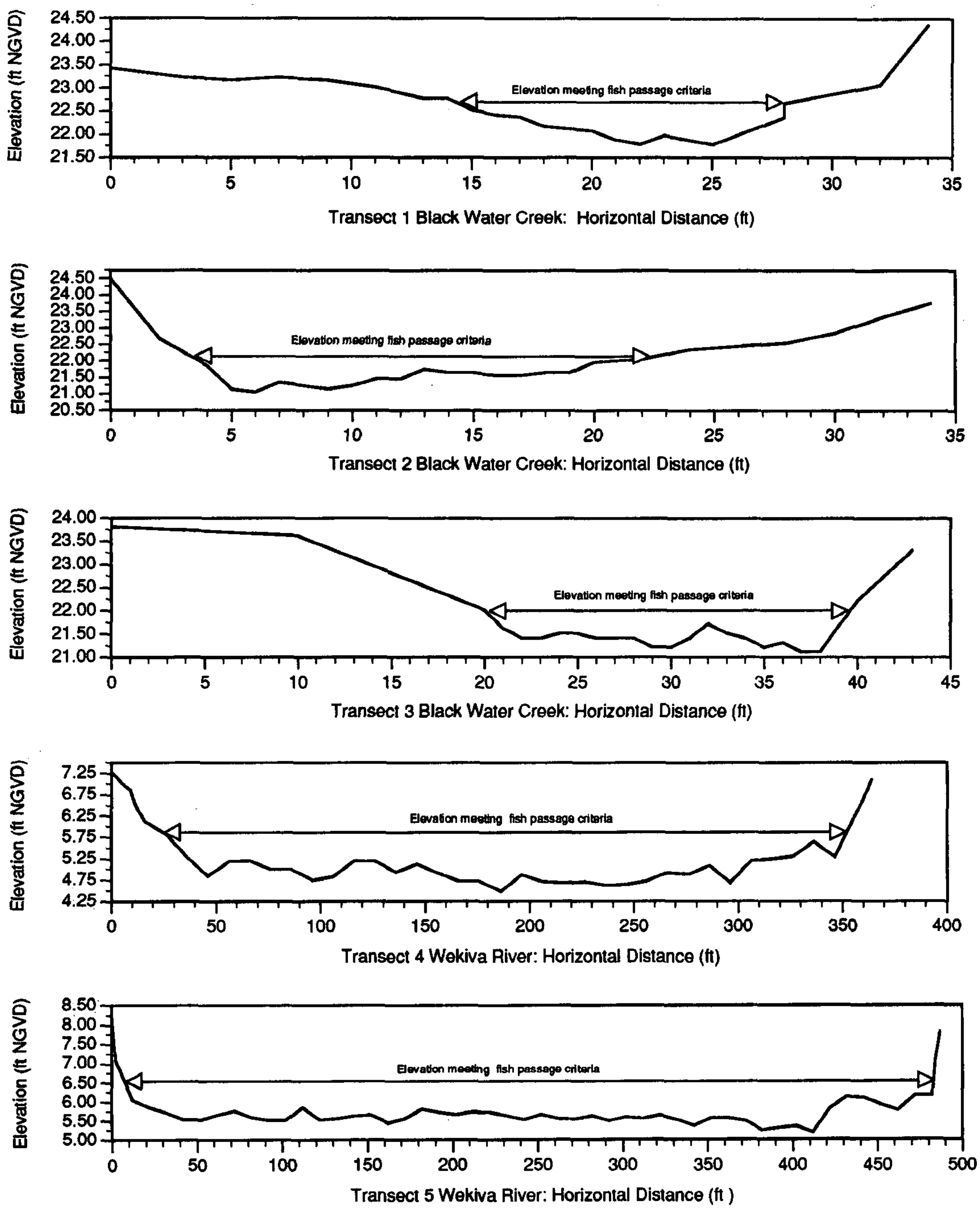

Figure 5. Cross sections of the stream channel at the threshold transects. ***Plotted are the portions of the transects below the floodplain and the elevations meeting the fish passage criteria.***

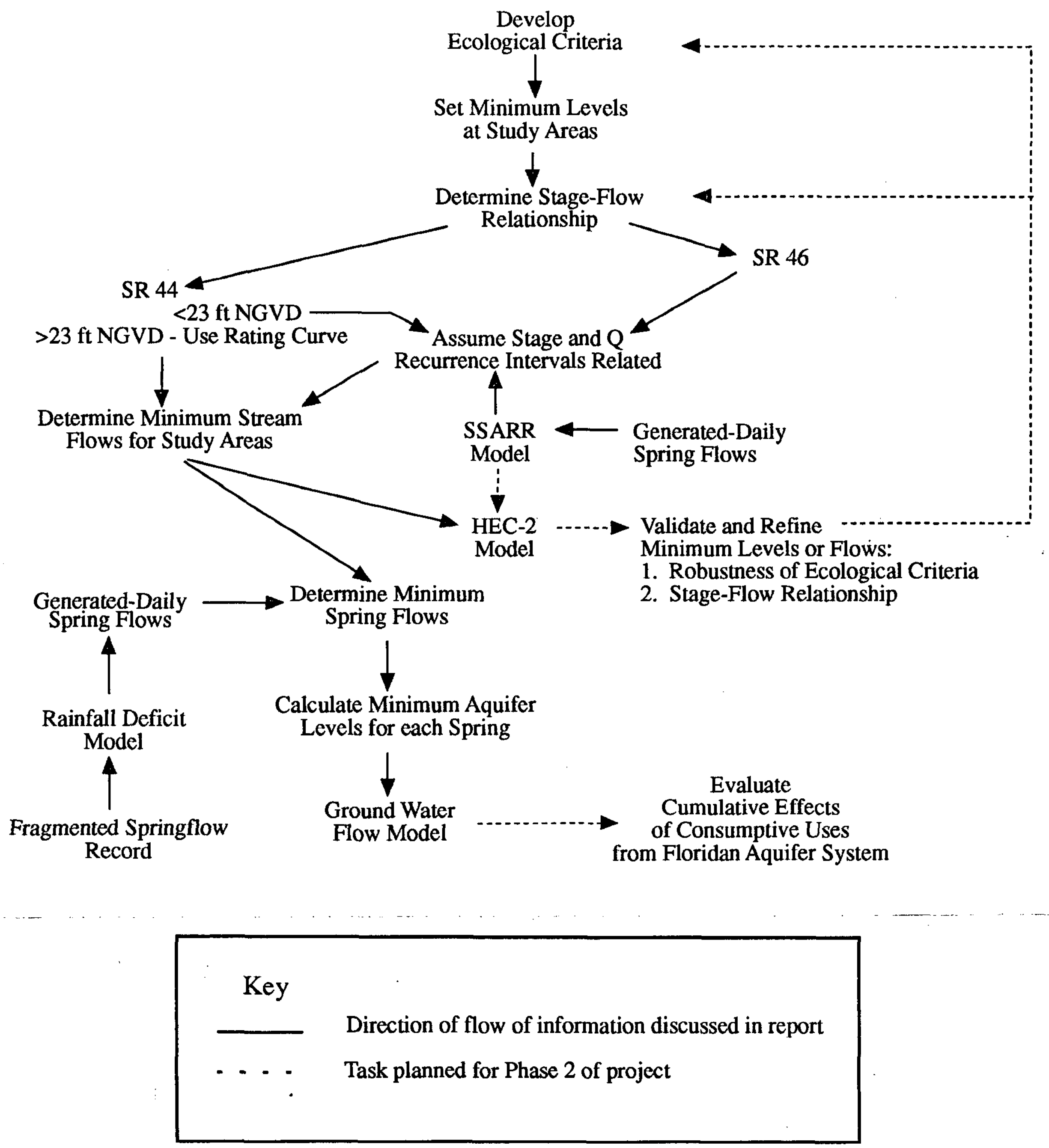

Figure 6. Flow of information through project components. *Shown are components discussed in the present report and components planned for Phase 2 of the project.*

Hydrologic analyses used in this report included frequency analyses of high and low flows/stages and duration analysis. The primary purpose of these analyses was to define temporal statistics from long-term hydrologic data and to determine the flows associated with the proposed minimum levels. Duration curves are cumulative frequency graphs that express the percentage of time during the period of record a given flow or water level was equalled or exceeded. Frequency analysis is a statistical technique by which extreme events of rare occurrence are estimated from historic data. Extreme events, such as the annual high or annual low water levels, are assumed to be the results of random phenomena, that is, governed by the laws of probability. There is no specific probability law known to govern these events, however. Commonly, an applicable probability distribution is chosen and fit to the data. One commonly used distribution in hydrology is the Log Pearson type 3 distribution. This distribution was used to estimate the probable frequencies (recurrence intervals) of stage and flow events for the Wekiva River and Black Water Creek. Frequency curves were adjusted graphically in some instances to achieve a better fit to the observed data, as suggested by Riggs (1972).

The frequencies of mean high and low flows and stages were determined for durations of 1, 7, 14, 30, 60, 120, and 183 consecutive days. The data for the analysis comprise the annual values of mean high or low flows/stages. For example, the 7-day mean high stages are the highest 7-day averaged values from each of the *n* number of data years.

For the evaluation of annual low flows and stages, the water year that is used by USGS, October 1 to September 30, is used as the reference year. However, for evaluating annual high flows and stages, a climate year ending May 31 was chosen, because maximum floods occur from June through October in this part of Florida. Using the USGS water year would divide the rainy season, and this would be an inaccurate procedure for the current analysis.

The data used in the specific analyses and the results of various analyses are presented in the following sections.

Discharge Data Used and Analyses

USGS monitors stream flow on the Wekiva River at SR 46 and on Black Water Creek at SR 44. Daily stage and discharge data are available for the Wekiva River since October 1935. Daily flow records are available for Black Creek for August 1967 to September 1969 and from March 1981 to the present. From March 1981 through May 1985, there are many periods where data are missing. The missing data for Black Water Creek were estimated by linear interpolation. Observed and interpolated data were used to develop stage and flow duration curves (Figures 7–8 and Figures 9–10, respectively) and in performing frequency analyses, results of which are presented in Tables 3-10.

The USGS gaging data are insufficient for deriving all of the hydrologic results needed for the basin because these data can provide results for only two locations. Data for other desired locations should be obtained by appropriate methods. For this project, basinwide data were generated by the hydrologic model SSARR (Streamflow Synthesis and Reservoir Regulation). The SSARR model, a long-term rainfall runoff model, was developed by the North Pacific Division of USACE (USACE 1986; Ponce 1989). The model generates simulated daily streamflow data for desired locations. The hydrologic modeling of the basin with the SSARR model will be discussed in a future report. The high- and low-flow frequency analyses were performed using data generated by the SSARR model for the Wekiva River at SR 46 (Tables 11 and 12). Flows generated by the SSARR model (Tables 11 and 12), in general, compare well with historic flows (Tables 9 and 10) for the range of values used in this study (i.e., 7- and 30-day high values for return periods 2 and 5 years and 30-day low flows).

The flows generated by the SSARR model will be used in a HEC-2 model being developed by SJRWMD for hydraulic analyses of water levels in a significant portion of the stream

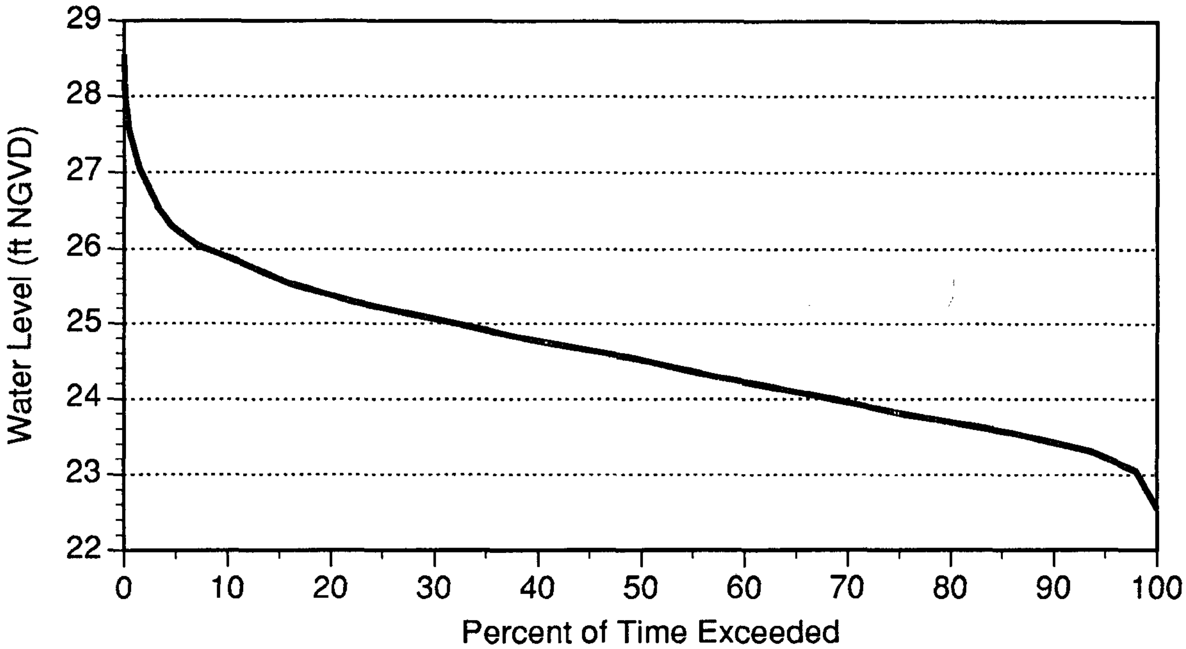

Figure 7. Stage-duration curve for Black Water Creek at SR44 (1967-69 and 1981-90)

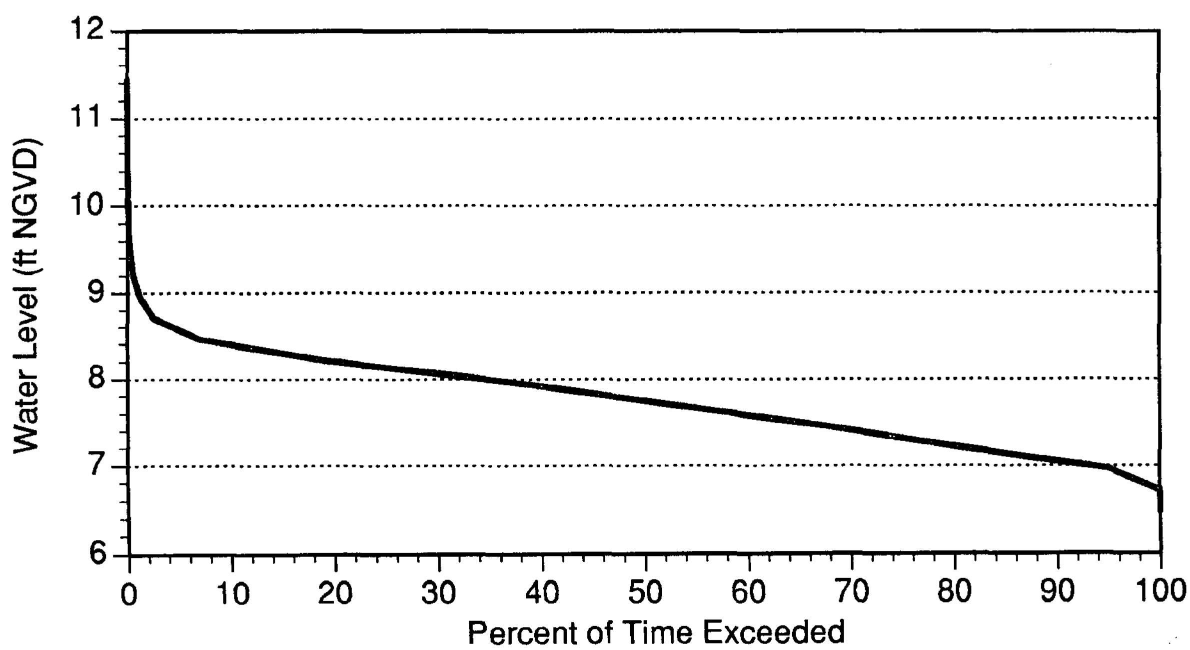

Figure 8. Stage-duration curve for the Wekiva River at SR46 (1935-90)

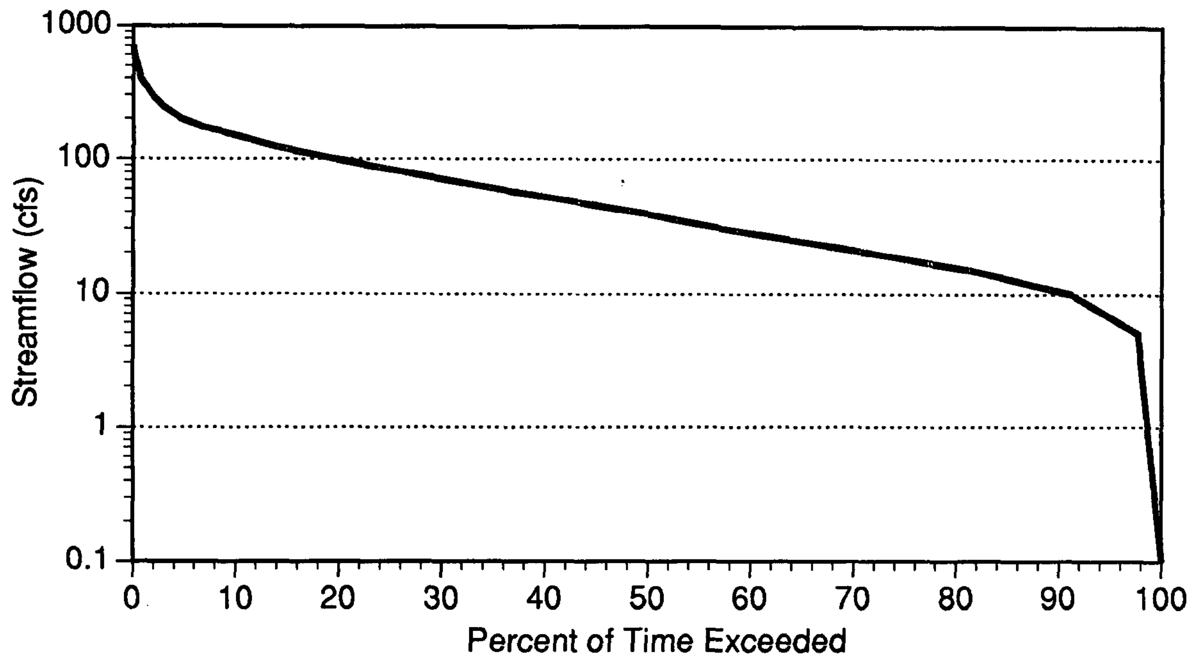

Figure 9. Flow-duration curve for Black Water Creek at SR44 (1967-69 and 1981-90)

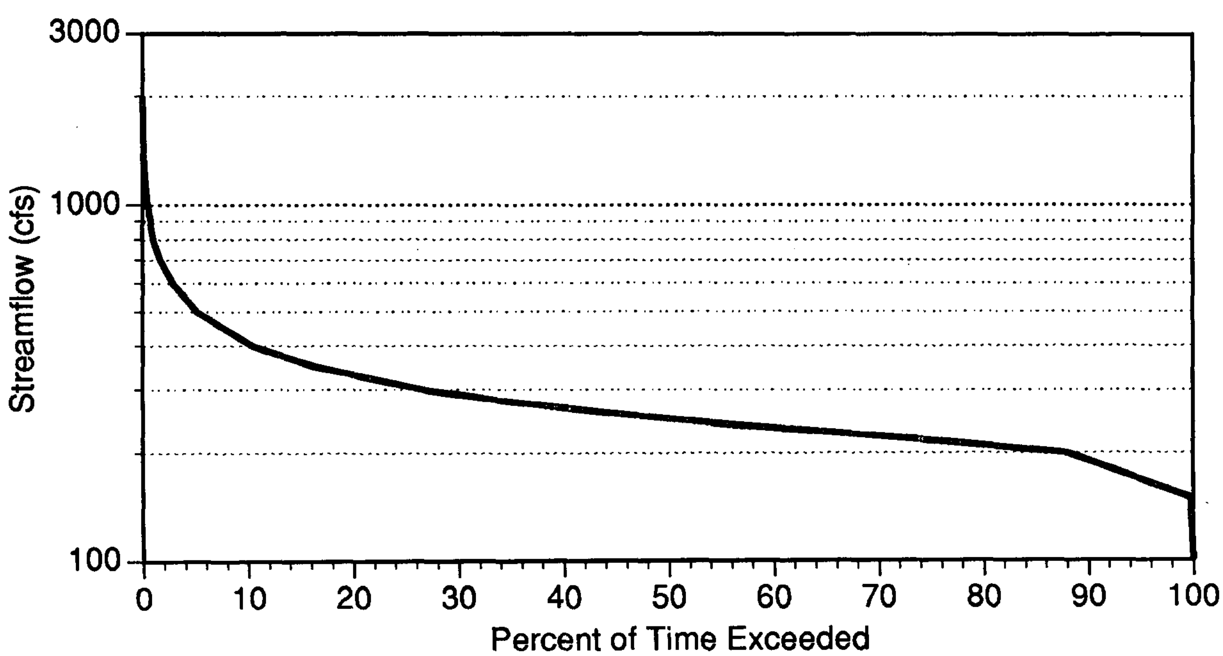

Figure 10. Flow-duration curve for the Wekiva River at SR46 (1935-90)

Table 3. Results of high mean stage frequency analysis for Black Water Creek. *Data are from the USGS SR 44 gaging station, 1967-69 and 1981-90.*

Return Period (years)	Duration (days)						
	1	7	14	30	60	120	183
	Stage Values (ft NGVD)						
2	26.64	26.47	26.31	26.04	25.81	25.43	25.15
5	27.44	27.25	27.05	26.71	26.38	25.86	25.56
10	27.86	27.68	27.45	27.05	26.65	26.07	25.76
25	28.32	28.14	27.89	27.42	26.92	26.27	25.96
50	28.61	28.45	28.18	27.66	27.08	26.39	26.08
100	28.87	28.73	28.45	27.88	27.22	26.50	26.18

Note: ft NGVD = feet, National Geodetic Vertical Datum

Table 4. Results of low mean stage frequency analysis for Black Water Creek. *Data are from the USGS SR 44 gaging station, 1967-69 and 1981-90.*

Return Period (years)	Duration (days)						
	1	7	14	30	60	120	183
	Stage Values (ft NGVD)						
2	23.43	23.45	23.48	23.53	23.64	23.82	24.17
5	22.97	22.99	23.03	23.11	23.17	23.43	23.59
10	22.79	22.81	22.85	22.93	22.98	23.16	23.35
25	22.63	22.65	22.69	22.75	22.80	23.03	23.14
50	22.53	22.55	22.58	22.66	22.69	22.93	23.03
100	22.45	22.47	22.50	22.57	22.60	22.85	22.94

Note: ft NGVD = feet, National Geodetic Vertical Datum

Table 5. Results of high mean flow frequency analysis for Black Water Creek. *Data are from the USGS SR 44 gaging station, 1967-69 and 1981-90.*

Return Period (years)	Duration (days)						
	1	7	14	30	60	120	183
	Discharge Values (cfs)						
2	259	232	209	174	143	107	87
5	427	385	343	276	223	160	130
10	546	494	438	346	274	196	159
25	701	639	563	433	336	241	195
50	818	750	658	497	380	274	221
100	935	863	755	560	422	306	247

Note: cfs = cubic feet per second

Table 6. Results of low mean flow frequency analysis for Black Water Creek. *Data are from the USGS SR 44 gaging station, 1967-69 and 1981-90.*

Return Period (years)	Duration (days)						
	1	7	14	30	60	120	183
	Discharge Values (cfs)						
2	10.20	10.80	11.40	12.50	15.00	20.20	34.70
5	4.83	5.13	5.45	6.10	7.17	9.77	15.60
10	3.03	3.23	3.46	3.94	4.68	6.49	9.47
25	1.73	1.87	2.02	2.35	2.87	4.10	5.21
50	1.17	1.27	1.38	1.64	2.06	3.01	3.42
100	0.80	0.88	0.96	1.16	1.51	2.26	2.28

Note: cfs = cubic feet per second

Table 7. Results of high mean stage frequency analysis for the Wekiva River. *Data are from the USGS SR 46 gaging station, 1935-90.*

Return Period (years)	Duration (days)						
	1	7	14	30	60	120	183
	Stage Values (ft NGVD)						
2	8.86	8.65	8.43	8.20	8.08	7.97	7.87
5	9.54	9.23	8.93	8.65	8.47	8.35	8.24
10	9.93	9.54	9.21	8.90	8.67	8.53	8.43
25	10.36	9.88	9.50	9.16	8.87	8.72	8.61
50	10.66	10.10	9.69	9.34	8.99	8.83	8.72
100	10.94	10.30	9.87	9.50	9.09	8.92	8.81

Note: ft NGVD = feet, National Geodetic Vertical Datum

Table 8. Results of low mean stage frequency analysis for the Wekiva River. *Data are from the USGS SR 46 gaging station, 1935-90.*

Return Period (years)	Duration (days)						
	1	7	14	30	60	120	183
	Stage Values (ft NGVD)						
2	7.36	7.38	7.39	7.41	7.49	7.54	7.59
5	7.02	7.03	7.04	7.06	7.09	7.12	7.16
10	6.89	6.90	6.91	6.92	6.94	6.97	7.00
25	6.76	6.77	6.78	6.79	6.82	6.84	6.87
50	6.69	6.70	6.71	6.72	6.75	6.77	6.79
100	6.62	6.65	6.66	6.67	6.69	6.71	6.73

Note: ft NGVD = feet, National Geodetic Vertical Datum

Table 9. Results of high mean flow frequency analysis for the Wekiva River. *Data are from the USGS SR 46 gaging station, 1935-90.*

Return Period (years)	Duration (days)						
	1	7	14	30	60	120	183
	Discharge Values (cfs)						
2	798	662	552	445	385	334	308
5	1147	920	744	578	486	409	371
10	1386	1095	876	676	550	463	406
25	1695	1318	1048	809	637	536	476
50	1929	1486	1180	916	705	594	524
100	2168	1657	1316	1031	776	655	574

Note: cfs = cubic feet per second

Table 10. Results of low mean flow frequency analysis for the Wekiva River. *Data are from the USGS SR 46 gaging station, 1935-90.*

Return Period (years)	Duration (days)						
	1	7	14	30	60	120	183
	Discharge Values (cfs)						
2	191	195	199	202	211	225	242
5	166	172	176	181	189	201	212
10	153	160	164	170	178	190	198
25	138	146	150	158	168	178	186
50	129	137	141	151	162	171	178
100	121	130	134	144	156	165	172

Note: cfs = cubic feet per second

Table 11. Simulated results of high mean flow frequency analysis for the Wekiva River at SR 46. *Data are simulated using SSARR model results, 1936-90.*

Return Period (years)	Duration (days)						
	1	7	14	30	60	120	183
	Discharge Values (cfs)						
2	760	679	575	454	382	335	309
5	1047	918	755	563	460	394	360
10	1250	1084	881	636	512	433	389
25	1521	1303	1048	728	578	482	427
50	1734	1473	1178	798	628	518	454
100	1957	1649	1313	868	679	555	482

Note: cfs = cubic feet per second

Table 12. Simulated results of low mean flow frequency analysis for the Wekiva River at SR 46. *Data are simulated using SSARR model results, 1936-90.*

Return Period (years)	Duration (days)						
	1	7	14	30	60	120	183
	Discharge Values (cfs)						
2	208	210	212	217	225	236	247
5	185	186	188	191	197	208	216
10	173	174	175	178	184	195	203
25	161	162	163	165	170	181	189
50	153	154	155	156	161	173	182
100	146	147	148	149	154	166	175

Note: cfs = cubic feet per second

system. These model results will aid in determining minimum water levels over an extensive portion of the Wekiva River System (Figure 3). The HEC-2 simulation will be used to determine if the minimum flows that are proposed protect water resources upstream of the monitoring sites; it is also valuable from a permitting perspective because the model will predict how modifying or adding structures to the stream channel will change water levels.

Spring Flow Data Used and Analyses

Spring flow contributes the majority of base flow into the Wekiva River and Black Water Creek, downstream of Seminole Creek. Since 1932, USGS has sporadically collected discharge data for most of the major springs in the Wekiva River Basin. These springs include Wekiva, Rock, and Miami springs on the Wekiva River; Sanlando, Palm, and Starbuck springs on the Little Wekiva River; and Seminole and Messant springs on Seminole Creek (Figure 1). A simple rainfall differential model was used to estimate daily springflow data for each of these springs in the absence of a more complete model and because USGS data were taken sporadically and, therefore, were inadequate for our analyses. What USGS data were available were used to calibrate this model. The cumulative difference between the monthly mean rainfall and the observed rainfall was used to estimate daily spring flows in the model. Long-term springflow hydrographs from the rainfall differential model were input into the SSARR model to calculate base flows for the Wekiva River and Black Water Creek. A detailed discussion on estimating spring flows will appear in a future report on hydrologic modeling of the basin. The minimum springflow values that were generated were used to calculate minimum ground water levels in the Floridan aquifer system (potentiometric surface elevations).

Minimum ground water levels in the Floridan aquifer system at the locations of major springs providing base flow to the Wekiva River System were estimated using a form of Darcy's equation, stated as follows:

$$Q = C \times (HFLOR - HPOOL) \qquad (1)$$

Where Q is the rate of discharge from the springs (length $[L]^3$/time [t]), C is the spring conductance (L^2/t), HFLOR is the elevation of the water level (L) in the Floridan aquifer system at the location of the spring, and HPOOL is the elevation of the spring pool (L).

To determine minimum water levels in the Floridan aquifer system at the locations of springs, Equation 1 was solved for HFLOR:

$$HFLOR = HPOOL + \frac{Q}{C} \qquad (2)$$

The values of Q used in Equation 2 were the minimum flows at the springs as determined by the minimum flows-and-levels analysis; the conductance values were derived by Huang (1994); and the spring-pool elevations were estimated or observed values as stated in the documentation of the regional ground water flow model (GeoTrans 1992a).

Observed springflow data are sparse and detailed statistical analysis was not possible. Wekiva and Rock springs data, however, exist since 1931. Frequency analysis of spring flows was performed using the annual 1-day maximum and 1-day minimum flow data (Tables 13 and 14). Table 15 presents the median and average flows for 10 springs in the basin based on observed (sporadic) data and median flow values simulated using the rainfall differential model. The average spring flows were calculated from annual mean springflow data.

The cumulative effect of ground water withdrawals on aquifer levels and spring flows will be evaluated using ground water flow models. Minimum spring flows and minimum surface water flows and levels can be used as standards to assess various Consumptive Use permits or Management and Storage of Surface Waters permits (Figure 6). A ground water flow model can

Table 13. Results of 1-day high- and low-flow frequency analysis from Wekiva Springs (1931-90). *Data were collected by the U.S. Geological Survey and the St. Johns River Water Management District.*

Return Period (years)	Low Flow	High Flow
	Discharge (cfs)	
2	66.7	70.5
5	60.8	78.3
10	58.3	83.6
25	55.9	90.3
50	54.6	95.3
100	53.5	100.5

Note: cfs = cubic feet per second

Table 14. Results of 1-day high- and low-flow frequency analysis from Rock Springs (1931-90). *Data were collected by the U.S. Geological Survey and the St. Johns River Water Management District.*

Return Period (years)	Low Flow	High Flow
	Discharge (cfs)	
2	58.5	61.5
5	53.8	68.4
10	51.7	72.9
25	49.7	78.4
50	48.5	82.5
100	47.5	86.6

Note: cfs = cubic feet per second

Table 15. Flows from the major springs in the Wekiva River System

Spring Name	Average Flow†	Median Flow†	Modeled Median Flow*	Receiving Watercourse
Wekiva Springs	70.0	68.0	68	Wekiva River
Rock Springs	60.8	60.9	58	Rock Springs Run
Seminole Springs††	29.1	35.0	37	Seminole Creek
Messant Spring	16.5	16.0	13	Seminole Creek
Sanlando Springs	20.2	19.5	17	Little Wekiva River
Starbuck Spring	14.3	14.3	14	Little Wekiva River
Palm Springs	8.0	7.9	8	Little Wekiva River
Witherington Spring	5	**	**	Wekiva River
Miami Springs	4.7	4.7	4	Wekiva River
Camp La No Che Spring	1	**	**	Lake Norris

†Summary statistics were compiled from USGS and SJRWMD data (i.e., observed values); there are large differences in the amount of data accumulated between years and among springs.
*Median springs values were calculated from data generated by the rainfall deficit model.
††Flow data were not collected from Seminole Springs during the 1960s, a period when spring flows were known to be high.
**Insufficient data to generate summary statistics.

predict the elevation of the potentiometric surface of the Floridan aquifer system as a function of the topographical location and magnitude of aquifer withdrawals (GeoTrans 1992a, 1992b, 1992c).

Determination of Minimum Flows

The flows necessary to maintain the minimum levels are termed minimum flows. A series of five minimum levels was selected to fulfill the biological criteria (see p. 20–23). Each minimum level also is required to satisfy a duration criterion. For simplicity in the hydrologic analyses, however, the 30-day duration is used as a standard (with few exceptions) to determine flows corresponding to the minimum levels.

Flows associated with a given stage can usually be obtained from stage-discharge relationships (rating curves) developed by USGS. The stage-discharge rating curve developed by USGS for Black Water Creek at SR 44 was found to be adequate ($r^2 = 0.77$) to calculate discharges for levels above 23 ft National Geodetic Vertical Datum (NGVD). Although the rating curve for Black Water Creek at SR 44 is adequate, point discharge measurements shown on the rating curve for the Wekiva River at SR 46 (supplied by the USGS office in Orlando) indicated that substantial variation occurred in the stage-discharge relationship, especially during low flows. Correlation analysis between the observed stage and flow data resulted in a correlation coefficient (r) of less than 0.2, confirming that large variations in the stage-discharge relationship occurred at the gaging station location. The reasons for the large degree of variation in the stage-discharge relationship at this location are unknown. Possibly the channel may degrade during very high flows and then slowly aggrade, or mats of floating plants may accumulate in the channel, temporarily changing the water profile. Large mats of water hyacinths (*Echihornia crassipes*) and pennywort (*Hydrocotyle* sp.) were observed at the gaging location at various times during the study.

The following paragraphs explain how minimum flows were set for the Wekiva River and Black Water Creek.

Wekiva River. To determine minimum flows for the SR 46 bridge location, the assumption was made that there was a correlation between the frequencies of stages and discharges, that is, that the discharges of a given recurrence interval would give rise to stages of the same recurrence interval. This assumption permitted determination of flows corresponding to the minimum levels, as follows.

1. From the results of the stage-frequency analysis, the recurrence intervals were determined for an established

minimum stage. The 30-day duration and historic stage-frequency distribution were used (see Tables 7 and 8). For example, assume that the Minimum Infrequent Low level is 7.2 ft NGVD. The recurrence interval for this level can be determined as 3 years by interpolating 30-day stage values given in Table 8. An exception was made for the Minimum Infrequent High flow, whhere the 7-day mean flow/stage curve was used.

2. The flow that corresponds to the recurrence interval determined in the step above was determined using Tables 11 and 12, which are based on flows derived from the SSARR model. For example, a flow of about 200 cfs is determined to have a recurrence interval of 3 years on the probability curve of annual 30-day mean low flows by interpolating flow values given in Table 12. The SSARR model results for flow were used instead of the observed flow data (Tables 9 and 10) because SSARR data were used to calculate the minimum spring flows (see p. 42).

Black Water Creek. Minimum flows were established for Black Water Creek at SR 44 using the stage-discharge rating curve developed by USGS for levels above 23 ft NGVD. To estimate flows for levels below 23 ft NGVD, the method described above for the Wekiva River was used with the data in Tables 3–6. Flow approaches zero as the water level decreases to near the Minimum Infrequent Low level.

DETERMINATION OF PHASED WATER RESTRICTIONS

Four additional levels and flows (phased water shortage restrictions) were placed between the Minimum Frequent Low and Minimum Infrequent Low to implement water conservation measures during periods of drought. Water conservation measures should help avoid the occurrence of a Minimum Infrequent Low flow or level and accelerate the recovery of stream flows. Phased water restriction levels were derived by subtracting the Minimum Infrequent Low level from the Minimum Frequent Low level and multiplying the difference by

0.15 (0.15 corresponds to the 15 percent phased water reductions in the Water Shortage Plan). This value is subtracted from the Minimum Frequent Low level to produce the phase 1 level, then subtracted from the phase 1 level to produce the phase 2 level, and so on. Between the phase 4 water restriction level and the Minimum Infrequent Low level is a zone where the Governing Board may choose to implement more restrictive measures relating to consumptive uses. The phased water restriction levels and flows are intended to be compared with the average daily stage or flow of the previous 30-day period. This average can be used to determine when to enter or exit a water restriction phase, thus avoiding taking action until a trend of improvement or degradation is established. This period also allows time for SJRWMD staff to make recommendations to the Governing Board and notify the public of impending management actions.

RESULTS

The range of water level fluctuation in Black Water Creek over a 12-year period (5.64 ft) exceeded the range of water level fluctuation in the Wekiva River over a 54-year period (4.79 ft) (Figures 7 and 8). The flow-duration curve of Black Water Creek has a greater slope between the upper and lower inflection points than that of the Wekiva River (Figures 9 and 10, respectively), indicating a greater range of fluctuation in response to seasonal precipitation (Figure 11). The Wekiva River flow-duration curve (Figure 10) falls less sharply to the right of the lower inflection point than the Black Water Creek curve (Figure 9) because base flow is sustained by the springs. These differences in the curves are reflected to a lesser degree in the stage-duration curves (Figures 7 and 8).

Vegetation sampling plots cover a wide range of inundation durations (Table 16). The actual period in which a plot exhibited soil anoxia due to soil saturation was longer than indicated in Table 16. This longer period is because soils may be saturated when the stream is near, but below, flood stage and because natural levees will impede surface flow toward the channel after flood waters recede. Three plots on the Wekiva River were classified as hydric hammock—4W, 5W, and 5E (E and W refer to the east or west bank of the stream) (see Figure 4). These plots had experienced shorter hydroperiods (plots were flooded less than 45 percent of the time) and had tree canopies dominated by bayhead, upland, and transitional wetland species (Table 16). These were the only plots containing bayhead tree species (*Gordonia lasianthus* and *Magnolia virginiana*). Plot 4E on the Wekiva River occurred on a small, low island in the river channel. This plot was heavily dominated by red maple, considered a pioneer or subclimax species (Fowells 1965, p. 60) that inhabits a wide range of soil types. The Black Water Creek plots had long hydroperiods (plots were flooded more than 45 percent of the time) and were composed of deciduous species characteristic of mixed swamp-type wetlands. Swamp laurel oak and sweet gum also occurred at many of the Black Water Creek

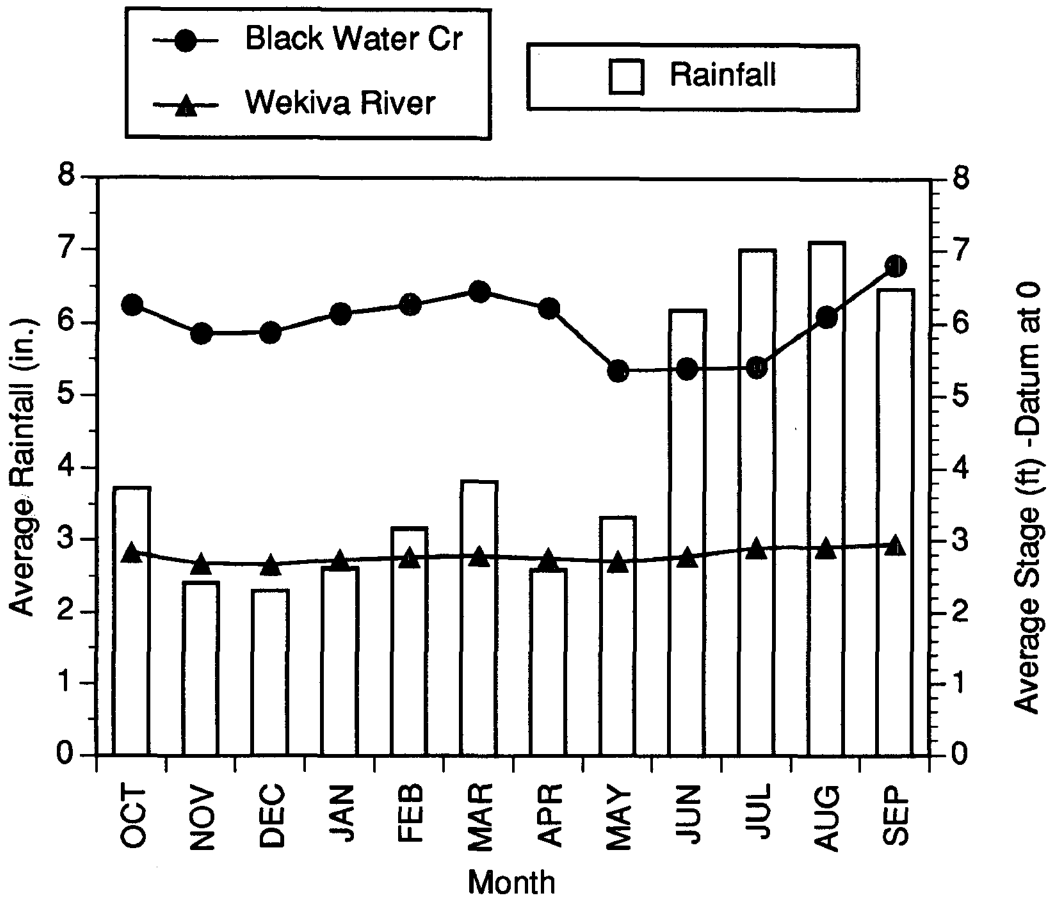

Figure 11. Average monthly rainfall at Sanford and average monthly stage (uncorrected for datum) at Black Water Creek (State Road 44; datum is 18.55) and Wekiva River (State Road 46; datum is 4.96) gaging stations. *Figure shows response of water level to precipitation patterns.*

Table 16. Tree composition† in plots adjacent to the stream channel. *The stage-duration record of the stream was used to estimate the percentage of time that the stream inundated each plot.*

Species	Black Water Creek Plots*						Wekiva River Plots*			
	1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
Acer rubrum	79	19	-	39	75	34	65	157	39	9
Agarista populifolia	-	-	-	-	-	-	-	-	-	8
Baccaris halimifolia	-	-	-	-	-	-	-	2	-	-
Carpinus caroliniana	-	-	-	-	-	-	14	-	-	9
Carya aquatica	-	56	33	-	-	-	-	-	-	-
Fraxinus caroliniana	26	25	54	63	27	89	20	-	-	-
Gordonia lasianthus	-	-	-	-	-	-	-	-	-	29
Liquidambar styraciflua	64	29	-	-	45	32	26	9	56	-
Magnolia virginiana	-	-	-	-	-	-	54	-	-	9
Myrica cerifera	-	-	-	-	-	-	-	15	-	-
Nyssa biflora	20	-	80	10	-	-	-	-	-	23
Quercus laurifolia	11	27	-	41	9	-	6	-	-	80
Sabal palmetto	-	-	-	-	-	-	14	-	91	32
Salix caroliniana	-	-	-	-	-	-	-	13	-	-
Sambucus canadensis	-	-	-	-	-	-	-	2	-	-
Taxodium distichum	-	-	33	47	-	-	-	2	-	-
Ulmus americana	-	46	-	-	44	45	-	-	14	-
Percentage of Period of Record Flooded										
	51	51	35★	51	51	46	25	56	40	1

Note: - = not applicable; species not found within a given plot.

†Species dominance is reported by importance values based on relative density and relative basal area. Values are calculated as discussed by Brower and Zar (1984); range of species importance index is 0-200.
*Figure 4 shows the location of the plots; E or W designates whether the plot was located on the east bank or west bank of the stream.
★The flood duration is likely higher in this plot due to a ponding effect from the presence of a natural levee.

plots. At these wetter plots, the latter two species grew on a slightly higher, discontinuous, natural levee adjacent to the stream.

The ecological, physical, and hydrological data were integrated to produce a minimum flow regime—a series of five recommended minimum levels and flows, with associated durations and recurrence intervals (Table 17). The rationale for each minimum level and flow and associated temporal statistics is discussed in the Minimum Flows and Levels Criteria Development chapter (see p. 15–23). The seasonal timing of fluctuations within this regime of flows and levels and stage recession rates will follow natural patterns because the river system is not regulated by control structures. The Wekiva River System minimum flow regime should not be construed to be a regulation schedule, such as the operating schedule of a regulated river. The next sections discuss the series of minimum levels for Black Water Creek and the Wekiva River.

BLACK WATER CREEK MINIMUM LEVELS AND FLOWS

Minimum Infrequent High

A Minimum Infrequent High water level of 27.0 ft NGVD and a flow of 340 cfs are recommended. The associated duration is at least 7 days, with a recurrence interval of not greater than 5 years. The water depth in the main channel of the creek will be approximately 5 ft (see Table 17). The Minimum Infrequent High level inundates the floodplain to near the landward extent of the wetlands. The average elevation of the upland/wetland (low pine flatwoods/mixed swamp) ecotone is 26.7 ft NGVD, slightly above the upper inflection area on the stage-duration curve (see Figure 7). Water depths will be near ground surface at the upper edge of the mixed swamp community and will increase to approximately 2.4 ft above the ground surface adjacent to the stream channel. A 7-day mean flood duration with a recurrence interval of 1 in 4 years has a water level of 27.0 ft NGVD (interpolated from Table 3). This elevation has been equalled or

Table 17. Recommended minimum level and flow regime

Minimum Flow Regime	Level (ft NGVD)	Flow (cfs)	Duration (days)	Acceptable Return Period† (years)	Actual Return Period* (years)	Water Depth° (ft)
Wekiva River at the SR 46 Bridge						
Minimum Infrequent High	9.0	880	≥7	≤5	4	3.9
Minimum Frequent High	8.0	410	≥30	≤2	1.7	2.9
Minimum Average	7.6	240	≤180	≥1.7	2	2.5
Minimum Frequent Low	7.2	200	≤90	≥3	5	2.1
Minimum Infrequent Low	6.1	120	≤7	≥100	>500	1.0
Black Water Creek at the SR 44 Bridge						
Minimum Infrequent High	27.0	340	≥7	≤5	4	4.8
Minimum Frequent High	25.8	145	≥30	≤2	1.7	3.6
Minimum Average	24.3	33	≤180	≥1.7	2	2.1
Minimum Frequent Low	22.8	2.5	≤90	≥15	25	0.6
Minimum Infrequent Low	21.9	0	≤7	≥100	>500	0

Note: cfs = cubic feet per second
ft NGVD = feet, National Geodetic Vertical Datum

†Withdrawals should not cause the Minimum Average, Minimum Frequent Low, or Minimum Infrequent Low levels or flows to occur more frequently or for longer durations than stated. Withdrawals or surface water works should not cause the Minimum Infrequent High or Minimum Frequent High levels or flows to occur less frequently or for shorter durations than stated.

*Based on high-stage (Minimum Infrequent High and Minimum Frequent High levels) or low-stage (other minimum levels) frequency analysis of the historic stage record.

°The water depth is no less than this amount over 25 percent of the channel width at the shallowest cross sections of the study stream reach.

exceeded for approximately 1.6 percent of the 12-year period of record.

Minimum Frequent High

The recommended Minimum Frequent High level and flow are 25.8 ft NGVD and 145 cfs, respectively. Water level and stream flow of this magnitude should occur at least once in 2 years, on average, for a duration of at least 30 days (see Table 17). Water depth in the main channel of the creek will be approximately 4 ft. Calculation of a Minimum Frequent High level required approximating the average elevation of the mixed swamp community adjacent to the watercourse. The mean floodplain surface elevation (24.6 ft NGVD; standard deviation [sd] = ±0.14 ft) was calculated from the average elevation of the six sample plots. Fifteen inches was chosen (Monk 1966) as the minimum wet-season flood depth for mixed swamp habitat adjacent to the stream, giving a Minimum Frequent High level of 25.8 ft NGVD. This water depth, in conjunction with an appropriate flood frequency and duration, should maintain the functions that the mixed swamp provides to the instream community. A duration of 30 days was chosen for these purposes. Historically, a 30-day mean flood duration with a recurrence interval of 1.7 years and a 60-day mean flood duration with a recurrence interval of 1 in 2 years occur at 25.8 ft NGVD (extrapolated from Table 3).

The minimum flood depth of 15 in. was based on a study by Monk (1966) of 23 mixed swamp stands and 9 bayhead forest stands. Monk reported that the water mark averaged 19 in. on trees in the mixed swamps; this mark ranged from 10 to 35 in. among the 23 stands inventoried. In bayheads, Monk found water marks ranging from 0 to 14 in., averaging 9 in. The recommended minimum depth of inundation (15 in.) is less than the average waterline for mixed swamps but greater than the flood range reported by Monk for bayhead communities.

The water lines on trees at transects 1 and 2 (Figure 4) had an average elevation of 26.55 ft NGVD (sd = ±0.23 ft). This stage results in a water depth of approximately 2 ft at the sampling locations. This depth is greater than the recommended minimum because the creek rises to 26.5 ft for about 4 days in every 2 years (Table 3).

Minimum Average

The Minimum Average level (24.3 ft NGVD) and flow (33 cfs) are intended to maintain the hydric nature of the soils and limit the potential encroachment of upland plant species into the wetlands. It should not occur for more than 180 days and should be attained, on the average, less frequently then once in 1.7 years (Table 17). Stephens (1974) demonstrated that oxidation of peat soils occurs when the elevation of the water table is more than 0.25 ft below the wetland surface for extended periods. We speculate that non-wetland species also may become established under these conditions (see p. 17).

The Minimum Average level is 0.26 ft below the mean elevation of the vegetation sampling quadrats (24.57 ft NGVD) that were located on the floodplain. In other areas of SJRWMD, the mean elevation of a floodplain marsh nearly coincided with a 60 percent frequency of inundation (Brooks and Lowe 1984; Hall 1987). We chose the 60 percent exceedance elevation from the stage-duration curve (24.3 ft NGVD, Figure 7) as the best estimate of the average elevation necessary to maintain hydric soils. This was because the sample size of elevations for calculating a mean elevation of the floodplain adjacent to the channel was small.

The Minimum Average water level is 0.36 ft less than the mean water level (24.66 ft NGVD) and 0.21 ft below the median water level (24.51 ft NGVD) of the 12-year period of record. The water depth in the channel of the creek will be approximately 2 ft at the Minimum Average level (Table 17).

The Minimum Average Flow (33 cfs) is approximately one-half of the average flow (69 cfs) and slightly less than the median flow (38 cfs) of the period of record.

A mean low level of a 180-day duration with a recurrence interval of 1 in 2 years has a water level of 24.3 ft NGVD (interpolated from Table 4). We believe that the Minimum Average level can occur as frequently as every 1.7 years without adverse impact (Table 14). The acceptable recurrence interval (1.7 years) was based on the premise that the Minimum Average level maintains soil saturation. No harm would occur to the floodplain if the water level that is equalled or exceeded 60 percent of the time (24.3 ft NGVD) was to occur as frequently as the median water level (24.51 ft NGVD, the 50th percentile on the stage-duration curve) (Figure 7, Table 4). This minimum water level permits typical recreational use of the stream (e.g., fishing and canoeing).

Minimum Frequent Low

The Minimum Frequent Low water level (22.8 ft NGVD) and flow (2.5 cfs) should occur during periods of moderate drought. This level and flow have an associated duration of ≤90 days and a recurrence interval of ≥15 years. Low stage frequency analysis indicates that a 90-day mean duration with a recurrence interval of 1 in 25 years has a value of 22.9 ft NGVD (interpolated from Table 4). We believe the ecology of the system would be significantly harmed if levels this low were to occur for extended durations more frequently than once in 15 years. This minimum level allows for fish passage at the threshold transects by providing a minimum water depth of 0.6 ft in riffle mesohabitats of the stream channel. The minimum fish passage depth calculated was 0.6 ft for over no less than 25 percent of the stream width. The standard deviation of the normalized mean depth meeting the fish passage criteria from the three transects was very small (0.02 ft). This small standard deviation indicates fish passage will be minimal at many locations simultaneously when the Minimum Frequent Low flow occurs.

Low-flow conditions of this nature are not unusual in blackwater streams. Low levels can be beneficial for some aspects of the wetland community if they do not occur too frequently. For example, the rates of microbial processes on the floodplain surface are increased and germination sites for wetland emergents become available on substrates normally inundated. However, low water levels can stress stream and riparian communities if the low levels occur for too long (years) or too frequently. If the Minimum Frequent Low level were prolonged indefinitely, then subsidence of organic soils or shrinkage of clay soils would occur.

Minimum Infrequent Low

The recommended Minimum Infrequent Low level is 21.9 ft NGVD, and the corresponding flow is 0 cfs. This level and flow have an associated duration of ≤7 days and a recurrence interval of ≥100 years. The Minimum Infrequent Low level and flow may be reached in an extreme drought. It was necessary to determine an Minimum Infrequent Low level so that water conservation actions could be invoked in a timely manner, before the water reaches this level.

The Minimum Infrequent Low level for Black Water Creek was calculated by determining the minimum elevation of the stream substrate at each threshold transect, normalizing these data by adjusting for stream slope, and calculating the mean of the normalized data. This mean averaged value (21.9 ft NGVD) became the Minimum Infrequent Low level at the SR 44 bridge gaging station. The small standard deviation (sd = 0.09 ft) among the three transects indicates that stream connectivity will be severed simultaneously in many riffle segments of the stream. The stream flow at this water level (21.9 ft NGVD) will be zero (Table 17). In the vicinity of transects 1, 2, and 3, the stream would be reduced to a series of pools, separated by exposed riffle segments.

Upstream of Seminole Springs, Black Water Creek has the characteristics of a blackwater system, adapted to highly fluctuating flows and water levels. A complete drydown (exposure) of the stream bed does not seem likely because of a small amount of spring inflow from Camp La No Che Spring and ground water seepage from the adjacent uplands. However, loss of riffle areas and stream connectivity may occur under extreme circumstances.

Historically, the Minimum Infrequent Low level (21.9 ft NGVD) likely has occurred less often than once in 500 years (extrapolated from Table 4). If this level occurs relatively infrequently in ecological time, the system is likely to recover rapidly from the disturbance. We believe that the system can recover rapidly from this disturbance if the duration of the water level does not exceed 7 days or occur more frequently than once in 100 years. This is a reasonable assumption in light of the adaptations of blackwater system biota to low flows. Structural and species composition changes to floodplain and instream biota may result if the Minimum Infrequent Low level were to occur more frequently or for longer periods than recommended.

WEKIVA RIVER MINIMUM LEVELS AND FLOWS

Minimum Infrequent High

The recommended Minimum Infrequent High level and flow are 9.0 ft NGVD and 880 cfs, respectively. On average, this level and flow should be attained for at least 7 days at least once in 5 years (Table 17). This level was more difficult to establish than that for Black Water Creek because the elevation of the upland/wetland ecotone did not correspond with the stage-duration record of the Wekiva River. The upland/wetland ecotone was considerably above any recorded river stage. The ecotone was located approximately from 2.5 to 14.6 ft above the 100-year flood stage as predicted by the frequency analysis. The broad range of the ecotone indicates that a considerable portion of the hydric hammock and bayhead communities in the study reach were dependent on a water source other than river overflow, such as lateral seepage from the surficial aquifer system. Thus, it was not appropriate to set the Minimum Infrequent High level by reference to the elevation of the upland/wetland ecotone.

The lack of mixed swamps in the study area posed problems for determining flows and levels that fulfilled the Minimum

Infrequent High and Minimum Frequent High criteria. The upper inflection area of the stage-duration curve for the Wekiva River (8.5–8.8 ft NGVD; Figure 8) was considered, but it was not adequate because these stages were exceeded annually (Table 7). The most satisfactory solution was to adopt the recurrence intervals and durations used for the Black Water Creek Minimum Infrequent High level (4-year, 7-day) and the Minimum Frequent High level (1.7-year, 30-day). This solution was appropriate because the Wekiva River has narrow, intermittent sections of mixed swamp adjacent to the river. Adopting identical recurrence intervals and durations addresses the temporal aspect of the wetland functions identified for mixed swamp habitat. Hydrochory (dispersal of plant propagules by flowing water), floodplain exploitation by fish, and the exchange of materials between the river and lower portions of the riparian wetlands has occurred historically.

Frequency analysis indicated that a 7-day mean flood duration with a recurrence interval of 1 in 4 years has a value of 9.0 ft NGVD (interpolated from Table 7). The Wekiva River has exceeded this elevation for about 1 percent of the 54-year period of record (Figure 8). A flood of this magnitude will inundate shallowly (0.1- to 1.1-ft depth) the lowest areas of the hydric hammock community. The hydric hammock gradually rises; therefore, portions away from the river will not be inundated.

The eastern portion of transect 4 traversed a small island in the channel of the river. The tree stratum on this island is dominated by red maples (Table 16) and is similar to an early successional stage of the mixed swamp community. Approximately 1.4 ft of water will cover the island at the Minimum Infrequent High level. This depth appears to be reasonable, compared with the average height (1.58 ft) of the water line on trees of mixed swamp communities sampled by Monk (1966). A broader evaluation of water levels in mature mixed swamp habitat occurring upstream or downstream of the study area will be possible after the HEC-2 model is calibrated.

The stage of the Wekiva River fluctuates over a relatively small range. For example, the 100-year, 1-day duration flood stage is only about 2 ft greater than the 2-year, 1-day flood stage (Table 7). However, river flow fluctuates over several orders of magnitude (Figure 12). The flow associated with the Minimum Infrequent High level (880 cfs) is relatively small compared with more extreme flows that have occurred historically. Flood events of a greater magnitude may be required occasionally to flush silt and deposited organics from the river channel. Scour may be necessary to limit the distribution and abundance of emergent macrophytes such as cattails and floating islands of pennywort and water hyacinth. This mechanism has been suggested by several authors in studies of the Little Wekiva River (McClelland 1982a; Canfield and Hoyer 1988).

Minimum Frequent High

The recommended Minimum Frequent High level is 8.0 ft NGVD and the Minimum Frequent High flow is 410 cfs. These should occur, on the average, for a period of at least 30 days no less frequently than once in 2 years (Table 17). The average elevation of the hydric hammock community adjacent to the river was 7.9 ft NGVD (range: 7.3–8.5 ft NGVD). The Minimum Frequent High level results in soil saturation or shallow flooding in these areas. The upper portion of the hydric hammock is not affected. The island of maple swamp habitat traversed by transect 4 will be inundated to a depth of 0.4 ft. The stage of 8.0 ft NGVD has an average recurrence interval of 1.7 years for a duration of 30 days for the 54-year period of record (interpolated from Table 7).

Minimum Average

The recommended Minimum Average level and flow are 7.6 ft NGVD and 240 cfs, respectively. These conditions should not occur for longer than 180 days and should be attained, on the average, less frequently than once in 1.7 years (Table 17). The elevation of the vegetation sample plots showed a great deal of variability. The vertical difference between the elevation of the

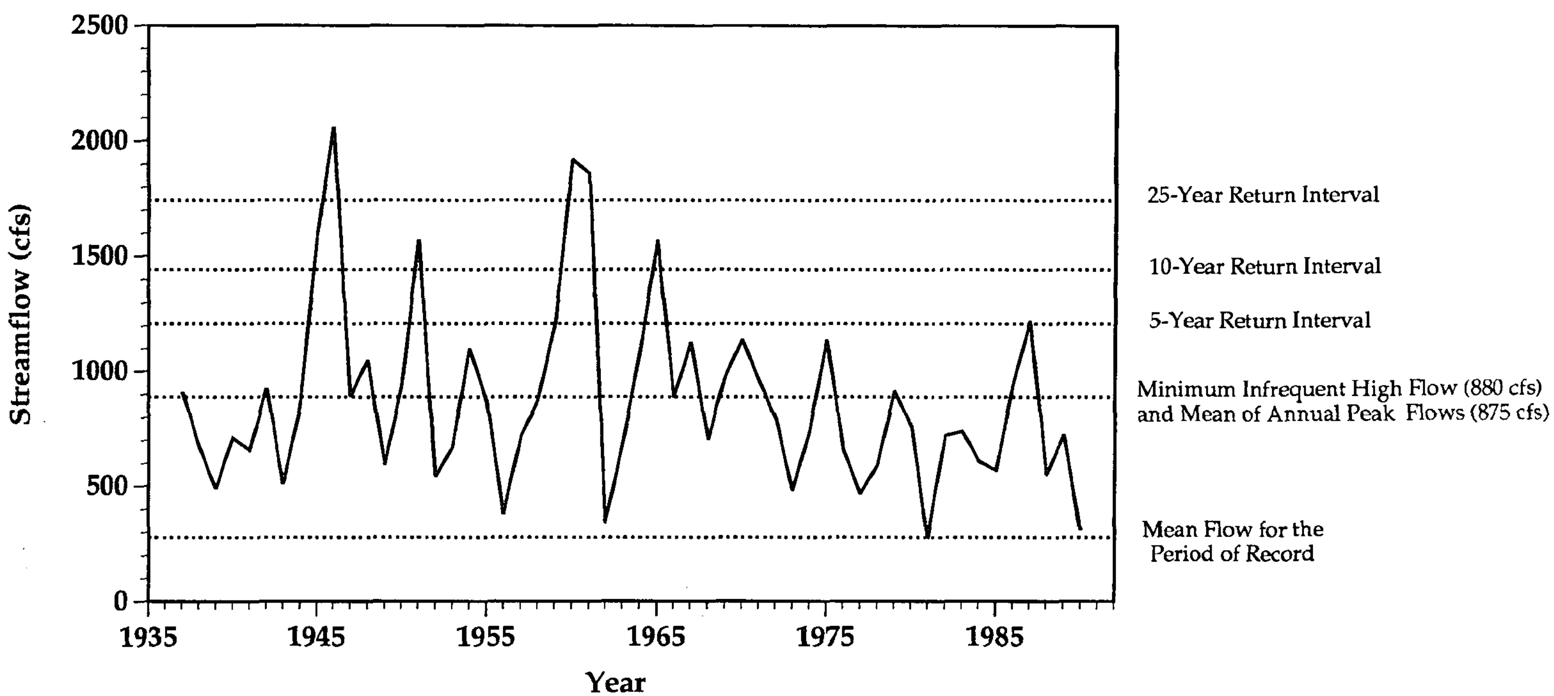

Figure 12. Annual maximum flows of the Wekiva River recorded at the State Road 46 bridge. *Shown are the return intervals of peak flows, the mean flow, and the recommended Minimum Infrequent High flow.*

floodplain and the Minimum Average surface water level ranged from 0.25 to 1.79 ft. The elevations of the hydric hammock plots (4W, 5E, 5W), and consequently the durations of flooding (Table 16), varied greatly. The large degree of elevation variability and the small sample size suggested that basing the calculation of the Minimum Average water level on the mean floodplain elevation may be imprecise; basing the Minimum Average on the 60th percentile of the stage-duration curve may be more appropriate.

The Minimum Average level for the Wekiva River (7.6 ft NGVD) was determined from the elevation that was exceeded 60 percent of the time for the period of record (Figure 8). The ecological basis for choosing this hydrologic datum was discussed previously (see p. 16 and p. 55). The Minimum Average water level is 0.16 ft lower than the average water level (7.76 ft NGVD) and 0.15 ft less than the median water level (7.75 ft NGVD) of the 54-year period of record. The corresponding discharge, 240 cfs, is approximately 16 percent less than the average flow (286 cfs) and 4 percent less than the median flow (250 cfs) for the period of record.

Consumptive uses of ground or surface water should not cause this level to re-occur more frequently than 1.7 years for a period not longer than 180 days. The water depth in the shallow areas of the main channel will be approximately 2.5 ft; therefore, recreational use of the river will not be impaired.

Minimum Frequent Low

The recommended Minimum Frequent Low level is 7.2 ft NGVD and the Minimum Frequent Low flow is 200 cfs. This minimum flow or level should not occur for longer than 90 days more frequently than once in 3 years (Table 17). Historically, these conditions have occurred, on the average, approximately once in 5 years for a duration of 90 days (interpolated from Tables 8 and 10).

Eelgrass beds are an important instream habitat. Extremely low water depths will expose the plants and associated aufwuchs to desiccation. Mechanical damage to the plants from boats and canoes may occur if the water depth is less than 20 in. for extended periods. The Conceptual Criteria Development chapter and the appendix present more detailed discussions about these concerns.

The elevation of the shallowest grass bed habitat was derived by adding one standard deviation to the average substrate elevation occupied by eelgrass and/or elodea (*Egeria densa*) at transects 4 and 5. The resulting substrate elevation includes approximately 68 percent of the elevation range that these species occupy in the riffle areas. Next, 1.67 ft (20 in.) was added to the average substrate elevation to guard against mechanical damage to submerged vegetation and still provide useable habitat for aquatic biota (see appendix). After normalizing for river slope, the average value from the transects was calculated to give the recommended Minimum Frequent Low level (7.2 ft NGVD).

Minimum Infrequent Low

The recommended Minimum Infrequent Low level is 6.1 ft NGVD, and the corresponding discharge is 120 cfs. The associated duration and recurrence interval are no more than 7 days and at least 100 years, respectively (Table 17). At this level, the flow at the SR 46 bridge will be approximately 50 percent of the flow occurring at the Minimum Average level and about 48 percent of the median flow for the period of record. The Minimum Infrequent Low level is 0.6 ft lower than the recorded lowest stage (6.71 ft NGVD, 1974), and the Minimum Infrequent Low flow is 12 percent greater than the lowest recorded flow (105 cfs, 1939). However, the record low flow (105 cfs) is an outlier among other recorded low flows and is somewhat suspect. Frequency analysis of the 54-year stage record indicated that the water level (6.1 ft NGVD) has had a recurrence interval of much more than 100 years (Table 8).

The Minimum Infrequent Low level was determined from the transect having the greatest coverage of aquatic macrophytes (transect 4). Of the areas examined, this location was most restrictive to fish passage and most susceptible to plant mortality at low water levels. Transect 4 had eelgrass present at 84 percent of the instream elevation points (31 of 37) and best represented the distribution of eelgrass habitat in riffles in this stream section.

We examined the relationship between stream width and water depth at transect 4. The elevation that included 25 percent of the stream width was determined, and 1.0 ft was added to this value. The resulting elevation determined the water level at which 25 percent of the cross section has a depth greater than 1 ft. Normalizing for stream slope (0.25 ft water surface difference) set the Minimum Infrequent Low level to 6.1 ft NGVD at the SR 46 bridge.

The Minimum Infrequent Low water level provides a water depth of 0.9 ft above the average substrate elevation occupied by eelgrass at transect 4. At the transect, 99 percent (mean + 3 sd) of the points where eelgrass occurs will be inundated. The upper portions of leaf blades and associated aufwuchs will be exposed to desiccation, particularly in the peripheral areas near the shore. The basal roseate of the plants will remain submerged, and the subterranean winter buds, roots, and stolens will be preserved in the substrate. Preserving the portions of the plants near and below the substrate is important for survival of the plant because asexual reproduction is favored by this species (Korschgen and Green 1988). Eelgrass habitat in pool sections of the river will remain completely inundated.

Faunal refugia will be provided in eelgrass beds on the side slopes of pools and in the deeper portions of the riffle areas and around the major springs. The St. Johns River downstream also will remain accessible to the biota. The recurrence interval that has been recommended, 100 years, will allow sufficient time for the system to recover from the conditions associated with this low flow. Significant ecological harm may occur rapidly if the water level were to fall below the Minimum Infrequent Low level, or if the low-flow event were to occur for longer periods (>7 days) or more frequently (<100 years) than recommended.

MINIMUM SPRING FLOWS

The minimum spring flows and minimum potentiometric surface levels (head) needed to maintain minimum flows and levels in the Wekiva River System are shown on Table 18. To provide a perspective on magnitude, the minimum spring flows of Wekiva and Rock springs compare to 1-day low-flow events with a 4.5- to

Table 18. Wekiva River System minimum spring flows

Spring Name	Flow (cfs)	Spring Pool Elevation (ft NGVD)	Spring Conductance (sfd)	Floridan Aquifer System Potentiometric Surface Level (ft NGVD)
Wekiva Springs	62	13	4.920×10^5	24
Rock Springs	53	30	4.080×10^6	31
Seminole Springs	34	32	1.295×10^6	34
Sanlando Springs	15	26	7.450×10^5	28
Starbuck Spring	13	26	2.100×10^5	31
Messant Spring	12	26	1.720×10^5	32
Palm Springs	7	26	7.450×10^5	27
Miami Springs	4	15	2.800×10^4	27

Note: cfs = cubic feet per second
sfd = square feet per day
ft NGVD = feet, National Geodetic Vertical Datum

Source: Huang 1994; GeoTrans 1992a

6-year recurrence interval based on frequency analysis of springflow data collected from 1931 to 1990 (Tables 13 and 14). Frequency analysis for longer durations is not possible due to the intermittent nature of flow measurements from the springs during any individual year. Springflow records of minor springs in the basin were too short to produce reliable frequency analyses.

Hydrographs of spring flows generated by the model compared well with the observed springflow data collected by USGS, indicating that the rainfall differential model was giving a reasonable estimation of spring flow. Median spring flows calculated from spring flows generated by the rainfall differential model compare reasonably well with the mean and medians of measured spring flows (Table 15). In order to determine how much spring flow is needed to maintain the minimum surface water flows and levels, the total springflow distribution from the model was reduced incrementally until a violation of one of the minimum flows determined for the Wekiva River occurred. This revised distribution thus became the springflow distribution needed to maintain minimum flows in the Wekiva River. The Minimum Frequent Low level, followed closely by the Minimum Average level, were the first minimum levels to be violated by using this process. To determine the critical springflow distribution of each spring, the flow distribution of each spring was reduced by the same percentage used to lower the model-generated total springflow distribution.

Because the ground water model simulates a steady-state condition, only one spring flow per spring was specified to maintain the critical springflow distribution for each spring. Therefore, minimum flows in the Wekiva River were assumed to be maintained by maintaining the median flow (50th percentile on the flow duration curve) of the critical springflow distribution. Until more information is gathered on Black Water Creek downstream of Seminole Creek, the same percentage of spring flow is assumed to be needed in this subbasin as in the Wekiva River subbasin.

PHASED WATER RESTRICTIONS

A primary benefit of determining a minimum flow regime is the ability to delimit the river condition when water conservation measures should be implemented. Defining a range where hydrologic conditions become critical allows increasingly stringent water conservation measures to be implemented. A phased series of four water levels and flows for implementing water use restrictions (Table 19) complements the series of four 15 percent water use reductions contained in the SJRWMD Water Shortage Plan (Chapter 40C-21, *F.A.C.*). The range of water levels and flows for implementing water use restrictions is located between the Minimum Frequent Low and Minimum Infrequent Low levels and flows.

Table 19. Recommended regulatory minimum levels and flows, with associated statistics

Minimum Flow Regime	Level (ft NGVD)	Flow (cfs)	Duration (days)	Acceptable Return Period† (years)
Wekiva River at the SR 46 Bridge				
Minimum Infrequent High	9.0	880	≥7	≤5
Minimum Frequent High	8.0	410	≥30	≤2
Minimum Average	7.6	240	≤180	≥1.7
Minimum Frequent Low	7.2	200	≤90	≥3
Phase 1 restriction	7.0	190	NA	NA
Phase 2 restriction	6.9	180	NA	NA
Phase 3 restriction	6.7	160	NA	NA
Phase 4 restriction	6.5	150	NA	NA
Minimum Infrequent Low	6.1	120	≤7	≥100
Black Water Creek at the SR 44 Bridge				
Minimum Infrequent High	27.0	340	≥7	≤5
Minimum Frequent High	25.8	145	≥30	≤2
Minimum Average	24.3	33	≤180	≥1.7
Minimum Frequent Low	22.8	2.5	≤90	≥15
Phase 1 restriction	22.7	2	NA	NA
Phase 2 restriction	22.5	1	NA	NA
Phase 3 restriction	22.4	0.6	NA	NA
Phase 4 restriction	22.3	0.3	NA	NA
Minimum Infrequent Low	21.9	0	≤7	≥100

Note: cfs = cubic feet per second
ft NGVD = feet, National Geodetic Vertical Datum

† Withdrawals should not cause the Minimum Average, Minimum Frequent Low, or Minimum Infrequent Low levels or flows to occur more frequently or for longer durations than stated. Withdrawals or surface water works should not cause the Minimum Infrequent High or Minimum Frequent High levels or flows to occur less frequently or for shorter durations than stated.

NA: This water restriction should be applied whenever the mean water level or flow of the past 30-day consecutive period meets or falls below the water restriction level or flow.

SUMMARY

Section 373.042, *FS*, directs SJRWMD to use the best information available to define the limit at which further withdrawals of water would be significantly harmful to the water resources or ecology of an area. The statute states that the minimum flows and levels may be calculated to reflect seasonal variation. Additionally, the State Water Policy (Paragraph 17-40.405[2c], *F.A.C.*) states that established minimum flows and levels shall be a consideration for the declaration of a water shortage.

A series of five minimum levels and flows has been recommended as a minimum flow regime for the Wekiva River Basin.

- Minimum Infrequent High
- Minimum Frequent High
- Minimum Average
- Minimum Frequent Low
- Minimum Infrequent Low

These minimum flows and levels have associated statistics that define an acceptable duration and frequency for each flow event. The Minimum Infrequent High and Minimum Frequent High flows and levels result from moderately high amounts of rainfall over the basin and are necessary to maintain floodplain communities. The Minimum Frequent Low and the Minimum Average levels and flows are necessary for maintaining a desirable range of stream base flow. Additionally, the Minimum Frequent Low flow was used to derive minimum spring flows, to protect stream base flow from excessive withdrawals from the Floridan aquifer system.

Minimum spring flows (Table 18) protect the minimum levels as well as the endemic aquatic species living within the spring pools and runs. The minimum springflow values in Table 18 are not considerably less than the medians of historical (measured) spring flows or median spring flows predicted by the rainfall deficit model (Table 15). The biota have experienced lower flows of shorter duration (Tables 13 and 14).

Four phased levels of water use restrictions can be invoked to prevent the Minimum Infrequent Low level or flow from occurring or being exceeded (i.e., going below the specified values). The Minimum Infrequent Low level or flow may be attained during periods of severe drought. Although this flow is too extreme to represent a desirable management condition, the river biota should recover. Significant ecological harm would likely result if any of these minima are violated.

The recommended minimum flow regimes are suitable for the biological and hydrological nature of the stream reach types present in the Wekiva River Basin. A similar multiple flow regime that considers instream and out-of-channel flow requirements is advocated by Hill et al. (1991). A single minimum level or minimum flow alone may provide short-term protection for fish, but will likely allow alterations to the instream and floodplain habitats (Hill et al. 1991). Hill et al. recommended that the streamflow regime maintain four types of flow: (1) instream flows for fish and other aquatic fauna, (2) channel maintenance flows, (3) riparian maintenance flows, and (4) valley maintenance flows. The minimum flow regime developed for the Wekiva River System addresses the first three of these concerns by assuring that frequent bankfull and flood flows will continue to occur and will not be affected significantly by withdrawals from the Floridan aquifer system. The fourth concern, valley maintenance flows, would result from large infrequent storm events (>25-year recurrence intervals) and would occur as nature dictates on an unregulated river system.

Base flow and the magnitude of seasonal variation of water levels and flows differs between blackwater and spring-fed stream reaches. These differences, in conjunction with physiographic factors, exert a considerable influence over floodplain hydroperiods. Black Water Creek has a floodplain composed of primarily mixed swamp, whereas the floodplain of the Wekiva River is composed primarily of hydric hammock. The minimum flood levels were tailored to provide periodic inundation of the riparian plant communities that require flooding. Mixed swamp habitats flood for longer durations and more frequently than hydric hammock habitats.

The portion of the minimum flow regime between the Minimum Average and Minimum Frequent High levels is important for maintaining stream morphology and instream and wetland habitats. The levels and flows between the Minimum Average and the Minimum Frequent High levels range from several tenths of a foot below bankfull to approximately a foot above bankfull. Bankfull stages generate flows in the intermediate range that are important for maintaining stream morphology (Hill et al. 1991). The recurrence intervals associated with these two minimum levels are on the order of less than 2 years. During rainy seasons with normal or above average rainfall, the median stage and flow can easily be reached or exceeded.

The relatively constant base flow in spring runs results in a relatively constant environment for instream flora and fauna (Odum 1957). The Wekiva River and the spring runs have expansive areas of eelgrass that require water depths sufficient to prevent damage by recreational craft, prevent desiccation of the plants, and allow aquatic fauna passage or refugia within. Additionally, several of the spring pools harbor endemic species. Minimum spring flows that prevent the Minimum Frequent Low flow from being exceeded (i.e., going below the specified values) address these requirements. A regional ground water flow model will be used as a management tool to ensure that projected withdrawals from the Floridan aquifer system do not cause a lowering of the elevation of the potentiometric surface that might cause a reduction in minimum spring flows.

The upper reach of Black Water Creek (upstream from Seminole Creek) can recover more quickly from lower water levels than the Wekiva River. Black Water Creek has biota adapted to variable flows and levels and does not have aquatic grass beds.

The minimum levels and flows were developed at transects on Black Water Creek and on the Wekiva River. The river system is a continuum; if a critical flow or stage is reached at the stream gaging stations, it is likely that other stream reaches in the system are in a similar condition. We believe that this is a reasonable assumption for an unregulated river. The validity of this assumption will be tested following the completion of the HEC-2 surface water model. The biology and hydrology of the Wekiva River System are sufficiently understood that minimum levels can be established elsewhere in the system if our assumption of spatial continuity is found invalid.

The spring flows and the potentiometric surface elevations (head) given in Table 18 will protect river base flow. The results of modeling efforts will determine the estimated elevation of the potentiometric surface under different pumping or withdrawal scenarios. Projected withdrawals should not reduce spring flows below the minimum flows needed to maintain the base flow in the Wekiva River Basin.

Monitoring of the springs and streams should be expanded if the phase 3 water restriction level or flow is exceeded (i.e., going below the specified values). The phase 3 level at the SR 46 gaging station is the lowest water level that has occurred in the Wekiva River over the period of record. Monitoring should evaluate the physical and chemical conditions of the streams, and any unusual biological phenomena occurring at the community or population level should be noted. These data will be important for evaluating the degree of harm and the resiliency of the system.

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APPENDIX: TAPEGRASS PROJECT

State of Florida

Department of Natural Resources Memorandum

August 21, 1990

To: Jim Murrium, Park Manager, Wekiwa Springs State Park
From: Al Kinlaw, Park Biologist, Wekiwa Springs State Park

RE: Tapegrass Project: Preliminary Report and Initial Recommendations

This memorandum summarizes the results of a preliminary project that investigated the possibility of "paddle gouging" of streambed (bottom) vegetation on Rock Springs Run (RSR) and the Wekiwa River (WR) by canoeists and boat prop damage to bottom vegetation on the Wekiwa River. Some concern has been expressed that this might be a problem; I was primarily interested in Vallisneria americana (wild celery, tapegrass, sometimes called eelgrass), because it is very common in these waterways and thus might be a good indicator of damage. This is a preliminary report and does not proport to have collected nor analyzed all factors relating to this project.

To briefly reiterate the history of this project, I initially set up a small pilot study involving 4 fenced enclosures in shallow areas where damage might be likely (2 on RSR, 1 on the WR, and 1 on Wekiwa Springs Run (WSR)) as a small pilot study to determine if vandalization would occur and if any possible damaged vegetation would re-grow in a short time (a 'quick' result). The enclosures are shaped like dimonds, and measure 8 feet on each of the 4 sides. The intent was to keep canoeists out of the protected area so no "paddle-gouging" would occur.

Problems such as this can be addressed using one of 2 different approaches. For many management problems, a simple qualitative approach can be followed, involving little accuracy. This is appropiate when the problem is not of outstanding importance, or money and manpower are limited. Often this approach works well and solves the problem, but we can't be sure that our actions are what solved the problem (i. e., this is a 'best guess' approach). As you can see at the end of this memo, my recommendation is to follow this approach.

If the problem is very important, and money and manpower are available, a quantitative, statistical approach is necessary. A researcher controls for the various environmental factors that affect the issue. If appropiate experimental procedures and statistical tests are used, the researcher can be reasonably sure that his research can determine the nature of the problem and will probably lead to a correct solution. Rather than being based on preconceived guesswork, this approach is more likely to determine what the real, underlying problem is.

If a study were to be done following the second approach, we need to be aware of a number of biotic and environmental factors that affect this plant; if this experiment is to be expanded to the necessary sample size adequate to demonstate a 'damage' effect from canoeists, appropiate statistical controls for these factors need to be implemented. Substrate (coarse sand, fine sand, muck, gravel, etc), temperature, alkalinity and pH have all been documented to affect the growth of Vallisneria , as well as hydrologic aspects related to channel geometry (water depth and turbidity, hydrostatic pressure, current or discharge, depth, uniform/varied flow, channel roughness, and several others), and could possibly be controlled for by the design of the experiment (how and where the enclosures are placed). Some variables might not present design problems, since there might be consistency in those variables along the runs. Obviously the enclosures would need to be set up before the tapegrass growing season.

My preliminary finding is that a long, controlled study is not needed. Based on surveys done along Rock Springs Run and Wekiwa Spring Run, it appears that some damage to tapegrass might have occurred, but only on less than 5% of the river. Common sense indicates that paddle-gouging can only occur where several conditions are simutaneously met:

1. The water depth is around 20 inches or less. When most people paddle canoes, they insert their paddles to approximately this depth. Thus, vegetation that is growing deeper should be protected from this type of damage.

2. A mucky (soft) substrate exists. Tapegrass can be dislodged from very soft substrate by paddle action. It is very difficult to break Vallisneria from a firm sandy bottom.

3. Heavy canoe use immediately above the tapegrass bed. There are a number of tapegrass beds along the shallow edge, where canoeists do not paddle. Usually the deeper, center part of the Run is used, where the current is faster.

Since the ground water levels are below normal and the flow from spring water exiting the Aquifer is lower than normal (according to the Surface Waters section of the SJWMD), this is a good time to measure the water depth at beds of tapegrass to see if damage could and has occurred, since we are in our peak canoeing season. We recently surveyed RSR, WSR, and a short portion of the Wekiwa River to inspect for damage and for areas that meet these conditions. There were only several "flats" areas (River Cabin and approximately 1 mile north of King's

Landing) in which it appeared there may be a problem with plant damage. Charles Dutoit reported that canoeists did not damage streambed vegetation in his study on the Ichetucknee River.

Additionally, I invited a private consultant with 20 years experience in aquascapeing to visit specific sites on RSR and WSR. His opinion was that that little damage has occurred on RSR and WSR due to canoe "paddle-gouging". I also discussed this project with a U.S. Fish and Wildlife biologist who has published articles dealing with tapegrass; although he hasn't visited our sites, he was skeptical that canoeists could cause major damage to tapegrass, because it has a good root system which allows it to exist in shallow water subject to wave wash.

Realistically, we must also be aware that "damage" due to grazing by wildlife is a normal process. Diving and dabbling ducks, turtles, and invertebrates commonly eat tapegrass. The damage we observed is certainly not of the magnitude that occurs naturally.

Results of the pilot study were inconclusive. After 6 weeks, two of the enclosures had been slightly tampered with, but not to the point that it made any difference. There was no regrowth of the tapegrass in the enclosures. The underwater part of the fencing used did affect the experiment somewhat, causing some redistribution of the sandy bottom, and floating macrophytes such as water lettuce, became entangled along the front edge of the enclosure (Figure 1). The underwater parts of the fencing on each enclosure have now been removed, so that the dynamics of stream flow are not affected, except only slightly by the stakes used (Figure 2).

It does appear that damage due to boat props has had some important negative effects on the Wekiwa River streambed, however (Figure 3). A study utilizing enclosures or minimum barricades is clearly needed. Again, the damage has occurred in areas where the water depth is around 20 inches or less. I would be happy to conduct such a study for Debra but would need your approval since that is out of the Park.

RECOMMENDATIONS

1. Monitor the existing enclosures for a full growing season. Tapegrass plants grown in enclosures have become established and were evident the following year, according to a published report.

2. In shallow areas discussed above where some damage has occurred, place additional enclosures. These should be as simple as possible, just a V-shaped arrangement, with the bottom of the V facing upstream. This should route the canoeists around the area, but cause minimal impact to stream hydrology.

3. Monitor the number of canoeists using all 3 river systems.

If possible, careful notes should be made if people start getting out of canoes to wade or swim, thus trampling vegetation. (This type of damage was noted in Dutoit's study.)

4. If damage does become a problem, transplanting could be done. It is unlikely this will be necessary.

CC: Debra Shelley
Walt Thomson
Rosi Mulholland
Jennifer McMurtray