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Water Management in Taylor Slough and Effects on Florida Bay

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Water Management in Taylor Slough and Effects on Florida Bay

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Executive Summary

Current water management practices in the L-31N, L-31W, and C-111 canals have contributed to lower groundwater levels and reduced surface water flows in the Rocky Glades and the Taylor Slough marshes. The reduced hydraulic gradients and the truncated periods of flow through the Taylor Slough basin are thought to be a major factor contributing to the hypersaline conditions and abrupt salinity changes in Florida Bay.

The progressive lowering of L-31N canal stages from 5.5 to 4.3 feet in response to pressure from expanding urban and agricultural development has increased drainage from the marshes in Everglades National Park into the bordering canal system. If one looks at the entire reach of L-31N from the S-335 to S-176, well over 270,000 acre-ft per year are drained from the western marshes into L-31N. Approximately 50,000 acre-ft are returned to Taylor Slough, while 180,000 acre-ft are dumped into the lower C-111 basin.

If we focus on the Rocky Glades, the historical headwaters of Taylor Slough, only about 60% of the water drained from this area is returned as deliveries to Taylor Slough via S-174. Thus, the source of water for S-174 water deliveries to Taylor Slough is primarily from drainage of the local Taylor Slough headwaters, not from the regional water supply system.

Prior to 1981 L-31W canal stages were routinely allowed to reach 5.0 feet. With the increasing agricultural activities in the Frog Pond, L-31W has been held at or below 4.5 feet, and L-31W is used frequently to drain water from the Frog Pond and consequently, Taylor Slough. In a typical year, L-31W drains 41,000 acre-ft from Taylor Slough, while S-332 pumps 33,000 acre-ft back into Taylor Slough. Moreover, since 1984, L-31W has been artificially lowered to accommodate early crop planting times in the Frog Pond. The current operational policy for L-31W represents a net loss of water from Taylor Slough, and a net harm to Everglades National Park.

This report also contains the analyses of water management operations during three representative storm events affecting the C-111 basin. These case studies indicate that the operational policy is to convey storm water from L-31N into C-111, rather than into Taylor Slough. As a consequence, large volumes of water have been quickly lost from the northern part of the system, overdraining the wetlands in Shark Slough, the Rocky Glades, and northern Taylor Slough. The diversion of flows from Taylor Slough and into the lower C-111 basin has necessitated emergency operations of S-176 and in addition, forced emergency releases through S-197, damaging Manatee Bay.

The District, the Corps, and the Park have been working steadily toward an agreement on L-31N and L-31W operations. This report represents the Park staff's preparatory analysis for this Taylor Slough demonstration project. We present the rationale for raising canal stages as well as increasing flows to Florida Bay. By increasing water levels in the wetlands upstream of Florida

Bay, more of the water put into Taylor Slough and C-111 will actually make it into the Bay. This is because if upstream water levels are low, much of the discharges into Taylor Slough will be consumed as evapotranspiration and groundwater recharge; if upstream levels are high, then discharges into Taylor Slough will immediately begin to move downstream as sheet flow. Given the limits to water availability, the surest way to increase flows to Florida Bay is to raise stages in the upstream marshes.

The complete recommendations are found in Chapter 6 on page 75.

Abstract

Taylor Slough has historically been a major contributor of fresh water to Florida Bay. Since 1982, progressive lowering of canal stages in and near the headwaters of Taylor Slough has lowered water levels throughout southern Dade County, and probably reduced freshwater flow to Florida Bay. The primary purpose of this report is to inform Everglades National Park management about the effects of changing water management in the L-31N, L-31W and C-111 canal systems on the Park's water resources. The report also provides some recommendations on how to protect and improve the Park's water resources.

The analysis is split into six parts. First, we document the operational rules of the water control structures along the eastern boundary the Park, along with their evolution, and their effect on water levels and flows in and near the Park. Second, we develop water budgets for the canals near the Park's eastern boundary, and demonstrate how current operational policies have resulted in significant drainage of the marshes west of L-31N and L-31W. Thirdly, we examine the Flood Control Project during several wet periods, documenting operations to divert water from Taylor Slough into C-111. Fourth, we look at salinity in Florida Bay and how fresh water inflows affect the pattern of salinity. Fifth, we apply the Natural System Model and the South Florida Water Management Model to estimate freshwater flows to Florida Bay and how increasing canal stages will modify the inflow regime. Lastly, the report concludes with recommendations for water resources management to be pursued by Everglades National Park.

Acknowledgments

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Virgil, Eclogue, iii 111

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Chapter 1

Background

Taylor Slough has historically been a major freshwater source for Florida Bay. This slough, encompassing more than 158 square miles of freshwater marsh, extends some 20 miles from its upstream end north of the Frog Pond to the coastal mangrove fringe along central Florida Bay. The headwaters of the slough originate in the Rocky Glades, which forms the hydrologic divide between Shark Slough and Taylor Slough. As seen in Figure 1, the largest portion of Taylor Slough and its headwaters are located within Everglades National Park, and they represent vital elements of the Park's hydrologic system. Besides being a freshwater source for Florida Bay, Taylor Slough and the Rocky Glades are critical habitat to several endangered species, and areas essential to the Park's ecosystem.

The purpose of this report is two-fold. Its primary intent is to inform Park management about the effects of past water management practices on the water resources of Everglades National Park. The report lays the foundation for a staff recommendation that Park management seek higher canal stages, as well as modifications of surface water flows on the eastern periphery of the Park. The secondary purpose of this report is to document our examination of the historical hydrologic record. This should serve as a baseline for subsequent modeling and analysis of the effects of modifications in water management practices in the Taylor Slough, Shark Slough, and lower C-111 basins.

Concern about the decline of Florida Bay has brought the question of water management practices to the forefront. The freshwater inflows to Florida Bay are now largely controlled by the Central and Southern Florida Project (Project), which is operated by the South Florida Water Management District (District). The construction and operation of this complex system of canals and levees has brought considerable changes in the hydrologic regime of Taylor Slough and the Rocky Glades.

Prior to the construction of the Project in western Dade County, water levels in the Taylor Slough headwaters were 1.5 to 2.5 feet higher than today [Johnson and Fennema, 1989]. These higher water levels kept the northern Taylor Slough marshes inundated for 2 to 3 months each

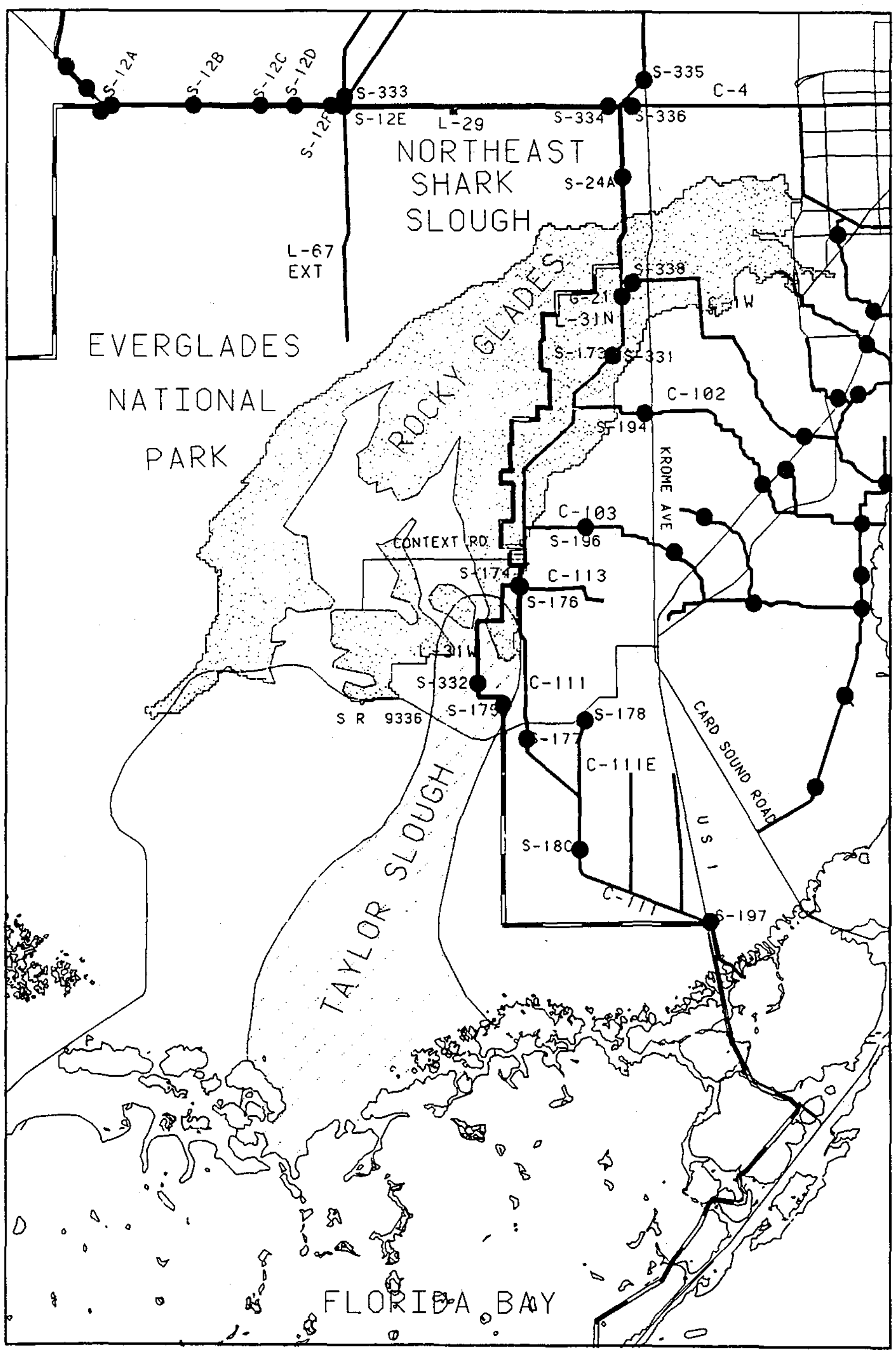

Figure 1: Location of Taylor Slough, Florida Bay, and the South Dade Conveyance System.

year, and sustained sheet flow and groundwater flow into Florida Bay. The higher water levels also maintained more persistent and gradual surface water flows into the downstream wetlands and estuary, which presumably produced more gradual salinity fluctuations in the nearshore areas of Florida Bay.

1.1 The Water Management System

One can conceptually break the water management system affecting Taylor Slough and the downstream areas of Florida Bay into three components. The first component is the levees and canals forming the Water Conservation Areas (WCAs). The southern-most WCAs are WCA 3A and 3B, located just north of Shark Slough along Tamiami Trail. The WCAs were designed to impound and store wet season runoff, and control the sheet flows that historically flowed through the Everglades. The objective of the Project was primarily twofold: 1) to create a continuous levee system to protect the Lower East Coast from the endemic flooding of the Everglades, and 2) to create water supply reservoirs for urban and agricultural development. The second component affecting Taylor Slough and Florida Bay, and most important to this analysis, is the L-31N, L-31W, and C-111 canal system of western Dade County. This canal system captures wet season runoff from the western portion of Dade County, and directs these flows southward and westward into Barnes Sound and Florida Bay (Figure 1). During the early 1980's, an additional set of water control structures was added to this canal system to form the South Dade Conveyance System (SDCS). These modifications were added for the purpose of conservation and conveyance of additional dry season water deliveries to the eastern portion of Everglades National Park, and for expanding urban and agricultural needs in southern Dade County. The third component is the network of canals in the developed portion of eastern Dade County. These canals were originally build for drainage, but are now used for water supply, flood control, and to control saltwater intrusion. This report concentrates on the effects of the L-31N, L-31W, and C-111 canals, since these canals most directly affect Northeast Shark Slough, Taylor Slough, and inflows into Florida Bay.

1.1.1 Congressional Authorizations and Corps' Design Documents

To ascertain the intent of Congress and to understand how the Project was designed, one must examine the Army Corps of Engineers design documents and record of Congressional action. An excellent summary of all of the Project authorizations and features is provided in the Corps of Engineers 1991 *Master Water Control Manual, Volume 1, Authorities and Responsibilities* [U.S. Army Corps of Engineers, 1991]. In addition, the Corps has developed a Water Control Plan specifically for the Water

Conservation Areas, Everglades National Park, and the South Dade Conveyance System [U.S. Army Corps of Engineers, 1992]. The system of canals and water control structures that deliver surface water to the Shark Slough basin were primarily constructed as outflow structures for the Water Conservation areas and were authorized by the Flood Control Act of 1948 (PL 80-858). The specific design plans and operational objectives of these structures were described in the General Design Memorandum (GDM) for Water Conservation Area No. 3 [U.S. Army Corps of Engineers, 1960c], and in the Detailed Design Memorandums (DDM) for Levees 67A and 29, Section 3 [U.S. Army Corps of Engineers, 1960a], and Levee 29, Sections 1 and 2 and the S-12 Structures [U.S. Army Corps of Engineers, 1960b].

Several different Congressional acts authorized the canals and control structures that deliver water to the eastern basins of the Park. The L-31N levee and associated borrow canal were authorized by the Flood Control Act of 1948, as part of the Eastern Protective Levee System. The Flood Control Act of 1954 (PL 83-780) authorized construction of the L-31W canal and levee. The Flood Control Acts of 1954 and 1962 (PL 86-645) authorized construction of the C-111 canal and levee system and improvements to several of the south Dade coastal canals.

Other more general Congressional Acts affecting the Park include the Flood Control Act of 1968 (PL 90-483) which authorized construction of the South Dade Conveyance System. The 1968 Act specifically directed the Corps of Engineers to modify the existing C&SF Project features for the purpose of conserving and conveying additional water supplies for Everglades National Park, and expanding agricultural and urban needs. The Minimum Delivery Schedule for Everglades National Park was authorized as part of the River Basin Monetary Authorization Act of 1970 (PL 91-282). The Supplemental Appropriations Act of 1983 (PL 98-181) modified the schedule of Minimum Deliveries to the Park and authorized the Experimental Program of water deliveries to ENP. This experimental program was extended two times under the authority of PL 99-190 and PL 100-676. Finally, the ENP Protection and Expansion Act of 1989 (PL 101-229) authorized construction of Project modifications to improve water deliveries to Shark Slough and to restore more natural hydrological conditions within Everglades National Park.

The design plans and operational objectives for the L-31N, L-31W, and C-111 canals and their control structures have gone through numerous modifications over the years. The overall operational plans for these canals and structures were first described in the Survey Review Reports for South Dade [U.S. Army Corps of Engineers, 1961] and Southwest Dade Counties [U.S. Army Corps of Engineers, 1963b]. During the late 1950s through the early 1970s, the Corps prepared three GDMs for the study area: (1) Levee 31 and Related Works [U.S. Army Corps of Engineers, 1959], (2) for all of South Dade County [U.S. Army Corps of Engineers, 1963c] and (3) for the Conveyance Canals to Everglades National Park and South Dade County [U.S. Army Corps of Engineers, 1973]. In addition, in 1975 a separate Environmental Impact Statement was prepared for the South Dade conveyance canals and the plan for East Coast backpumping [U.S. Army Corps of Engineers, 1975]. Finally, a series of Detailed Design Memorandums (DDMs) for the specific reaches and control structures in the L-31N, L-31W, and C-111 canals were released including: (1) the DDM for Section 1 (lower portion) of the C-111 Canal and Control Structure 18C [U.S. Army Corps of Engineers, 1963a], (2) the DDM for Sections 2 and 3 of the C-111 Canal and Control Structures 176, 177, and 178 [U.S. Army Corps of Engineers, 1965], (3) the DDM for the L-31N Canal and Control Structure 173 [U.S. Army Corps of Engineers, 1966], (4) the DDM for the L-31W Canal and Control Structures 175 and 175 [U.S. Army Corps of Engineers, 1967], (5) the DDM for the enlargement of the L-31N Canal, C-1, C-103, and Pumping Station 331, built as part of the South Dade Conveyance System [U.S. Army Corps of Engineers, 1973], and (6) the DDM for the enlargement of L-29 and L-30, Pumping Station 332, and Control Structures 194 (modifications), 333, 334, 335, 336, and 338, built as part of the South Dade Conveyance System [U.S. Army Corps of Engineers, 1974].

1.1.2 Early Canal Construction in Southwestern Dade County

The original plan of improvement for southwestern Dade County was presented in the Survey Review Report for South Dade County [U.S. Army Corps of Engineers, 1961]. The plan called for gravity drainage of an area of 227 square miles of southwestern Dade County using a system of 12 primary canals. Although the Corps found that the natural drainage in the western portion of south Dade was to the southwest (into Taylor Slough), gravity drainage primarily to the south and east (into Florida Bay, Barnes Sound, and Biscayne Bay) was found to be most practical. The General Design Memorandum (GDM) for South Dade County [U.S. Army Corps of Engineers, 1963c] provided the specific design elements for the water management features of southwestern Dade County. The plan was designed to provide the area with flood protection up to 40% of the Standard Project Flood (SPF), or roughly, a flood event with a 10% chance of occurring in any given year. Runoff from the area east of L-31N and north of Homestead was to be drained to Biscayne Bay via six proposed canals (C-101 through C-106). The area south of Homestead was to be drained southward into Florida Bay and Barnes Sound via six proposed canals (C-107 through C-112). During the project review, the National Park Service wrote correspondence to the Corps concurring with the plan for eastern Dade County, but the Service requested that the area west and northwest of Homestead be drained westerly into Everglades National Park. These Park Service objections led to design and construction of L-31W. The Park Service also objected to the southerly extension of the C-110, C-111, and C-112 canals to tidewater, and requested that the canals be terminated at the one- foot contour to promote sheetflow.

In response to the written comments of the National Park Service, the Flood Control District, and local land developers, the 1961 plan was modified in the 1963 GDM for south Dade County. Everglades National Park asked that all excess water west of the divide on the Coastal Ridge be drained westward into Taylor Slough. The motivation was to offset the drainage effects of the C&SF Project. This was the specific reason why the L-31W canal was added to the 1963 GDM. The works were constructed so that, during the design storm, approximately 28 square miles of land east of L-31N and west of the Seaboard Airline Railroad would be drained westward into Taylor Slough via L-31W canal. During smaller storms, the contributing areas was expected to increase, and extend eastward as far as S-165 and S-167 (near U.S. Highway 1.) The L-31W levee was build to protect the developed areas to the from inundations from Taylor Slough. The Frog Pond agricultural area was to be protected by the C-111 canal to the east, and further drainage was expected in the form of a locally operated, interior drainage system [U.S. Army Corps of Engineers, 1963b].

The earliest canal construction in western Dade County began in 1951, with the construction of the L-30 and the northern portion of the L-31N canal and levee systems. The levees were built as part of the Eastern Protective Levee System, to protect the populated east coast from Everglades flooding. In 1961, construction began on the L-29 canal and levee system; its completion in 1962 largely finished the closure of Water Conservation Areas 3A (WCA 3A) and WCA 3B along the northern Park boundary. Initially, there was no surface water connection between the L-29 canal and the canal systems making up the western boundary of the urban and agricultural areas (L-30 and L-31N). Therefore, L-30 and L-31N had no significant flood control or water supply capabilities.

In 1965, construction began on the remainder of the L-31N canal system. The 1963 GDM specifically recommended that the L-31N canal be used "to provide southerly drainage to ENP in Taylor Slough for the westerly portion of south Dade County". The benefits of maintaining optimum canal stages in these areas was also well known, and structures S-165, S-166, S-167, S-177 and S-178 were built to maintain groundwater levels as high as possible to promote water conservation. During 1965, several of the coastal canals (C-1, C-102, and C-103) were extended westward and connected to the L-31N canal to improve flood protection for the extreme western agricultural areas and to allow for water supply to these basins. The S-173 control structure was added to divide the L-31N canal into two reaches: the reach north of S-173 was designed to drain eastward via C-4 and C-1W, while the reach south of S-173 drained southward and westward into the L-31W and C-111 canal systems.

The first proposed operating criteria for the southern reach of L-31N and L-31W canals were described in an Army Corps of Engineers letter to the Flood Control District in 1966. At that time, the intention was that S-175 and S-176 would remain closed under normal conditions, and L-31N would be held as high as 6.5ft msl to promote the discharge of water into L-31W via S-174. Water would then spill overbank from L-31W canal into Taylor Slough. Under flood conditions, up to 500 cfs would be discharged into L-31W via S-174 and out S-175, to maximize Taylor Slough inflows. The final authorized operating criteria were modified in the 1967 DDM for the L-31W canal. Under these criteria, water would be discharged into the L-31W canal whenever the S-174 headwater stage exceeded 5.3ft msl. Structure 176 would remain closed until its headwater stage exceeded 5.5ft msl, again to maximize flows into Taylor Slough. Structure 175 was designed to remain closed until its headwater stage rose above 4.5 feet [U.S. Army Corps of Engineers, 1967]. When S-332 was added in 1983, the pump station was authorized to be operated according to the monthly Minimum Delivery Schedule, or up to its maximum capacity, with the concurrence of the Corps, the District, and the Park.

In 1968 the Corps of Engineers began construction on the L-31W canal and control structures S-174 and S-175. This canal was designed specifically to provide an outlet for a portion of the L-31N flood waters and to convey flow to replenish the freshwater supply to the Taylor Slough area of the Park. Structure 174 was designed to "maintain optimum water levels up to 6.5 feet in the L-31N borrow canal, and discharge up to 500 cfs into the L-31W borrow canal". Structure 175 was designed to "maintain optimum water levels up to 5.0 feet and provide a means of either diverting the borrow canal discharge overland into Taylor Slough, or passing it south to be distributed overland from the borrow canal south of State Road 27". At this time the system still lacked a direct connection with the WCAs, and did not have water control structures capable of moving significant quantities of water into southern Dade County.

1.2 The South Dade Conveyance System

Concerns by Everglades National Park that more freshwater was needed for Taylor Slough and the downstream areas of Florida Bay prompted Congress to authorize construction of the South Dade Conveyance System (SDCS) as part of the Flood Control Act of 1968. The conveyance canal system was designed to provide supplemental water supply from Water Conservation Area 3A to a 524 square mile area of Dade County, including the Taylor Slough and Eastern Panhandle drainages of the Park. The GDM for Conveyance Canals to Everglades National Park and South Dade County [U.S. Army Corps of Engineers, 1973] noted that the period from November through May of each year was normally a period of insufficient rainfall in south Dade, and that additional dry season water deliveries would be required. The Corps also identified the importance of maintaining optimum canal stages in the L-31N canal, stating that "deficient water levels in this area create a groundwater gradient from adjacent Shark Slough, thereby diverting water that would normally be destined for Everglades National Park". In 1975, the Corps completed an Environmental Impact Statement for the SDCS and for the proposed plan for East Coast backpumping [U.S. Army Corps of Engineers, 1975].

The first phase of the SDCS was completed in 1978 with construction of structures 333 and 334 in the L-29 canal (see Figure 1). The S-332 pump station in the L-31W canal was constructed next, and it became operational in 1980. The SDCS was finished in 1983; L-31N was enlarged and pump station S-331 was completed making the South Dade Conveyance System fully operational. This pump station was placed next to the S-173 divide structure, giving the District the ability to move significant volumes of water from the northern end of L-31N into the southern end. All of these structural changes were designed to provide additional dry season water delivery capabilities to the L-31N and L-31W canals.

The Corps estimated that the dry season supplemental flow requirements to the SDCS were 318,500 acre-feet annually. This represents the average annual inflows that would need to be made to the northern reach of the L-31N canal system. Average annual dry season water supply pumping needed at S-331 was estimated to be 264,800 acre-feet. Of this amount, a minimum of 55,000 acre-feet would be provided to the Taylor Slough and Eastern Panhandle portions of Everglades National Park to meet the Congressionally mandated Minimum Delivery Schedule, which went into effect in October 1970 [U.S. Army Corps of Engineers, 1973]. Prior to the construction of S-331, the southward movement of water down the L-31N canal was limited to 100 cfs due to the capacity of structure S-173. This limited capacity was intentional, since S-173 was constructed as a divide structure. Structure 173 was designed to remain closed during flood events, and operated only during low water periods. Since the completion of pump station S-331, this operational plan has been altered and the S-331 pump station is now routinely used routinely during the wet season to provide additional flood protection for the developed areas west of L-31N.

The Project works in western Dade County were originally designed under the assumption that most of the southern C-111 basin would be undeveloped, and that the land use in the northern developed areas would be primarily seasonal agriculture [U.S. Army Corps of Engineers, 1961]. Canal water levels were designed to remain relatively high during the wet season, and were expected to recede naturally throughout the dry season. In contrast, expanding urban and agricultural development into the lower-lying areas of western Dade County has pressured the District and the Corps to steadily lower water levels in the L-31N, L-31W, and C-111 canals over the past 20 years. Tables 1—3 provide summaries of the initial operational settings for the control structures in the L-31N, L-31W, and C-111 canals and a history of the changes in these operational stages since the mid 1960s. Note that wet season water levels at S-176 were approximately 1.2 feet lower than the initial design settings. Reduced wet season canal stages at S-176 has lowered water levels in the adjacent Rocky Glades leading to the drainage of this important wetland system. Since the L-31N

Date	S-176			S-177			Comments
	open	static	close	open	static	close	
8/65	6.7	6.0	5.8	5.2	4.3	4.1	Design settings (from DDM)
7/67	6.0	5.5	5.3	4.7	4.5	4.3	Initial settings (op. logs)
10/67	5.5	5.3	5.0	4.5	4.3	4.0	Unknown reason for change
6/82	5.0	4.7	4.5	4.2	3.9	3.6	Interagency Agreement
8/84	4.5	4.3	4.1	4.0	3.8	3.5	NESS 30-day test
10/84[a]				3.5	3.3	3.1	Frog Pond drawdown test
3/85[b]	5.0	4.8	4.6	3.5	3.3	3.1	NESS 2 year test, dry season
7/85	4.5	4.3	4.1	4.2	3.9	3.6	NESS 2 year test, wet season

[a]The Frog Pond drawdowns continued for 3 additional years (1985–1987) as part of the NESS delivery test agreement between the District and the South Dade Farmers.

[b]The Northeast Shark Slough (NESS) experimental water delivery program has continued beyond the original 2 year test under PL 102-229. The wet and dry season operational stages have remained the same for the last seven years.

Table 1: Canal operational settings for selectedwater control structures in the central C-111 basin. Stages are referenced to ft NVGD. The "open" refers to stages when gates are opened, "close" refers to levels when gates are closed, while "static" is the design optimum stage.

canal system cuts through the Rocky Glades, management of water levels in this reach of the canal system largely controls the water levels and inflow volumes to the downstream areas of the Taylor Slough basin.

Note that the initial lowering of operational stages in the L-31N canal occurred in June 1982, apparently in response to pressure by urban and agricultural interests in the East Everglades following the flooding caused by Tropical Storm Dennis in August 1981. To our knowledge, there are no assessments of the environmental effects of reduced canals stages were made at the time of this operational change. In this report, we document the detrimental effects that these lower canal levels have had on the resources of Everglades National Park.

1.3 Chronology of Improved ENP Water Deliveries

A chronology of events leading to the current iteration of the Experimental Water Delivery Program should clarify how operations of the C&SF Project by the Corps and the District has unfolded in response to various legistative directives and legal actions. Here, we review the authorizations and major operational programs affecting Taylor Slough since 1980.

Date	S-174			S-175			Comments
	open	static	close	open	static	close	
11/67	5.7	5.5	5.3	5.0			Design settings (from GDM)
3/68	5.5	5.3	5.1	4.5			FCD recommendations
7/71	5.8	5.5	5.1	4.5			Initial settings (op. logs)
6/82	4.9	4.6	4.4	4.5			Interagency Agreement
8/83	5.0	4.7	4.5	4.5			No reason known
10/84[a]				3.5			Frog Pond drawdown test
3/85[b]	5.2	4.9	4.7	3.5			NESS 2 year test, dry season
7/85	4.7	4.5	4.3	4.5			NESS 2 year test, wet season

[a]Same as in Table 1.

[b]Same as in Table 1.

Table 2: Canal operational settings for the L-31W water control structures.

1.3.1 Factors Leading to the Experimental Water Delivery Program

Following the implementation of the Minimum Delivery Schedule in 1970, the Park completed a number of research studies describing problems that were believed to be related to the inadequacy of the fixed monthly water delivery allocations and the impacts of large regulatory flows through the S-12 structures. A request by the National Park Service prompted the Senate Committee on Environment and Public Works and the House Committee on Public Works and Transportation to pass two resolutions in April 1978, to reexamine the practice of providing inflows to the Park. The resolutions specifically directed the Corps to examine the operation of the C&SF Project to allow for the redistribution of surface water flows back into the northeastern portion of Shark Slough, that would more adequately meet the environmental needs in Everglades National Park. The resolutions further state that "the investigation shall include, but not be limited to, consideration of structural and other appropriate measures to improve the future environmental condition of the Park with special regard to providing adequate supply and distribution of water with an acceptable quality to the Everglades National Park."

In August and September of 1981, two extreme rainfall events produced extensive flooding in western Dade County, particularly in the unprotected East Everglades area west of L-31N. In June of 1982, District lowered the operating criteria in the L-31N canal. It is our understanding that this occurred in response to threats of lawsuits by landowners in the East Everglades/south Dade area. These changes marked the start of a long period of operational adjustments in the canals that

S-331/S-173 Water Supply Mode[a]	
Begin pumping when stages drop below:	
Structure (HW)	Critical
S-174/S-176	4.0
S-177/S-175	3.0
S-194/S-196	4.0

S-331/S-173 Flood Control Mode[b]	
Pumping based upon water level at Angel's well	
Angel's	S-331 HW
< 6.0	5.0
> 6.0	4.5
Downstream control elevations can limit S-331/S-173:	
Structure (HW)	Stage
S-174/S-176	> 6.0
S-177	> 4.3
S-175	> 5.0
S-18C	> 3.3

S-334/S-335 Water Supply Mode	
Make releases when stages drop below:	
Structure (HW)	Critical
S-331	3.5
S-25B/S-22	2.8

S-334/S-335 Stage Maintenance Mode		
When water supplied not needed, release to maintain optimum:		
Structure (HW)	Optimum	Maximum
S-334	6.0	7.2
S-335	6.0	

[a] Original operational criteria.

[b] Supplemental criteria added as part of 2-year test NESS agreement.

Table 3: Canal operational settings for selected L-31N water control structures.

boarder the eastern portion of the Park. In September 1982, the Corps completed a draft feasibility study and draft Environmental Impact Statement (EIS) for Shark River Slough, as directed in the 1978 House and Senate Resolutions [U.S. Army Corps of Engineers, 1982]. This was the first official document describing the plan to restore surface water flows to the Northeast Shark Slough basin. The report was focused directly on the question of the feasibility of using S-333 to mitigate extreme high water events in ENP and the redistribution of surface water flows to the full width of the Shark Slough flow section.

In March 1983, following a period of record rainfall and extremely high dry season flows through the S-12 structures, the Park presented a Seven Point Plan to the SFWMD Governing Board calling for immediate relief from these regulatory releases. The plan called for diverting excess surface water flows into Northeast Shark Slough through the use of S-333, construction of new water control structures in the L-28 Levee to pass surface water from WCA 3A into the Big Cypress National Preserve, installing plugs in the L-67 extension canal to promote sheetflow, and the immediate development of an improved water delivery schedule for Shark Slough, based on a more natural rainfall-runoff relationship. In late March 1983, the SFWMD and the Corps approved the temporary use of S-333 to mitigate severe high water problems in ENP. Structure 333 remained open until the middle of June, when concerns were raised related to the potential of increased flooding in the East Everglades. Structure 331 flood control operations began in June 1983, prior to our efforts to reintroduce surface water flows into Northeast Shark Slough. These operations were not an authorized element of the original structure's design. Clearly, the mandate for the South Dade Conveyance System, under which S-331 was built, was for water supply and did not include a flood control element.

In June 1983, the Corps, the District, and the Park agreed to establish a field test of improved water deliveries into the western portion of the Shark Slough basin. A Flow Through Plan was adopted which established a free flow system of water from WCA 3A into western Shark Slough. During the first year, the S-12A, B, and C structures remained open full (S-12D was closed while plugs were being installed in the L-67 extension canal). During the second year, free flow occurred through all of the S-12 structures. The Flow Through Plan produced high sustained flows into western Shark Slough throughout the test period and allowed for a more natural dry season recession. The plan was discontinued in 1985 because the combination of below normal rainfall and uncontrolled flows at the S-12s depleted the water storage capabilities of WCA 3A.

1.3.2 Establishment of the Experimental Water Delivery Program

In November 1983, Congress passed PL 98-181 authorizing the program of experimental water deliveries for Everglades National Park. This enabled the establishment of a series of iterative field tests to collect hydrologic and ecologic data, with the ultimate goal of developing optimum water delivery plans for ENP. Public Law 98-181 further authorized the Secretary of the Army to acquire interest in agricultural lands threatened by the program, and to construct necessary flood protection measures in the East Everglades. The Law also required that each iteration would be conducted by agreement between the Corps of Engineers, the SFWMD, and ENP, and would not significantly impact residential and agricultural interests in the East Everglades.

Throughout 1983, the SFWMD had been negotiating with representatives of the south Dade farmers to establish an agreement to allow for the reintroduction of surface water flows into Northeast Shark Slough. In January 1984, the Corps completed an Environmental Assessment (EA) and issued a Finding of No Significant Impact (FONSI) on the plan to reintroduce surface water flows into Northeast Shark Slough via the S-333 structure. The Corps FONSI specifically stated that "flooding impacts [in the East Everglades] resulting from the proposed plan, however, appear to be inconsequential". The Corps' analyses did not show a clear link between S-333 inflows and water levels in the East Everglades, but operating criteria to link S-333 releases and groundwater levels in the East Everglades were added as a safeguard.

In March 1983, after repeated discussions with some agricultural representatives failed to produce an agreement, the District proceeded with implementation of a 30-Day field test and opened the S-333 spillway. Attorneys for some agricultural interests obtained a temporary restraining order in Federal Court and the S-333 gates were closed the same day. The court refused to lift the restraining order and directed the two sides to reach an agreement. A formal agreement between the SFWMD and the agricultural representatives was signed in April 1984. The agreement stipulated that S-333 had to be operated according to the Corps EA guidelines, and that S-333 would be closed when water levels at G596 were above the Corps specified rule curve. With the agreement the 30-Day field test was re-initiated in late April, 1984.

In July, 1984 a second agreement was reached between the SFWMD and the representatives of the south Dade farmers allowing for a wet season field test of S-333 releases into Northeast Shark Slough. An additional set of limiting conditions was added as part of this agreement, these included: (1) an agreement by the District to maintain canal water levels at a maximum of 4.5 feet throughout the entire reach of L-31N (from S-335 to S-176), and (2) the adoption of additional groundwater monitoring wells as measurement points to control the operation of S-333. This 90-Day test was initiated in August 1984 and was interrupted (S-333 closed) for two extended periods, when groundwater levels rose above the trigger well criteria, even with below normal rainfall. Unfortunately, the Corps 1984 Environmental Assessment did not address these issues related to the lowering of L-31N operational criteria, or the use of S-331 for flood control.

In June 1985, the Corps of Engineers completed an EA and issued a FONSI on a set of modified operating procedures for S-333 and the L-31N canal, similar to those established during the District's 90-Day wet season test. There are two points of disagreement between the results of the Corps EA and the criteria established for the 90-Day test: (1) the EA found that alternatives which allowed the groundwater well criteria that triggered S-333 closing to be less restrictive (raised up to 0.4 feet above the 90-Day test criteria) could be implemented without significantly increasing the risk of flooding in the East Everglades, and (2) the operational stages in the L-31N canal upstream of S-331 could be more flexible (not forced to remain below 4.5 feet) and should be linked with groundwater levels in a well closer to the canal system. Both of these adjustments were incorporated, to a limited degree, in the 1985 test described below. Three technical studies by the South Florida Water Management District have failed to show that there is no clear link between S-333 inflows into Northeast Shark Slough and water levels in the East Everglades [MacVicar and VanLent 1984; MacVicar 1985; Neidrauer and Cooper 1989]. The District's report on the first two years of the Rainfall-Based water delivery plan [Neidrauer and Cooper, 1989] showed that the current lowering of L-31N canal stages overcompensates for any impacts caused by the NESS experimental program, and produced water levels in the East Everglades that were lower than the pre-test conditions.

1.3.3 Artificial Canal Drawdowns/the Frog Pond Agreements

In early 1984 farmers in the Frog Pond area requested that the District develop a plan to lower canal water levels in the adjacent canals to allow land preparation and planting to begin in mid October. In June 1984, an experimental one-year agreement was signed between Everglades National Park and representatives of the Frog Pond farmers to allow water levels in the L-31W and C-111 canals to be lowered to 3.50 feet by October 15th, 1984. ENP agreed to the experiment as a way of evaluating the effects of L-31W drawdowns on the water resources of Taylor Slough. Park hydrologists presented on the test's findings in a report to the Superintendent in June 1985 and recommended that no future drawdowns should be considered [Wagner *et al.*, 1985].

Artificial drawdowns in the L-31W and C-111 canals were continued after the one-year experiment for three additional years (1985, 86, and 87) without the Park's concurrence. This continuation was done through agreements between the District and representatives of some south Dade farmers, related to the Northeast Shark Slough experiment. The Corps of Engineers supported the continuation of drawdowns until 1988, when the Park completed a second technical report describing the hydrologic effects of the 1984 through 1986 L-31W canal drawdowns [Johnson *et al.*, 1988]. In June 1988 the Corps made a statement to the SCWMD Governing Board explaining why they could no longer approve the Frog Pond drawdowns. Note that the artificial lowerings of L-31W and C-111 canal stages were never formally evaluated in any of the Corps Environmental Assessments, and that artificial drawdowns have continued, most recently in November 1992.

1.3.4 The Experimental Three Party Agreements

In July 1985, the Corps of Engineers established the protocol for the Letters of Agreement, requesting written concurrence by the SFWMD and the Park on implementation of the Experimental Program of Water Deliveries to Everglades National Park. The first set of operational criteria for the experiment was attached as addendum 1, and included the procedure for implementation of a Rain-Driven water delivery formula for the Shark Slough Basin. The operational limitations on the use of S-333 and management of L-31N canal water levels were included, but they were slightly modified from the findings in the Corps Environmental Assessment. The Park wrote a response letter October 9, 1985 asking for additional information concerning the proposed limitations on the use of S-333. We also disagreed with the inclusion of the statement that it has been determined that high water problems are occurring in the East Everglades, and implying that they were related to S-333 operations. We further asked that the consultation and decision protocols related to actions taken to mitigate unanticipated adverse water conditions be clarified. Finally we stated that any actions leading to the continuation of the Frog Pond artificial drawdowns be removed from the three-party agreement, since these operations were not consistent with the objectives of the water delivery experiment. The Corps wrote back to the Park on November 18, 1985 agreeing to remove the clause that linked S-333 releases with high water conditions in the East Everglades, but they insisted that the Frog Pond drawdown criteria be included in the three party agreement. Several interagency meetings were held to resolve these outstanding issues, but the Park did not concur with the final draft of the three party agreement. Our specific disagreements were related to: (1) the inclusion of L-31W and C-111 drawdowns for the 1985 and 1986 growing seasons, (2) the continued excessive use of S-331 for flood mitigation in the East Everglades, and (3) disagreements related to the operational levels in the L-31N canal. Since these issues were not resolved, a letter of concurrence was never sent to the Corps.

A second Letter of Agreement was sent to the Park in December 1987, asking for written concurrence on continuation of the experimental program through December 1988, as authorized by

PL 99-190. The experimental program would be operated according to the criteria in the attached addendum 2. The Park did not submit a letter of concurrence because of our opposition to the continuation of Frog Pond drawdowns, excessive flood control pumping at S-331, and disagreements over the operational criteria in the L-31N canal. A third Letter of Agreement was sent to the Park in August 1988, asking for written concurrence on continuation of the experimental program through December 1988. The operating criteria in the attached addendum 3 were slightly modified at the request of the SFWMD, after the legal agreements with the south Dade farmers had terminated. The Park again refused to submit written concurrence because of our continuing disagreements, as stated above.

A fourth Letter of Agreement was sent to the Park, dated April 21, 1989, asking for written concurrence on continuation of the experimental program through December 1991, as authorized by PL 101-676. The experimental program would be operated according to the criteria in the attached addendum 4. In August 1989, the Park transmitted a letter of concurrence on continuation of the experimental program. A fifth Letter of Agreement was sent to the Park in February 1992, asking for written concurrence on continuation of the experimental program until the Modified Water Deliveries improvements are fully implemented. The Park did not submit written concurrence for the continuation of the experimental program. The sixth Letter of Agreement was sent to the Park in July 1993. To date we have transmitted one letter of concurrence associated with the wet season operating plan for the Taylor Slough Demonstration Project.

Chapter 2

Operations in L-31N, L-31W, and C-111

As seen in Tables 1–3, the operation of L-31N, L-31W, and C-111 have been changing since the South Dade Conveyance System was completed in the early 1980's. Operational policies for the canals in South Dade continue to evolve. In this section, we examine the hydrologic effects of these operational policies of the 1980's and 1990's on the marshes in the Rocky Glades, Taylor Slough, and the Park's Eastern Panhandle. The analyses in this section are based upon the long-term and average effects of the general lowering of canal stages. We limit our investigations to the available hydrologic record. While the hydrologic data base almost certainly contains errors and missing information, it is also the most reliable available information on the hydrology of South Dade. Complete calculations for analyses in this section are found in Appendix A.

2.1 Operation of the L-31N canal

The L-31N canal is conveniently split into two sections. The northern section, defined as the reach between S-335 on upstream end and S-331 on the downstream end, cuts through Shark Slough (see Figure 2.) Surface water and seepage that this canal intercepts would have historically moved west into Shark Slough. Structure 331 marks the divide between the southern reach of L-31N, defined as the reach between S-331 and S-176. Prior to S-331, structure 173 marked the hydrologic divide; areas north of S-173 historically drained into Shark Slough, while areas south of S-173 flowed towards Taylor Slough and Florida Bay.

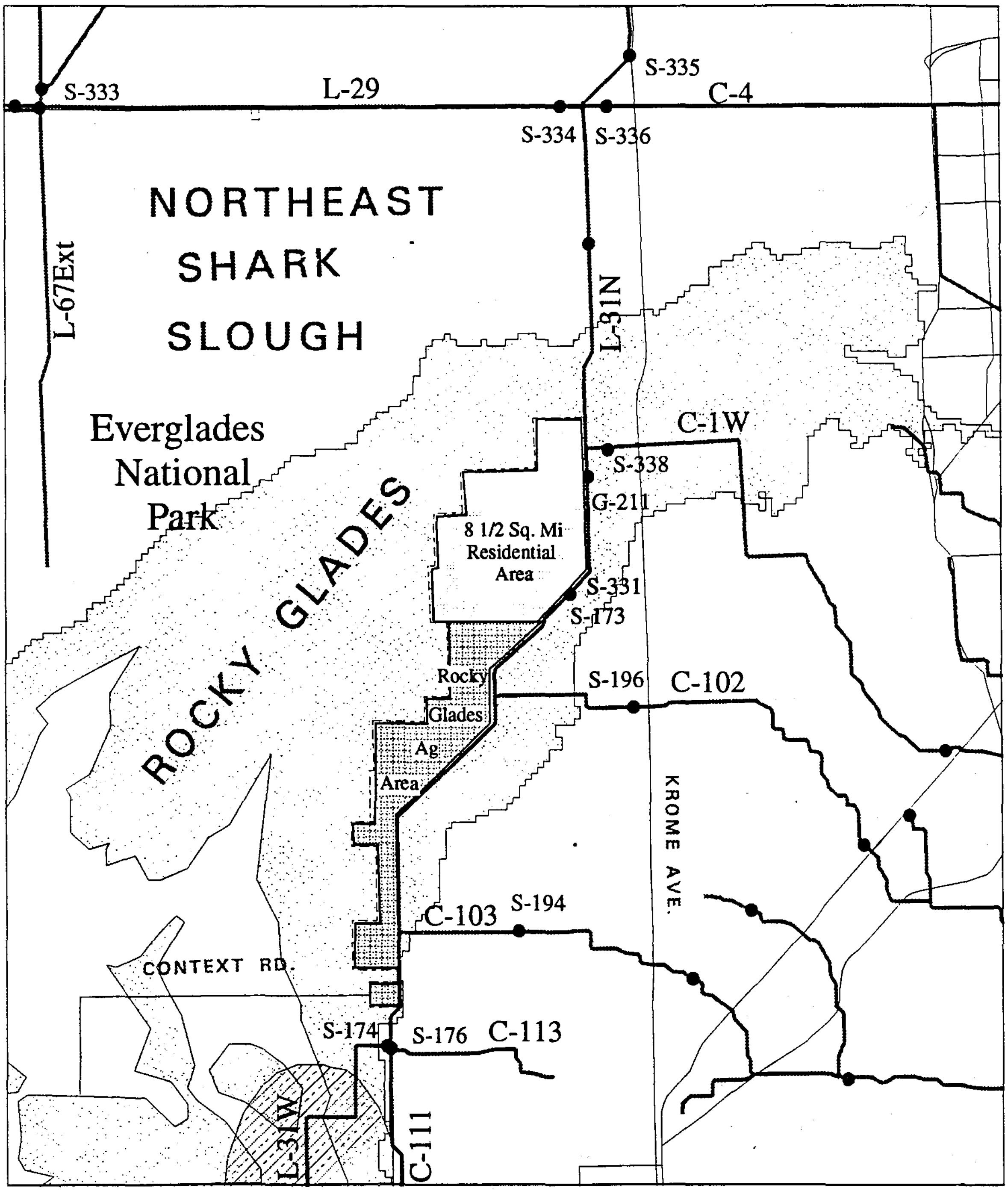

Figure 2: Map of the L-31N borrow canal.

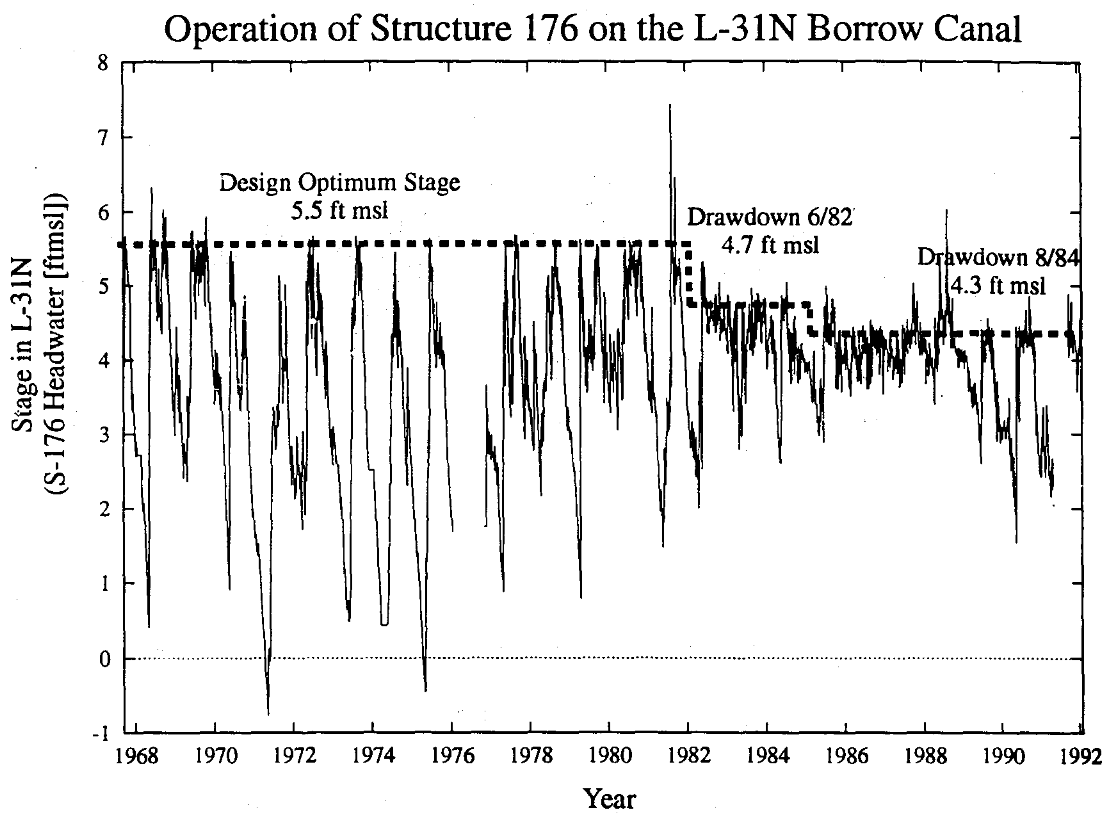

Figure 3: Stage at S176 headwater.

2.1.1 Stages in L-31N South of S-331

We begin analysis of the operational policies in L-31N by looking first at the southern reach, between S-331 and S-176. There is more information available for this reach than the northern reach, and hence the effects of operations are clearer. Figure 3 is a plot of the stage at the downstream end of the L-31N canal. One can clearly discern the changes in operational levels over the past 25 years. In the fall of 1981, South Dade was hit with two tropical storms within a month. The rainfall for the 1981 wet season was approximately 52 inches, which translates to about a 1-in-25 year rainfall total; the Project was designed only for the 1-in-10 year event. Because the storms were locally very intense, flooding was extensive in western Dade County. Homeowners and agricultural interests, primarily representing the areas east of L-31N, sued the District over their operations in response to the storms. Under the threat of litigation, the District lowered S-176 operational stages from 5.5ft NVGD to 4.7ft NVGD.

Canal stages in L-31N were lowered again in August of 1984 from 4.7ft NVGD to 4.3ft NVGD

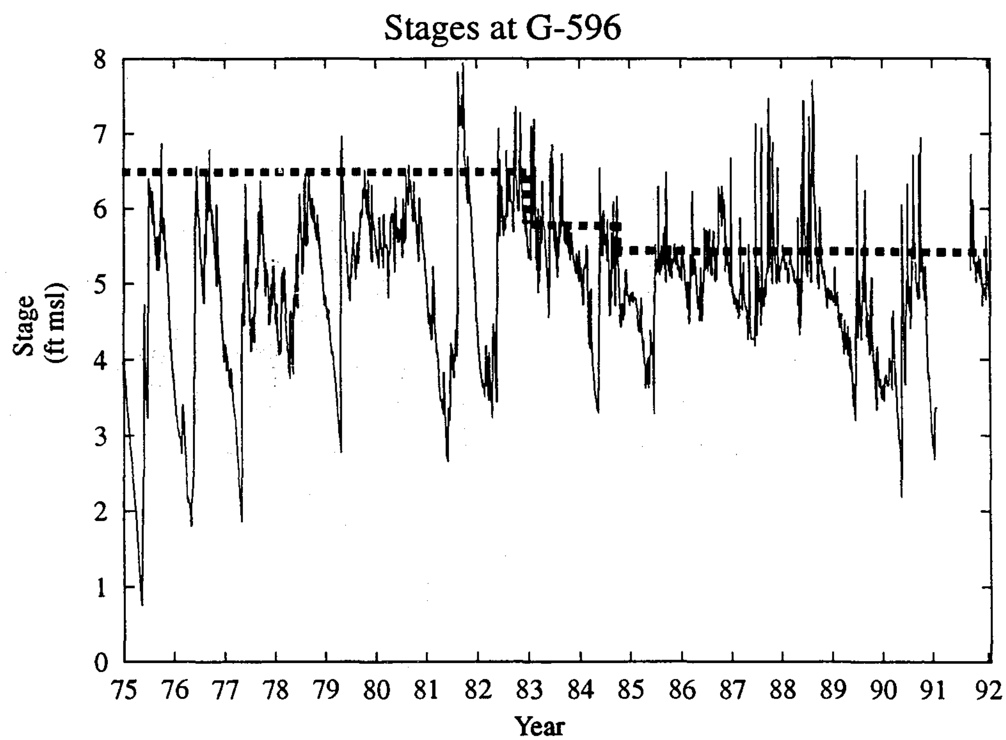

Figure 4: Stages at G-596. See Figure 2 for the location.

in the wet season as part of an agreement to experiment with water deliveries in Shark Slough. Agricultural interests feared increased flooding potential from more flow in Northeast Shark Slough and won a concession to lower canal stages as part of a 30-day test. The wet season canal stages have remained at 4.3ft NVGD since that time. The Park has often voiced concern over this lowered canal stage, and has repeatedly refused to sign the Three-Party Experimental Water Delivery Agreement over this issue.

2.1.2 Stages in L-31N North of S-331

The stages in the northern reach of the L-31N canal are somewhat sketchy, as the S-173 headwater stages are not available on the District's data base. One can infer the operation of the canal, however, by looking at nearby wells. One of the longest records available in the area is at G-596, operated by the USGS since 1950. Figure 4 is the plot of part of the G-596 time series. The stage histories show much the same behavior as seen at S-176. The successive lowering of L-31N stages has reduced groundwater levels. Since G-596 is located west of L-31N, one can directly infer that lowering of

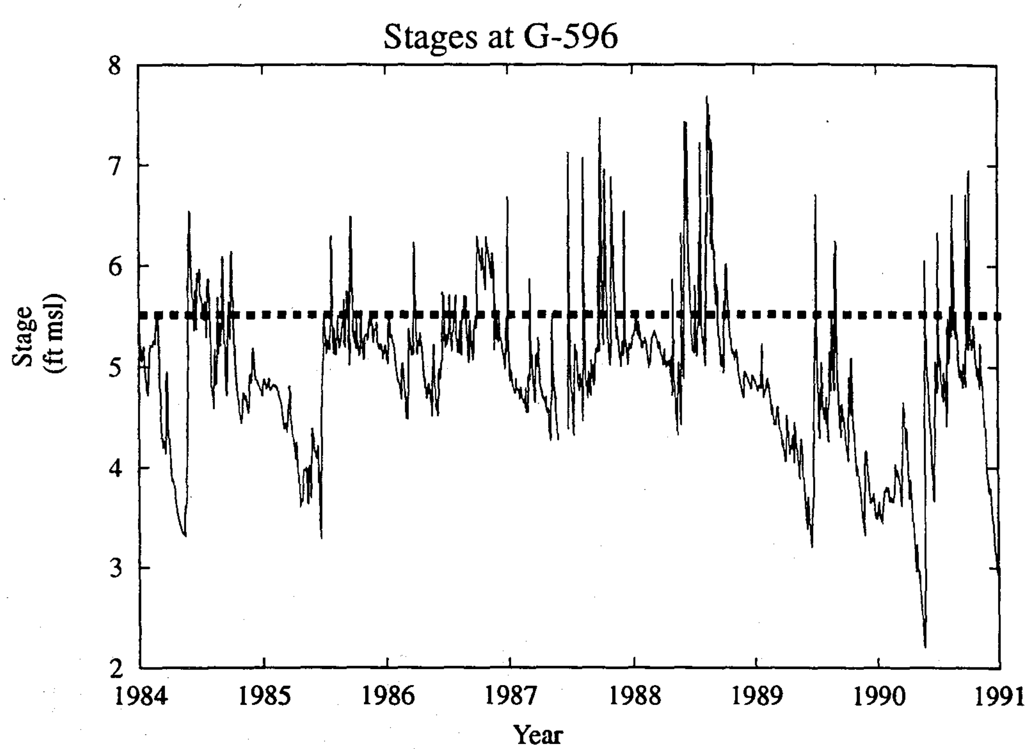

Figure 5: Stages at G-596 for the years 1977–1990.

L-31N stages has generally reduced water levels in the adjacent marshes.

Because the G-596 gage is in the marshes west of L-31N, the record is more "noisy." The marsh responds quickly to rainfall. However, as seen in Figure 5, the stages are rapidly drawn down following storm events. After heavy rains, the stage jumps. Under pre-drainage conditions, these high stages would have persisted, and would have resulted in significant surface water flow south and west. Under the managed condition, large amounts of water are drained from the area and stages brought down, usually within days of the rainfall.

Some information on L-31N stages is available. Recent headwater stages for S-338 and S-331 are shown in Figure 6. Both structures have their headwaters in the L-31N northern reach, and until 1991, had similar stage readings. The design stage for this reach of the canal is 5.5 ft NVGD. However, prior to 1982, stages at G-596, and by implication, L-31N, normally reached 6.5ft in the wet season. While this may appear in contradiction to operational policy, the District had little capability to modify stages in that canal reach. However, when S-331 became operational, in June of 1982, the District could enforce operational stages as 5.5ft NVGD. Table 3 provides the current rules for S-331 operation. Most notably, flood control operation of S-331 was not part of the original

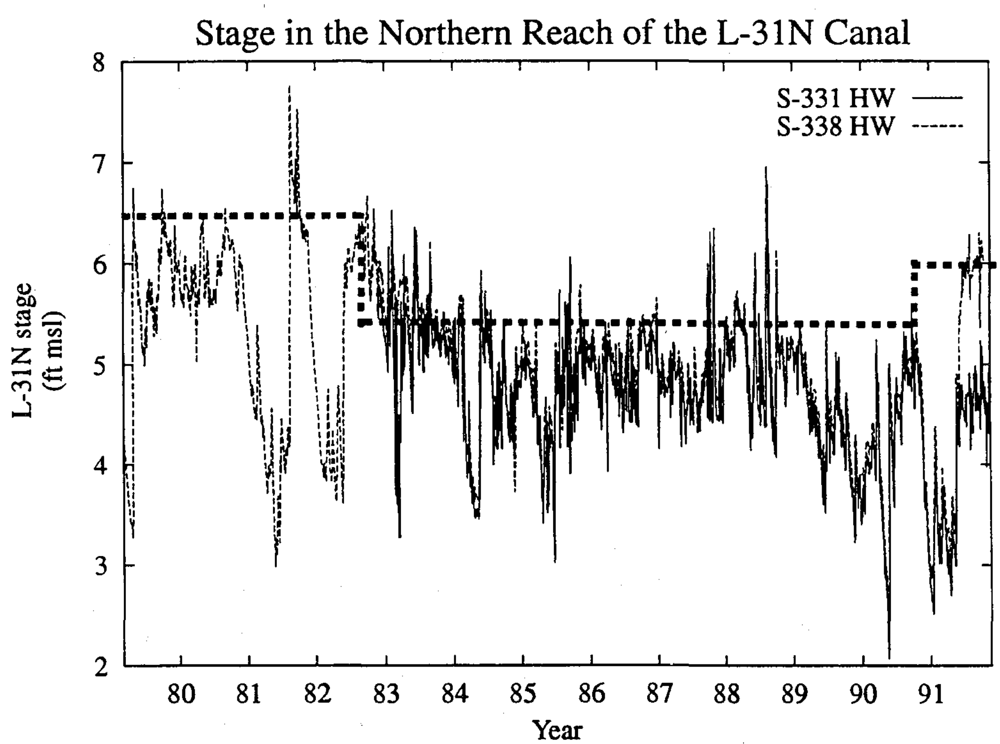

Figure 6: Stage in the L-31N northern reach.

design, and operational rules for flood mitigation have been developed as part of a modified water deliveries test to Shark Slough.

Stages in the upper part of the reach have climbed because of the recent completion of G-211. With the completion of the G-211 structure in L-31N just downstream of the C-1W junction (see Figure 2), water managers are now able to hold higher water levels in the upper reach of L-31N. This should reduce seepage from Northeast Shark Slough, and generally improve hydroperiods in the adjacent marshes north of G-211. However, the data required to perform this analysis is not yet available on DBHYDRO, the District's hydrologic data base.

2.1.3 Effects of L-31N on the Rocky Glades

The effect of lowering canal stages on the marshes to the west of L-31N has been dramatic and detrimental. Figure 7 shows the reconstructed monthly flow hydrograph along Context Road (see Figure 2.) Context Road is at the southern end of the Rocky Glades and the northern extent of Taylor Slough. The flow across Context Road essentially represents a surface water contribution to Taylor Slough; the USGS in fact published these records as *Taylor Slough at Context Road.* The times series of the flow across Context road is shown in Figure 7. This hydrograph clearly shows the drop in surface water flow into the northern reaches of Taylor Slough from the Rocky Glades. Since June, 1982, when L-31N was lowered, surface water flows have virtually been eliminated.

In terms of the average hydrograph, shown in Figure 8, we see a dramatic loss of flow. Prior to dropping the canal, we see a fairly typical Everglades hydrograph: peak flows in August and September, with a gradual decrease into the dry season. Following the drop in canal stages, sheet flow in the headwaters to Taylor Slough has been considerably reduced.

The explanation is that the ground surface elevations in the area are about 4.7ft NVGD, and by holding the canal stages well below the ground level, surface water is drained off into the canal rather than flowing south into Taylor Slough. The loss of surface water averages 11,200 acre-ft per year, as compared to the 37,000 acre-ft per year mandated for Taylor Slough deliveries. Lowering of canal stages in L-31N directly translates to a loss of surface water flow in Taylor Slough. This also supports the Park's position that stages in L-31N need to be raised to *at least* 5.0ft NVGD in order to reintroduce any significant surface water flows in the Rocky Glades area. Returning L-31N stages to their design flood control optimum of 5.5ft would restore the more desirable hydrograph, and would be a step closer to historical hydroperiods.

Appendix Section A.3 provides more information on how the estimates of flow across Context Road were estimated. Although this analysis is predicated on flow information that the USGS labels as poor, the results are fully consistent with observations of marsh damage in the areas

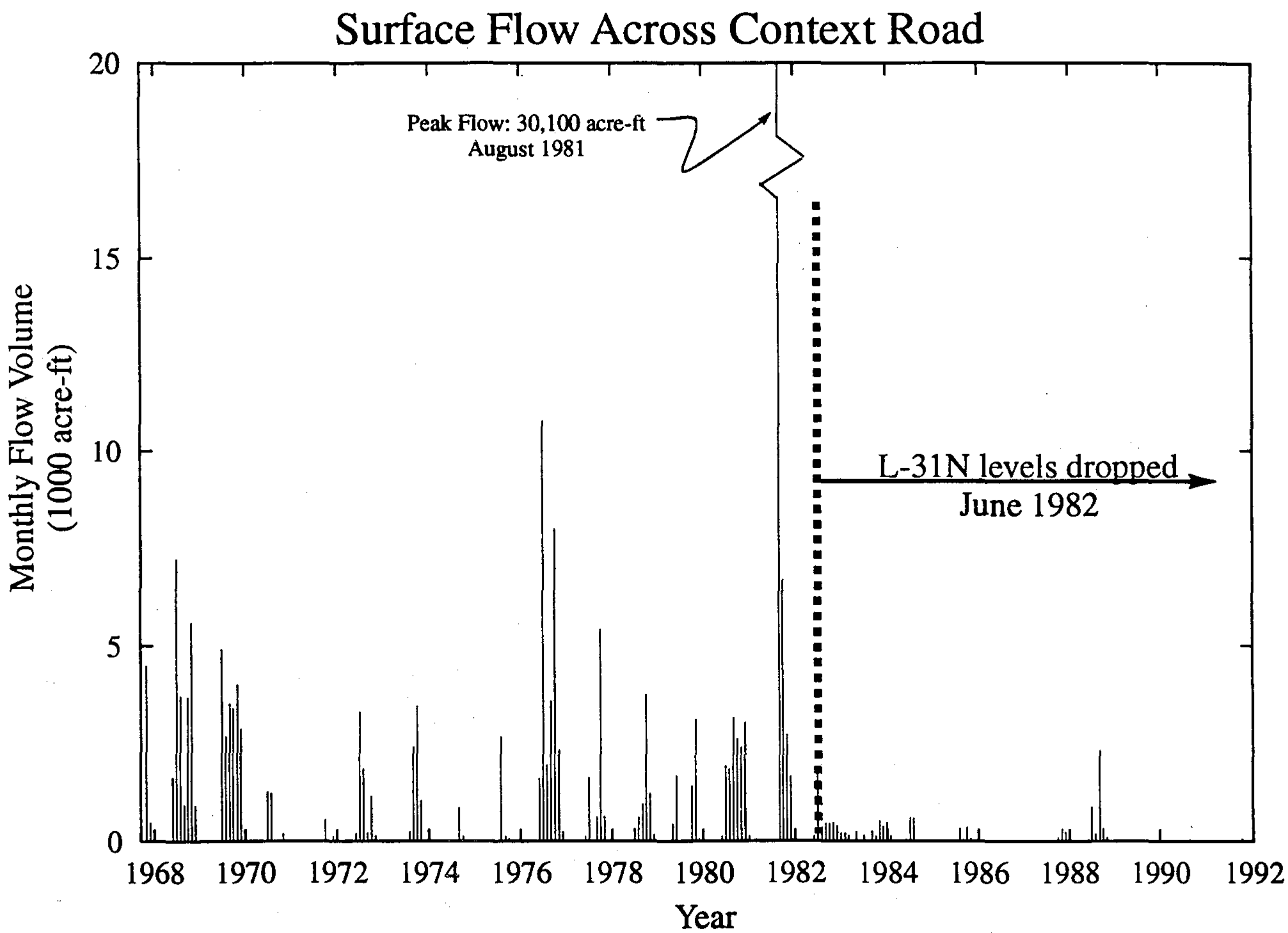

Figure 7: Monthly flow volumes at Context Road. The USGS published this data as *Taylor Slough at Context Road near Homestead, FL.* Data is reconstructed from published records; Section A.3 contains complete details on reconstruction methods.

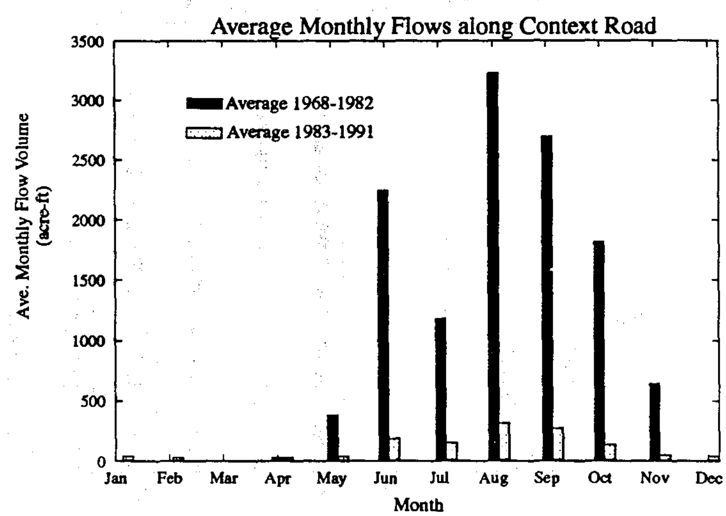

Figure 8: Average monthly flow volumes at Context Road.

immediately west of L-31N. Curnutt and Pimm [1993] document an invasion of woody vegetation in the Rocky Glades. This vegetation change is induced by loss of surface water in the marsh. The result, according to Curnutt and Pimm [1993], has been a loss of Cape Sable seaside sparrows (*Ammodramus maritima mirabilis*) and their habitat in the Rocky Glades. We hypothesize that this damage to the habitat of an endangered species is a direct result of lower canal stages. No assessment of how lower canal stages would affect the sparrow was ever made, and there is strong evidence that lower canal stages has adversely affected their ability to survive. This analysis simply corroborates these field observations and links the habitat loss to canal operations.

2.1.4 Water Budget of L-31N

The most elementary step in determining the water management implications of canal operations is to calculate the water budget. Inflows and outflows are tabulated, with the difference between the inflow and outflow being the volume contributed by basin drainage. The water budget is for the canal only, not the contributing basin. We have neglected the effects of rainfall and evaporation on the canal. All flow data is taken from the District's hydrologic data base, DBHYDRO and reproduced in Appendix C.

Figure 9 is a comparison of the inflows and outflows for the entire reach of the L-31N canal. It is immediately apparent that substantially more water is being removed from this canal than is being input. That is, the canal serves primarily to drain the basin, not to supply the area with water. Had

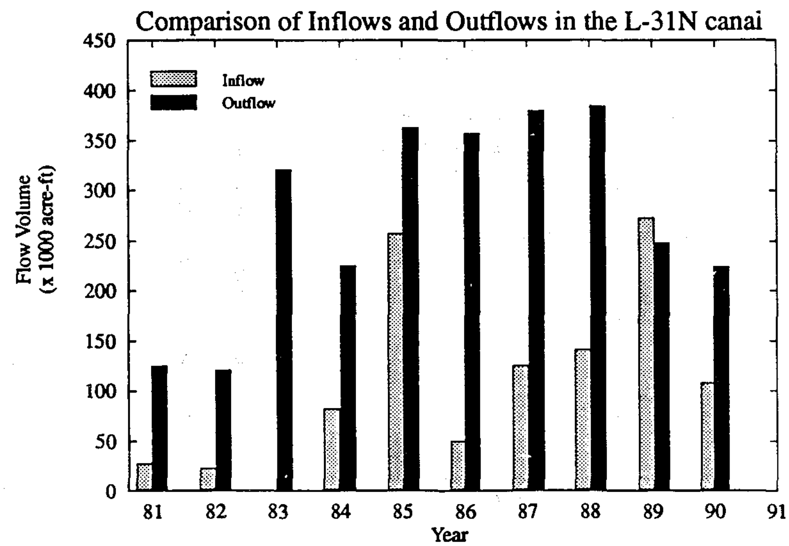

Figure 9: Comparison of annual inflows and outflows to L-31N between S-335 and S-176. Inflow is S-334 & S-335, while outflow is S-336 & S-338 & S-194 & S-196 & S-176 & S-174.

the latter been true, one would see many years like 1989, where inflows meet or exceed outflows. Between 1983 and 1991, the net drainage by L-31N canal amounted to 210,000 acre-ft per year, on the average. As a comparison, the Minimum Delivery Schedule called for a 260,000 acre-ft annual delivery to Shark Slough through the S-12 structures.

The net drainage by the canal explains only part of the picture. Further examination can yield more information on the relative impacts to Shark Slough, and the Rocky Glades. We therefore break the analysis into two components: L-31N north of S-331 and south of S-331.

Northern Reach of L-31N

Surface water inflows to the northern reach of the L-31N canal are made through structures 335 and 334, located on the L-30 and L-29 borrow canals, respectively. These are integral components of the South Dade Conveyance System; flows through these structures represent the contribution from the regional water supply system. That is, no flood releases are passed through S-334 and S-335, as a general rule. Outflows, defined as S-336 + S-338 + S-173 + S-331, represent a combination of regional water supply deliveries and drainage.

The annual inflow and outflow totals for the L-31N between S-335 and S-331 is shown in Figure 10. This water budget shows that, except for severe drought years, the northern reach of L-31N is the major contributor of water to the downstream basins. On the average, 169,400 acre-ft per year

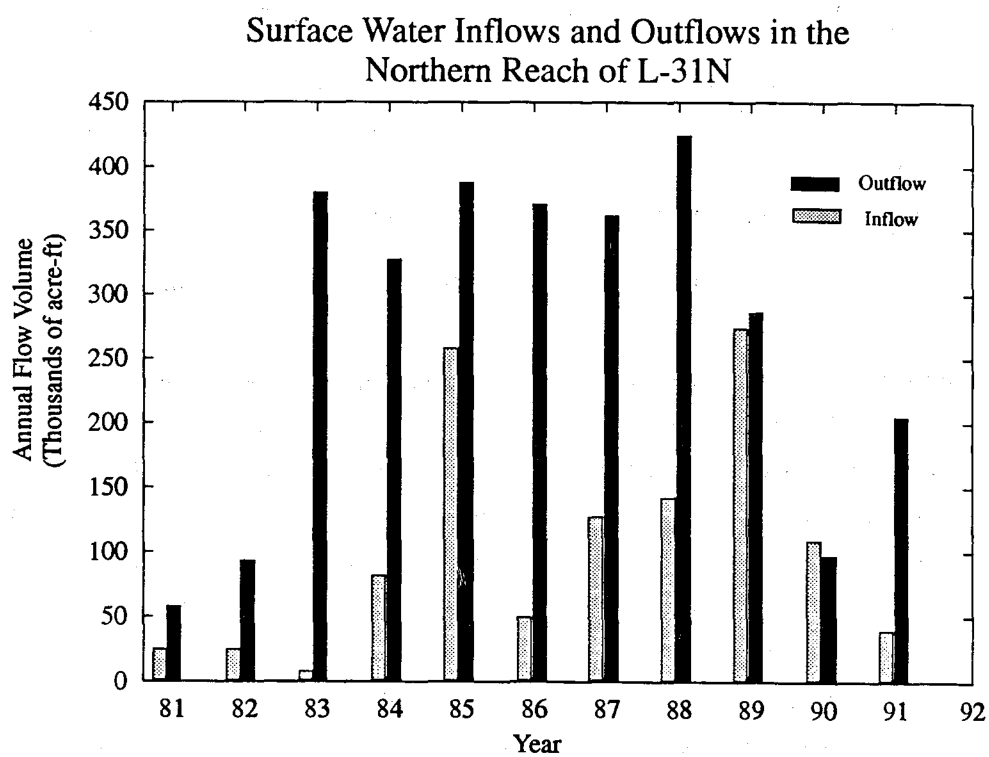

Figure 10: Comparison of annual inflows and outflows to L-31N between S-335 and S-331. Inflow is S-334 & S-335, while outflow is S-336 & S-338 & S-331 & S-173.

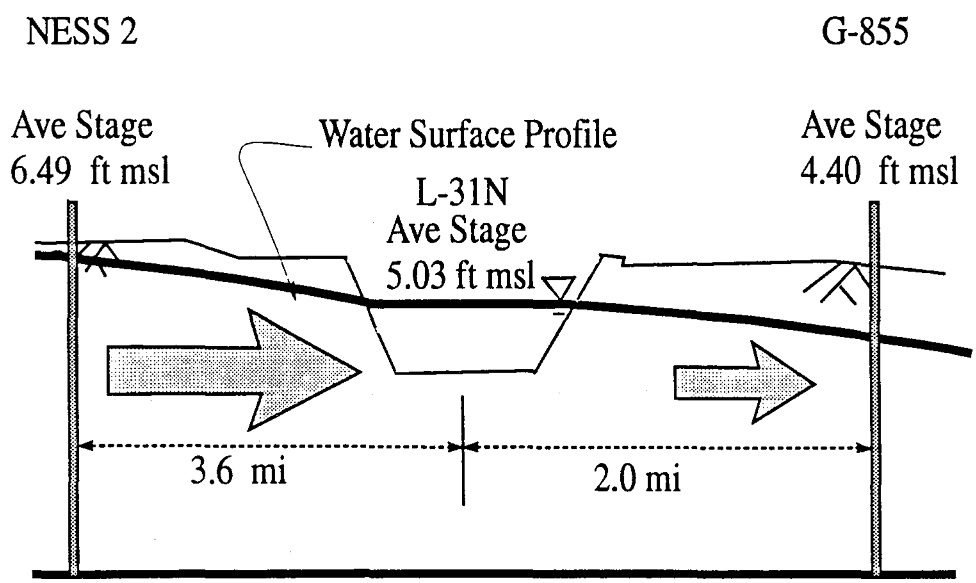

Figure 11: Estimated regional groundwater gradients in the vicinity of L-31N.

was extracted from the basin between 1981–1991. The large withdrawals occurred after 1983; this coincides with S-331 pump station becoming operational. This also demonstrates that S-331 is primarily used for drainage and flood protection rather than for water supply. If the latter operation were predominant, one would see inflows matching outflows, as in the drought year 1989. Instead, the huge disparity (outflows average 187% of inflows) indicates that lower canal stages and higher pumping rates at S-331 for flood protection have resulted in enormous losses of water from the marshes adjacent to L-31N.

The average net difference between inflows and outflows into the northern reach of L-31N is approximately 200,000 acre-ft per year. This number represents a groundwater seepage contribution to the canal from the surrounding area, both east as west of the levee. Also, L-31N has a 1.5 mile groundwater connection with WCA-3B. While the groundwater flow regime and the surface water/groundwater interactions in this area make detailed analysis difficult, one can make some general statements about the behavior of groundwater flow in the area. Figure 11 depicts the groundwater slopes in the vicinity of the L-31N canal north of S-331. Clearly, there is a gradient of water from west to east. The implication is that, over the long-term, water flows from the marshes of Northeast Shark Slough into L-31N, and then out of L-31N as recharge to areas to the east. Therefore, it must then be true that Northeast Shark Slough contributes more than the net amount of seepage. In other words, Northeast Shark Slough seepage losses averaged *at least* a 190,000 acre-ft per year contribution to the regional water system.

Conservatively assuming that the net groundwater seepage is equal to the amount drained from Northeast Shark Slough, we can summarize the annual water budget for the northern reach of L-31N for the years 1983–1990 as in Figure 12. This graphic shows, in essence, that large volumes of water are drained from Northeast Shark Slough, and then passed down L-31N via S-331. The new G-211 structure should help reduce these seepage losses. However, this is offset by plans to provide flood "mitigation" for the 8.5 sq. mi. residential area in the Rocky Glades. Demands for flood protection in areas near L-31N will continue to result in large seepage losses from the marshes in Everglades National Park.

Southern Reach of L-31N

The annual inflow and outflow totals for the southern reach of L-31N between S-331 and S-176 are shown in Figure 13. Surface water outflows exceed inflows in nearly every year; more water is extracted from the basin than is brought in from the regional system. On the average, outflows are 115% of inflows.

The net drainage calculation, however, is incomplete in determining the extent of the effects of canal stages on the marshes to the west of L-31N. One can ask the question: What fraction of the net drainage comes from the eastern agricultural and urban areas, and what fraction comes from the western marshes, i.e, the Rocky Glades and Everglades National Park? With current state of knowledge about the groundwater and surface water system in the area, we cannot answer that question definitively. However, there are ways of getting estimates of the ratio, and thereby an idea of where the canal seepage originates.

By the fundamental law of groundwater mechanics, the flow of water in the subsurface is proportional to the slope of the water surface. We can therefore estimate the relative importance of the eastern and western seepage components by comparing the groundwater slopes. We used two gages, G-1502 and G-1363, roughly equidistant and perpendicular to L-31N, to estimate average groundwater slopes east and west of the canal. The result is depicted in Figure 14. In effect, the marshes contribute more than the net amount, and the canal recharges the areas east of L-31N. That is, water is drained from the Rocky Glades and Everglades National Park and is used to recharge the agricultural and urban lands east of L-31N. If we were to apply the calculated ratio (see Section A.2) and use the average annual net drainage (1983–1990) of 36,300 acre-ft, approximately 71,200 acre-ft per year is drained from the Rocky Glades west of L-31N and 34,900 acre-ft per year are recharged to the lands east of L-31N. Again, these values should serve to illustrate the relative magnitudes of the groundwater flows, and not absolute quantities. They do clearly show that the Rocky Glades and Everglades National Park contribute large volumes of water as seepage to L-31N. Thus, raising canal stages in L-31N will tend to decrease the loss of water from the Rocky Glades area. This

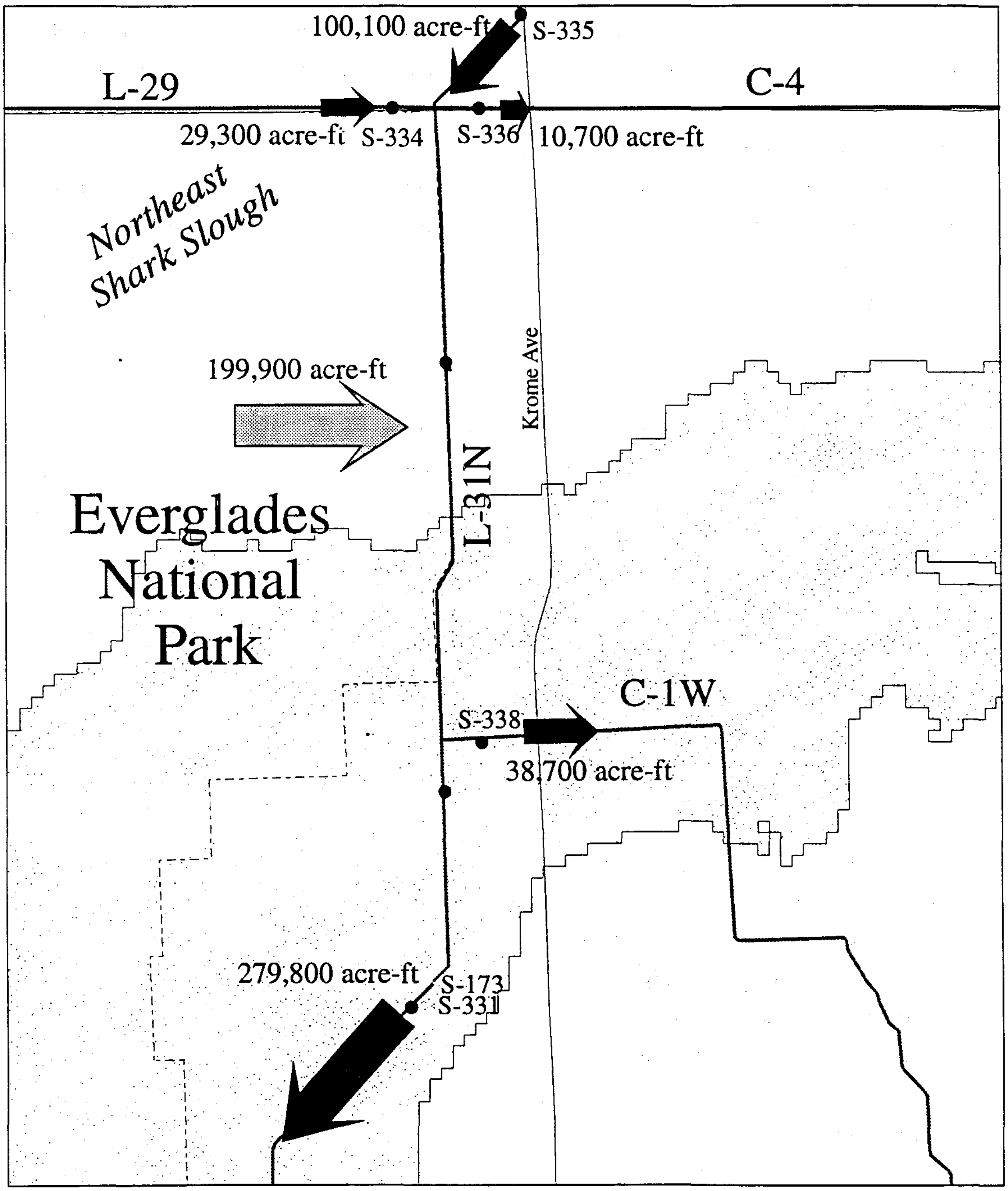

Figure 12: Summary of the average annual water budget for the northern reach of the L-31N canal, between S-335 and S-331 for the years 1983–1990. The solid arrows represent flows through structures, while the shaded arrows represent groundwater seepage into L-31N.

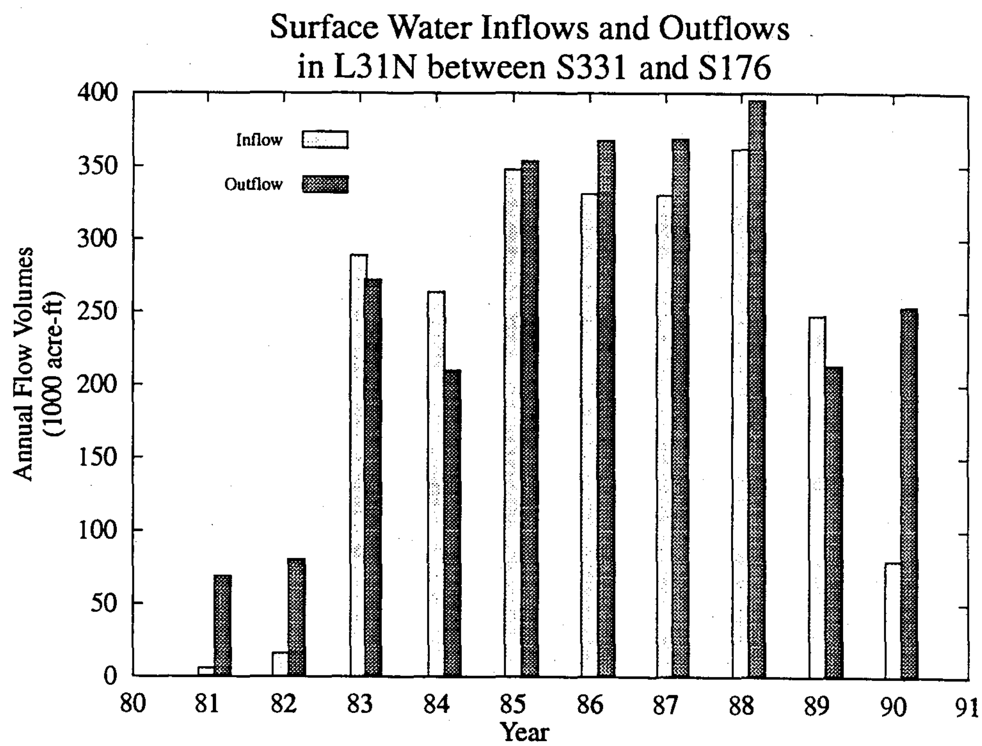

Figure 13: Comparison of annual inflows and outflows to L-31N between S-331 and S-176. Inflows are S-331 and S-173, while outflows are broken into flow to Taylor Slough (S-174) and outflows east and south (S-194 & S-196 & S-176).

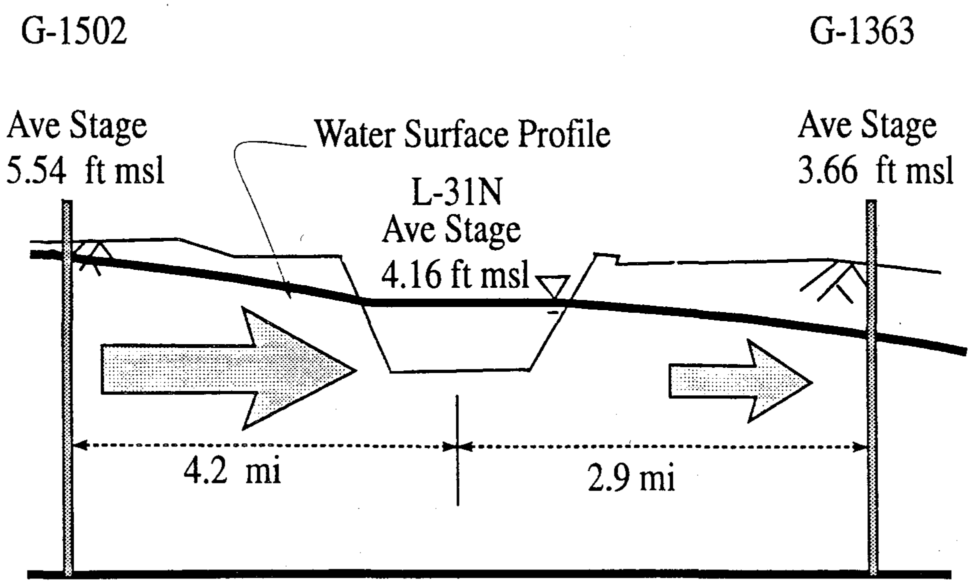

Figure 14: Estimated regional groundwater gradients in the vicinity of L-31N.

will have positive impacts on the marshes in Everglades National Park and the downstream estuary, Florida Bay.

We can summarize the L-31N water budget for the areas south of S-331 for the years 1983–1991 as in Figure 15. There are several points which we need to emphasize. Firstly, the inflow at S-331/S-173 complex largely represents the drainage of Northeast Shark Slough. This is a significant shift in operational policy since 1983. Prior to that date, there were only small interbasin transfers. That is, little flow was passed between the northern and southern reaches of L-31N. With the completion of S-331, which was authorized as a water supply structure, the District now moves large volumes of water southward out of the Shark Slough basin. This is done primarily to satisfy demands for lower L-31N stages.

Another important point from Figure 15 is the size of the flows eastward through S-194 and S-196. Almost 30% of the S-331/S-173 flow is diverted into S-194 and S-196, after which it presumably is dumped into Biscayne Bay. These discharges represent flows which historically would have moved south and west, but are now diverted to the Atlantic. The lowering of canal stages has forced the District to find outlets for the water drained from Taylor Slough and the Rocky Glades, and moving it eastward is one alternative.

The third important feature of Figure 15 is that the contributed flow to Taylor Slough via S-174 amounts to only 66% of the volume drained from the Rocky Glades. Taylor Slough is therefore being deprived of water which would have flowed southward as sheet flow through the slough and

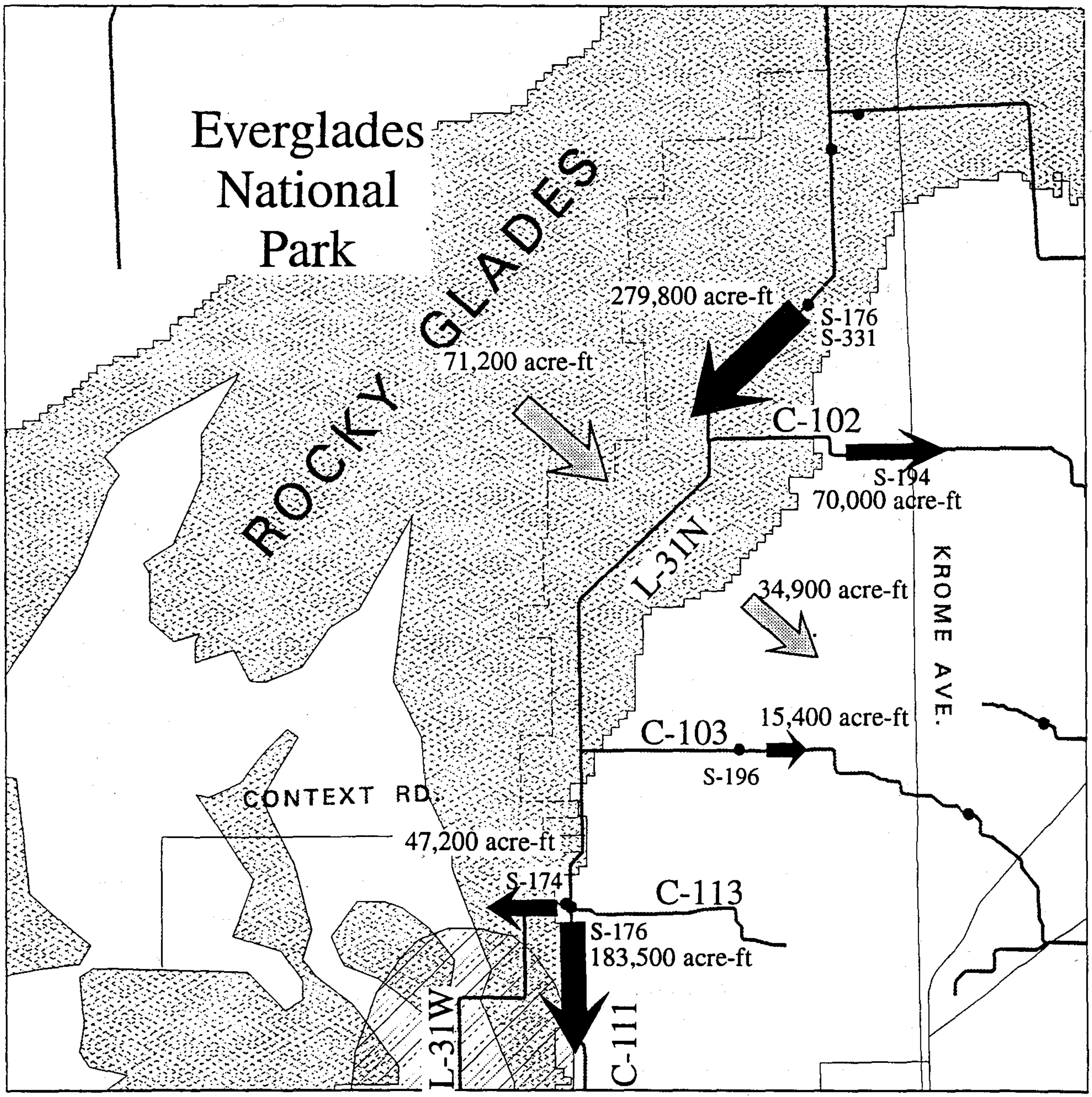

Figure 15: Summary of the average annual water budget for the L-31N canal between S-331 and S-176 for the years 1983–1990. The solid arrows represent flows through structures, while the shaded arrows represent groundwater seepage into L-31N.

into Florida Bay. It also means that the regional water system is not the source for most of the water sent to Taylor Slough. Although the SDCS was designed to bring water in from the WCA's and the regional system, the historical record shows that the Rocky Glades, not the SDCS, supply the water delivered to Taylor Slough. The SDCS operates as designed during drought years, but during normal and wet years, it serves primarily to provide flood control and drainage.

2.1.5 Supplemental Inflows to the South Dade Conveyance System

Figure 13 shows the annual inflows to the northern reach of the L- 31N canal system (S-334 & S-335) for the 1983 through 1991 period. Essentially all of these inflows were made during the dry season (November through May) to meet the supplemental water supply requirements of the SDCS. This is clearly seen in Figures 16–17. For this period, the average dry season inflow volume to the northern reach of the canal was approximately 108,000 acre-feet. (For this analysis, the dry season is defined as the months of November through May, which represents the period of deficit rainfall, when inflows to the SDCS would be expected [U.S. Army Corps of Engineers, 1973]). In contrast, the GDM for the South Dade Conveyance System estimated that the average annual dry season supplemental flow requirement to the upper reach of the L-31N canal was 318,500 acre- feet. Note that during two extreme drought years, 1985 and 1989, dry season inflows exceeded 250,000 acre-feet, but on average the dry season supplemental flows have been less that 34 percent of the Corps estimates.

According to the design documents of the South Dade Conveyance System [U.S. Army Corps of Engineers, 1973], there was no flood control element. The intention was that it function only as a water supply system. However, Figure 17 shows that, since its initial operation in 1983, the SDCS has been used for flood control, as evidenced by the large wet season pumping volumes at S-331.

The extent of the flood control operation is seen in Figures 18. Here, the wet and dry season flow history is summarized for the S-331 pump station for the period from January 1983 through December 1991. Figure 18 compares the wet season and dry season pumping at S-331 for the period 1983–1991. Note that on average, nearly half of the annual flow for S-331 occurred during the wet season, and that in the high flow years of 1985, 1986, and 1988 wet season flows accounted for 60 to 70 percent of the annual total flow. The use of S-331 for flood control and drainage is clearly inconsistent with the original project purpose. Yet, since its construction, S-331 has been used as often for flood control as for water supply. This practice adds an additional burden to the flood control requirements of the downstream basin, and causes overdrainage of the Northeast Shark Slough wetlands.

As noted earlier, the Corps estimated that the annual average supplemental dry season flow

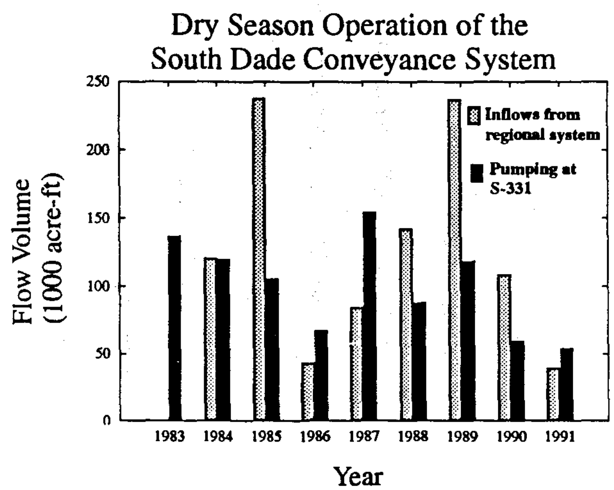

Figure 16: Comparison of S-331 pumping to the inflows from the regional water management system during the dry season. In this case, deliveries are the combination of S-334 and S-335 flows.

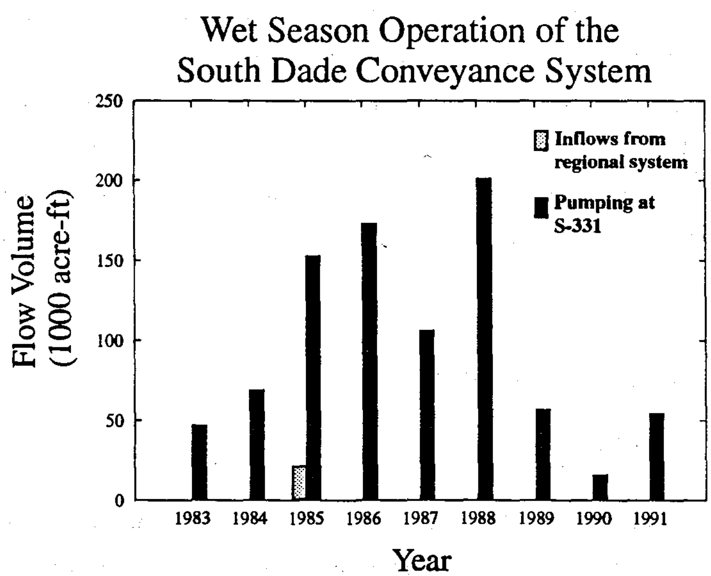

Figure 17: Comparison of S-331 pumping to the inflows from the regional water management system during the wet season. In this case, deliveries are the combination of S-334 and S-335 flows.

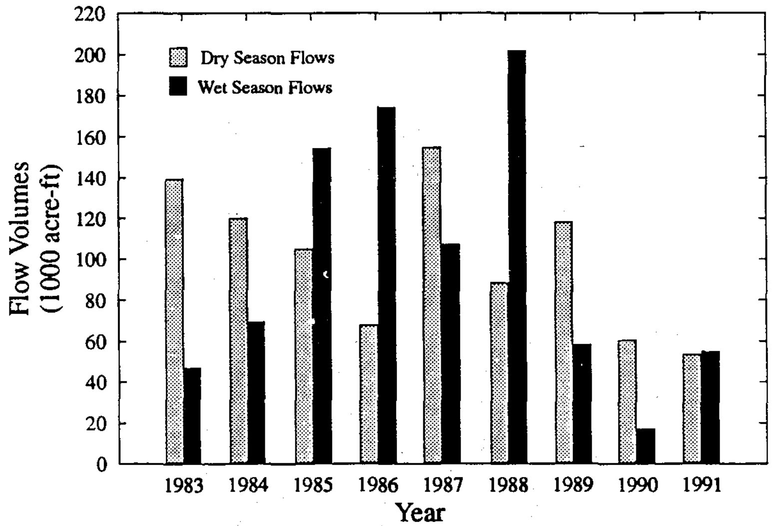

Figure 18: Comparison of wet and dry season pumping at S-331.

requirements for water supply pumping at S-331 were 264,800 acre-feet per year [U.S. Army Corps of Engineers, 1973]. Our analyses indicate that the actual dry season supplemental inflows averaged 100,500 acre-feet per year. This represents less than 38 percent of the supplemental flows expected by the Corps to be provided to the downstream areas of south Dade County. Moreover, when we look at the deliveries from the regional water supply system to the SDCS, as in Figure 16, we see that in 5 of 9 years, more water was removed from the basin that was delivered. That is, L-31N supplied water for downstream uses more than one half of the dry seasons. The dry season water supply requirements of south Dade County (including Taylor Slough, the Eastern Panhandle, and Florida Bay) need to be re-examined as part of the District's ongoing regional water supply planning process.

2.1.6 Summary of L-31N analysis

The important aspects of analysis of L-31N are:

1. Lowering of canal stages in L-31N since 1982 has had a detrimental effect on the Rocky Glades marshes. Sheet flow in the late wet season has been virtually eliminated in the headwaters of Taylor Slough, as indicated by the estimated flow along Context Road. Raising S-176 headwater to a minimum of 5.0ft will be a first step toward re-introducing sheet flow in the area and recovery of the headwaters of Taylor Slough.

2. The source of water for S-174 deliveries to Taylor Slough is primarily drainage from the upstream L-31N basin, not the regional water supply system. About 66% of the amount comes from just upstream, from the Rocky Glades, the headwaters of Taylor Slough. The wet season deliveries to Taylor Slough via S-174 are, in effect, simply the rearrangement of water from the headwaters (the Rocky Glades) to the northern end of the Taylor Slough.

3. Even the large volume of surface water inflows to the southern L-31N canal reach via S-331 do not constitute a significant regional water supply contribution. The majority of this water originates as seepage into the northern L-31N canal from Northeast Shark Slough. These routine interbasin transfers represent a significant shift in operational policy since 1981.

4. In the period 1983–1990, the pump station S-331 was used as frequently for flood control during the wet season than for water supply during the dry season. This is in contrast to the Corps of Engineers design and authorized operation; the pump was intended as a dry season water supply structure, with no flood control element authorized.

5. The dry season deliveries from the regional water supply system to L-31N have averaged 38% of design target of 318,500 acre-ft, while average withdrawals from the L-31N have been 198,500 acre-ft per year, 75% of the design estimate of 264,800. However, approximately half of the S-331 pumping is for wet season flood control. In about one half of the dry seasons for which we have information, the L-31N basin supplied water for downstream uses.

2.2 Operation of L-31W

The L-31W west canal is the canal bringing water from the South Dade Conveyance System to pump station S-332, which in turn, discharges into Taylor Slough. In 1972, Congress mandated a minimum delivery of 37,000 acre-ft per year. L-31W was constructed for the purpose of bringing the minimum delivery allocation to Taylor Slough from the regional water system. Figure 19 depicts the major hydrologic features of the area. Water enters L-31W from S-174, and is pumped into Taylor Slough at S-332. Structure 175 serves to control the stage in the canal. Structure 175 is also now used to provide flood protection to the Frog Pond, although this use is not expressly authorized.

2.2.1 Stages in the L-31W canal

If we examine the historical record of water levels in the L-31W canal (shown in Figure 20), one can see an apparent change in the operational policy in 1981. The design optimum stage in L-31W is 4.5ft NVGD, but prior to 1981, stages were routinely allowed to reach 5.0ft. The 1981 change

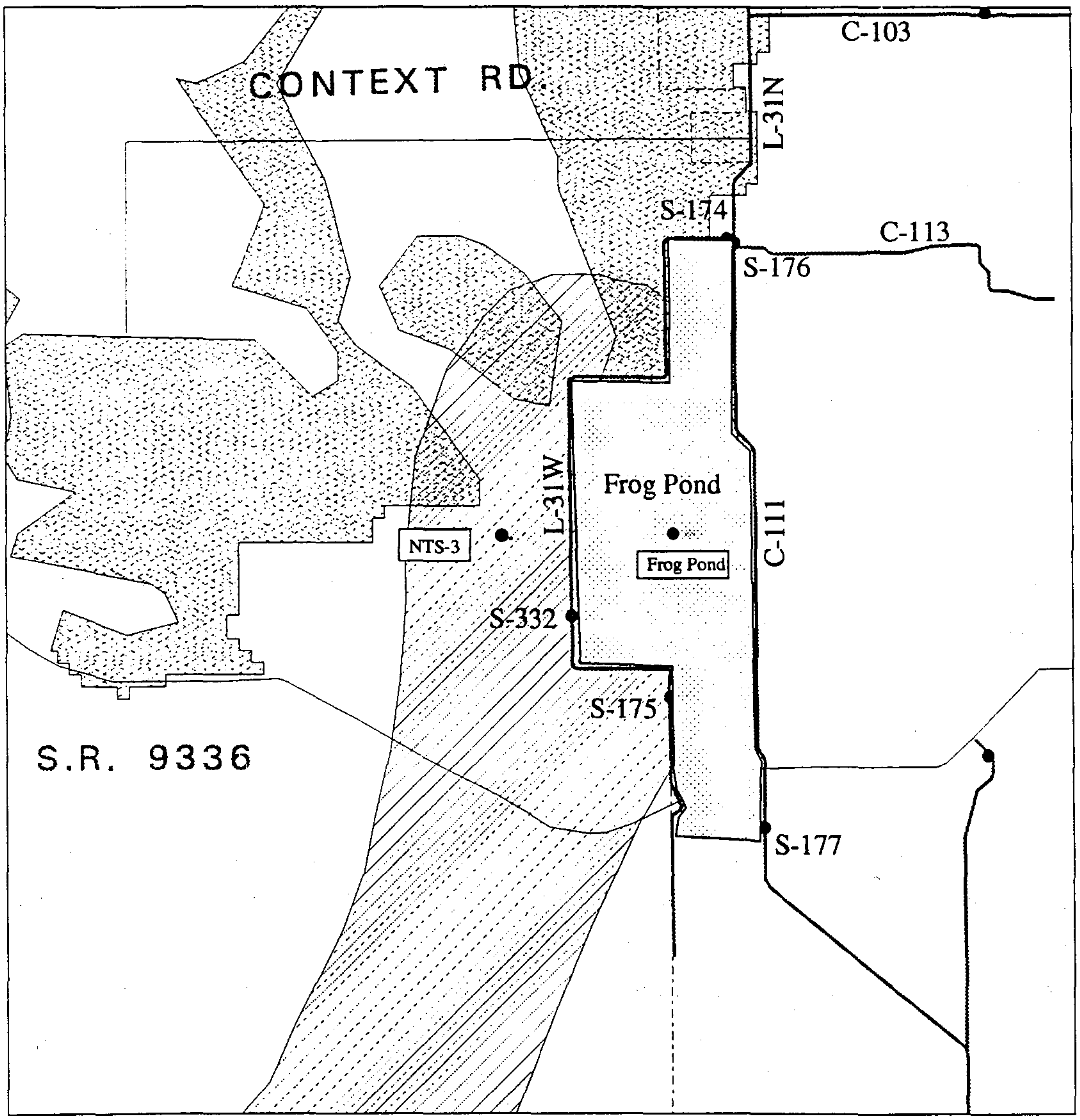

Figure 19: L-31W and vicinity.

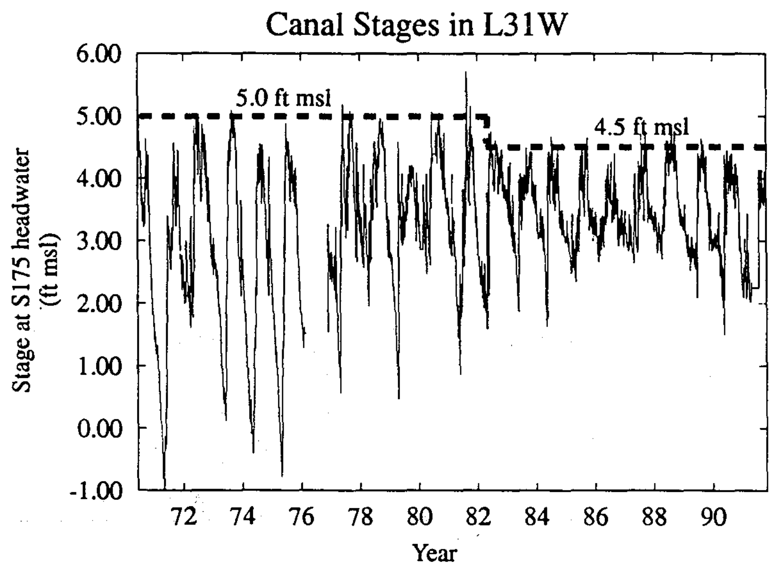

Figure 20: Stages in the L-31W borrow canal. Shown is the headwater at S-175.

coincides with a period of extensive West Dade flooding and the beginning of intensive agriculture in the Frog Pond. These factors combined to require strict adherence to lower water levels in the regional system, emphasizing flood control and drainage. The effect of the South Dade Conveyance System is also evident from the higher dry season minimum levels seen after 1982. The effectiveness of the water management system at controlling water levels is apparent. Prior to 1981, the canal would normally range from 5.0ft to 0.5ft. After 1981, the typical range was between 4.5ft and 2.5ft. The narrowing of stage ranges is indicative of an intensely managed system.

The strict maintenance of L-31W stages since 1981 is accomplished by increased operation of S-175. When we compare the stages in L-31W with the flows at S-175, as in Figure 21, it becomes apparent that S-175 is now opened so that wet season stages in L-31W do not exceed 4.5ft. That is, S-175 is operated to drain Taylor Slough and the Frog Pond during the wet season, not to provide water deliveries to Taylor Slough from the regional system.

The requirement of not allowing wet season stages in L-31W to exceed 4.5ft is likely a combination of two factors. First, agricultural interests in the Frog Pond have objected to any plan to increase wet season stages in L-31W. The Park Service agreed in 1983 to a drawdown of the Frog Pond (see Table 2, page 10) as part of a test of higher wet season and lower dry season stages. However, the increase wet season stage aspect of the experiment was blocked by the Frog Pond farmers.

A second factor in the maintenance of L-31W wet season stages at 4.5ft or lower is a result of the

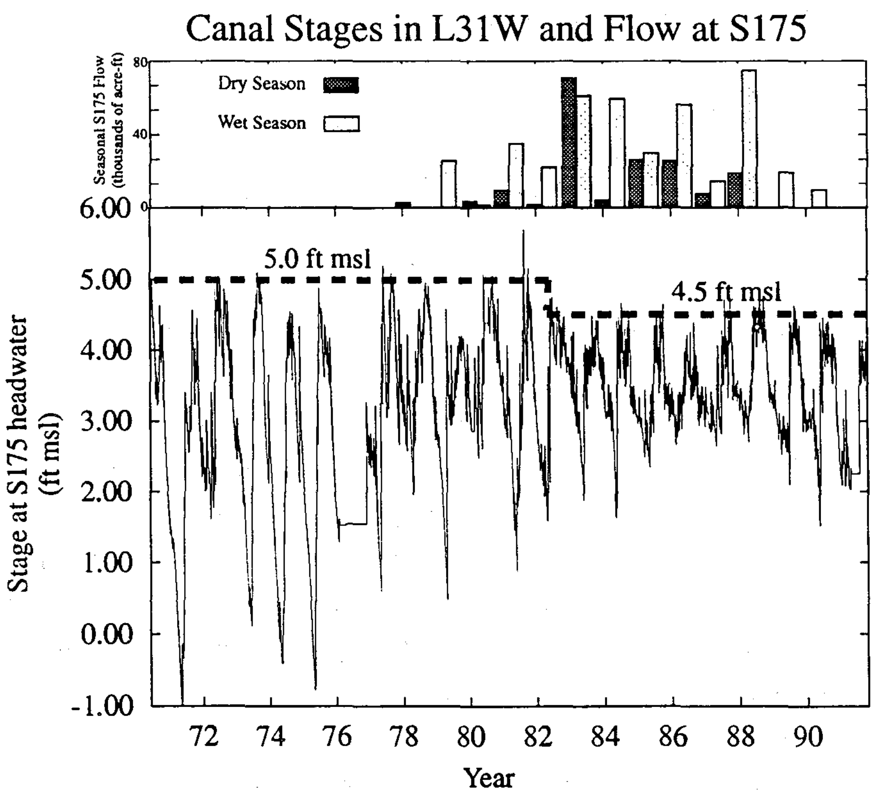

Figure 21: Comparison of stages in L-31W to flows at S-175.

general lowering of L-31N canal stages. When L-31N is held at 4.3 ft, it is not possible to use gravity to bring water to L-31W unless L-31W is below 4.3ft, and preferably much lower. To lower L-31W, water managers can either a) open S-175 and lower L-31W stages sufficiently to allow deliveries through S-174, or b) close S-174 (disconnecting L-31W from L-31N), and pump S-332. Neither of these alternatives is desirable from an environmental standpoint. The former results in lower water levels in the marsh, which in turn means shorter hydroperiods. The latter operation extracts water from Taylor Slough and then pumps it back in, which is a wasteful recirculation of water. Neither of the above operational policies are beneficial to Taylor Slough.

The lowering of L-31N stages and the use of S-175 to drain L-31W in the wet season are linked. It is clear that raising L-31N stages would also reduce the need to drain Taylor Slough in the wet season. Raising canal stages in L-31N would provide more operational flexibility to reduce adverse drainage of Taylor Slough and the Rocky Glades. It would help insure that L-31W is not used to drain the marshes to the west, and that deliveries through S-332 do indeed represent a net contribution to flows in Taylor Slough.

2.2.2 L-31W water budget

In much the same manner as for L-31N, we can also develop a simple water budget for L-31W. Figure 22 compares the total surface water inflows and outflows. The inflow to the canal is S-174, while the outflow is the sum of S-175 and S-332. The only time in the available record when inflows from S-174 exceeded outflows was in 1989, a drought year. On the average, outflows from S-332 and S-175 average double the inflows from S-174. The difference between the surface water inflows and outflows represents the water drained by L-31W. In a typical year, 38,000 acre-ft are drained from the L-31W basin. This means that the 37,000 acre-ft minimum delivery schedule can be primarily accounted for by groundwater seepage into L-31W from Taylor Slough.

Once again, by looking at the average groundwater slopes, one can obtain an estimate on how much of the water drained by L-31W comes from Everglades National Park and how much comes from the Frog Pond. Figure 23 depicts the typical groundwater gradients in the area. What this shows is that in northern Taylor Slough, represented by gage NTS-3, groundwater moves out of the marsh and into the canal. Moreover, there is a small difference in stages between the canal and the Frog Pond. This small difference indicates that the Frog Pond tends to receive water as seepage slightly more often than it contributes water as drainage. Most likely, the amount drained from the Frog Pond in the wet season roughly balances the amount the Frog Pond receives from L-31W in the dry season. The low C-111 canal stages on the eastern boundary of the Frog Pond probably contribute to a flow out of L-31W through the Frog Pond and into C-111.

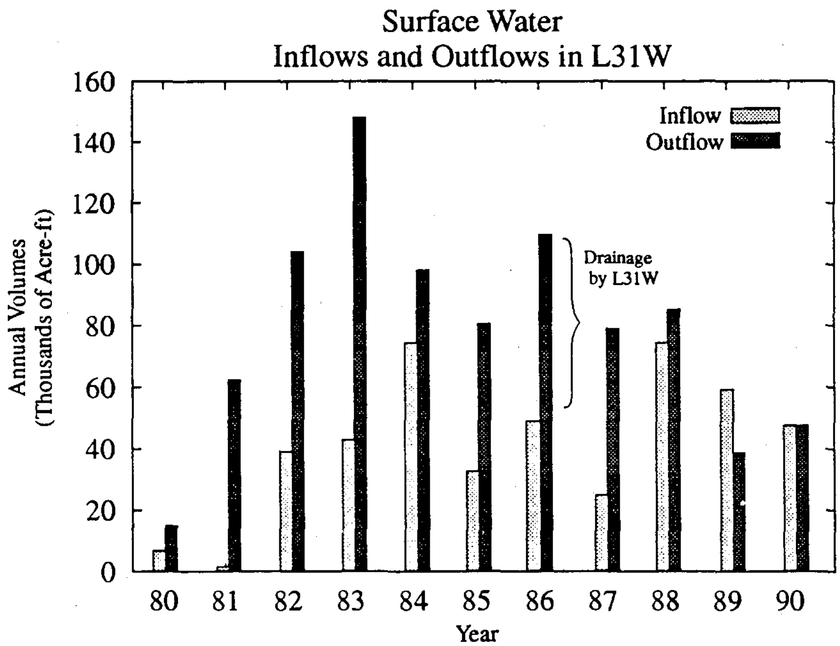

Figure 22: Comparison of surface water inflows to surface water outflows in L-31W.

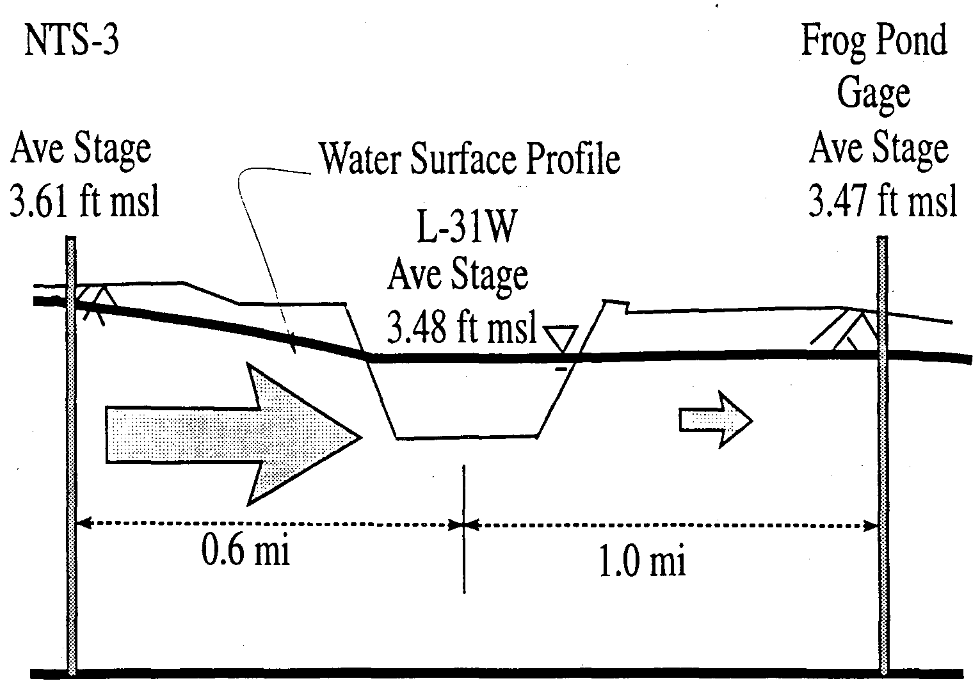

Figure 23: Average groundwater stages in the vicinity of L-31W.

Figure 24 summarizes the average annual water budget for L-31W. As an average, many of the important operational features are lost, but one can interpret the budget in the following way. Because L-31W canal stages are not allowed to exceed 4.5ft NVGD in the wet season, large volumes of water are pulled into L-31W from Everglades National Park and then dumped through S-175. Also, inflows at S-174 and outflows at S-332 were not balanced; pumping at S-332 often exceed inflows at S-174. To prevent L-31W from draining the marshes in Everglades National Park, S-174 inflows must meet or exceed the combination of outflows from S-332 and S-175.

This has important implications on pumping at S-332. If S-332 is used, then an equivalent volume must be brought in through S-174. If pumping is increased at S-332, then the increased pumping must be offset by increased flows at S-174. Otherwise, pumping amounts to recirculating water in L-31W; pumping in L-31W without increasing S-174 deliveries means that the water is pumped out of the canal into the marsh, and then seeps back into the canal. Thus, we need to be sure that increased pumping at S-332 represents true contribution to Taylor Slough, rather than a drainage of Taylor Slough.

If water is brought in through S-174 to match any increased pumping, we must determine if increased S-174 flow is the result of extracting water from the Rocky Glades west of L-31N. By taking the position that S-174 flows be increased to match pumping at S-332 and that stages in L-31N be raised, we are taking positive steps in assuring that plans for increased flow to Florida Bay via Taylor Slough do not merely extract water from the Park and reintroduce it downstream.

2.2.3 Summary of L-31W analysis

We can summarize the findings of our L-31W analysis as follows:

1. Prior to 1981, canal stages in L-31W were routinely allowed to reach 5.0ft NVGD. After that date, stages were held at or below 4.5ft NVGD.

2. To accomplish this, S-175 was used to drain water from the L-31W basin during the wet season. In an average year, 52,000 acre-ft is passed through S-175.

3. Current operational policy has the effect of removing 41,000 per year from Taylor Slough, and then pumping 33,000 acre-ft back into Taylor Slough via S-332.

4. Any plan to continue or increase pumping at S-332, using either the existing pump and/or the auxiliary pump, will require flows at S-174 which meet or exceed the pumping rate.

5. Increasing stages in L-31N will allow for increased flexibility in operating L-31W and S-332 for the *benefit* of Taylor Slough.

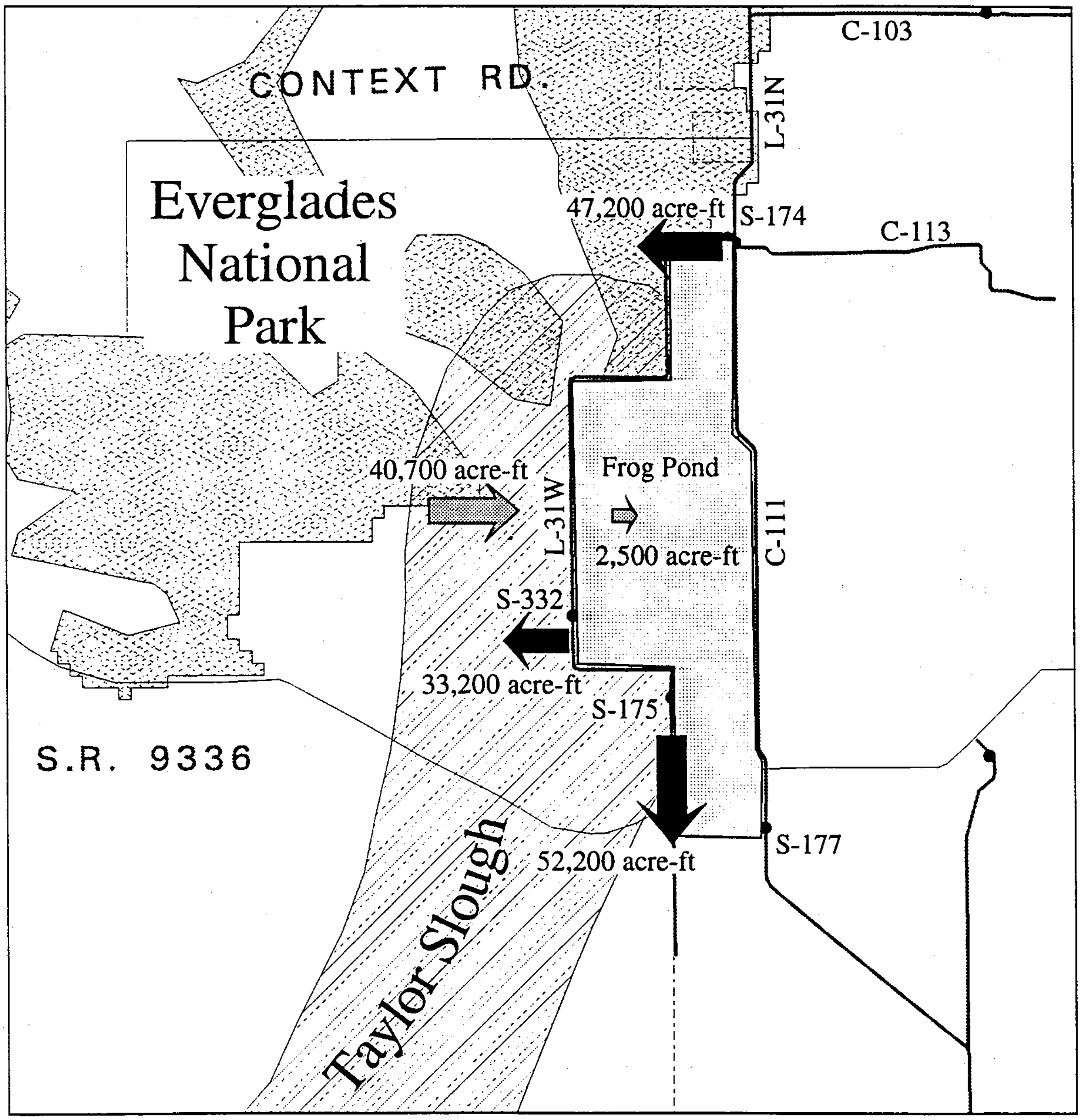

Figure 24: Summary of the average annual water budget for the L-31W borrow canal for the years 1983–1990. The solid arrows represent flows through structures, while the shaded arrows represent groundwater seepage into L-31W.

2.3 Operation of the C-111 Canal

The lowest reach of the South Dade Conveyance System is the C-111, shown in Figure 25. This canal can be broken into three reaches: from S-176 to S-177 is the upper reach, S-177 to S-18C is the middle reach, and from S-18C to S-197 is the lower reach. Historically, there was little surface water connection between the area north of S-177 and the wetlands and downstream estuaries of the lower C-111 basin. When the C-111 canal was constructed in the early 1960's, the canal breached the coastal ridge, allowing large volumes of surface water to flow rapidly from northern Taylor Slough into the Eastern Panhandle. For this reason, C-111 has an undeniable effect on Florida Bay. Most importantly for the Park, the middle reach potentially drains water from Taylor Slough. In the lower reach, water flows out of the canal, through a series of gaps in the levee south of the C-111 canal, and then southward into the Park's Eastern Panhandle. As it stands, this outflow through the gaps is the major contributor of overland flow to Florida Bay.

The hydrologic records from the C-111 basin are not as complete or as reliable as those of the L-31N and L-31W canals. Therefore, detailed water budget analyses similar to that performed for L-31N and L-31W will not be reliable. Thus, we will present only some of the raw data, and make some general observations.

Figure 26 shows how the C-111 canal adjacent to the Frog Pond has been manipulated since records began in 1981. The optimal design headwater at S-177 prior to 1981 was 4.5ft. Subsequent operations have reduced the stage to 3.9 in the wet season and 3.3 in the dry season. During drought years, such as 1989 and 1990, it has not been possible to maintain the dry season stage, dry season stages have averaged much lower than design conditions. These low stages could mean that water discharged from S-175 might seep eastward into C-111 around the S-177 structure (see Figure 26.)

These lower S-177 stages often necessitate the closure of S-174 during storm events. Because L-31N stages are much lower than design optima, S-177 must also be lowered in order to provide enough of a gradient for gravity flow southward. Since S-174 has inadequate capacity to pass all of the water drained in the L-31N basin, S-176 must often be opened to dump the storm water into C-111. When S-176 and S-174 are both opened, the net effect is to pull water backwards through S-174, through S-176, and into C-111. Thus, with low stages in C-111, it is difficult to simultaneously open S-174 and S-176 without draining L-31W. One way to improve the ability to pass storm flows through S-174 and Taylor Slough is to return to the design optimum stages of 4.5ft at S-177 (see Table 1 on page 9.)

Although a water budget for C-111 would be very desirable, the flow data available from the District's database indicates clear problems with the record. Figure 27 shows the annual flow volumes for the four structures in C-111. Of particular concern is that S-177 flows are less than both the

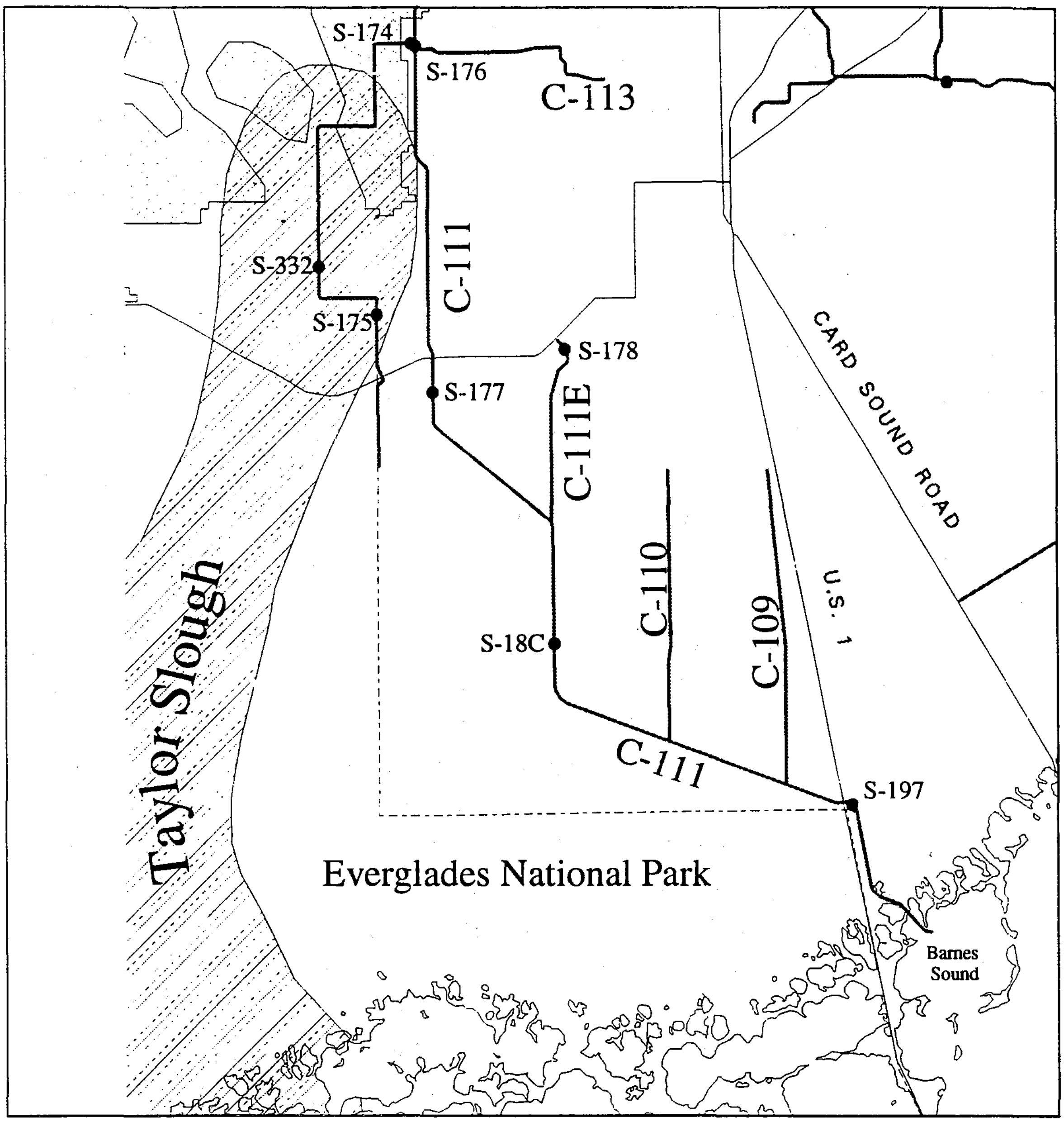

Figure 25: The basemap of the C-111 Basin.

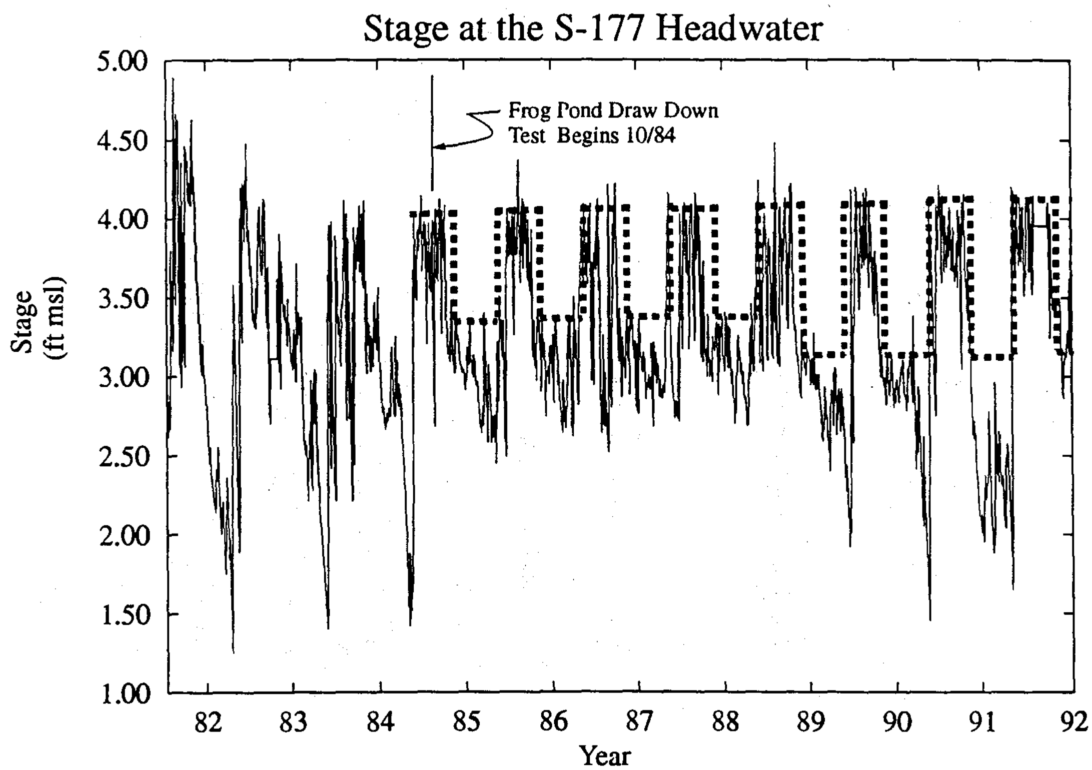

Figure 26: Stages at the headwater of S-177.

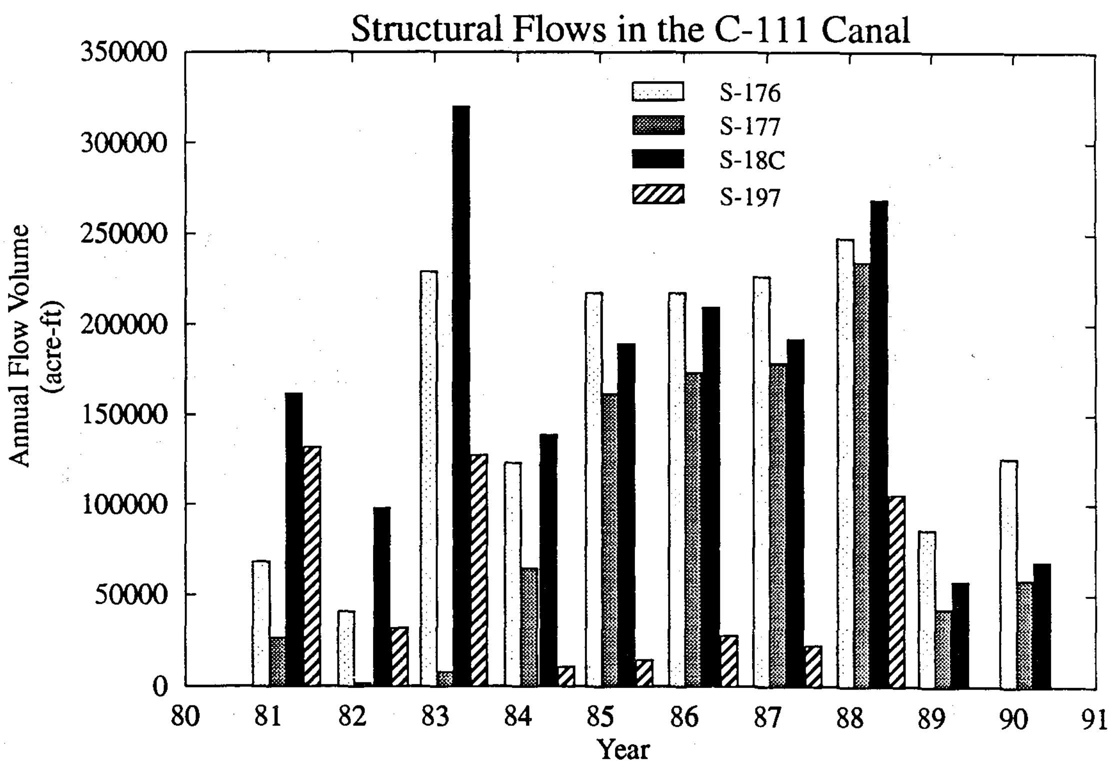

Figure 27: Water Budget for the C-111 canal between S-177 and S-18C.

upstream and the downstream structure. This indicates problems with the flow calculations at either S-177, S-18C, or most likely, both structures. Moreover, the record for S-197, the southern-most structure, are poor. Prior to 1990, the structure consisted of three culverts and an earthen plug. Five times from 1981 to 1990, the earthen dam was removed and tens of thousands of acre-ft of water flowed into Barnes Sound, unfortunately the flow records during these events are missing from the database.

The C-111 basin is the subject of a number of current investigations. The Park and the District are engaged in a joint investigation to document the impacts of the lower C-111 canal system on the adjacent wetlands and downstream estuarine environments. This work will result in a set of operational and structural recommendations for the C-111 Interim Project. The Park and the District are also cooperating in an investigation of the hydrology of the Frog Pond and the adjacent areas. We expect these investigations to result in significantly improved estimates of flows at S-176, S-174, S-177, S-175, and flows in C-113. This information will be used to recommend improved management and operations in L-31N and L-31W canals. These efforts will result in a better picture of C-111 flows and operations.

Chapter 3

Operation of the SDCS during Storm Events

Besides being an integral part of the South Dade Conveyance System, the L-31N borrow canal is also used to provide flood protection to southern Dade county. To examine how the SDCS is used during storm events, this chapter looks at three individual cases. The first case is the 1988 rainy season, which is an example of a storm resulting in the discharge of large volumes of water through S-197 into Barnes Sound. This storm also is prior to the adoption of the C-111 Interim Project, calling for structural and operational modifications to L-31N and C-111. The second and third cases we examine, are subsequent to the Interim Project, and are comparatively recent. These cases look at operations of the L-31N and L-31W canals during June and November, 1992.

3.1 Wet Season, 1988

Consider first the 1988 rainy season. Here is an example of a storm which resulted in the opening of S-197, which released large volumes of water through C-111 and into Barnes Sound. The 1988 rainy season represents a situation where, historically, large volumes of freshwater would have gone to Florida Bay via Taylor Slough, but were instead diverted into C-111 and into Barnes Sound.

Figure 28 shows how two gages in the upper Taylor Slough basin responded to the heavy rains of August, 1988. Gages G-1363 and G-1502 (see Figure 2 on page 18 for locations) are generally indicative of the behavior of the areas east and west of L-31N, respectively. The eastern gage, G-1363, reached a peak stage of 8.42ft on August 15. In general, the heaviest rainfall occurred on the areas east of L-31N. Even though G-1363 saw heavier rainfall amounts that G-1502, the stage at

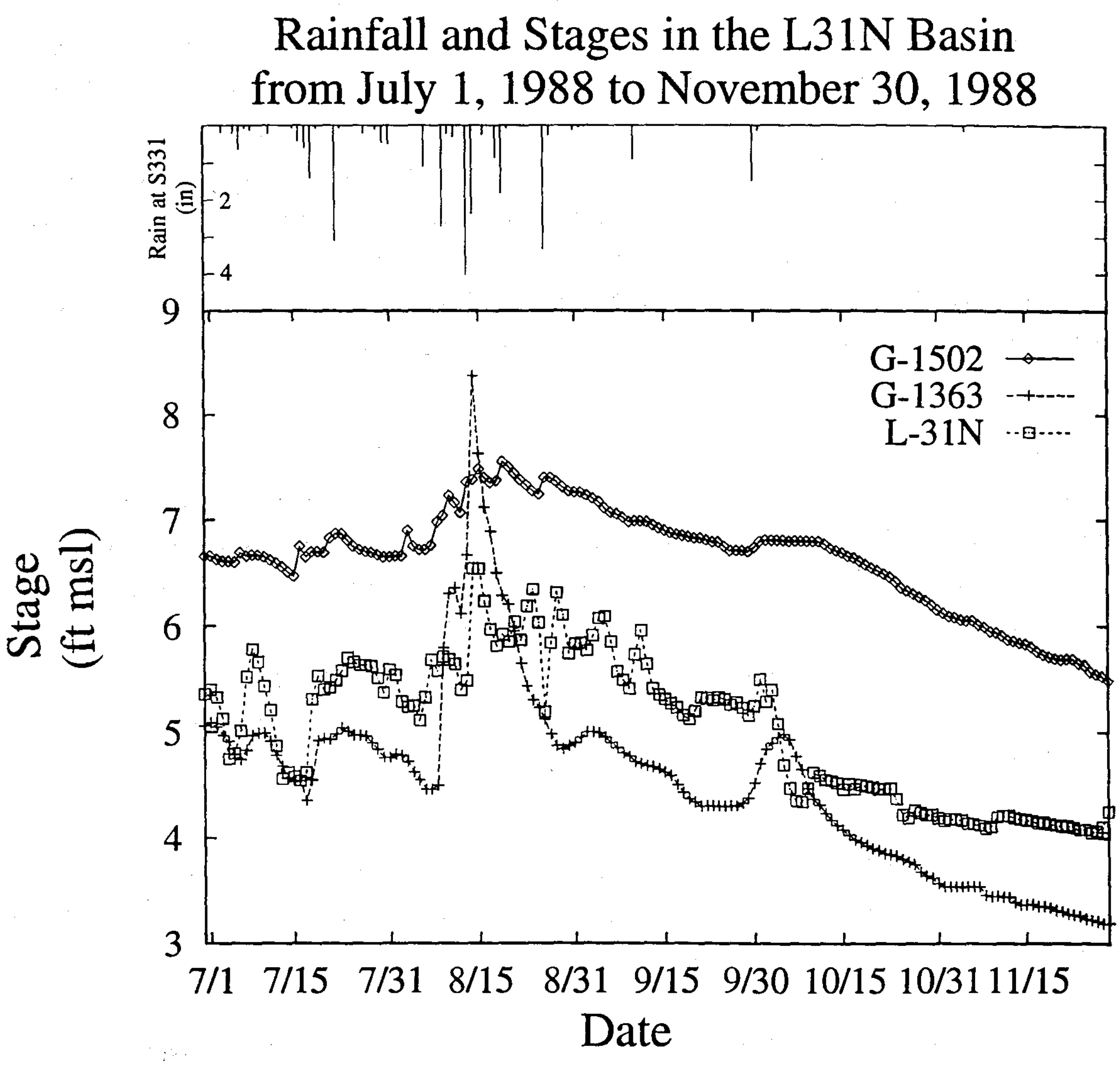

Figure 28: Stages in the L-31N basin from July, 1988 to November, 1988.

G-1363 exceeded 5.5ft for only 12 days. The western gage, G-1502, saw smaller increases due to rainfall, but also a more persistent stage, with much slower recession.

Looking at only the August, 1988 flow totals, shown in Figure 29, gives a view of the relative magnitudes of the L-31N water budget. The relative seepage contributions are again based upon the ratio of groundwater slopes; these estimates should be viewed as very rough. This water budget demonstrates a number of points. Firstly, L-31N is used to mitigate high water levels in the areas east of L-31N, and does not always recharge this area. However, using L-31N to reduce stages east of L-31N has a detrimental impact west of the levee. We estimate that seepage from west of the levee is approximately 50% higher than that from the east during the month of August, 1988. Secondly, even in this wet month, inflows to Taylor Slough via S-174 were probably less than the volume removed from the Rocky Glades and Taylor Slough. Even during this storm event, the SDCS did not contribute a net volume of water to Taylor Slough and the Rocky Glades.

Lastly, we again note that the seepage collected in L-31N is largely routed to C-111 via S-176. This aggravates the high water conditions downstream, potentially increasing the frequency of discharges from S-197 in Barnes Sound. Historically, the bulk of late wet season flows went through Taylor Slough to Florida Bay; current operational policies tend to put the bulk of late wet season flows into the lower C-111 basin, the Park's eastern panhandle, and into Barnes Sound. The basis for increasing flows to Florida Bay should begin by reducing the drainage of the Rocky Glades and Taylor Slough by raising L-31N canal stages, and also by routing high wet season flows into Taylor Slough via S-174.

One way to look at the overall drainage effect of the lower L-31N canal is to examine the cumulative inflows and outflows, as in Figure 30. Of interest here are the slopes of the inflow and outflow curves, indicative of the discharge. There rate of inflow does not exceed the outflow discharge for any significant period. The L-31N canal drains the basin throughout the entire five month period, with the rate of drainage more or less constant from July through September. The net drainage from July 1–November 30 is 58,000 acre-ft. Moreover, one can safely say, based upon the fact that heads west of L-31N exceed those east (see Figure 28), that the Rocky Glades and Taylor Slough lost *at least* 58,000 acre to L-31N; most likely, the true value is in the range of 75,000—90,000 acre-ft for these five months. Contrasting this with the total S-174 volume of 47,500 acre-ft, we again see that the SDCS, operating in flood mode, represents a net loss of water from the Rocky Glades and Taylor Slough into the lower C-111 basin.

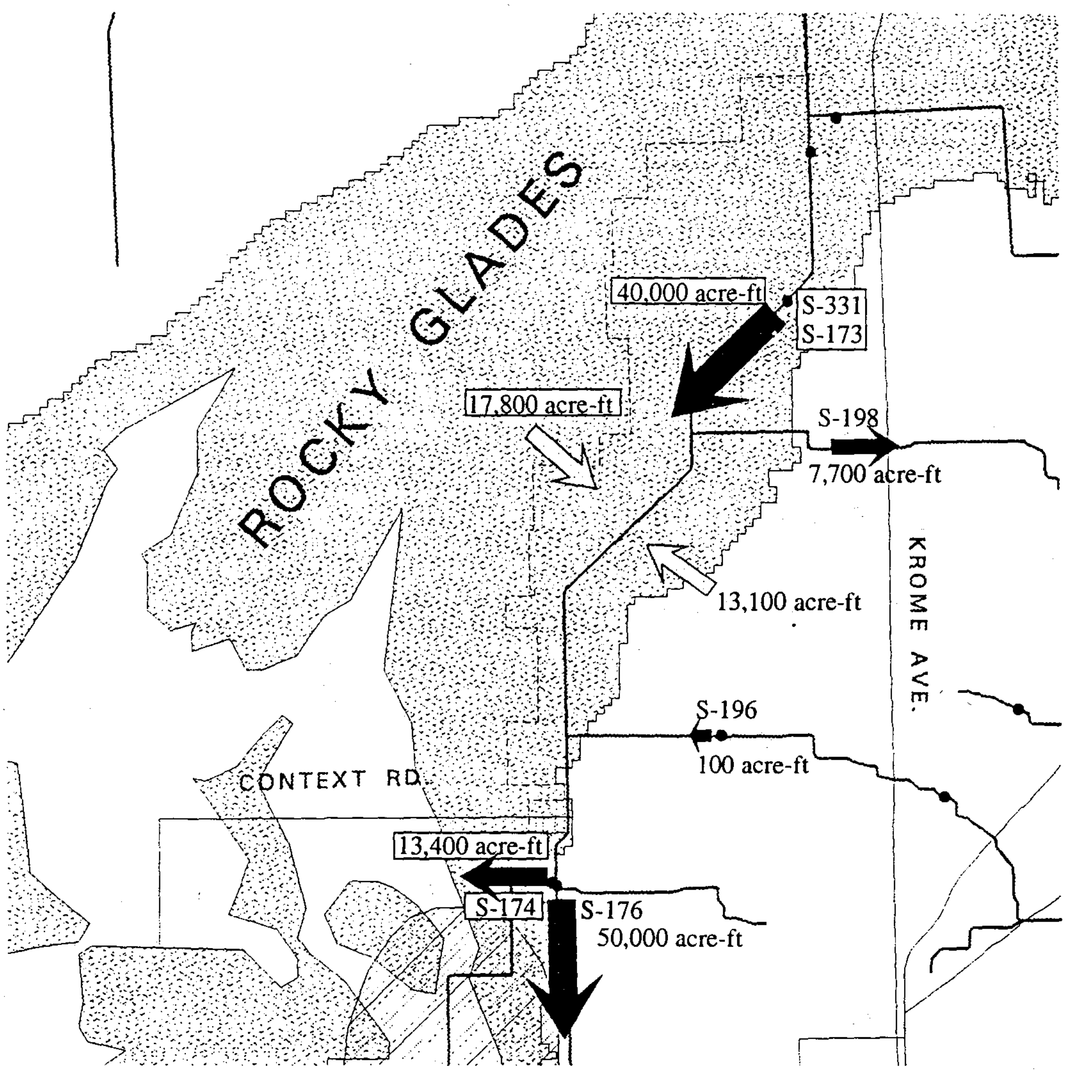

Figure 29: Total flow volumes in the L-31N borrow canal during August, 1988. The dark arrows represent flow through structures, while the light arrows represent estimated groundwater seepage.

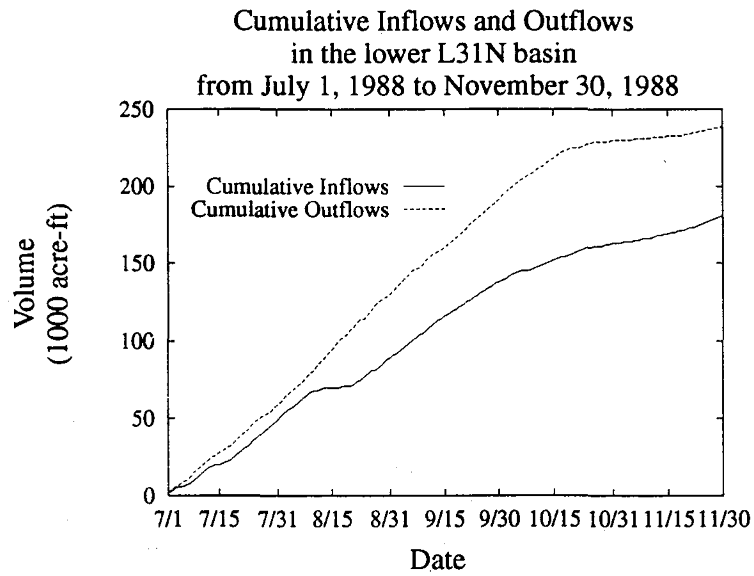

Figure 30: Cumulative inflows and outflows L-31N from July, 1988 to November, 1988.

3.2 Canal Operations and the C-111 Interim Project

In December 1988 the South Florida Water Management District proposed a new set of interim operational recommendations for the C-111 basin. The six proposed structural and operational changes were designed to address two major problems in the C-111 basin: (1) increased flows into the lower C-111 basin resulting from implementation of wet season stormwater pumping at S-331, and (2) the lack of water management flexibility of the earthen plug at the downstream end of the C-111 canal. By 1991, two new structural features were added to address these problems.

To control seepage into the L-31N canal from Northeast Shark Slough, a new water control structure (G-211) was constructed immediately south of the intersection of the L-31N and C-1W canals. This structure has allowed the District to maintain wet season stages up to 6.0 feet in the northern reach of the L-31N canal, which is 1.0 to 1.5 feet higher than design stages. SFWMD analyses have shown that the subsequent reduction in seepage losses has significantly decreased the frequency, duration, and volume of wet season pumping at the S-331 pump station.

In 1991 the District modified the earthen plug at S-197 by adding 10 additional gated culverts. The installation of an operable structure has allowed gate openings to be more gradual, and eliminated the need to pull the earthen plug. The first test of the benefits of this modification occurred in June 1992, following a period of intense rainfall. The new gates were opened gradually, with the structure remaining fully open (13 gates out of water) for only three days. The results of this storm showed that the new operable structure was able to reduce the magnitude, although still substantial, and duration of large freshwater releases through S-197 into Manatee Bay.

3.2.1 Wet Season Operations

A one and one-half month period, centered on the June 1992 storm, was reviewed to characterize wet season canal operations under the C-111 Interim Project. Figure 31 shows daily rainfall, canal water level changes, and structure operations for the L-31N canal between G-211 and S-176. The daily data on actual canal stages and structure discharges were not available at the time of this report, so we used the daily water readings record supplied to the park by the Data Management Division of the SFWMD. For this reason, a detailed water budget analysis could not be performed.

Canal 111 water levels remained low throughout May and early June, following a long period of below normal rainfall. During the first two weeks of June structures G-211 and S-331 were used to make water supply deliveries to the Taylor Slough and lower C-111 basins. By June 15th, downstream stages had reached their allowable optima, and G-211 was closed to prevent over-drainage of Northeast Shark Slough. S-176 headwater stages were maintained at or below the 4.5 foot wet season criteria throughout the first three weeks of June.

Canal stages rose rapidly on June 23rd, in response to widespread rainfall associated with a stationary, low pressure system. By June 24th, S-331 began flood control pumping, S-176, S-177, and S-18C was opened full, and S-197 had 3 and later 7 gates pulled. On June 26th, G-211 headwater stage exceeded 6.00 feet, the gates were opened full, and S-331 pumping was halted to limit inflows to the downstream reach of L-31N. By July 6th, upstream water levels had stabilized, G-211 was closed and downstream canal water levels had fallen sufficiently to resume S-331 pumping.

Figure 32 shows the changes in canal stages and gate operations during the same period for the structures controlling the L-31W canal. Stage data from the recorder at NTS-1 is also show to demonstrate the close linkage between L-31W operations and marsh water levels in Northern Taylor Slough. The gate operational records indicate that the L-31W control structures were fully utilized during this storm period. Structure 174 was opened full on June 26th and remained open full through mid July. Structure 175 was opened full on June 23rd, and remained fully opened until July 6th. Structure 332 was similarly operated at its maximum pumping capacity throughout the entire period.

The early closure of S-176 helped to prevent over-drainage of the Rocky Glades. This is a key element of any effort to restore more natural flows to Taylor Slough. Similarly, the prolonged use of S-174 had the beneficial effect of diverting much of the excess flows away from the lower C-111 canal and into Taylor Slough. The water level record for NTS1 suggests however, that following

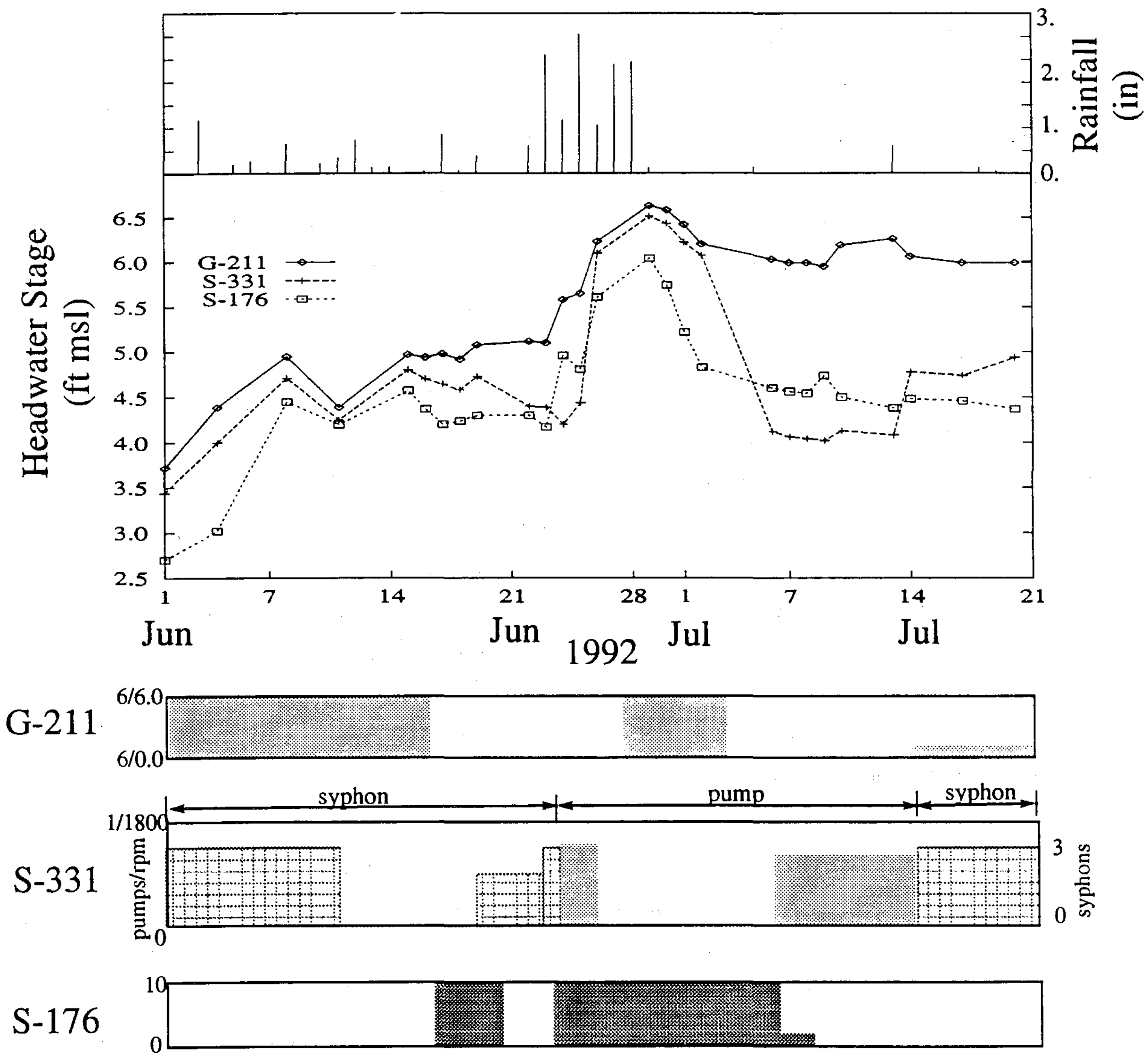

Figure 31: Operations of L-31N in June–July, 1992. The stage values are taken from SFWMD daily water readings. The rainfall is measured at R-3110.

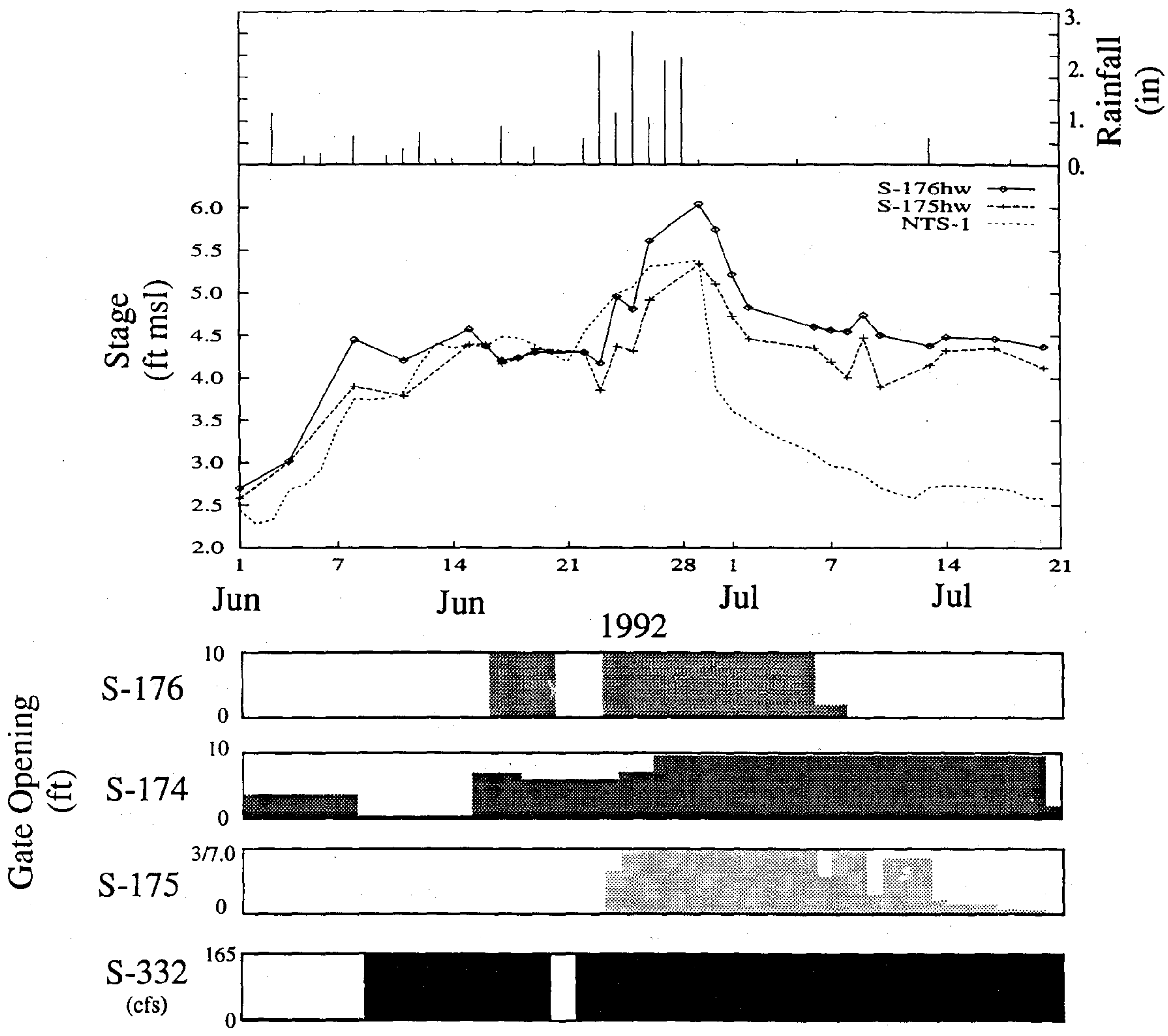

Figure 32: Operations of L-31W in June–July, 1992. The stage values are taken from SFWMD daily water readings. The rainfall is measured at R-3110.

the initial L-31W stage reduction, S-175 and S-332 outflows greatly exceeded S-174 inflows. This indicates that more attention is needed to track L-31W operations, or the canal system will continue to over-drain the adjacent Taylor Slough marshes.

3.2.2 Dry Season Operations

A period of just over two months, from October 1st through early December 1992, was similarly reviewed to characterize the dry season canal operations under the C-111 Interim Project. Figure 33 shows daily rainfall, canal water level changes, and structure operations for the L-31N canal between G-211 and S-176. Again the daily data on actual canal stages and structure discharges were not available and we relied on the daily water readings record provided by the District. Canal 111 water levels were high throughout the early dry season following above normal rainfall in the late wet season. Throughout October and the first week of November G-211 stages remained generally at or above 6.0 feet, and water supply releases were made into the downstream canal system. The S-331 pump station passed most of the excess water southward by setting the three units in a syphon mode. During this period, S-176 headwater stages remained below 4.8 feet, and the gates were kept closed. Structure 174 was left open throughout this period, and the excess water was passed into the Taylor Slough basin.

High rainfall between November 3rd and the 10th raised water levels in the upstream C-111 basin. In response, G-211 was closed, and S-331 began flood control pumping. By November 10th, S-176 was opened to help control stages in the lower reach of the L-31N canal. By November 17th, additional rainfall prompted the opening of G-211, S-331 began pumping near its maximum capacity, and the gates at S-176 were opened full. High water conditions persisted through the end of November. On December 1st, G-211 was closed, pumping at S-331 was cut back, and S-176 was partially closed.

Figure 34 shows the changes in canal stages and gate operations during the same period for the structures controlling the L-31W canal. Again, NTS1 water levels are included to show the impacts of canal operational changes on the adjacent Taylor Slough marsh. Water supply releases were made through S-174 throughout October and early November. On November 12th, S-174 was closed, and it remained closed until November 26th, when the headwater stage dropped below 4.8 feet. Structure 175 was opened full on November 12th, and it remained fully open until December 1st. During this period L-31W water level dropped by more than 1.2 feet, from a high of 4.60 to 3.34 feet. Inflows into the L-31W canal were not resumed until S-175 headwater stage dropped below 3.5 feet. The early closure of S-174 essentially denied Taylor Slough of any of the benefits that the dry season rainfall could have provided. Similarly, the excessive discharges through S-175 artificially forced the

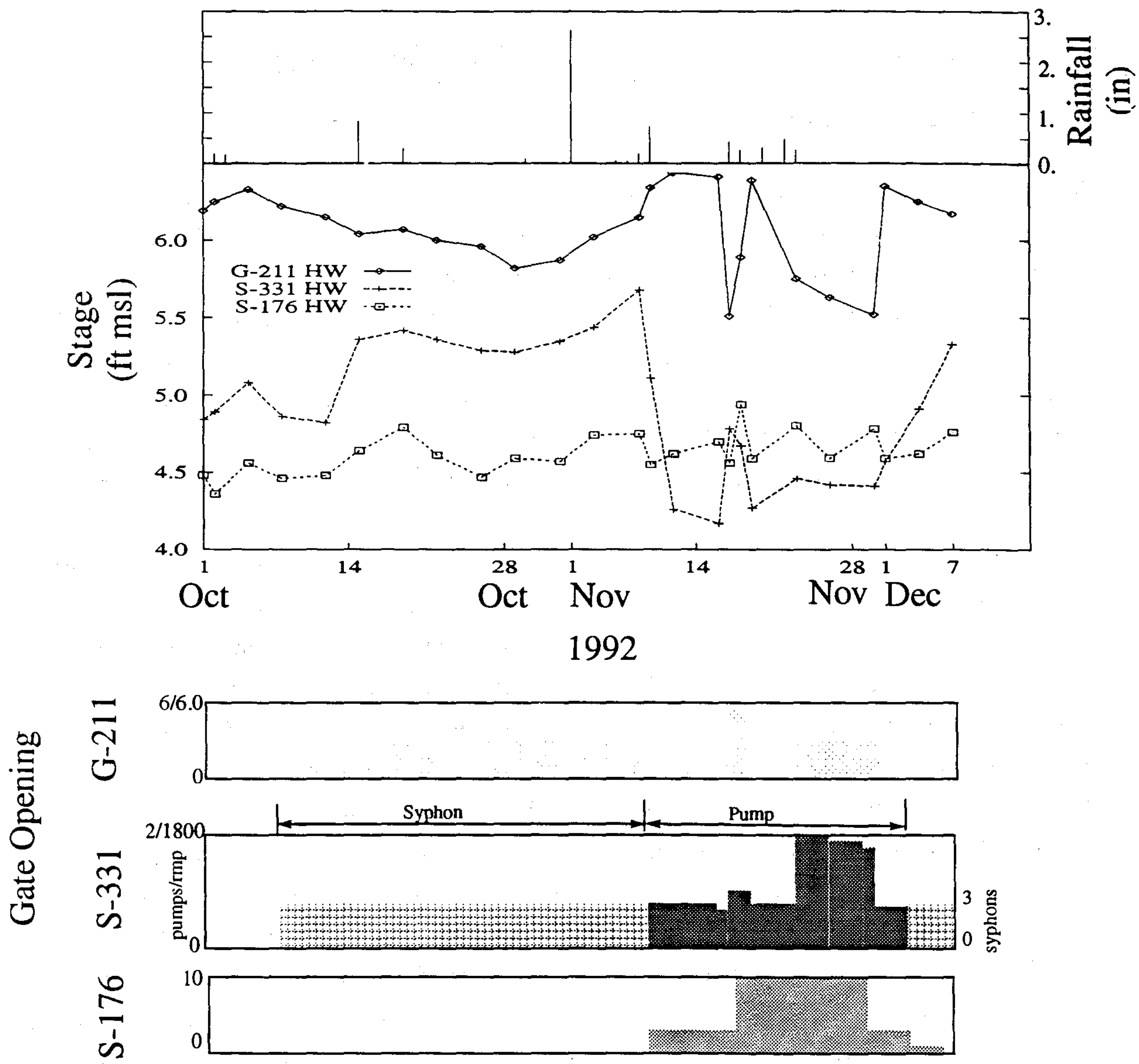

Figure 33: Operations of L-31N in October–November, 1992. The stage values are taken from SFWMD daily water readings. The rainfall is measured at R-3110.

L-31W canal system down to the 3.5 foot level, instead of allowing water levels to recede naturally into the dry season. The water level record at NTS1 shows that much of the S-175 outflows were the result of drainage of the adjacent Taylor Slough marshes.

3.3 Canal Operations and the Taylor Slough Demonstration Project

Review of the C-111 canal operations under the interim project guidelines clearly points to the need for additional operational improvements to control over-drainage of Northern Taylor Slough. The two most important operational changes were included as part of the original recommendations for the C-111 Interim Project. First, the operational guidelines for S-176 need to be revised to reflect the reduced flood risk to the canal reach between S-331 and S-176 resulting from improved seepage control upstream of S-331. The proposed Taylor Slough Demonstration Project calls for raising the wet season control elevation at S-176 from 4.3 to 5.0 feet. Second, the plan calls for increasing the pumping capacity of S-332 by an additional 100 cfs, and for more effective use of S-332 during the wet season.

It is clear that the reductions in C-111 canal operational stages over the past ten years were done without adequate environmental assessments. It is also apparent that these operational changes have detrimentally contributed to the wetland drainage problems in the Taylor Slough basin. For these reasons the starting point for all of our restoration efforts should be a return to the original authorized canal operational stages. This means that the demonstration project is at best, a modest first attempt to restore historical water levels in the Taylor Slough basin. The 100 cfs increase in S-332 pumping capacity should also be viewed as only a first step toward reaching the required flow capacity that will most likely be needed in the Taylor Slough basin. Indeed, given the current L-31W operational guidelines, the additional capacity could prove to be detrimental if it is used to quickly lower canal stages during periods of high rainfall. Obviously, additional criteria will be needed to fully define the operational guidelines of the proposed Taylor Slough Demonstration Project.

The Park's major goal for the demonstration project is to maintain optimum wet season water levels in the L-31N and L-31W canals, and to allow canal stages to recede naturally into the dry season. This will be difficult since it will require adherence to the 5.0 and 4.5 foot optimum criteria for S-176 and S-175, whenever excess water is available, while allowing canal water levels to fluctuate in response to rainfall. The best approach is to have all outflows from these canals balanced, as much as possible, by inflows from their upstream water control structures. To maximize Taylor Slough inflows, S-174 should remain open as long as possible, except when closure is needed to maintain

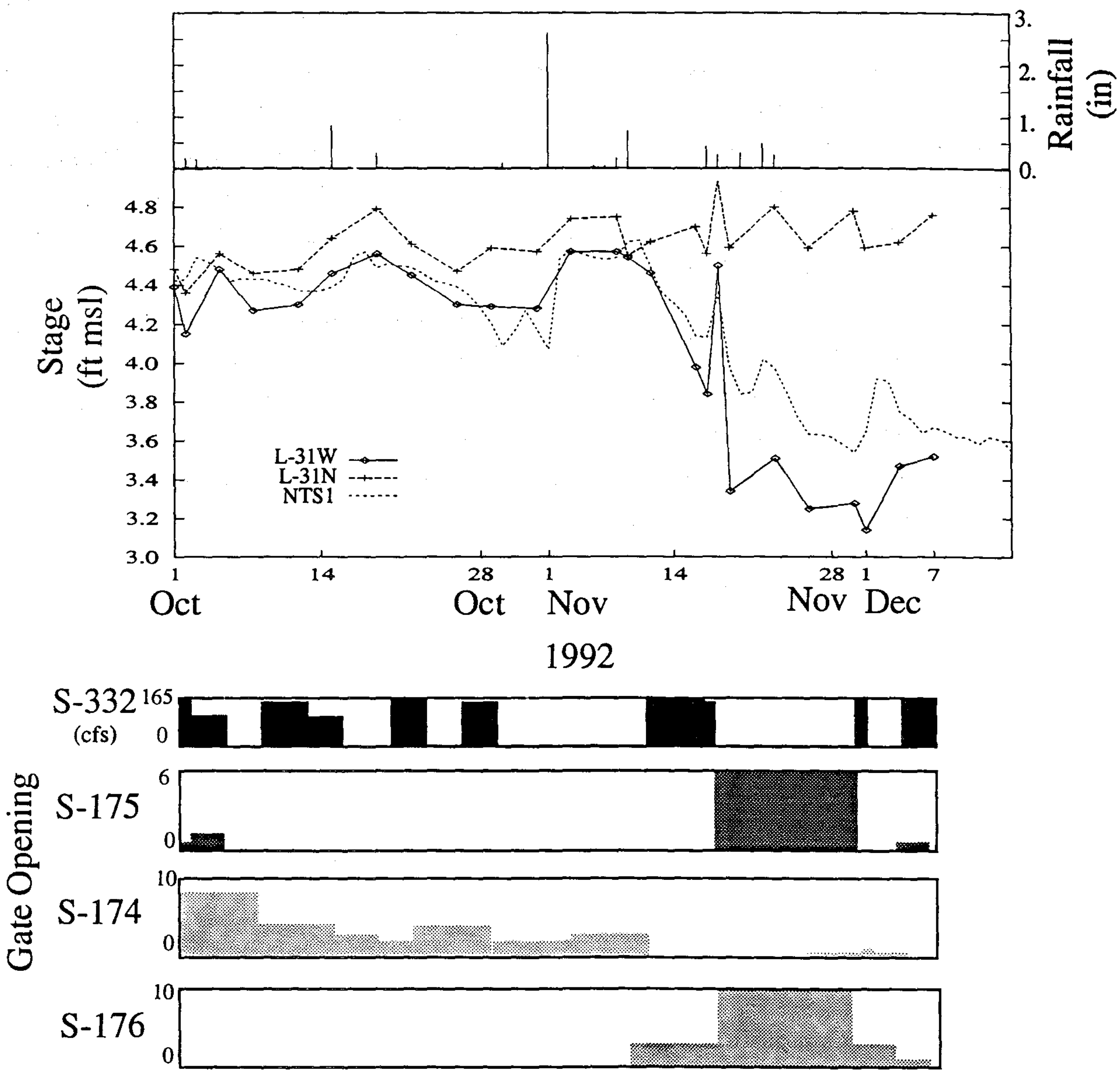

Figure 34: Operations of L-31W in October–November, 1992. The stage values are taken from SFWMD daily water readings. The rainfall is measured at R-3110.

upstream optimum stages, or to control backflows. Similarly, the opening of S-176 should limited, so that all excess flows are directed westward into Taylor Slough, except those required to meet the delivery needs of the lower C-111 basin.

All gate operational changes should be made as gradually as possible, so that excess stormwater is not rapidly forced through the L-31N and L-31W canal systems. When large releases are needed to control L-31N canal stages S-174 should be used to the maximum extent possible. When L-31W stage reductions are needed, outflows should concentrate on prolonged S-332 pumping, and S-175 operations should be reduced, as much as possible, to short periods of limited releases. During the dry season, water supply deliveries should continue to be made to Taylor Slough whenever upstream water is available and stages are below 4.5 feet. Once the canal stage has receded to 3.5 feet, S-332 can be used to maintain L-31W water levels. If needed, S-175 releases can be made so that water supply and flood control releases through S-174 do not significantly raise L-31W stages. As quickly as possible the three agencies should begin testing and implementation of a new rainfall-based water delivery formula for the Taylor Slough basin. In the interim, we should set a target for annual water volumes to be split so that approximately 70 percent of the available L-31N flows pass westward through S-174 into Taylor Slough. The remaining 30 percent would pass through S-176 to meet the environmental needs of the lower C-111 basin.

Chapter 4

Salinity in Florida Bay

Concerns about Taylor Slough have become more pressing with the increased attention to problems in Florida Bay. There are a number of scientific hypotheses about the cause of the observed declines in Florida Bay, but one cause generally agreed to be a significant factor is the modification of freshwater inflow to Florida Bay. In this chapter, we present some of the available information on salinities in Florida Bay and how they are related to flows in Taylor Slough and the lower C-111 basin.

The data base for salinity in Florida Bay is incomplete. One of the best salinity data sets was collected by Dr. Micheal Robblee of the South Florida Research Center subsequent to Hurricane Floyd on October 12, 1987. We begin our presentation of salinity information by examining his data. Hurricane Floyd hit the south Florida coast with Category 1 winds, and with approximately 100mm (3.90in) of rain in the areas upstream of Florida Bay, as measured at Homestead. The storm was not particularly intense or wet, but does reflect the typical response of the Project to a storm.

4.1 Project Flows

We can examine inflows to Taylor Slough and the Eastern Panhandle of the Park by looking at S-174, S-18C, and S-197 discharges. These are shown in Figure 35. There are a number of important features here. Firstly, note that the operational response to the storm was to *shut off* water to Taylor Slough. Eight days after the storm, S-174 was completely closed, and no water was sent to Taylor Slough. Instead, flood water was sent down to C-111. The reason for diverting the flood water into C-111 was probably to increase the rate of drainage in L-31N and the upper C-111 basins. By moving water south as fast as possible, this decreases the likelihood that the urban and agricultural lands will experience any flooding. This operation contradicts the stated operational criteria whereby

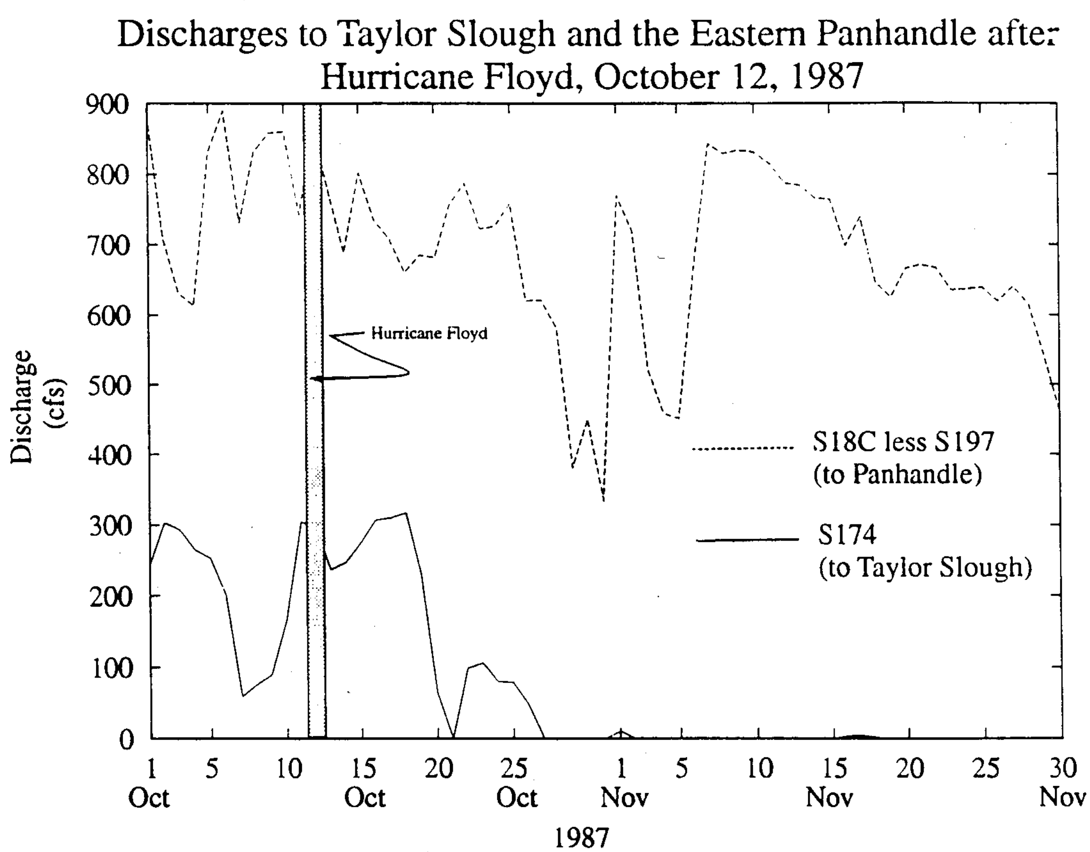

Figure 35: Discharges to Taylor Slough and the Eastern Panhandle after Hurricane Floyd, October 12, 1987.

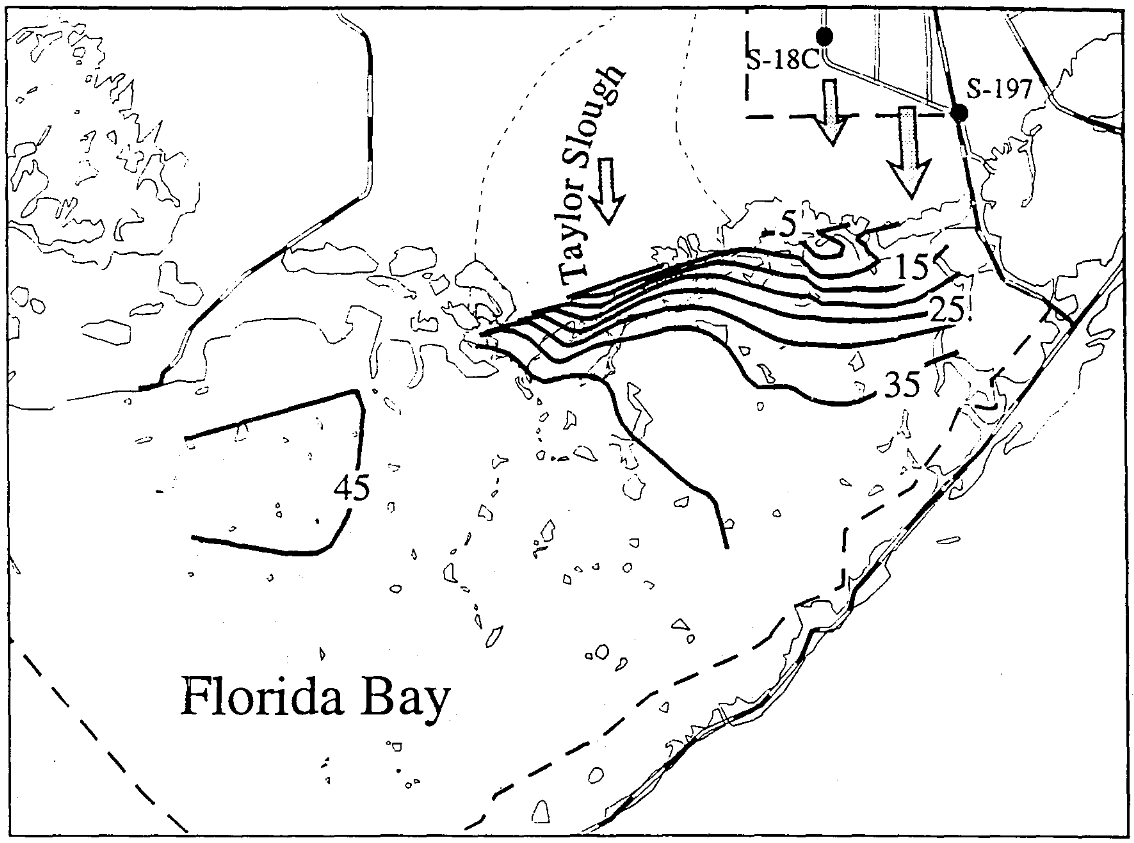

Figure 36: Salinity contours 1 day after Hurricane Floyd.

S-174 is opened first, giving Taylor Slough higher priority as a flood release mechanism.

Secondly, note that the flows to C-111 are much larger than those going to Taylor Slough. For October–November, 1987, 9,900 acre-ft went to Taylor Slough, while 83,800 acre-ft went into the Panhandle, giving about a 10%–90% split. Compare this to the current minimum delivery schedule calling for about a 70%–30% split. Again, this disparity occurs because development pressures force the District to dump water south as quickly as possible, rather than move water into Taylor Slough.

4.2 Florida Bay Salinity

The effects of these operations on Florida Bay can be seen in Figures 36–38, which are snapshots of salinity measurements taken one, nine, and seventeen days, respectively, after Hurricane Floyd.

These pictures are telling in a number of ways. Firstly, note how the easternmost end of Florida becomes fresh very rapidly. Water flows out of the eastern cut-outs on the C-111 canal and moves

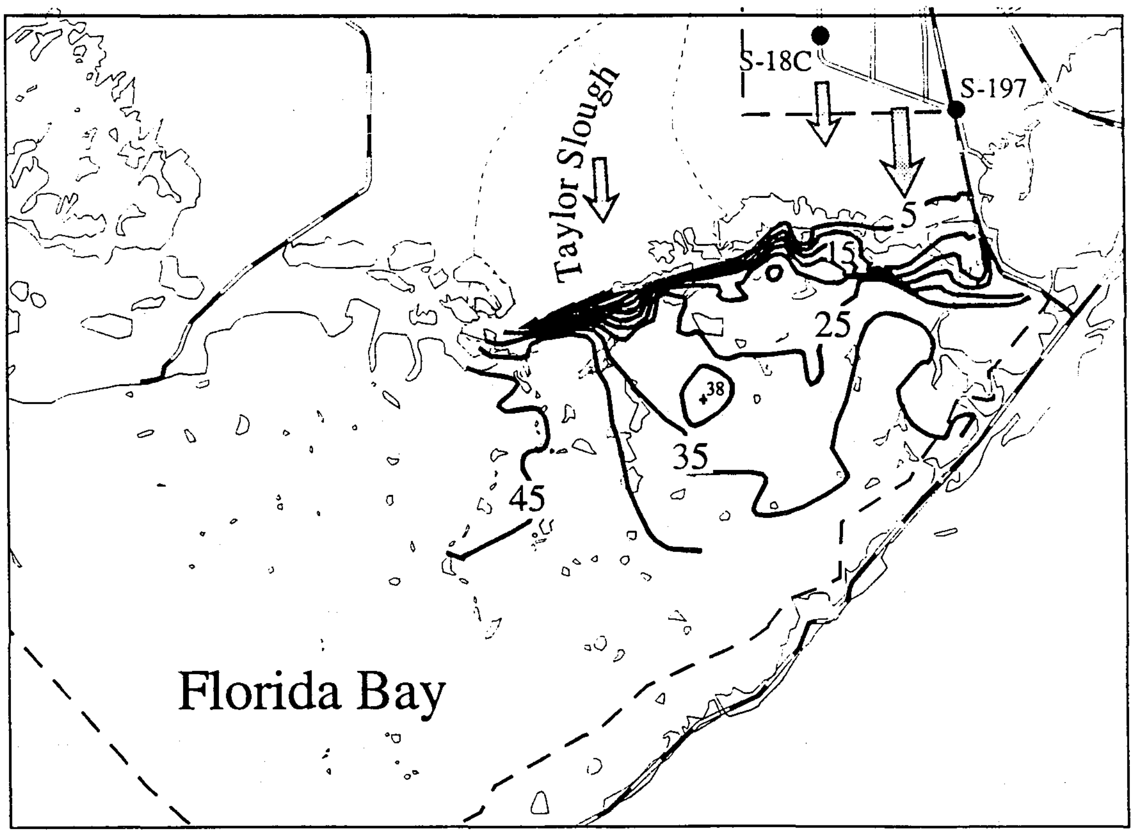

Figure 37: Salinity contours 9 days after Hurricane Floyd.

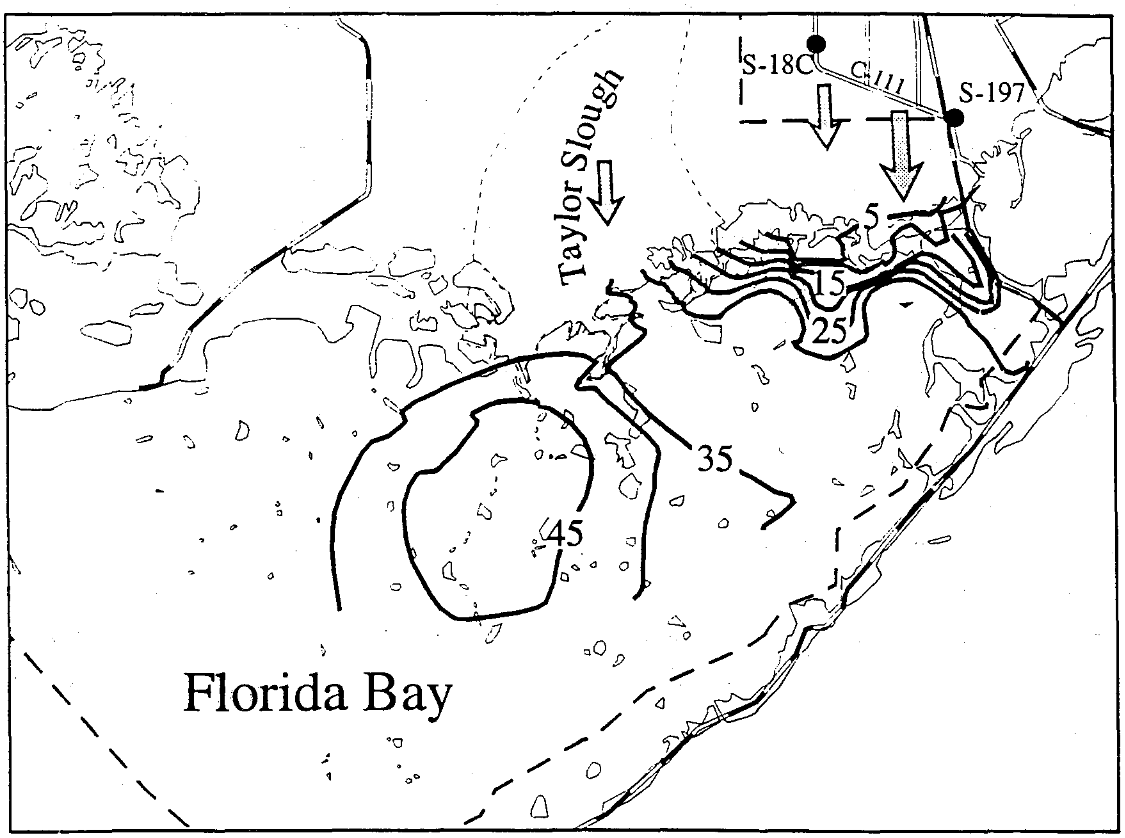

Figure 38: Salinity contours 17 days after Hurricane Floyd.

quickly into the Long Sound/Blackwater Sound region. This area is also bordered to the east by US Highway 1, and on the west by Shell Key. There is little tidal exchange, and the region becomes increasingly fresh in response to the C-111 inflows.

Similarly, one can see a plume of fresh water emanating from Joe Bay, which is directly downstream of the western C-111 cutouts. Clearly, the water coming from C-111 is moving into the eastern portion of Florida Bay and the salinities in that region are reflecting this. However, there is also indication that the fresh water is not being rapidly mixed, an indication of incomplete tidal exchange. That is, the water passed down C-111 was not distributed throughout Florida Bay, but remained in the shallow embayments of northeast Florida Bay, blocked by shoals and other natural obstructions.

These graphs also demonstrate the effect on Florida Bay of the reduced surface water flows to Taylor Slough. Even after this storm event, the areas of Florida Bay south of Madeira and Little Madeira Bays remained at 45 parts per thousand (35ppt is typical marine salinity.) At this time of the year, when the largest surface water flows historically occurred, hypersaline conditions would not be expected.

Based upon the size of the contributing area, Taylor Slough contributed much more freshwater than the saline marshes to the east. But this pattern has been reversed by current operational policies. Moreover, the easternmost areas of Florida Bay have the poorest circulation, so freshwater flows are not redistributed throughout the Bay.

At this point, there is little hard information on historical flow volumes to Florida Bay, and one cannot directly determine of the C-111 flows are larger than historical or not. However, one can certainly deduce that Taylor Slough flows must have been much higher than today. The reintroduction of significant Taylor Slough flows will allow freshwater in the areas that are currently the most hypersaline, and will help to redistribute flows across the entire Florida Bay/upland marsh boundary.

Chapter 5

Modeling of Flow to Florida Bay

The next step in our assessment of the potential impacts of upstream water management on Taylor Slough and the downstream areas of Florida Bay was to compare pre- and post-project surface water flow volume estimates across a flow line in the lower Taylor Slough basin. The comparison was made based on daily surface water flow estimates from the Natural System Model (version 3.6) and the South Florida Water Management Model (version 1.1) for four grid cells (cells 20-6, 21-6, 22-6, and 23-6) in the lower Taylor Slough basin. This flow line was chosen for two reasons. First, by choosing a flow line well south of the upstream water management system we can reduce any conflicting effects caused by groundwater seepage into the L-31N and L-31W canals. Second, we wanted to focus on the potential surface water flow changes in the southern part of the basin, since these changes will have the greatest impact on freshwater flows to Florida Bay.

5.1 Surface Water Flow Comparisons

Figure 39 is a comparison of the calculated annual flow hydrographs for the ten year period from 1980 through 1989. The flows are highly variable but it is clear that the Natural System Model predicts that surface water flows would have been much higher that what would be expected under current operations. Figure 40 is a comparison of the average monthly surface water flows along the same flow line. This plot suggests that substantially more water is needed throughout the year if we are to reproduce NSM flow conditions. These are only rough estimates, since problems exist with the grid cell resolution and the downstream boundary conditions in both models when they are applied to small watersheds like Taylor Slough. However, the estimates are useful and show that potentially large volumes of water will be needed to restore natural flow conditions in Taylor Slough and ensure the larger, historical flows to Florida Bay. The overdrainage of the head waters of

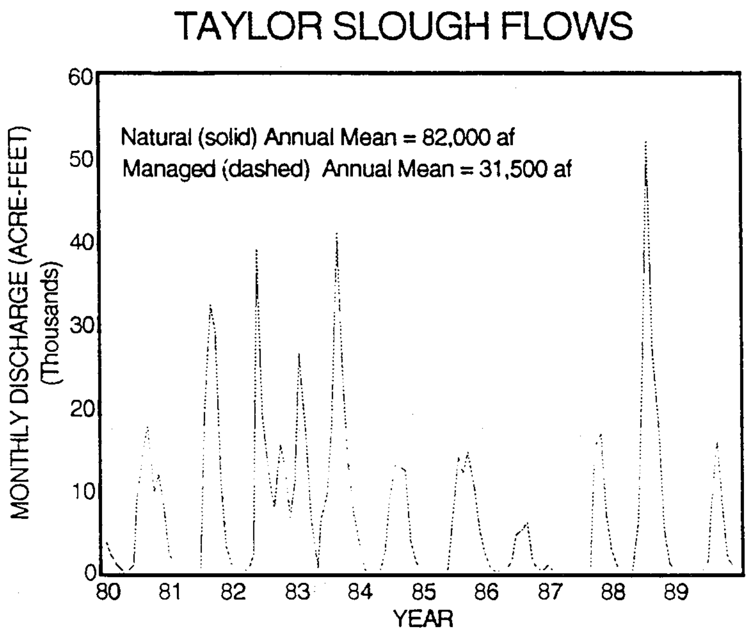

Figure 39: Comparison of calculated surface water flows into southern Taylor Slough and Florida Bay.

the Taylor Slough basin has most likely contributed significantly to the loss of downstream flows by reducing the hydraulic gradients throughout the basin. The lowering of the groundwater stage has eliminated a large volume of water from storage, which historically contributed to flow to Florida Bay well into the dry season.

5.2 Comparison of Ponded Water

The spatial distribution of surface water depths for section of the model calculated by the NSM and the SFWMM is shown in Figure 41 for the "average year" of 1978. Both the driest month, April, and the wettest month, October, are plotted to demonstrate how much wetter the sloughs are under pre-drainage conditions. The area of the model shown in the figure includes Shark Slough, south of the Trail, and Taylor Slough. Almost complete drydowns of the peripheral wetlands of the sloughs, as shown occurring in April under managed conditions, seldom occurred under natural conditions. During April of this particular year no standing water occurs in the SFWMM over 75% of the 1844 mi^2 area shown in the graphic, which is double the percentage (37%) of dry land in the NSM. Deep pools of water were naturally present in and to the north of the Park. These pools slowly drained

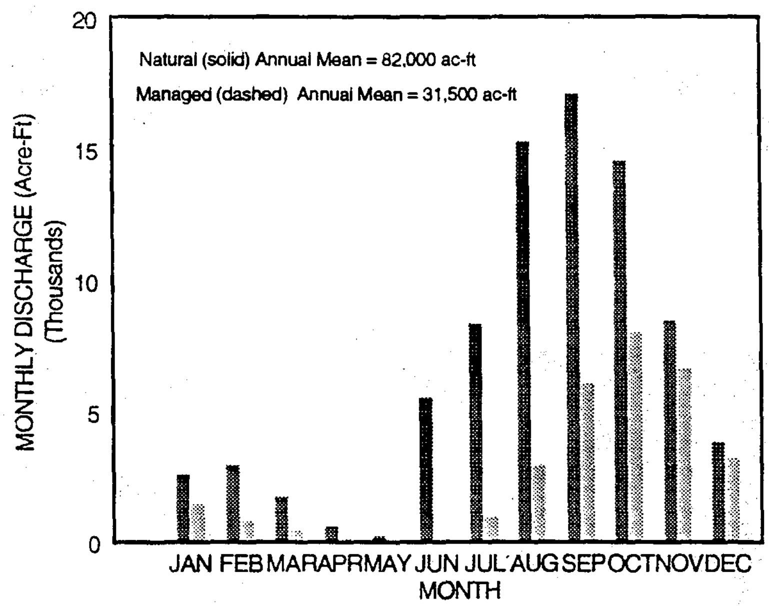

Figure 40: Average annual hydrographs for surface water flows into southern Taylor Slough and Florida Bay.

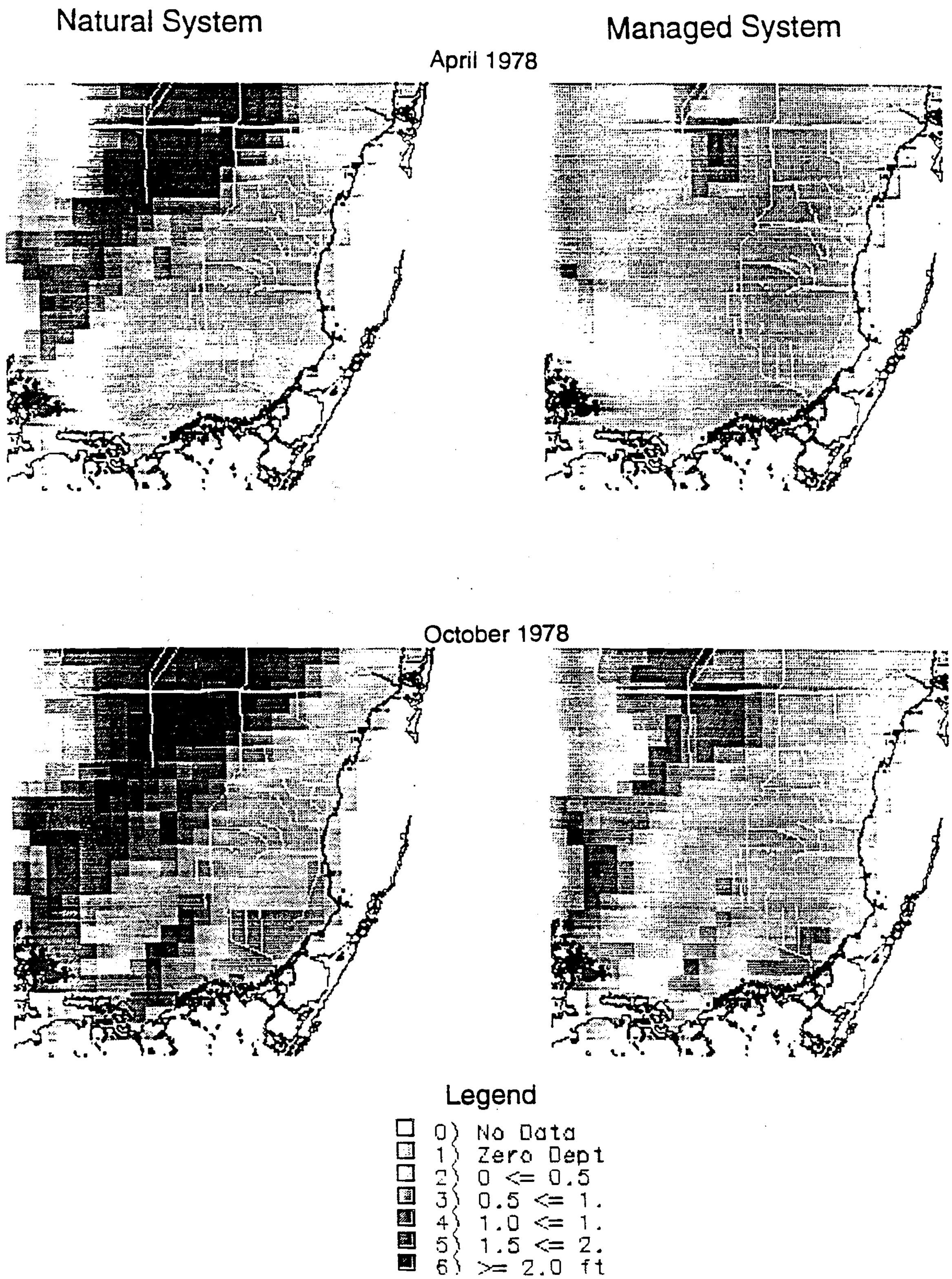

Figure 41: Comparison of ponded water depths between the managed system and the pre-drainage condition.

southward well into the dry season, keeping the main drainage ways full of standing water. These deep pools of water diminished, from 20% of the NSM area covered during April by more than one foot of water, to 0.4% of the SFWMM area.

Although it appears that natural drydowns occurred in April in the wetlands and the headwaters of Taylor Slough, the Rocky Glades had up to a foot of water on the surface. The SFWMM shows that under current conditions no surface water is present on the Rocky Glades at any time and not much water is present in the lower reaches of the Slough. This condition continues well into the wet season, when as illustrated by the October plots, the deep water pools are almost non-existent. The 2 by 2 mile grid size of the models limit their usefulness in small basins such as C-111, where only a few cells simulate the area. Comparison of the NSM and the SFWMM for these and other time periods illustrate profoundly the enormous reduction in surface water depths and fresh water flows which has occurred in the wetlands as a result of the canal system.

5.3 Groundwater Flow

The NSM can be used to illustrate general groundwater flow patterns under pre-project conditions. Figure 42 is an average of 25 years worth of monthly groundwater flow directions and magnitude. East of the coastal ridge, significant quantities of groundwater seep from the ridge into the Atlantic Ocean, while the predominant flow patterns along the western side of the ridge are west to southwest. The coastal ridge thus acted as a drainage divide for both ground and surface water flows in pre-drainage conditions. Under managed conditions the pattern west of the ridge has reversed and large groundwater flows occur to the east from Everglades National Park into the adjacent drainage canals.

This pattern of groundwater flow is in direct contrast to what is suggested in Figure 9 on page 26. This water budget would suggest large seepage losses from the wetlands west of L-31N into the developed coastal areas. This is also supported by Leach *et al.* [1972], who used post-Project water levels to document a general eastward and southward movement of groundwater. Figure 42 suggests the Project has signficantly altered the groundwater flow patterns. Prior to construction of the C&SF Project, groundwater moved southward and westward off the coastal ridge. Today, seepage flow is predominately eastward. Thus, the seepage losses from wetlands in Taylor Slough and Northeast Shark Slough represent the drainage effects of the Project, and not historical groundwater flow patterns.

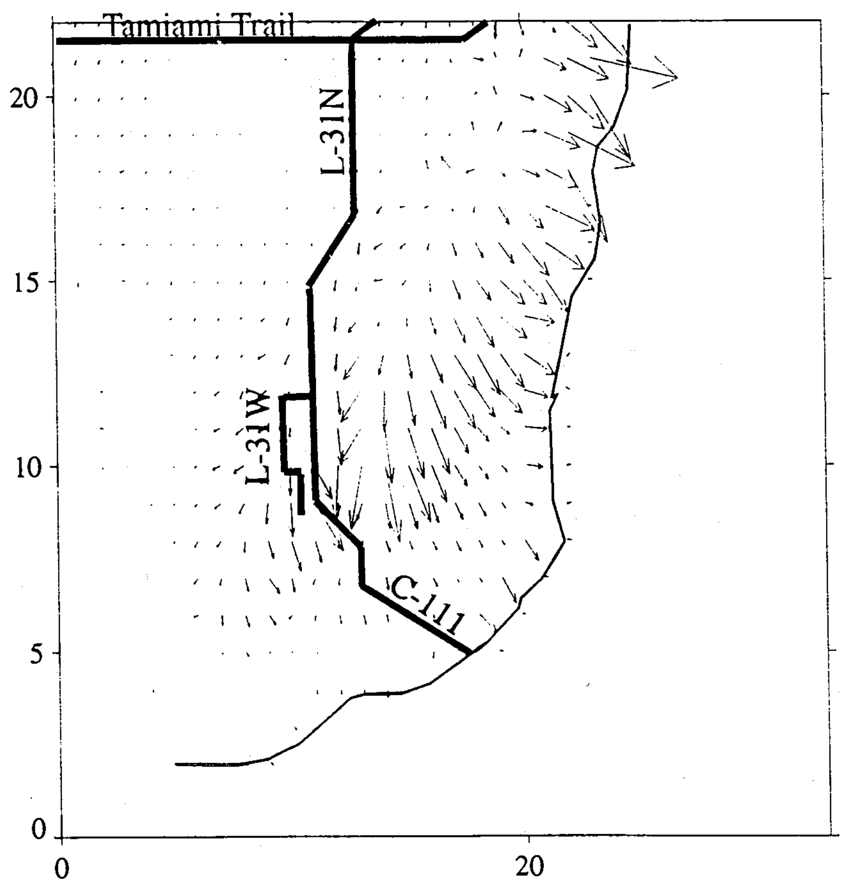

Figure 42: Flow direction and magnitude for groundwater in the C-111 drainage basin.

Chapter 6

Recommendations

The primary purpose of this report is to acquaint the Park management staff about hydrologic information that most directly affects policy decisions about Taylor Slough and its freshwater inflows to Florida Bay. The Park's immediate objectives for improvement and protection of the Park's water resources in Taylor Slough, the Eastern Panhandle marshes, and Florida Bay, should be

- Pursuit of water management policies that increase hydroperiods of the marshes in the Rocky Glades and Taylor Slough. *Water levels, not flows, are the key indicator of marsh restoration.*
- Establishment of a rainfall-based water delivery formula for flows into Taylor Slough and the Eastern Panhandle.
- Protection of water quality standards for water deliveries to Taylor Slough and the Eastern Panhandle.

The Corps, the District, and the Park have agreed in principle to pursue an experimental test of operational policies and structural modifications for Taylor Slough and the C-111 basin intended to remedy the environmental decline of the past several decades. There are several actions that can be undertaken during this first experimental test for Taylor Slough. We recommend that, for this initial test:

1. The District return canal operations to original design optimum flood control levels in L-31N and C-111. This would require a 5.5ft stage at S-176, 4.5ft at S-177, and 3.0ft at S-18C. This is the single most important recommendation. This signals that environmental protection elements of the Project design will be considered co-equal with flood control.
2. The flood control operations of S-331 need to be curtailed, in conformity to the design objective of a dry season, water supply structure. The large interbasin storm water transfers during wet

periods are inconsistent with efforts to restore historical flow patterns in Taylor Slough and the lower C-111 basin.

3. Keep S-174 open as long as possible, except when closure is needed to maintain upstream optimum stages, or to control backflows. Backflows from L-31W to L-31N via S-174 can be limited by returning to design flood control optimum stages of 5.5ft NVGD at S-176 and 4.5ft NVGD at S-177.

4. The operation of S-176 should be limited, so that all excess flows are directed westward into Taylor Slough, except those required to meet the delivery needs of the lower C-111 basin. We tentatively propose a 70-30 split of base flows between S-174 and S-176, respectively. As our understanding of the hydrology of the C-111 improves, we will be in a better position to have more definitive recommendations on Eastern Panhandle needs.

5. Structure-175 should be operated with 4.7ft open, 4.3ft close, and 4.5ft static operations criteria. That is, gates will open when L-31W stages exceed 4.7ft, and will close again when stages reach 4.2ft. This will reduce the potential of using S-175 for excessive L-31W drawdowns.

6. Under normal operation, S-175 should be closed. S-332 pumping should be roughly balanced with inflows at S-174. This will allow a gradual and more natural recession of L-31W.

7. During the dry season, water supply deliveries should continue to be made to Taylor Slough and the Eastern Panhandle whenever upstream water is available. We should re-examine the role of the SDCS in providing supplemental dry season deliveries, since the current volumes of inflows from the regional system are approximately 38 percent of the November to May inflows anticipated by the Corps when they designed the Soth Dade Conveyance System.

8. Storm water that is generated in the C-102 and C-103 canals west of S-194 and S-196, should be routed westward into L-31N and then into Taylor Slough. That is consistent with the original design of the water management system in southwestern Dade County. If this cannot be done, then the demands on the regional water supply system will increase.

9. All gate operational changes should be made as gradually as possible, so that excess stormwater is not rapidly routed through the L-31N and L-31W canal systems. We should establish a goal of conserving as much of this wet season runoff as possible, since this will reduce the need for supplemental dry season deliveries for the regional system.

10. As quickly as possible the Corps, the SFWMD, and the Park should begin testing and implementation of a new rainfall-based water delivery formula for the Taylor Slough basin.

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Appendix A

Calculations

This appendix contains the calculations and any summary data required to replicate the calculations performed in this analysis.

A.1 Water Budgets

A.1.1 Data Summaries

Tables A.1–A.14 contain the monthly summary information used in the calculations of water budgets. The summaries are based upon the daily data presented in Appendix C.

In all but two cases, the annual average was calculated over the the period 1983–1990. The two exceptions where S-194 and S-196. In each of those cases, only five years of relatively complete information was available; therefore, S-194 and S-196 were averaged for the available data. This was thought to be a conservative estimate, that is, it underestimates the flow to the east.

These data also provide the basis for the calculation of the water budgets presented in the text. For the L-31 northern reach we defined the inflows and outflows as

$$\Delta S^u = Q^u_{\text{in}} - Q^u_{\text{out}} \quad \text{(A.1)}$$

$$Q^u_{\text{in}} = Q_{\text{S335}} + Q_{\text{S334}} \quad \text{(A.2)}$$

$$Q^u_{\text{out}} = Q_{\text{S338}} + Q_{\text{S336}} + Q_{\text{S173}} + Q_{\text{S331}} \quad \text{(A.3)}$$

where the superscript u represents the "upper" L-31N basin. For the southern reach of L-31N, the inflows and outflows were

$$\Delta S^l = Q^l_{\text{in}} - Q^l_{\text{out}} \quad \text{(A.4)}$$

S-18C Flow Volumes (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
68	0M	0M	0M	0M	0M	0M	0M	0M	0M	50873	17391	2765	71029
69	10649	2529	3106	1420	5794	59370	6040	17316	29441	23441	14724	1880	175710
70	1658	1004	267	0	0	1346	5635	488	548	1638	689	0	13274
71	0	0	0	0	0	48	195	53	1191	925	785	84	3280
72	0	2	0	91	15812	65291	10947	4261	1970	2307	1164	105	101950
73	85	0	0	0	0	9	2035	12540	7640	2481	391	308	25490
74	17	0	0	0	0	0	0	0	0	0	0	0	17
75	0	0	0	0	0	4795	11399	7143	0	1839	1044	0	26219
76	0	0	0	0	1043	25544	1964	13771	14039	2220	0	0	58580
77	0	0	0	0	2999	12066	0	1997	25127	2876	0	0	45065
78	0	4165	0	1353	0	0	3537	0	15380	20817	5927	0	51178
79	0	0	0	10501	12452	81	2354	0	12147	2874	12	3828	44250
80	0	0	0	34	200	12074	6686	9328	20525	4374	6085	8122	67429
81	0	7821	0	0	0	0	0	46118	58069	21154	0	0	133162
82	0	0	0	133	0	19587	1638	6226	14075	32686	22027	3293	99665
83	8277	49107	59362	31490	3868	36223	13494	31597	59580	0	26492	964	320454
84	0	0	2828	0	7972	12809	21709	29901	34787	23683	4011	1952	139652
85	2850	1226	1014	575	224	910	42935	20882	46707	43286	23421	5534	189565
86	9378	686	8773	7922	0	26625	46985	47727	42738	4967	8269	5833	209904
87	11566	891	5798	167	4790	6456	7323	11463	20513	58878	45866	18136	191846
88	9188	1666	399	0	2501	56911	30542	90838	35701	32490	3654	3231	267120
89	2261	863	351	175	204	728	11536	18002	13567	5342	2247	2465	57742
90	1863	766	407	83	1726	478	2293	25714	13266	15900	4346	2733	69573
91	2095	0	0	0M	0M	0M	0M	0M	0M	0M	0M	0M	2095
Average Annual Total 1983-1990 180732													

Table A.1: Flow data at S-18C.

S-173 Discharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
67	0M	0M	0M	0M	0M	0M	0	0	0	0	0	0	0
68	0	0M	0	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0M	0M	0
70	0M	0	0	0	0	0M	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	0M	0	0	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0M	0	0	0	0M	0M	0M	0M	0	0	0	0
77	0	0	0	0	0	0M	0	0	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0M	0M	0M	0	0M	0
80	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0
81	0M	0M	0M	0M	0M	0M	0M	1908	0M	0M	0M	0M	1908
82	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	2555E	10511	13065
83	10318	5433	486	4489E	15317	10340	10457	9303	9751	8612	8561	8114	101180
84	4042	8870	1985E	4495	10507	8015	6262M	0E	5712	6028	6958	10023	72898
85	10969	10487	9483M	8297	9178	7454	4485E	831E	0E	2374E	10187	12306	86050
86	6732M	10981	9015	9765	9900	5463E	3017E	916E	3820	11268	10362	9354	90592
87	7865	9164	6710	10901E	6990E	7761E	7488	2410E	52E	1109E	58E	5613E	66120
88	10616	11564	11556	9203	6177E	1200E	1908E	69	-10467	7694E	10225	11270	71015
89	10989E	10747	11361	10336	9828E	7135E	2737	4572	3546M	0M	0M	0M	71251
90	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0
91	0M	255M	6631	7179M	147M	4255	6182	4950	4163	5079	5018	0M	43861
Average Annual Total 1983–1990: 69888													

Table A.2: Flow data at S-173.

S-174 Discharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
71	0M	0M	0M	0M	0M	0M	0M	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	0	30	0	0	0	0	0	0	30
77	0	0	0	0	0	0	0	0	256	0	0	0	256
78	0	0	0	0	0	0	0	0	79	0	0	0	79
79	0	0	0	0	0	0	0	0	73	0	0	0	73
80	0	0	0	0	0	101	0	1031	3098	1470	30	0	5730
81	0	0	0	0	0	0	0	3334	3429	-7331	1642	0	1075
82	0	0	0	0M	307M	2440	2797	1853	4042	10796	13220	3554	39009
83	4124	4415	1785	0	0	7976	4487	3316	8335	3158	4142	881	42617
84	228	1617	956	1384	3987	8983	7676	12875	6756	3832	0	0	48294
85	377	0	0	0	0	3564	4074	1216	10743	10231	2438	422	33065
86	0	514	4104	2709	3178	5927	11191	13170	7299	6	732	42	48871
87	0	0	0	26	2511	4967	3907	1539	1706	9816	40	565	25077
88	0	339	2543	4401	1404	14967	11096	13075M	11524M	6163M	3777M	4310M	73600
89	4076	3453	4633	4048	3773M	6732	5223M	2735	5119M	7137	7301	5945	60175
90	6101	6476	4846M	3915M	3420M	6066	581	678	3846	5647	3416	2846M	47838
91	1172M	1958M	820	1776	2364M	0M	0M	0M	283M	15830M	5176M	4012M	33391
92	8052M	3630M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	11681
Average Annual Total 1983–1990: 47442													

Table A.3: Flow data at S-174.

S-175 Discharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
70	0M	0M	0M	0M	0M	0M	0M	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	647	0	0	0	647
78	0	1924	2192	936	0	0	0	0	0	0	0	0	5052
79	0	0	0	1587	7442	12401	14416	2930	8061	12379	0	1260	60475
80	0M	0M	0	220	0	1736M	0M	621	0	0	3822	3598	9997
81	0	2325	196	0	0	0	0	13367	13918M	8723	1381	0	39910
82	0	0	0	0M	748M	8089	1057	0	4780	17005	20174	2523	54376
83	8944	17001	10969	12631	1323	16556	4748	11689	18933	2539	0	597	105929
84	970	0	2380	0	5080	13410	8400	21995	10146	3594	131	0	66106
85	0	0	1023	0	0	0	6805	8569	11524	12250	4717	549	45438
86	3880	0	6403	2743	0	9600	18155	20196	10154	173	0	2225	73528
87	2626	0	2640	0	760	1613	222	2128	1936	15646	7752	3461	38783
88	532	0	0	464	1379	20603	9908	25006	15031	4792	0	0	77714
89	0	0	0	0	0	0	1960	0	0	0	0	0	1960
90	0	0	0	0	0	0	32	220	2646	5355	0	0	8253
91	0M	0	0	0M	6309	8959	7207	15870	20100	16359	0M	0M	74804
Average Annual Total 1983–1990: 52214													

Table A.4: Flow data at S-175.

S-176 Discharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
67	0M	0M	0M	0M	0M	0M	0M	0M	0	1133	0M	0	1133
68	0M	0M	0	0	1726	33355	12659	0	9233	7950M	0M	0	64922
69	0	0	0	0	0	25551	339	5492	5082	11853M	5758	0	54076
70	0	0	0	0	0	504	1640	0	0	0	0	516	2660
71	0	0	0	0	0	2674	0	0	0	0	0	0	2674
72	0	0	0	0	0	1575	1922	0	0	0	0	0	3497
73	0	0	0	0	0	0M	0	2287	2398	0	0	0	4685
74	0	0	0	0M	0M	0M	0	0	0	0	0	0	0
75	0	0	0	0	0	0	415	0	0	0	0	0	415
76	0	0	0	0	8M	6613	0	1428	1410	0	0	0	9459
77	0	0	0	0	0	4891	0M	0M	3499M	0M	0M	0M	8390
78	0	0	0	0	0	0	0	0	4530	0	0	0	4530
79	0	0	0	2255	2491	0	0	0	3693	7369	0	0	15808
80	8	36	0	0	0	234	0	887	7694	4	2198	0	11060
81	0	0	0	0	0	0	0	22160	36483	8243	2	0	66888
82	0	0	0	75	391	5693	91	0	9568	14787	8908	0	39513
83	2955	28055	45470	29284	4901	28658	14095	30078	21388	11901	8243	3467	228495
84	889	0	7359	0	7513	5050	18445	28779	21862	12516	9007	12199	123618
85	12363	10584	7591	3822	16364	3812	26521	30681	40346	42205	20533	3505	218328
86	7272	200	10171	9908	25430	29655	35941	40668	33868	7097	10390	6744	217344
87	11722	4413	6290	5459	13381	10766	12375	14140	21953	48657	50413	27176	226746
88	8525	724	11730	11106	3541	46505	38010M	47671M	41677	29292M	2354M	6770M	247906
89	4864M	5552	6696M	6460	5595M	135	12921	16485	5348M	0	7160	14186	85402
90	20922	17118M	15773M	13198M	11421M	89	8741M	0M	6434M	17229M	5508M	3679	120113
91	859M	1577M	8187	5744M	743M	0M	0M	0M	2044M	28197	2474M	2948M	52773
92	6777M	2421M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	9198
Average Annual Total 1983-1990 183494													

Table A.5: Flow data at S-176.

S-194 Discharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
84	0M	0M	0M	0M	0M	0M	0M	7966	6790	5659	0	1303M	21717
85	7313	6550	6982	2908	5447	2858	5699	4570	4931	2636	5562	5086	60540
86	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0
87	5804M	5151	5899	5812	7646	6246	5348	4931	5058	6909	7327	7398	73528
88	6298	6355	7311	6432	7283	5405	7619	7710	8230	6522	6173	7289	82627
89	7363	6710	7730	6873	6893	5292	6625	7910	8041	7504	6310	5613	82863
90	5183	4971	5802	3739	1156	6393	7373	6617	6615	6847	6331	5121	66148
91	5175	4697	5836	6065	6954	6139	0M	0M	0M	0M	0M	0M	34866
Average Annual Total 1983–1990: 48428													

Table A.6: Flow data at S-194.

S-196 Discharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
81	0M	0M	0M	0M	0M	0M	0M	752M	0M	0M	0M	0M	752
82	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0
83	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0
84	0M	0M	0M	0M	0M	0M	0M	3701	3362	3947	2848	659M	14517
85	5300	4177	4386	1833	3723	1736	3967	3013	1382	3055	4272	3796	40640
86	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0
87	3265M	4659	5006	4495	2646	3840	3255	3834	3913	2222	3372	2945	43453
88	2075	466	-551	2541	1160	549	-3681	-50	-1402	-3909	-3616	-2717	-9136
89	-2210	-3176	-3931	-3295	-3949	-3822	605	-202	1847	1579	859	129	-15567
90	426	1553	1428	107	-1450	1127	3689	1486	2327	1751	3100	2864	18409
91	0M	0M	0M	0M	0	0M	0M	0M	0M	0M	0M	0M	0
Average Annual Total 1983-1990: 11540													

Table A.7: Flow data at S-196.

S-197 Flow Volumes (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
70	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	0	0	0	1696	6912	3124	1029	553	274	0	0	13589
73	0	0	0	0	0	0	411E	0E	0E	0E	0E	0E	411
74	0E	0E	0E	0E	0E	0E	0E	0E	0	0	0	0	0
75	0	0	0	0	0	0	0	609	0	0	0	0	609
76	0	0E	0	0	0	0	0	0E	0E	0	0	0	0
77	0	0	0	0	0E	4717	0E	0E	0	0	0	0	4717
78	0E	0	0E	0	0	0	0	0	1837E	1101E	0E	0E	2938
79	0E	0E	0	0	4021	0E	0E	0	2823	3072	0	0	9916
80	0	0	0	0	0	0	4967	4866	16411E	1823E	6702	0	34769
81	0	2940	0	0	0E	0	0	60372E	41654E	26777E	0E	0E	131742
82	0	0	0	0	0	10205	1781	0	3779	7940	8607	0	32311
83	5935	20761	27801	4799	0	19883E	6206E	9711	32238E	1250M	0M	0M	128583
84	0M	0M	0M	0M	0M	0M	7168M	2731E	841	0	0	0	10741
85	0E	0	0	0	0	0	3707	0	12000	0	0	0	15707
86	0	0	0	0	0	3620	0E	17861	6550	0E	534E	430E	28995
87	0E	0	0E	0E	0	0	0E	0	2491E	15400	5526E	0E	23416
88	0E	0E	0	0E	0E	20356E	0E	75022E	2379E	5718E	0	0	103476
89	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0E	0E	0E	0E	0
91	0	0	0	0	0	0E	0E	0E	0	2327	0M	0M	2327
Average Annual Total 1983–1990: 38865													

Table A.8: Flow data at S-197.

S-331 Discharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
82	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	157E	147	303
83	214	26303	57839	26968E	0	9166	2571M	11342	11524	12615	13728	12534	184803
84	10711	20809	29796E	12718	8368	12466	7091M	31593E	10092	8696	16655	20613	189609
85	25609	20922	14303M	9586	13555	7547	21140E	28808E	50542E	46067E	18728	2551	259359
86	4798	403	13914	9515	19665	23708E	47385E	57111E	40269E	5036	14882	4544E	241231
87	14273E	14704	10094	14156E	17137E	23776E	4873	23899E	8263E	46392E	51085E	32736E	261390
88	10665	2751	17677	25442	5004E	37831E	47483E	39880E	59317E	16925E	8388	18264M	289629
89	18742	18656	22562	21049	20238	15797	11322	10552	9340	10344	10844	6143	175589
90	19343	19494	13656	0	688	0M	0M	0M	5361	11574E	2180	4893M	77190
91	13722	584M	14420	16693M	0M	6178	4936	10811	16556	16047	7853	0M	107800
Average Annual Total 1983-1990: 209850													

Table A.9: Flow data at S-331.

S-332 Discharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
80	0M	0M	0M	0M	0M	0M	0	0	3184	2023	0	0	5207
81	0	2408	0	0	0M	0	0	1035	11159	5496	2136	0	22235
82	0M	0	0	0	0	2172	4332	7303	8874	10001	10840	6022	49544
83	4280	4707	0	0	0	1690	6982	2898	4881	7160	8297	811	41707
84	657	292	282	206	462	7095	6601	1894	4441	6173	4328	926	33357
85	891	331	234	270	288	6321	5923	2745	4784	6599	4677	1144	34207
86	879	585	262	286	288	4935	7607	2678	6109	7434	3896	871	35828
87	873	557	298	264	474	5808	8107	7049	5238	6548	3537	990	39741
88	984	601	276	216	405	3723M	0M	0M	0M	0M	0M	0M	6204
89	268M	300	60M	46M	511	4628M	7343	4001	6413	8458	3180	781	35987
90	547	498	151	119	1144	5457	5980	5455	6109	7976	4203	877	38516
91	940	533	492	536	2803	5622	6701	6204	4647	0M	0M	0M	28479
Average Annual Total 1983–1990: 33193													

Table A.10: Flow data at S-332.

S-334 Discharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
78	0M	0M	0M	0M	0M	0M	0M	0M	0M	0	0	0	0
79	0	0	0	15213	0	0	0	0	0	7000	0	668	22882
80	0	0	0	8908	9088	0	0	0	910M	3856	0	0	22763
81	0	0	0	13857	11340	0	0	778	2	0	0	0	25976
82	0	1069	10086	10810	0	0	0	0	0	958	0	0	22923
83	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	2884	0	0	0	0	545	1365	0	4794
85	11014	16292	31325	31413	47057	20628	0	526	0	0	0	0	158256
86	0	0	0	0	0	0M	0	0	0	0	0	5040	5040
87	11258	27333E	8144	5720	2551	0	0	0	0	0	0E	0	55006
88	0	0	0	11818	0	0	0	0	0	0E	0	0	11818
89	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0M	0M	0M	0E	0E	0	0	0	0M	0M	0M	0
92	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0
Average Annual Total 1983–1990: 29364													

Table A.11: Flow data at S-334.

S-335 Discharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
83	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0	0
84	3810	36048	10592	0	8142E	0E	0	0	0	0	0	17730	76383
85	39573E	38347	22235	0	0E	0E	0	0	0	0	0	0	100155
86	0	0	6171	3172	16707E	5423E	0E	0	0	0E	12413	0	43885
87	0	0E	0	17998E	10590	33097	8239E	0E	0	0	0E	0	69924
88	0	6062	40793	39087	5074	0	0	0	0	0	2682	35971	129667
89	40368	43938	53844	46757	43629	35080	0	0	0	0	1248	8037E	272902
90	34273	35987	35919E	1343	0	0	0	0	0	0	0	0	107522
91	11548	0M	0M	10410M	17561	0	0	0	0	0M	0M	0M	39519
92	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0
Average Annual Total 1983-1990: 100055													

Table A.12: Flow data at S-335.

S-336 Discharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
78	0M	0M	0M	157	12	250	1109	2517	3122	5701	6744	8142	27753
79	9374	9693	12002	11943	3896	7982	6746	7022	6109	6621	6776	6907	95069
80	6256	5818	6438	6893	6706	6807	7333	1527	6131	6869	6004	6137	72919
81	4967	4362	4604	5143	3354	2467	3564	2694	169	-401	0	0	30923
82	0	0	1728	1779	0	3681	5871	6434	4306	125	0	0	23925
83	0	248	5901	2694	0	0	0	0	0	0	0	0	8842
84	0	0	0	0	1097	0	0	0	0	0	0	0	1097
85	444	7355	7164	4604	6857	3291	0	0	0M	0	0	0M	29715
86	0M	0M	0	0	0	0	0	0	0	0	0	0	0
87	0E	0E	0E	0E	0E	2469	0	0	0	0	0	0	2469
88	0	0E	0E	1815	0	-1888	0	0	0	0	0	0	-73
89	0	3499	7591	5530	5758	5330	0	0	0	0E	0	0E	27708
90	4342	5663	5611	450	0	0	0	0	0	0	0	0	16066
91	0	0	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0
92	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0
Average Annual Total 1983–1990: 10728													

Table A.13: Flow data at S-336.

S-338 Diacharge (acre-ft)													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
79	0M	0M	0	726	4580	0E	0	0	0	2176E	0	0	7482
80	0	0	1432	3120	2739	1980	1910	3283	3011	0	0	(	17475
81	0	0	0	0	0	0	0	4409E	10062	8918	2592	0	25982
82	0	0	0	0	149	3537	10154	10401	3045	16112	13250	242	56889
83	1392	12173	14390	8013	0	10112	6490	9025	9947	7373	5655	0	84571
84	2821M	3404	2214	0	2134	6458	8053	11367	13801	13654	1206	0	65112
85	0	0	0E	0	4	375	-827	512	494M	1825	2830	7270	12482
86	4679M	3705M	5631	3983	0	960	2398	0	3193	8146	7151	0	39847
87	5278E	6784E	5615E	6397E	1525E	879	-1642	0	-77	635	1853	4126	31371
88	8114E	7708	11183	9826	:252	4566	2118	6292	0	4933	2138E	5625E	63756
89	8483	2085	0	0	0	1004	0	0	0M	0M	492E	0	12064
90	0	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0E	0	0	0E	979M	11796	15459	14254	11406	0M	0M	53894
92	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0
Average Annual Total 1983–1990: 38650													

Table A.14: Flow data at S-338.

Year	Inflow	Outflow	Outflow-Inflow
81	25.9760	58.8130	-32.8370
82	22.9230	94.1820	-71.2590
83	.0000	379.3950	-379.3950
84	81.1770	328.7160	-247.5390
85	258.4110	387.6050	-129.1940
86	48.9250	371.6700	-322.7450
87	124.9300	361.3500	-236.4200
88	141.4850	424.3270	-282.8420
89	272.9020	286.6120	-13.7100
90	107.5220	93.2560	14.2660
91	39.5190	205.5540	-166.0350

Table A.15: Ann ual Inflow and outflow summary for the northern reach of L-31N. Values are in 10 0's of acre-ft.

$$Q^l_{\text{in}} = Q_{S331} + Q_{S173} \tag{A.5}$$
$$Q^l_{\text{out}} = Q_{S176} + Q_{S174} + Q_{S194} + Q_{S196} \tag{A.6}$$

where the superscript l represents the "lower" L-31N basin. For L31W, the relations are

$$\Delta S^w = Q^w_{\text{in}} - Q^w_{\text{out}} \tag{A.7}$$
$$Q^w_{\text{in}} = Q_{S174} \tag{A.8}$$
$$Q^w_{\text{out}} = Q_{S332} + Q_{S175} \tag{A.9}$$

A.2 Calculation of Groundwater Seepage

The estimation of the seepage is based upon an application of Darcy's Law. We write the ratio of the seepage entering the canal from the east to the that coming in from the west as

$$R = \frac{Q_e}{Q_w} = \frac{-K_e b_e \frac{\partial h_e}{\partial x}}{-K_w b_w \frac{\partial h_w}{\partial x}} \tag{A.10}$$

where h is the head, b is the aquifer depth, and K is the aquifer hydraulic conductivity. Assuming that the aquifer conductivities and depths are equal, R can be expresses in discretized terms as

$$R \approx \frac{\Delta L_w}{\Delta L_e}\frac{\Delta h_e}{\Delta h_w} \tag{A.11}$$

where Δh is a head difference and ΔL is the distance over which the head difference occurs. This ratio can then be used to estimate the relative amounts of seepage from east and west of the canal as follows. Since the net seepage is the sum of the eastern and western contributions

$$\Delta S = Q_w - Q_e \tag{A.12}$$

where ΔS is the net seepage, and the two seepage components are related by

$$\begin{aligned} R &= \frac{Q_e}{Q_w} \\ Q_e &= RQ_w \end{aligned} \tag{A.13}$$

one can find the contribution from the west as

$$Q_w = \frac{\Delta S}{1 - R} \tag{A.14}$$

Tables A.16–A.18 give some averaged stages for several of the gages in the area, along with the distances to the canals. Two of the cases, that of the southern reach of L-31N and L-31W, have gages which are located approximately perpendicular to the canal and have gages which appear to be located in a line parallel to the general regional gradient. For the southern reach of L-31N, we can calculate the ratio using G-1502, G-1363, and the average of S-176 headwater and S-331 tailwater as indicative of the L-31N stage

$$\begin{aligned} R &= \frac{\Delta L_w}{\Delta L_e}\frac{\Delta h_e}{\Delta h_w} \\ &= \frac{\Delta L_w}{\Delta L_e}\left(\frac{H_{L31N} - H_{G1303}}{H_{G1502} - H_{L31N}}\right) \\ &= \left(\frac{4.2}{2.9}\right)\left(\frac{4.16 - 3.69}{5.54 - 4.16}\right) \\ &= 0.49 \end{aligned} \tag{A.15}$$

For the L-31W case, we use the NTS-3 and the "Frog Pond" gages as representative of the groundwater stage, and S-175 headwater as representative of the canal stage, which results in a ratio of east to west seepage of

$$\begin{aligned} R &= \frac{\Delta L_w}{\Delta L_e}\frac{\Delta h_e}{\Delta h_w} \\ &= \frac{\Delta L_w}{\Delta L_e}\left(\frac{H_{L31W} - H_{Frog}}{H_{NTS3} - H_{L31W}}\right) \end{aligned}$$

Station	Distance to Levee (mi)	Averaging Dates	Average Stage (ftmsl)
NESS2	3.6	1/1/81–1/15/87	6.49
		1/1/81–7/29/84	6.66
G-855	2.0	1/1/81–1/15/87	4.40
		1/1/81–7/29/84	4.47
G-799	6.6	1/1/81–1/15/87	2.96
		1/1/81–7/29/84	2.99
G-596	0.8	1/1/81–1/15/87	5.14
		1/1/81–7/29/84	5.19
S-338HW	—	1/1/81–1/15/87	4.97
		1/1/81–7/29/84	4.97
S-338TW	—	1/1/81–1/15/87	4.53
		1/1/81–7/29/84	4.60
S-336HW	—	1/1/81–1/15/87	5.09
		1/1/81–7/29/84	5.09
S-336TW	—	1/1/81–1/15/87	5.57
		1/1/81–7/29/84	5.54

Table A.16: Average Stages for selected gages in the northern L-31N basin.

Station	Distance to Levee (mi)	Averaging Dates	Average Stage (ftmsl)
G-1502	4.2	1/1/81–12/01/90	5.54
		1/1/81–7/29/84	5.75
G-1363	2.9	1/1/81–12/01/90	3.69
		1/1/81–7/29/84	3.65
S-331HW	—	1/1/81–12/01/90	4.23
		1/1/81–7/29/84	4.84
S-174HW	—	1/1/81–12/01/90	4.08
		1/1/81–7/29/84	4.55

Table A.17: Average Stages for selected gages in the southern L-31N basin.

Station	Distance to Levee (mi)	Averaging Dates	Average Stage (ftmsl)
Frog Pond	1.0	1/1/85–12/31/88	3.47
NTS-3	0.6	1/1/85–12/31/88	3.61
S-175HW	—	1/1/85–12/31/88	3.48

Table A.18: Average Stages for selected gages in the L-31W basin.

$$= \left(\frac{0.8}{1.0}\right)\left(\frac{3.48-3.47}{3.61-3.48}\right)$$
$$= 0.06 \qquad (A.16)$$

A.3 Flow at Context Road

This section outlines the analysis used to reconstruct flows at Context Road (see Figure 19. The data was originally published by the United Stages Geological Survey as *Taylor Slough at Context Road*, with the identifier 252948080352700. The notes for the station report the record as poor. The station does, however, provide a reasonable indication of the surface water behavior of the Rocky Glades prior to the 1982 drawdowns in the L-31N canal. The recorder was removed in 1980 because the site was severely vandalized, and proved too difficult to maintain.

A.3.1 Comparisons of Context Road and S-173 Stages

The stage recorder for the Context Road station was approximately 1.9mi (3.1km) west of the L-31N canal, approximately 1.?mi (?.?km) northeast of S-176. One would expect, therefore, that the two stages would be similar. Figure A.1 is the historical record for the two stations for the period of record of the Context Road gage. The two gages do indeed track closely. When one plots Context Road vs. S-176 headwater, the result is seen in Figure A.2. The two stages are indeed closely related. We calculated the relation as

$$h_{\mathbf{Context}} = 1.1h_{\mathbf{S176hw}} - 0.1 \qquad (A.17)$$

We can then use this relation to estimate the stages at Context Road for the period where S-176 information is available. The comparison of the estimated stage and the measured stages for the period of record is Figure A.3.

In 1981, the L-31N borrow canal near S-176 was enlarged. This canal modification may change the above relation somewhat. However, enlargement will tend to increase the connection of the canal

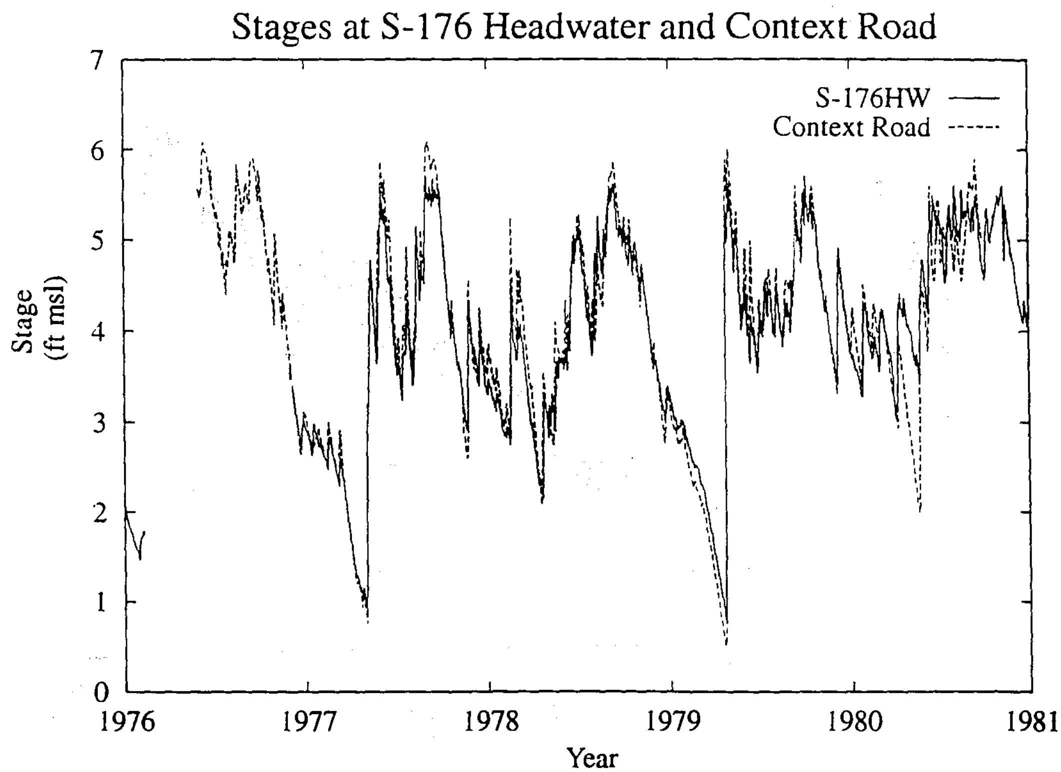

Figure A.1: Temporal Comparison of stages at Context Road and S-176 headwater.

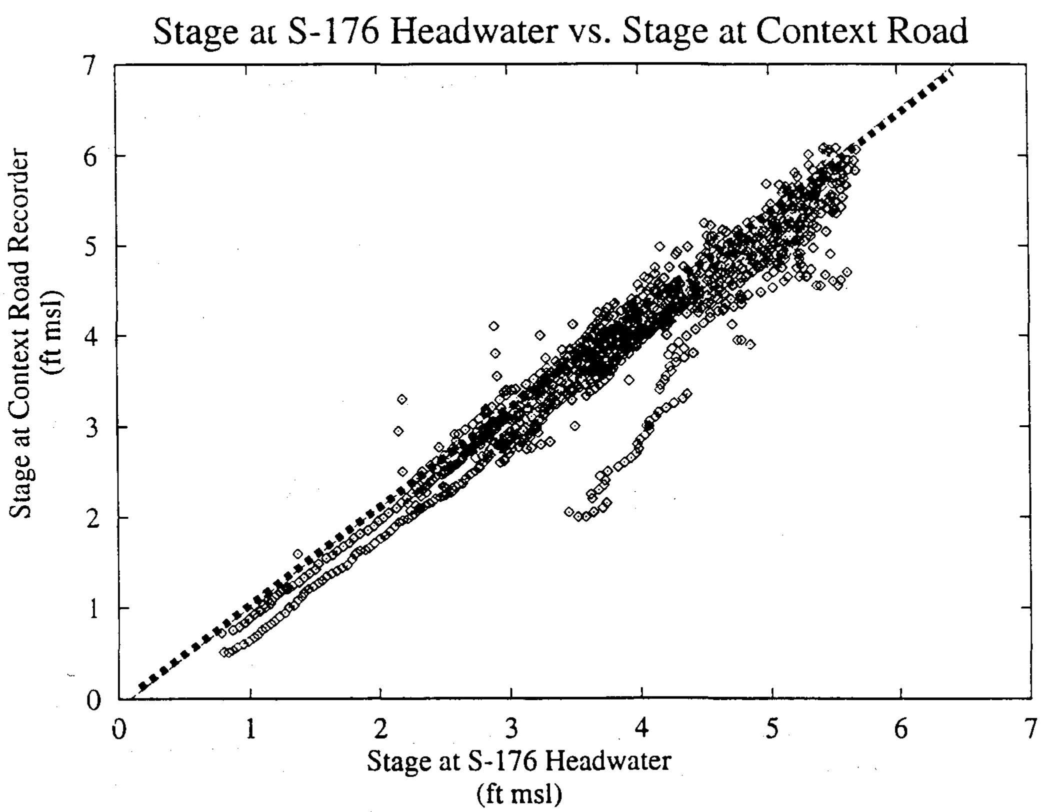

Figure A.2: Comparison of stages at Context Road and S-176 headwater.

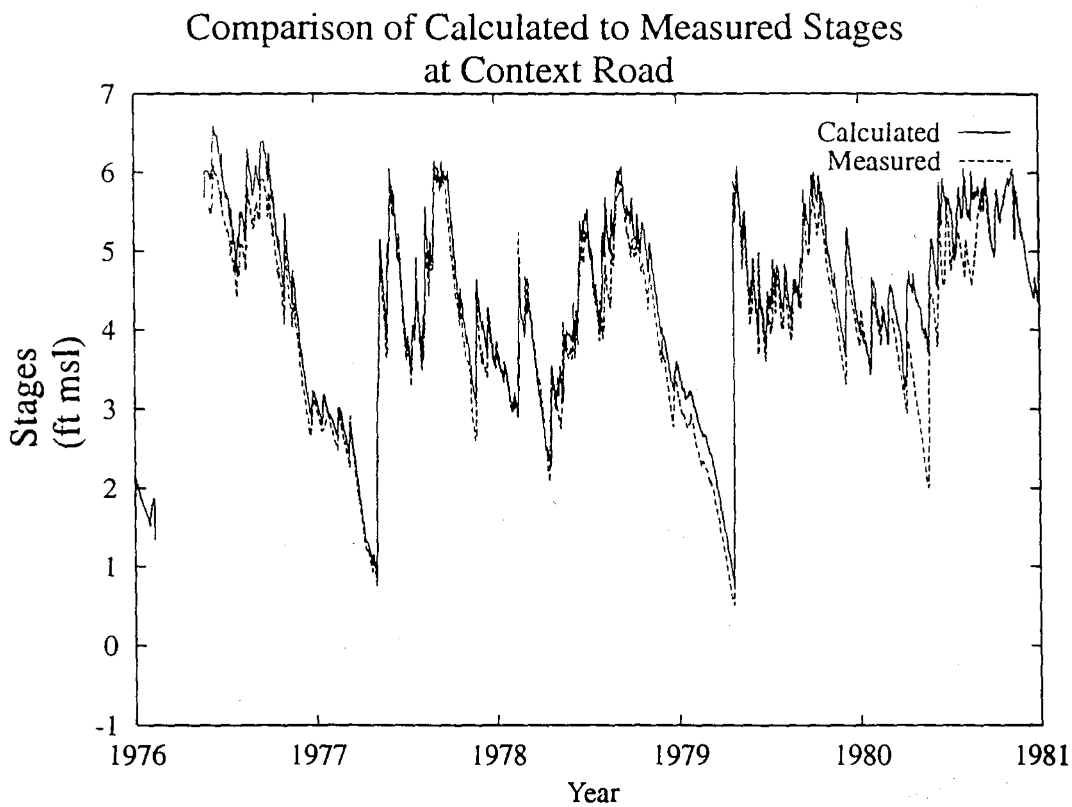

Figure A.3: Comparison of estimated and measured stages at Context Road. Eqn (A.17) relates S-176 headwater to Context Road, and S-176 headwater is the basis for the stage estimation.

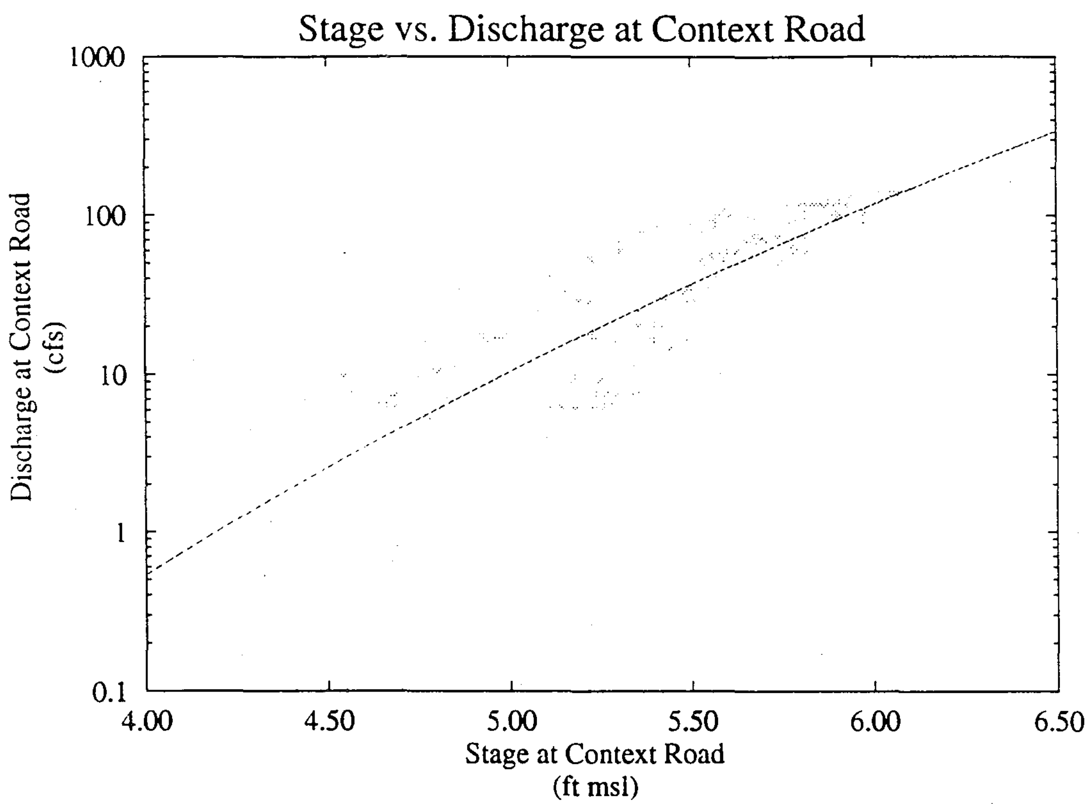

Figure A.4: Stage vs. Discharge Relation for Context Road.

and to the aquifer, which in turn, will make the canal more efficient at drainage. Thus, (A.17) will continue to overestimate stages at Context Road.

A.3.2 Stage vs. Discharge Relations at Context Road

When published stage and discharge measurements at Context Road are plotted, as in Figure A.4, no easily discernible relationship is apparent. There are a number of features of importance, however. Note that there is very little flow at stages less than 4.5ft. Moreover, the stage vs. discharge values exhibit a great deal of scatter. Since the flow actually occurs through a system of culverts, it is advisable to use a discharge relation in the form $Q = KH^m$, where K and m are coefficients. By a linear regression of the data, we obtained the following relation

$$Q = \begin{cases} 10^{-8.27} H^{13.2} & H \geq 4.0 \\ 0 & H < 4.0 \end{cases} \tag{A.18}$$

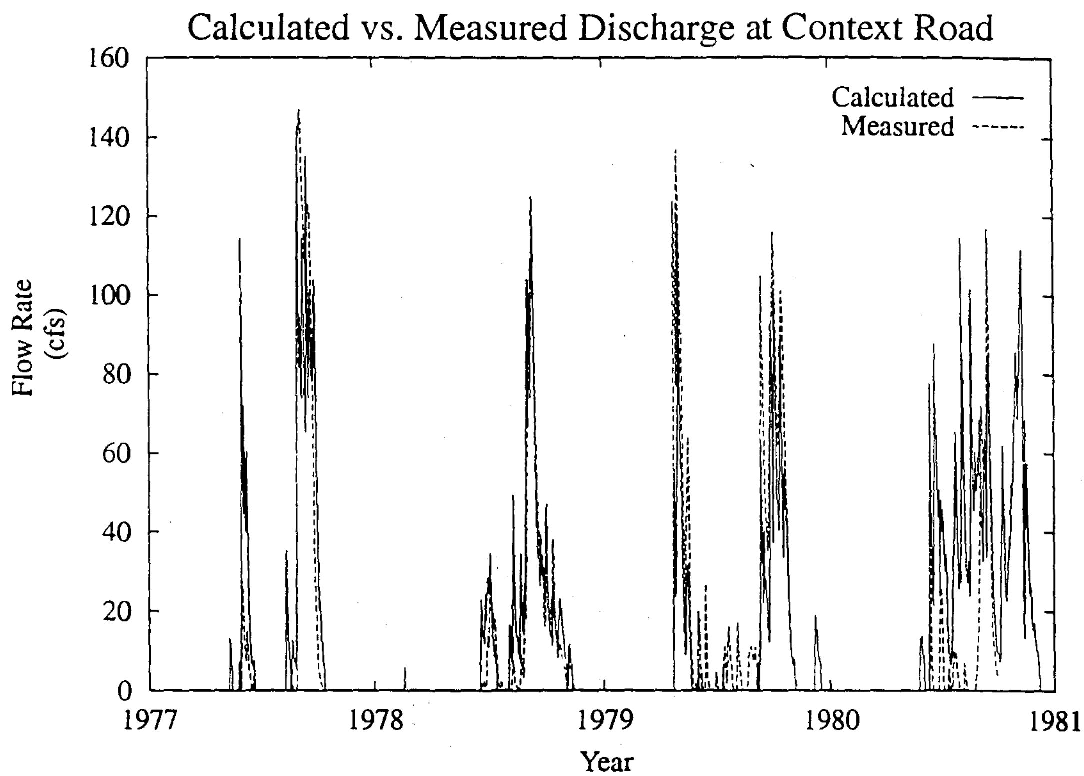

Figure A.5: Comparison of calculated and measured discharges at Context Road.

where Q is the discharge at Context Road (cfs) and H is the stage at the recorder (ft msl). Figure A.5 shows that the reproduced data does a reasonable job of replicating the available measurements.

Table A.19 summaries the available record at Context Road, while Table A.20 is the summary of the estimated flow volumes.

Measured Flow Volumes at Cont													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
76	0M	0M	0M	0M	0M	4040	336	597	2821	809	0	0	8603
77	0	0	0	0	0	379	0	145	6480	127	0	0	7131
78	0	18	2	0	0	28	600	217	3543	1098	132	0	5638
79	0	0	0	1192	2972	248	270	298	2624	4287	79	0	11970
80	0	0	0	0	0	373	272	184	2778	0M	0M	0M	3605
Average Annual Total 1983–1990: 0													

Table A.19: Measured flow volumes at Context Road

Estimated Flow Volumes at Con													
	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
67	0M	0M	0M	0M	0M	0M	0M	0M	34E	4589E	503E	0E	5126
68	0E	0E	0E	0E	1710E	7387E	3793E	957E	3832E	5713E	1002E	3E	24397
69	52E	0E	0E	0E	0E	5045E	2758E	3614E	3485E	4108E	2948E	178E	22189
70	10E	6E	0E	0E	0E	1339E	1301E	32E	16E	348E	25E	0E	3077
71	0E	0E	0E	0E	0E	0E	0E	0E	617E	3E	195E	0E	814
72	0E	0E	0E	0E	259E	3395E	1956E	316E	1197E	240E	36E	0E	7400
73	0E	0E	0E	0E	0E	0E	343E	2495E	3556E	1125E	0E	0E	7519
74	0E	0E	0E	0E	0E	0E	116E	969E	276E	53E	0E	0E	1413
75	0E	0E	0E	0E	0E	44E	2742E	246E	194E	141E	22E	0E	3389
76	0E	0E	0E	0E	1650E	11040E	2013E	3675E	8165E	2427E	347E	0E	29315
77	0E	0E	0E	0E	186E	1717E	22E	671E	5545E	718E	27E	0E	8886
78	0E	29E	12E	0E	0E	364E	689E	976E	3850E	1252E	263E	0E	7433
79	0E	0E	0E	455E	1768E	63E	160E	126E	1484E	3199E	170E	284E	7708
80	25E	25E	48E	118E	165E	2040E	1892E	3232E	2681E	2466E	3102E	269E	16061
81	3E	69E	0E	0E	0E	0E	0E	30867E	6826E	2794E	1698E	106E	42362
82	0E	0E	0E	0E	142E	1743E	491E	523E	523E	539E	490E	398E	4848
83	344E	281E	152E	283E	0E	224E	133E	403E	312E	593E	507E	551E	3783
84	250E	237E	159E	19E	81E	619E	665E	111E	150E	106E	42E	53E	2491
85	0E	0E	6E	0E	0E	46E	444E	280E	453E	172E	61E	53E	1514
86	111E	0E	117E	107E	39E	100E	149E	35E	143E	162E	155E	138E	1257
87	145E	44E	95E	27E	106E	40E	143E	188E	263E	442E	360E	155E	2008
88	134E	58E	53E	65E	167E	930E	340E	2465E	457E	170E	71E	96E	5005
89	57E	16E	0E	0E	0E	0E	113E	175E	186E	80E	0E	0E	628
90	0E	0E	0E	0E	29E	79E	185E	247E	218E	213E	72E	0E	1043
91	0E	0E	0E	0E	0E	0E	0E	0E	37E	260E	174E	72E	542
92	184E	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	0M	184
Average Annual Total 1983-1990. 2216													

Table A.20: Estimated flow volumes at Context Road.

Appendix B

Documents

This appendix contains various documents and correspondence cited and used within this report.

The first set of documents are copies documents related to the Experimental Water Deliveries program. These documents support the chronology of events described in Section 1.3.4 on page 15.

The second set of documents are the operations logs obtained from the South Florida Water Management District. These documents record the operations of the C&SF water control structures for any periods that we have examined in this report. Rather than reproduce this extensive document set, these will be available on request by contacting

South Florida Research Center
Everglades National Park
40001 State Road 9336
Homestead, FL 33034-6733

The complete set of operations logs are available from the South Florida Water Management District.

Hydrologic Data Management Division
Department of Research and Evaluation
South Florida Water Management District
P.O. Box 24680
West Palm Beach, FL 33416-4680

Appendix C

Raw Data

In this analysis, the raw hydrologic data was obtained from the South Florida Water Management District's hydrologic data base, DBHYDRO. As this data base is continuously updated and modified, we include the data used in the analysis for completeness. All retrievals were made between November 1 and November 12, 1992, and do not contain modifications made by the District after that date.

Rather than including this lengthy appendix directly in the report, a copy of it may be obtained from

South Florida Research Center
Everglades National Park
40001 State Road 9336
Homestead, FL 33034-6733

The hydrologic data used here is available from the South Florida Water Management District by contacting:

Hydrologic Data Management Division
Department of Research and Evaluation
South Florida Water Management District
P.O. Box 24680
West Palm Beach, FL 33416-4680

Should you need the data used in this analysis, please contact

Dr. Thomas Van Lent
Department of Civil Engineering

South Dakota State University
Brookings, SD 57007

for a distribution on electronic media.