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HYDROLOGIC MODELS FOR THE MELBOURNE-TILLMAN WATER CONTROL DISTRICT, BREVARD COUNTY, FLORIDA

by

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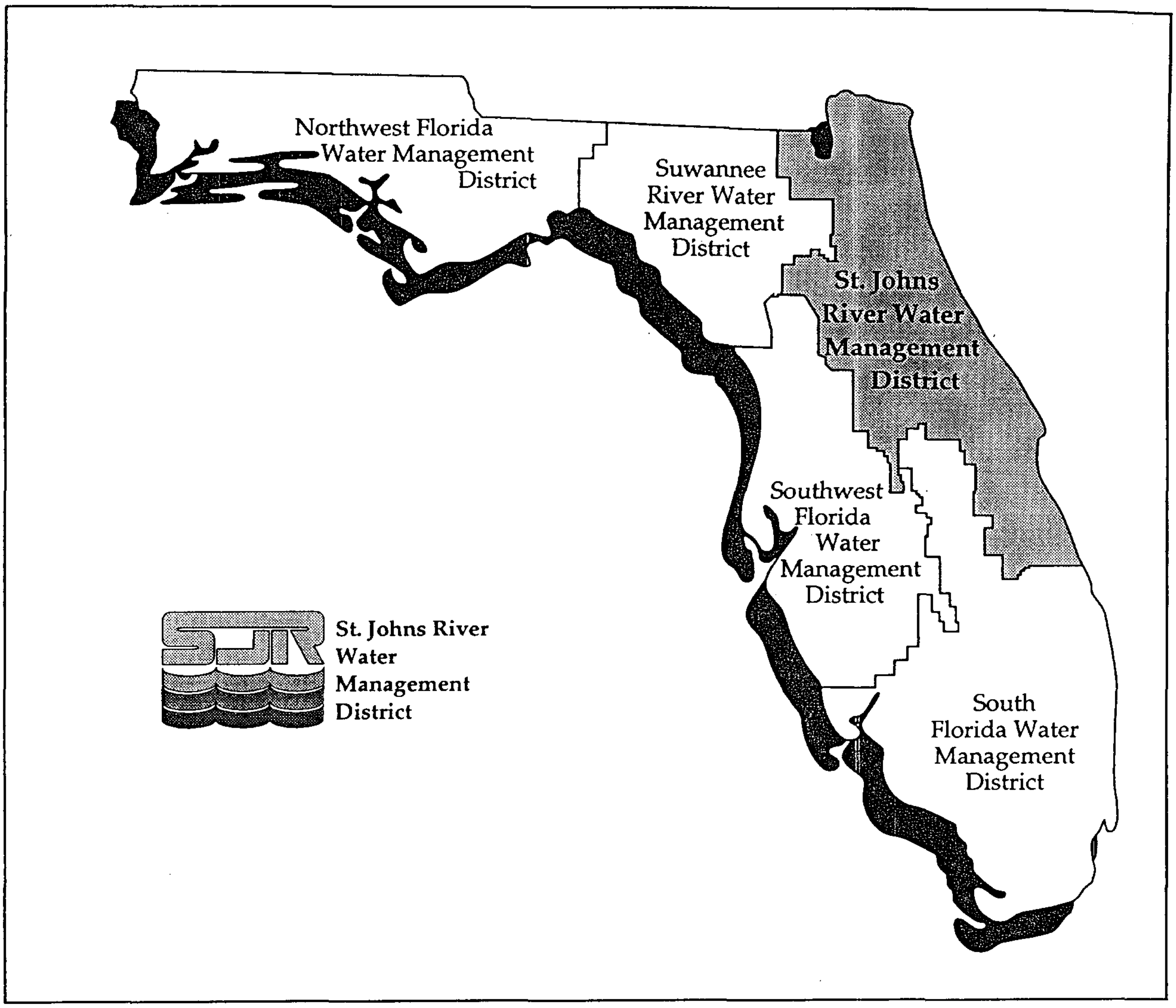

The **St. Johns River Water Management District** (SJRWMD) was created by the Florida Legislature in 1972 to be one of five water management districts in Florida. It includes all or part of 19 counties in northeast Florida. The mission of SJRWMD is to manage water resources to ensure their continued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

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EXECUTIVE SUMMARY

The Melbourne-Tillman Water Control District (MTWCD) lies within Brevard County, Florida, south of U.S. 192. It has an area of approximately 100 square miles (mi^2). Levees constructed in the 1920s either totally or partially define the northern, southern, and western boundaries of the MTWCD. The drainage system of the MTWCD consists of a network of canals with the C-1 canal as the main canal conveying discharge to the Indian River Lagoon via Turkey Creek. The MS-1 structure controls the discharge from the C-1 canal into Turkey Creek. The MTWCD is one of the major sources of freshwater discharge into the Indian River Lagoon.

To the west of the MTWCD is the upper St. Johns River. The St. Johns River Water Management District (SJRWMD) and the U.S. Army Corps of Engineers are implementing a flood protection and environmental enhancement plan for the Upper St. Johns River Basin (USJRB). The plan, in part, includes creating marsh conservation areas and water management areas.

One marsh conservation area will be created from land previously a part of the MTWCD—Three Forks Marsh Conservation Area. This marsh conservation area will retain floodwater, provide long-term conservation storage, and restore and preserve floodplain wetlands for USJRB. However, removal of this land from the MTWCD will remove runoff area and reduce surface water storage. For this reason, SJRWMD and MTWCD staff are working together to address the surface water drainage concerns arising from the boundary change.

In addition to USJRB restoration activities, state water policy requires that SJRWMD develop stormwater management goals and establish pollution load reduction goals to preserve or restore the beneficial uses of Turkey Creek and the Indian River Lagoon. High storm-event peak discharges and large volumes of freshwater periodically released from the MTWCD may be harmful to the resources of the Indian River Lagoon, particularly to water quality and the hard clam fishery. Preliminary results show that harm can occur as a result of a freshwater discharge-induced drop in lagoon salinity. The central lagoon receives large freshwater discharges originating from the

MTWCD, transporting substantial pollution loads, and inducing sustained reductions in salinity. Thus, stormwater management goals and pollution reduction goals will be formulated to limit these discharges and to protect this important fishery.

In anticipation of the development of stormwater management and pollution reduction goals, a surface water management plan has been proposed. The plan will restrict flow into Turkey Creek, will detain that water in stormwater management areas, and will redivert some water to the west, into USJRB. For this purpose, SJRWMD bought 5.5 mi^2 of land north of the Three Forks Marsh Conservation Area along the western levee of the MTWCD. This land will be divided into two areas, the Sawgrass Lake Water Management Area, consisting of 3.5 mi^2, and the C-1 Retention Area, consisting of 2 mi^2. The C-1 Retention Area will detain a portion of the floodwaters. The Sawgrass Lake Water Management Area will provide additional water quality treatment before the surface water discharges into USJRB.

This report presents the development of two models to simulate the hydrology and hydraulics of the MTWCD that are needed to evaluate various planned activities for the MTWCD. One of the models, Hydrologic Simulation Program—Fortran (HSPF), performs continuous simulations of hydrology and hydraulics of the MTWCD for extended periods. The other model, Storm Water Management Model (SWMM), performs storm-event simulations to predict flood stages.

The HSPF model was calibrated for discharge and discharge volume (cumulative discharge) from the MTWCD for the period January 1988 to December 1989. Overall, the gaged hydrographic trend is represented by the simulation.

The HSPF model was verified for discharge and discharge volume at the same location as was used in the calibration. The period January 1990 to October 1991 was used to verify the model. Deviation from normal MS-1 operations and canal excavation within the MTWCD altered the conditions for verification. However, the results were consistent with the calibration.

An additional comparison of discharge and discharge volume was made for the period January 1977 to December 1980. The simulated discharge hydrograph was close to the observed hydrograph with the exception of the overestimated peak discharge events. The urban area has grown since 1980. The impervious surfaces of roadways and rooftops associated with urban areas increase runoff rates and volumes. For this reason, peak discharges during this earlier period are expected to be smaller than current-day peak discharges. The simulated discharge peaks were consistent with calibration of the model, in which a 1-day rainfall of about 6 inches produced a peak discharge of 2,000 cubic feet per second for October 1989. Over the period of comparison, the simulated discharge volume closely matched the measured discharge volume.

SWMM was calibrated for the October 1989 storm event and verified with data from Hurricane Erin, August 1995. The simulated peak discharge matched the October 1989 peak discharge in Turkey Creek at Palm Bay. In the verification run, the simulated peak discharge overestimated the gaged peak discharge in Turkey Creek at Palm Bay by 7.6%. The simulated peak stage in the C-10 canal at Malabar Road was 18.6 feet, compared with an estimated single observed stage of 17.8 feet. The single observed stage is not necessarily the peak stage.

In general, both models, HSPF and SWMM, represent the hydrologic and hydraulic character of the MTWCD for the intended purpose. The continuous simulation model produces extended periods of freshwater discharge data to evaluate environmental concerns of Turkey Creek and the Indian River Lagoon. The storm-event simulation model produces flood stage results to evaluate flooding concerns within the MTWCD. Both models will be used to evaluate the impacts of the USJRB restoration activities and the proposed surface water management plan.

CONTENTS

FIGURES

TABLES

INTRODUCTION

The Melbourne-Tillman Water Control District (MTWCD) lies within Brevard County, Florida, south of U.S. 192 (Figure 1), comprising an area of about 100 square miles (mi^2). It was formed in 1922 as an agricultural drainage district to provide an efficient drainage system so that land could be developed for agriculture. The drainage system consists of a flood control levee and a network of canals, with the C-1 canal acting as the primary conveyer of discharge to the Indian River Lagoon via Turkey Creek. Since the 1960s, significant urban development has occurred in the MTWCD, with a current composition of about 55% agriculture and 45% urban. The MTWCD discharges to Turkey Creek are controlled by the MS-1 structure. Turkey Creek is one of the major sources of freshwater discharge into the Indian River Lagoon. Excessive freshwater discharge into the Indian River can deteriorate water quality of the estuary and harm the fisheries.

To the west of the MTWCD is the upper St. Johns River (Figure 1). The St. Johns River Water Management District (SJRWMD) and the U.S. Army Corps of Engineers are implementing a flood protection and environmental enhancement plan for the Upper St. Johns River Basin (USJRB). The USJRB restoration plan, in part, includes creating marsh conservation areas and water management areas. Marsh conservation areas are created for the purpose of restoring and preserving floodplain wetlands. Water management areas are created for the purpose of temporarily retaining agricultural discharges, segregating farm discharges from more pristine wetlands, and providing water reuse.

This USJRB plan will move the western boundary of the MTWCD eastward to create the Three Forks Marsh Conservation Area (TFMCA) (Figure 2). TFMCA will retain floodwater, provide long-term conservation storage, and restore and preserve floodplain wetlands for USJRB. However, removal of this land from the MTWCD will remove runoff area and reduce surface water storage. SJRWMD and MTWCD staff are working together to address the surface water drainage changes that will arise from the boundary change.

State water policy required SJRWMD to develop regional stormwater management goals and to establish pollution load reductions necessary to preserve or restore the beneficial uses of both Turkey Creek and the Indian River Lagoon (Steward et al. 1994). High storm-event peak discharges and large volumes of freshwater periodically released from the MTWCD may be harmful to the resources of the Indian River Lagoon, particularly to water quality and the hard clam fishery. Preliminary results show that harm can occur as a result of a freshwater discharge-induced drop in lagoon salinity. The central lagoon receives large freshwater discharges originating from the MTWCD, transporting substantial pollution loads, and inducing sustained reductions in salinity. Thus, stormwater management goals and pollution reduction goals will be formulated to limit these discharges and to protect this important fishery.

In anticipation of the development of these stormwater management and pollution reduction goals, a surface water management plan has been proposed. The plan will restrict flow into Turkey Creek, will detain that water in stormwater management areas, and will redivert some water to the west, into USJRB. For this purpose, SJRWMD bought 5.5 mi^2 of land north of the TFMCA along the western levee of the MTWCD. This land will be divided into two areas, the Sawgrass Lake Water Management Area (SLWMA), consisting of 3.5 mi^2, and the C-1 Retention Area, consisting of 2 mi^2 (Figure 2). The C-1 Retention Area will detain a portion of the floodwaters. SLWMA will provide additional water quality treatment before the surface water discharges into USJRB.

The objective of this study was to develop, calibrate, and verify hydrologic and hydraulic models to simulate the discharges and stages of the MTWCD. The Hydrologic Simulation Program—Fortran (HSPF) model (Bicknell et al. 1993) was used to perform continuous simulations of extended periods of discharge from the MTWCD into Turkey Creek. The Storm Water Management Model (SWMM) (Huber and Dickenson 1992) was used to perform storm-event simulations for the evaluation of flood stages within the MTWCD. Each model has capabilities and features that make it particularly suitable for its intended purpose.

In a future study, these hydrologic models will be used for the following purposes:

- To assess the impact of restoration activities in USJRB on the MTWCD

- To evaluate subsequent surface water management activities for the MTWCD

- To provide simulated discharge data to investigate the impact of freshwater discharges from the MTWCD into Turkey Creek

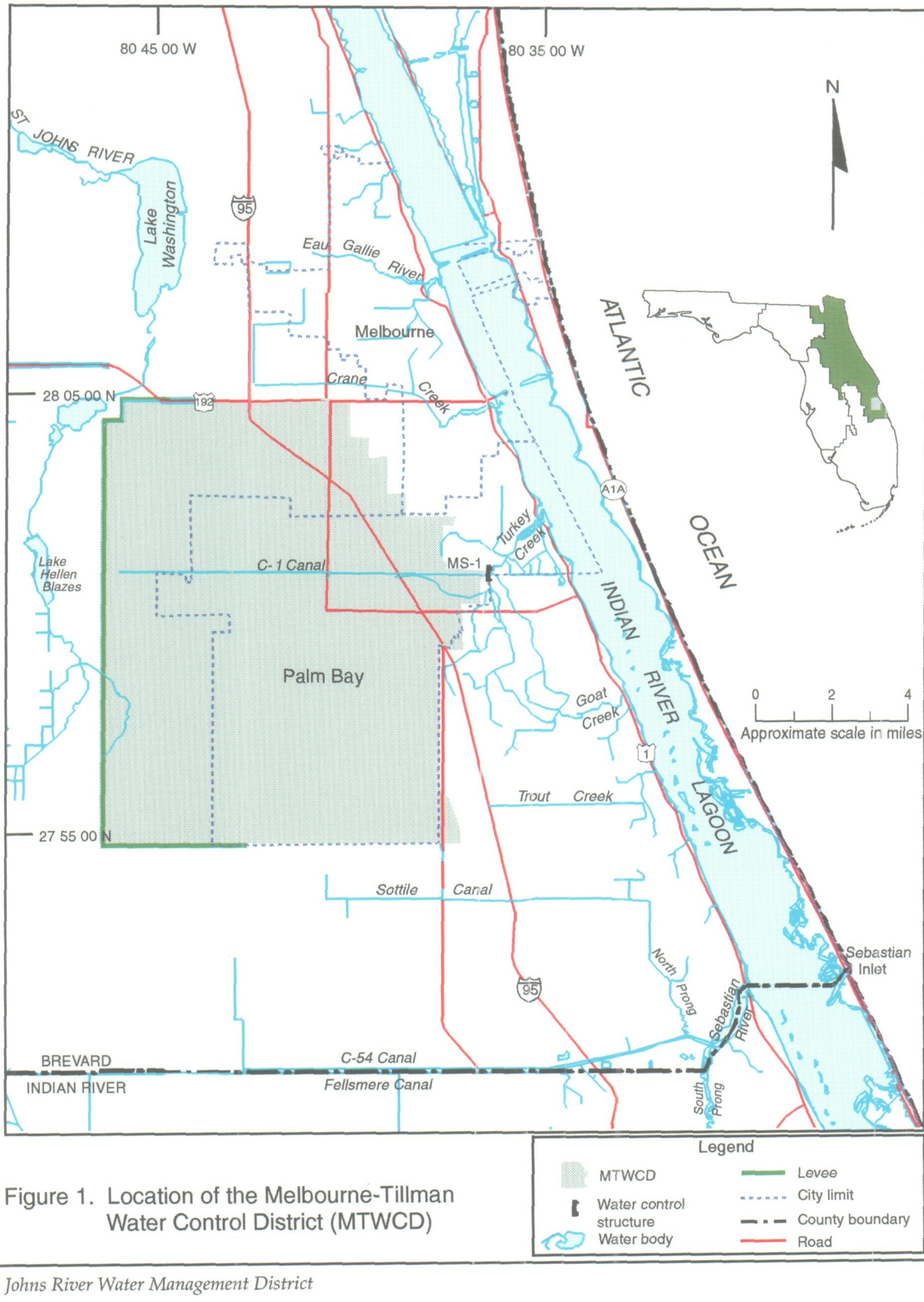


Figure 1. Location of the Melbourne-Tillman Water Control District (MTWCD)

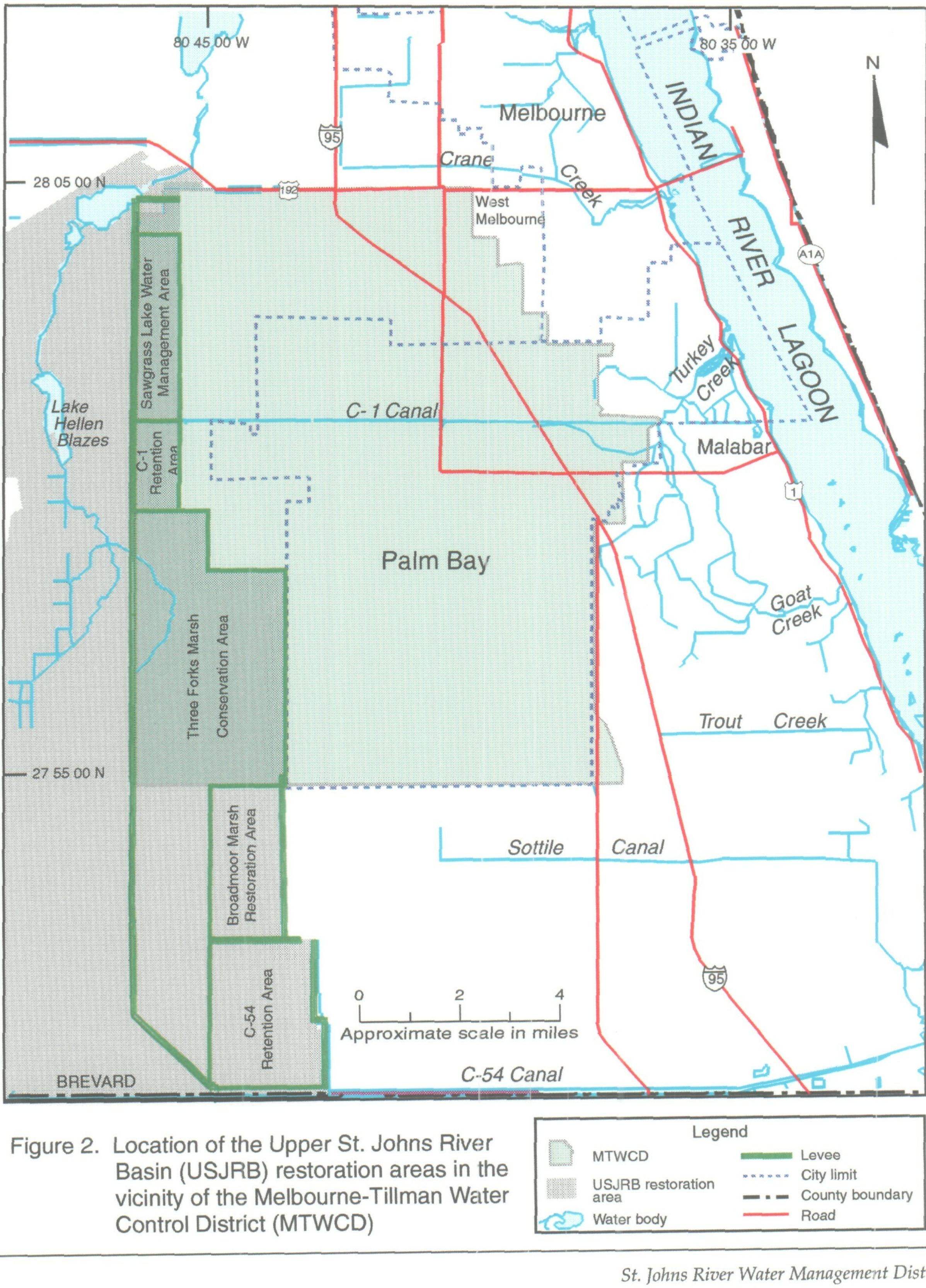


Figure 2. Location of the Upper St. Johns River Basin (USJRB) restoration areas in the vicinity of the Melbourne-Tillman Water Control District (MTWCD)

DESCRIPTION OF THE MELBOURNE-TILLMAN WATER CONTROL DISTRICT

The MTWCD encompasses approximately 100 mi^2 in Brevard County. Its northern, southern, and western boundaries are totally or partially defined by a levee system constructed in the 1920s.

The drainage pattern of the MTWCD obtains its character primarily from the arrangement and location of a series of canals. The major MTWCD drainage canal is C-1 (Figure 3). Its discharge into Turkey Creek is controlled by structure MS-1. Thirty-five percent of the MTWCD area lies to the north of the C-1 canal. Five major canals discharge directly into the C-1 canal: C-69, C-37, C-61, C-10, and C-2. Each of these canals has lateral canals at half-mile intervals. In addition to the discharge from these lateral canals, the C-10 canal receives discharge from the C-9R canal, which drains the central and eastern areas along the southern boundary of the MTWCD. The C-10 canal also receives discharge from the C-16 canal, which in turn has north-south lateral tributaries. The C-2 canal receives discharges from the C-83 canal, which drains the area along the northern boundary of the MTWCD.

Turkey Creek has three additional tributaries that contribute minor discharges to it compared with the C-1 canal. These tributaries are Turkey Run, Turkey Creek's South Branch, and the Jersey Waterway. The South Branch and the Jersey Waterway flow into Turkey Creek from the south, Turkey Run flows in from the north. Turkey Creek's South Branch receives discharge from the C-82 canal, an MTWCD drainage canal that does not flow into the C-1 canal. The Jersey Waterway encircles the urban area south of Turkey Creek and is connected to Turkey Creek at both ends.

PHYSIOGRAPHIC DESCRIPTION

Three physiographic sections are identified near the MTWCD (defined by Brooks [1982]). These three sections run approximately parallel to the coast in this area (Figure 4). The eastern section is the Cocoa-

Sebastian Ridge. In undisturbed areas, a sand pine scrub vegetation occurs on the ridge, with flatwood terrain on the terrace.

The middle physiographic section is the Upper St. Johns Karst. This area, also referred to as the Ten Mile Ridge (Clapp 1987), is an area of predominantly internal drainage in which dissolution of shell deposits has resulted in karst depressions. The section is not naturally well drained and is a flatwood. The Ten Mile Ridge is the natural drainage divide between the Indian River Lagoon and the St. Johns River. However, the C-1 canal drains surface runoff west of the ridge into Turkey Creek, which drains into the Indian River Lagoon.

The western physiographic section is the St. Johns Marsh. Here, marshes and grass prairies with clumps of cabbage palms and willows are seasonally flooded. Lake basins are controlled by geologic structures in the underlying Ocala Limestone. The surficial fine sand, silty sand, and clayey sand are Late Pleistocene lagoonal deposits. Elevations are mostly above 18 feet (ft), organic soils are common, and there are no karst features.

The elevations near the MTWCD (Figure 4) range from approximately zero feet (referenced to the National Geodetic Vertical Datum [NGVD]) at the edge of the Indian River Lagoon to 35 ft NGVD about 4 miles (mi) inland. Then the elevation gradually declines to below 20 ft NGVD in the northwest, and in the southwest the elevations continue to decline below 15 ft NGVD.

HISTORY OF THE MTWCD

The MTWCD was formed in 1922 under Chapter 298, *Florida Statutes*, to provide drainage facilities necessary to expand and improve agricultural land use. The drainage plan called for a grid system of drainage canals with an outfall dam and spillway across Turkey Creek. The plan also proposed a 22-mi dike, most of which would be located along the western and southern boundaries of the MTWCD to provide protection against the floodwaters of the St. Johns River.

Construction of the drainage system began in late 1922. However, construction was halted 6 years later as a result of financial difficulties associated with the Depression. Approximately 85% of the proposed improvements had been constructed. The western levee had been completed, but the dam and spillway had not.

General Development Corporation (GDC) became the major MTWCD landowner in 1960, when it bought approximately 62 mi^2 within the MTWCD. Following the purchase, GDC began platting and selling homesite lots within its Port Malabar community. As growth in West Melbourne and Malabar (Figure 2) moved westward into the MTWCD, the need for some modification of the existing agricultural drainage system became increasingly apparent.

In 1969, sponsored by GDC, Reynolds, Smith and Hills Corporation (RS&H) developed a revised plan of reclamation for the MTWCD. However, the plan met with resistance from the U.S. Army Corps of Engineers and the Central and Southern Florida Flood Control District, and it was never implemented.

In 1977, RS&H presented another plan for reclamation that was approved by the MTWCD Board of Supervisors. In 1978, the MS-1 water control structure was built. MS-1 consists of two radial gates and two Amil gates.

Charged with overseeing stormwater management, SJRWMD imposed a regulation schedule for the operation of MS-1 (MSSW permit 4-009-0030). During the dry season (November through May), the maximum allowable discharge is 3,000 cubic feet per second (cfs). Minimum discharge during these months is 25 cfs, and the prescribed water level is 8 ft NGVD. Allowable discharge during the wet season (June through October) differs slightly: 3,000 cfs is the maximum discharge and 35 cfs is the minimum. The prescribed water level for the wet season is half that determined for the dry season, or 4 ft NGVD.

In recent years, growth in the MTWCD has increased rapidly. Open areas and agricultural lands are being replaced by residential housing. Areas that once could be flooded with minimal damage are fast becoming lands that, if flooded, will cause extensive property damage. For this reason, MTWCD has increased its efforts to develop a stormwater management plan that will minimize flooding in the water control district. Because SJRWMD wants to ensure that no additional flooding occurs in the MTWCD as a result of its own plans for USJRB, SJRWMD has joined the MTWCD in the effort to develop and implement the surface water management plan.

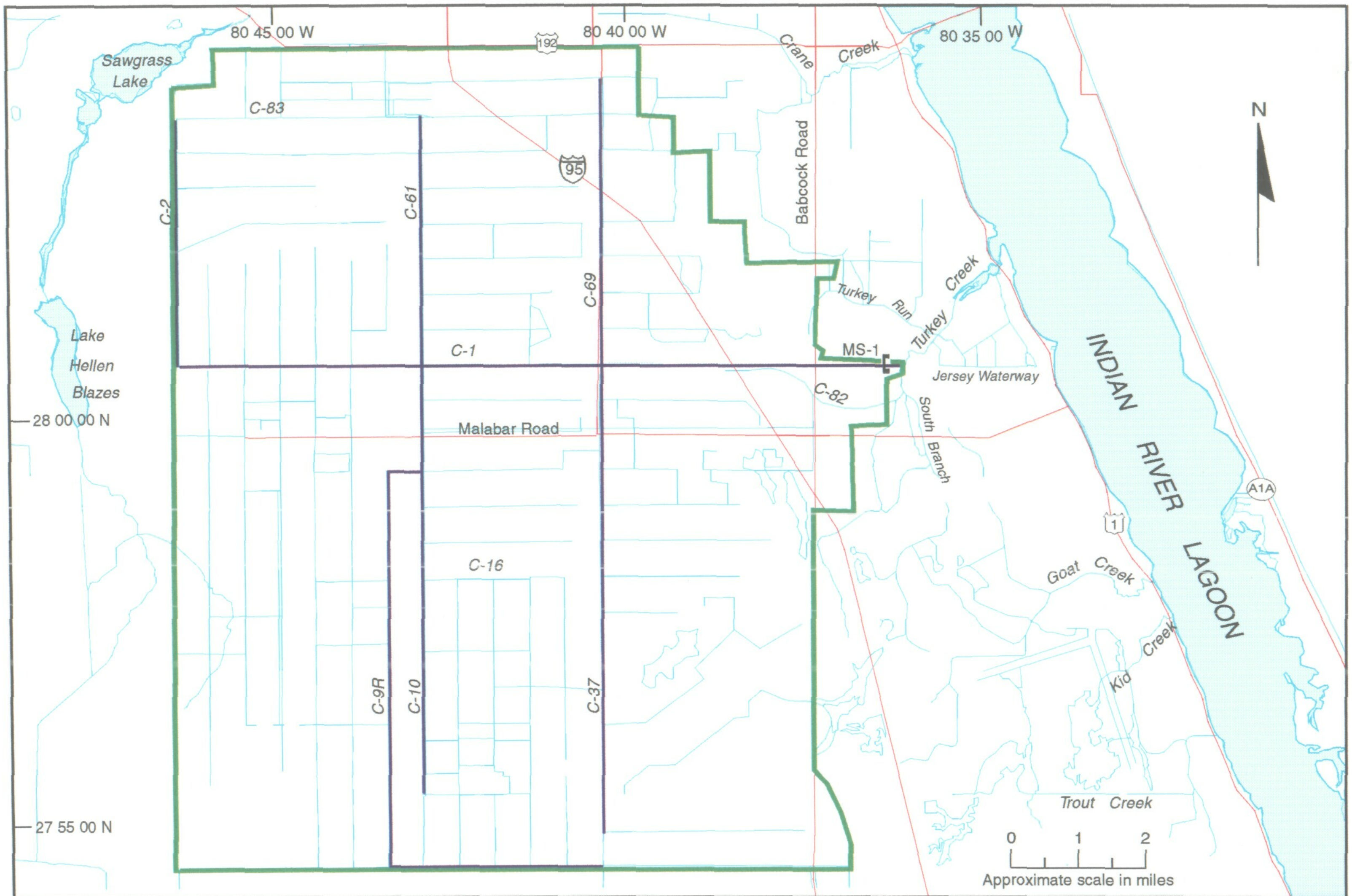


Figure 3. The Melbourne-Tillman Water Control District (MTWCD)

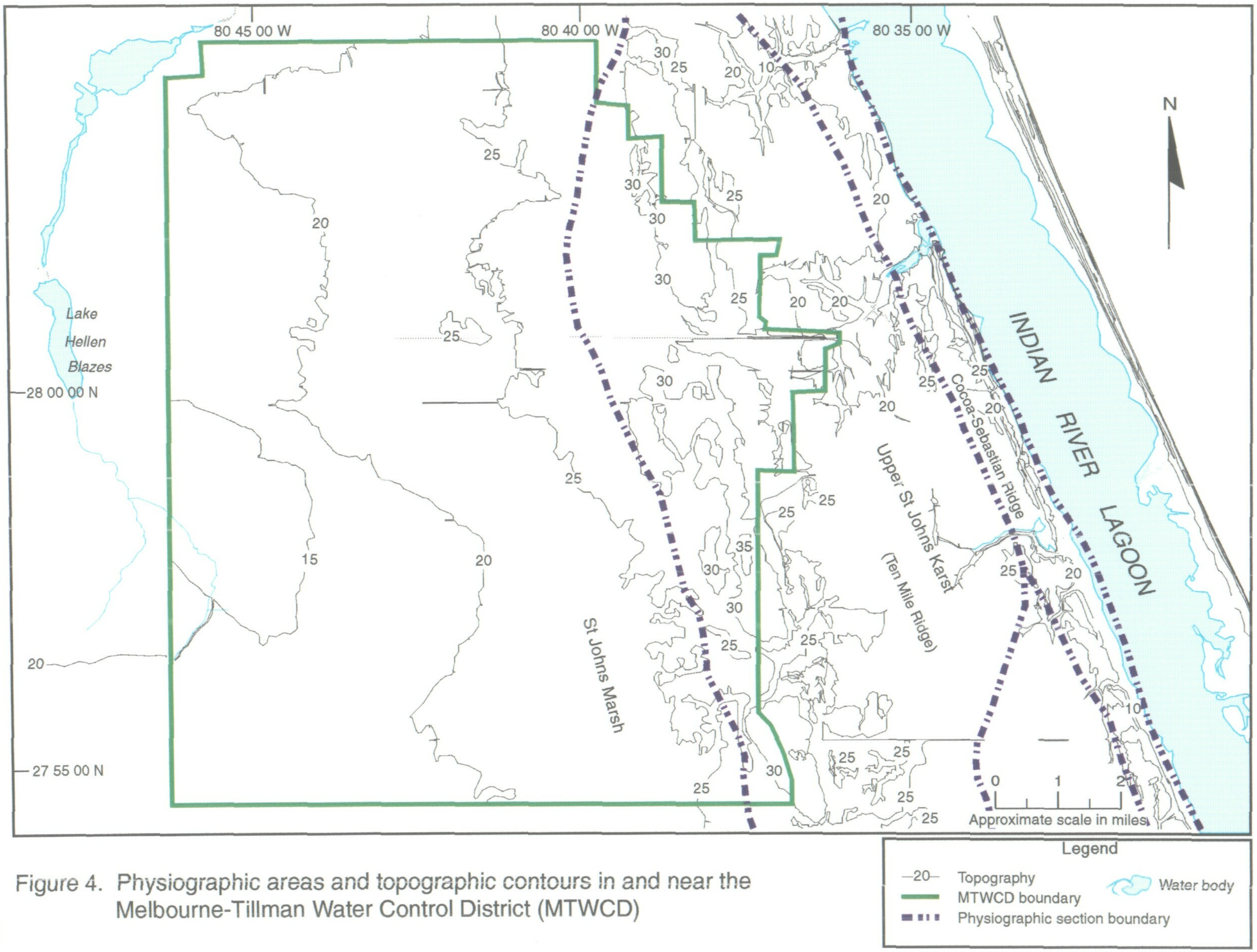


Figure 4. Physiographic areas and topographic contours in and near the Melbourne-Tillman Water Control District (MTWCD)

DATA COLLECTION

To develop hydrologic and hydraulic models for any drainage basin, data must be collected to characterize the area. This section presents the data used for development of the MTWCD models. These data are grouped into three categories: meteorological data, hydrologic data, and watershed data.

METEOROLOGICAL DATA

Precipitation

Data from seven rainfall stations within or near the MTWCD were used to characterize the areal distribution of precipitation within the MTWCD (Figure 5). Three stations collect rainfall data daily, three collect rainfall data hourly, and one station initially collected data once a day but was later switched to hourly collection (Table 1). Only the National Oceanic and Atmospheric Administration (NOAA) station (5612) at Melbourne, Florida, collected rainfall before 1969. Also, most of the stations that collect rainfall at an hourly interval were established after July 1989.

At the Melbourne station (NOAA 5612) for the period of record (1938–95), the wetter months of the season are, on average, May through October (Table 2). The wettest month, on average, is usually September. The wettest year in the period of record was 1947, with over 74 inches (in.) of rain.

Table 3 shows the maximum annual 1-day rainfall at Melbourne, as well as the maximum annual rainfall for 2-day through 5-day and 10-day events. The maximum 1-day rainfall event occurred in August 1995.

Rao (1991) estimated the maximum 24-hour rainfall depth for the MTWCD; for that duration, the annual mean was 5.0 in., and the 10-year (yr), 25-yr, and 100-yr depths were 7.5 in., 9.5 in., and 12.5 in., respectively. In an earlier report, Rao (1988a) estimated the maximum 96-hour rainfall depths; the annual mean was 6.6 in., and the 10-yr, 25-yr, and 100-yr depths were 9.8 in., 11.8 in., and 16.5 in., respectively.

These rainfall depths are point values. To apply rainfall over the 100-mi^2 MTWCD area, the 24-hour rainfall depths are multiplied by a basin area adjustment factor of 0.93 (Rao 1988b). Also, the rainfall depth is distributed over the 24-hour period using Rao's method (1991).

Evaporation

The nearest site with pan evaporation data is Vero Beach (NOAA 9219, about 30 mi south of Palm Bay, on the coast) (Table 4). The months with the highest mean pan evaporation, above 6 in., are generally April through August, with the highest evaporation occurring during May. The months with the lowest mean pan evaporation, below 4 in., are November through February, with the lowest evaporation occurring during December.

HYDROLOGIC DATA

Stage and discharge were monitored at five locations (Table 5 and Figure 6). Three gages, C-1 canal near Red Bud Circle, C-10 canal at Malabar Road, and C-69 canal at Palm Bay Boulevard, were installed in 1988 to determine the contribution of runoff from different areas within the MTWCD (Table 6). Theses stations were removed in 1992. The remaining two locations, C-1 canal near MS-1 and Turkey Creek at Palm Bay, have recorded discharge intermittently since 1956 (Tables 7 and 8). The C-1 canal near MS-1 was recorded by the U.S. Geological Survey (USGS) from January 1956 to June 1968 and by SJRWMD from March 1977 through 1980 (Table 7). From 1980 to 1995, discharge through the MS-1 structure has been reported by the MTWCD; the data from this period are not included in Table 7 for reasons explained below. Turkey Creek at Palm Bay, Florida, has been recorded by USGS from February 1981 to September 1983 and from September 1986 to the 1995 (Table 8).

Discharge

The discharge at MS-1 has been determined by comparing the MS-1 structure discharge-rating curve with observed upstream and downstream water surface elevations and gate openings. The time periods overlap in which discharges at MS-1 and in Turkey Creek were reported. Comparison of these discharges during this overlap period showed that discharge computed at MS-1 was greater than the discharge gaged downstream in Turkey Creek at Palm Bay. This situation is unusual. Typically, downstream gages record greater discharge than upstream gages.

After closely inspecting the discharges, SJRWMD staff determined that the Turkey Creek data and methodology were more reliable. USGS determines the discharge at Turkey Creek using continuous velocity and stage gages and a stage area rating. In contrast, the discharge at MS-1 is determined once a day using upstream and downstream stage, the gate opening, and the water control structure rating curve. Thus, the discharge calculated at MS-1 was completely discarded after 1980 when the gage in Turkey Creek at Palm Bay was established. Because the Turkey Creek gage is directly downstream of MS-1, because inconsistencies could not be satisfactorily corrected, and because USGS is qualified and experienced at recording streamflow, the discharge at Turkey Creek was accepted as an appropriate approximate measure of the discharge through MS-1.

A reference year of June 1 to May 31 is used to maintain a continuous wet season in the evaluation of peak flows. The USGS water year ends September 30, when the wet season peak flows are likely to occur, so it cannot be used to evaluate peak flows.

Average peak discharges for selected event lengths are shown in Table 9. The maximum peak discharge gaged in this watershed was at Turkey Creek in August 1995 (reported in the hydrologic year ending May 1996) (Table 8). At gages on C-1 canal and Red Bud Circle and Malabar Road, the maximum peak occurred in the year ending May 1990. All these peaks resulted from an October 1989 storm.

Stage

Average peak stages for selected event lengths are shown in Table 10. Records for the stage data in the C-1 canal near MS-1 begin in 1978. Although the discharge data at MS-1 are questionable, the stage data at the structure are accurate because these are observed data.

WATERSHED DATA

This section identifies and references information that is used to characterize the rainfall-runoff-streamflow processes in the MTWCD watershed. Subbasin delineation computes the areas that drain into major canals. Also, the general drainage patter of the MTWCD is defined. Soils and land use information are useful for characterizing the processes that convert rainfall into runoff. Canal cross sections provide information about the capacity of canals that drain the runoff from the MTWCD into Turkey Creek.

Subbasin Delineation

The MTWCD, upstream of MS-1, is divided into ten subbasins (Figure 6). Two additional subbasins, one of which (C-82) is in the MTWCD, contribute runoff to Turkey Creek downstream of MS-1. Each subbasin within the MTWCD is identified by the major channel that drains it. Four subbasin names deviate from this naming convention: C-1A is that part of the C-1 canal west of the USGS gage near Red Bud Circle, SW C-1A is the southwest part of the C-1A canal separated by levees and drained by pumping, TC South is the South Branch of Turkey Creek, and C-2 subbasin is the area drained only at the head of the C-2 canal.

The areas of these subbasins are totaled in Table 11A. Table 11B presents the anticipated area of the TFMCA, the SLWMA, and the C-1 Retention Area after the completion of levee L-74N in 1999. Prior to construction of L-74N, the largest drainage area is C-1A, but there are other major drainage areas as well: C-10, C-37, and C-61. After the construction of the L-74N levee, C-1A, C-10, and C-37 will be of comparable size.

Figure 7 is a schematic of the drainage pattern. The drainage pattern is dendritic in nature; minor canals drain into larger canals that finally discharge into the C-1 canal. As discussed in the general description of the MTWCD, the C-10 canal not only drains the C-10 area but also receives the discharge of the C-9R canal. The same is true for C-1A, which receives flow from SW C-1A and C-2.

Soils

The majority of the soil types in the MTWCD are poorly to very poorly drained sandy soils (USDA 1974). Table 12 lists the types of soils found in the MTWCD and identifies their total areas. These soils have a water table depth of between 10 and 40 in. for most of the year. They have high permeability and low water capacity.

Land Use

The land in the MTWCD has been classified according to the Florida Land Use Cover Classification Scheme (FDOT 1985). This classification system consists of four levels increasing in specific land description from Level I to Level IV. The MTWCD watershed contains eight Level I land use categories: Urban and Built-up (classification code 100), Agriculture (200), Rangeland (300), Upland Forest (400), Water (500), Wetlands (600), Barren Land (700), and Transportation, Communication, and Utilities (800). These eight categories are then broken down into many Level II land use subcategories (Table 13).

The largest Level I land use is Urban and Built-up, amounting to about 42% of the total area, of which Medium Density Residential is the largest area. The Level I land uses Agriculture, Rangeland, and Upland Forest total about 43%. Together, Wetlands and Water make up about 12% of the total area.

Channel Geometry

Three sources were used to obtain the cross-sectional geometry of the drainage canals in the MTWCD and the natural channel of Turkey Creek. SJRWMD contracted with Herrera, William, & Powell to survey cross-sectional geometry of the first- and second-order drainage canals in the MTWCD. Cross-sectional geometry of third-order and smaller drainage canals was obtained from the 1977 revised plan of reclamation (RS&H 1977). Finally, cross-sectional geometry of Turkey Creek and its tributaries was obtained from the data used in the Hydrologic Engineering Center (HEC-2) model (U.S. Army Corps of Engineers 1982) by the Federal Emergency Management Agency (FEMA) for a flood insurance study of the area (FEMA 1989a).

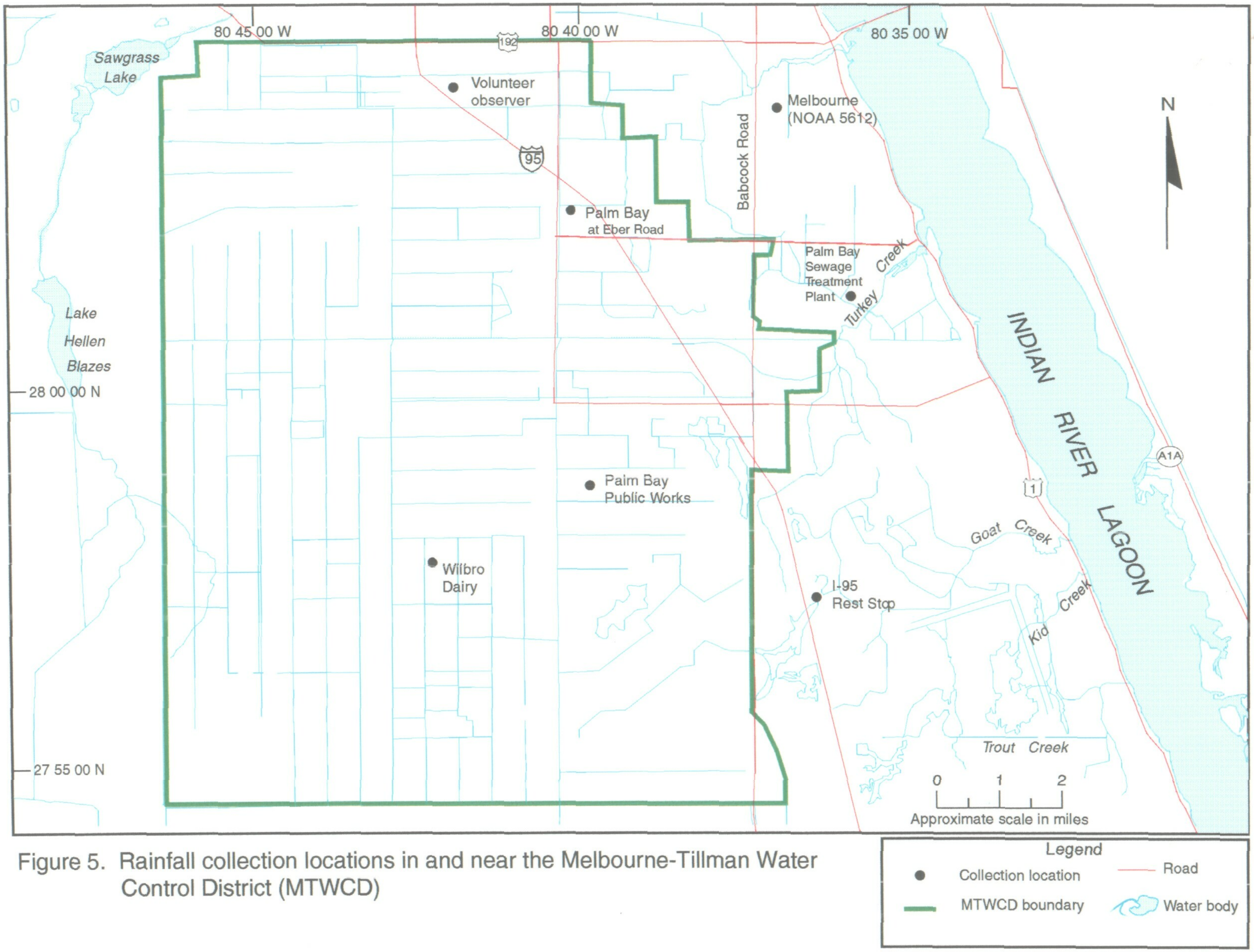
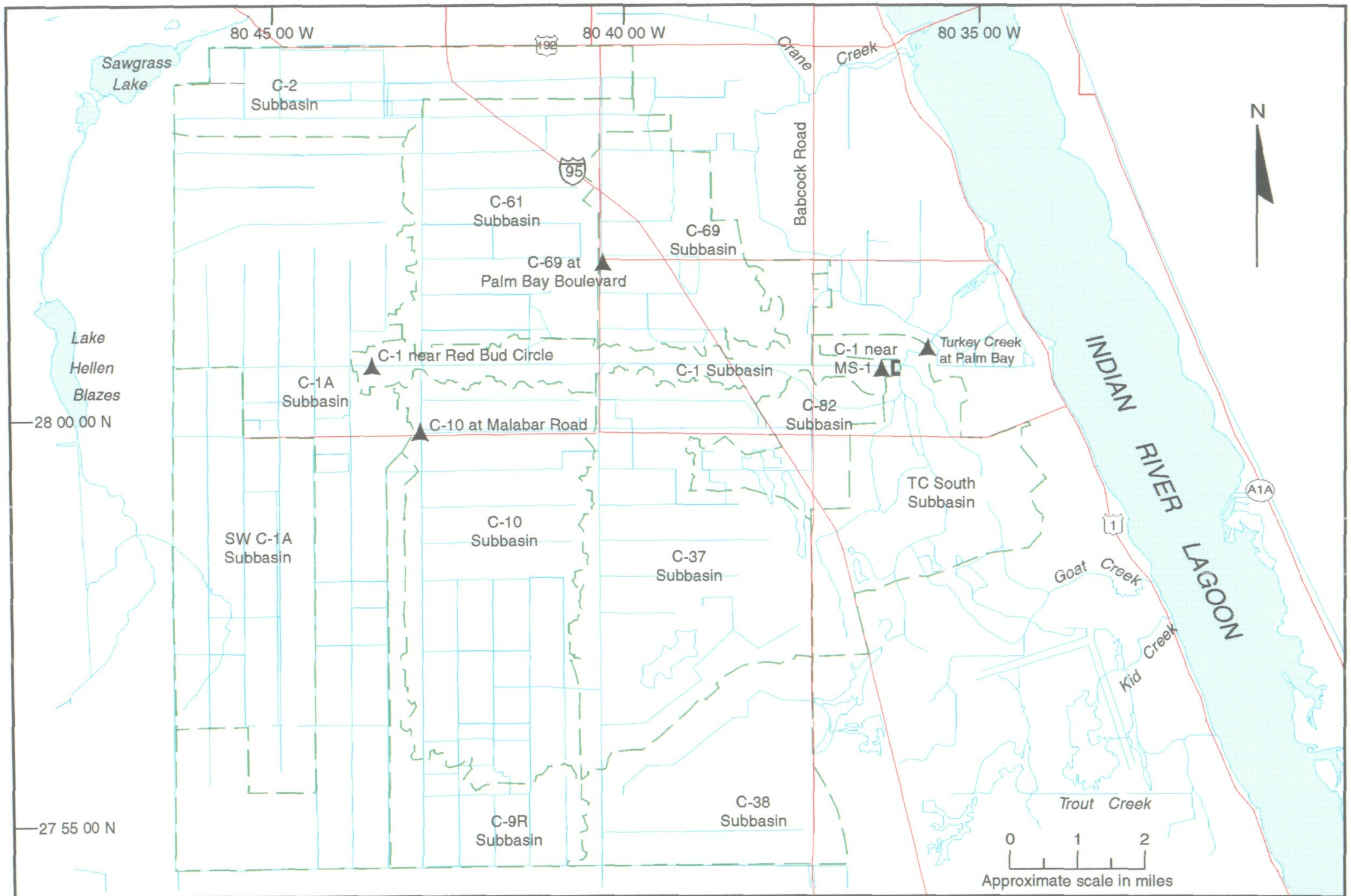


Figure 5. Rainfall collection locations in and near the Melbourne-Tillman Water Control District (MTWCD)



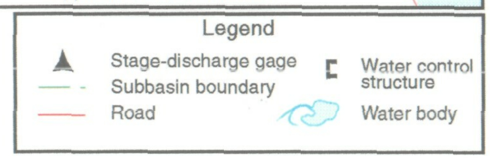


Figure 6. Stage-discharge gage locations and subbasin boundaries

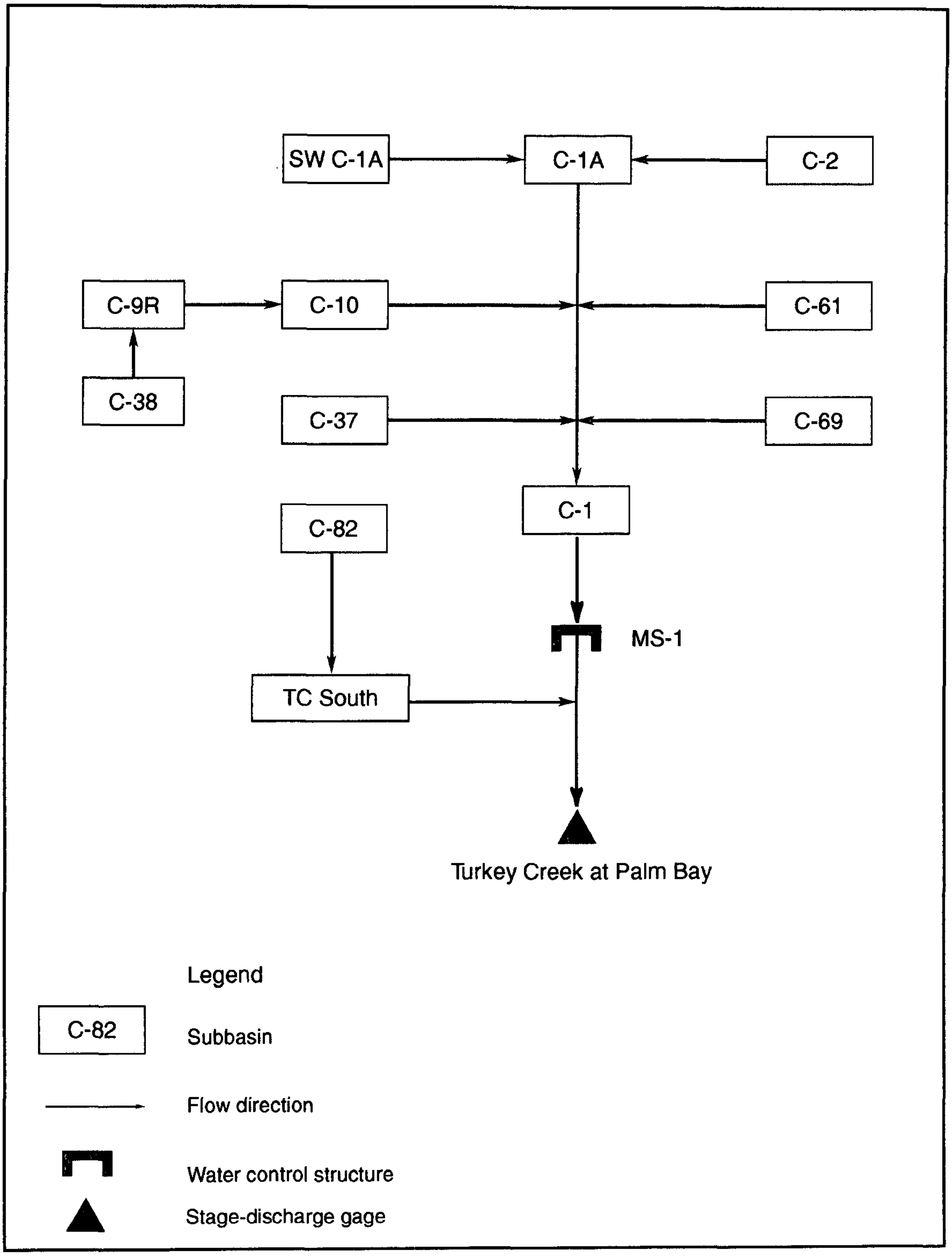


Figure 7. Schematic of drainage upstream of Turkey Creek at Palm Bay

Table 1. Active rainfall collection stations within or near the Melbourne-Tillman Water Control District

Rainfall Station	Installation Date	Interval	Latitude	Longitude	Collecting Agency	Model*
Melbourne (NOAA 5612)	January 1938	Hour	28 04 00	80 37 00	NOAA	HSPF/SWMM
Palm Bay STP	June 1973 June 1994†	Day Hour	28 01 20	80 35 55	City of Palm Bay STP	HSPF SWMM
Palm Bay Public Works	January 1979	Day	27 58 50	80 39 50	City of Palm Bay Public Works	HSPF
SJRWMD	August 1978	Day	28 04 03	80 41 35	Volunteer observer (SJRWMD)	HSPF
Wilbro Dairy	January 1969	Day	27 58 00	80 41 50	Wilbro Dairy Farms	HSPF
Palm Bay at Eber Road	August 1989	Hour	28 04 22	80 40 05	U.S. Geological Survey	SWMM
I-95 rest stop	June 1990	Hour	27 57 15	80 36 37	SJRWMD	SWMM

Note: HSPF = Hydrologic Simulation Model-Fortran
NOAA = National Oceanic and Atmospheric Administration
SJRWMD = St. Johns River Water Management District
STP = sewage treatment plant
SWMM = Storm Water Management Model

*This column identifies the hydrologic model for which the rainfall data were used. A discussion of the hydrologic models is in the next section of this report.
†SJRWMD converted this station to hourly collection in June 1994.

Table 2. Monthly and annual rainfall (in inches) recorded for the Melbourne station (NOAA 5612)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1938	1.49	1.33	1.30	0.57	2.59	2.87	3.33	1.31	5.59	4.14	1.02	0.85	26.39
1939	0.37	0.11	2.79	3.17	5.43	6.79	7.39	8.01	10.92	8.25	1.37	0.48	55.08
1940	3.55	3.42	3.43	1.29	0.80	2.08	5.47	3.63	9.44	0.67	0.48	7.89	42.15
1941	4.23	5.23	3.11	3.42	1.06	7.58	6.64	3.96	5.27	7.75	7.02	3.52	58.79
1942	2.44	3.72	5.78	2.83	3.94	8.62	4.09	5.36	3.73	0.90	0.55	2.54	44.50
1943	1.12	0.40	6.19	1.86	3.23	4.23	10.72	4.52	5.44	3.63	2.99	0.54	44.87
1944	0.78	0.14	5.03	3.21	0.66	7.12	13.40	6.71	3.47	8.00*	1.09	0.40	50.01
1945	4.91	0.32	1.16	2.00	0.22	8.97	7.23	3.08	18.77	3.70	4.74	1.66	56.76
1946	1.06	3.60	2.22	0.53	6.46	5.90	9.13	6.65	6.39	4.27	3.63	0.89	50.73
1947	1.57	4.93	5.00	2.63	6.92	13.45	6.07	9.05	11.64	8.22	2.99	1.81	74.16
1948	3.99	1.21	3.15	1.41	5.47	3.17	4.88	6.79	19.68	2.70	1.32	2.28	56.05
1949	0.35	1.72	0.97	2.50	2.15	9.19	1.46	9.99	9.97	3.96	1.31	3.14	46.71
1950	0.57	2.02	6.59	2.10	5.08	1.44	3.95	2.93	3.91	10.45	0.93	0.93	40.90
1951	0.24	3.04	1.05	8.15	3.16	2.62	6.02	2.18	9.81	5.52	4.19	1.49	47.47
1952	2.30	2.97	4.11	0.35	3.12	1.64	3.94	4.15	10.40	11.31	0.70	1.05	46.04
1953	1.97	3.25	2.92	7.37	1.75	5.39	4.58	10.88	8.83	10.72	4.87	1.49	64.02
1954	1.09	2.02	2.24	2.75	5.68	8.90	7.44	2.41	6.06	4.75	2.10	1.07	46.51
1955	1.73	1.39	1.59	1.98	2.69	6.10	0.81	5.21	8.86*	6.87*	0.34*	1.12	38.69
1956	1.30	0.88	0.03	2.81	1.63	3.21	8.93	2.16	5.69	13.86	0.53	0.15†	41.18
1957	1.53	3.74	4.54	4.86	6.04†	4.60	8.65	6.56	9.24†	2.99†	1.82	3.19	57.76
1958	7.46	3.31*	5.09*	4.26*	2.06*	3.79*	5.67*	7.57*	4.22	7.19	3.87	3.45	57.94
1959	2.93	4.31	6.45	3.51	3.81	8.33	1.90	3.82	7.87	6.01	4.14	1.76	54.84
1960	0.50	5.52	7.88	1.80	7.00	6.20	11.58	6.80	16.04	4.28	0.70	0.60	68.90
1961	3.50	0.60	2.35	2.94	5.40	5.15	6.54	5.79	5.52	1.38	2.15	0.26	41.58
1962	1.08	1.00	3.01	1.57	0.83	3.53	9.46	10.45	9.45	0.96	3.08	0.81	45.23
1963	2.18	7.24	2.28	0.29	4.82	5.31	4.41	2.67	14.07	2.19	9.72	2.07	57.25
1964	2.89	5.55	2.07	0.37	4.67	3.31	6.00	12.12	5.48	3.65	2.38	1.90	50.39
1965	0.71	2.77	3.92	0.69	0.17	6.46	2.55	3.45	3.11	4.55	2.22	1.92	32.52
1966	5.50	5.20	3.71	1.20	5.45	15.98	5.18	7.96	7.04	3.78	0.90	1.72	63.62
1967	1.08	3.87	1.56	0.12	1.20	11.03	7.28	3.39	7.72	1.48	0.31	1.63	40.67
1968	0.60	2.28	0.64	2.03	4.74	16.37†	3.60	5.51	4.90	8.90	1.60	0.00	51.17
1969	2.00	0.90	10.13	0.28	4.47	7.62	4.30	8.55	6.16	7.69	5.24	2.54	59.88
1970	4.43	1.32	5.04	1.62	3.69	1.74	5.65	1.62	7.86	4.45	0.32	0.97	38.71
1971	0.13	4.47	1.75	0.54	1.76	3.83	4.68	1.14	6.05	6.20	2.72	3.28	36.55

Table 2—*Continued*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1972	0.69	5.10	1.91	3.05	5.78	9.59	2.38	6.59	1.80	3.13	5.10	1.71	46.83
1973	4.08	1.41	2.32	6.11	3.85	6.10	4.85	4.03	5.02	6.11	0.82	3.26	47.96
1974	0.09	0.85	0.10	1.12	2.36	7.39	9.05	4.17	5.04	2.63	1.31	2.39	36.50
1975	0.51	3.08	2.37	1.92	4.47	7.58	5.60	2.10	8.67	5.26	1.06	0.41	43.03
1976	1.04	0.56	0.70	0.63	13.83	4.96	2.18	3.74	13.56	0.62	2.91	2.12	46.85
1977	2.41	1.91	1.98	0.40	2.09	4.64	5.37	2.94	6.98	7.00	7.03	3.21	45.96
1978	1.88	3.48	3.21	0.05	4.70	7.24	11.61	6.98	4.53	5.42	0.42	5.68	55.20
1979	8.17	0.67	0.79	1.96	7.31	5.84	4.01	2.91	14.05	0.69	3.67	0.72	50.79
1980	3.34	3.31	1.67	1.95	4.18	2.19	4.09	2.59	4.18	1.59	3.07	3.79	35.95
1981	0.30	3.81	1.49	0.39	3.07	1.53	2.62	8.36	3.95	1.75	3.75	0.95	31.97
1982	1.67	1.38	5.16	4.87	7.24	6.88	4.15	2.27	5.00	1.50	2.63	2.42	45.17
1983	4.67	11.14	4.05	1.88	3.35	5.24	2.60	6.16	5.38	7.15	1.81	4.24	57.67
1984	0.76	2.69	0.77	0.77	7.35	1.68	3.62	4.48	6.19	0.39	9.11	0.72	38.53
1985	0.49	0.25	1.72	5.38	2.27	6.21	3.12	7.11	12.49	7.21	2.52	2.75	51.52
1986	3.59	1.56	1.07	0.02	0.56	6.64	3.66	5.60*	5.59	8.19	0.00	3.42*	39.90
1987	1.42	1.34	5.66	0.01	7.35	4.25	6.87	3.50	8.10*	1.32	9.60	0.96	50.38
1988	2.12	2.61	6.62	0.65	0.65	3.20*	6.13	7.13	2.21	0.81	2.62	1.36	36.11
1989	3.74	0.59	1.77	3.65	1.84	3.34	4.33	7.56	3.27	8.26	0.80	3.84	42.99
1990	0.78	3.50	0.49	0.27	2.08	7.22	8.51	6.46	6.93	9.80	1.21	0.77	48.02
1991	2.95	1.11	4.90	4.27	5.97	6.25	11.32	6.14	9.15	4.45	1.59	0.48	58.58
1992	1.41	3.26	4.01	4.21	1.46	12.30	2.88	5.83	7.22	2.67	2.59	1.52	49.36
1993	5.24	1.75	8.55	1.75	2.01	1.30	3.97	3.01	5.37	4.63	1.22	0.49	39.29
1994	3.20	3.34	0.74	2.73	2.42	11.17	6.90	10.09	9.21	6.92	8.78	4.35	69.85
1995	2.57	2.04	2.82	3.08	4.58	8.65	7.86	19.05	7.94	10.05	0.65	0.82	70.11
Mean	2.22	2.66	3.17	2.21	3.77	6.10	5.70	5.61	7.59	5.05	2.72	1.93	48.73
30-year Normal	2.19	2.81	2.68	1.56	3.95	6.13	5.15	5.21	6.59	4.14	3.00	2.08	45.49
Maximum	8.17	11.14	10.13	8.15	13.83	16.37	13.40	19.05	19.68	13.86	9.72	7.89	74.16
Minimum	0.09	0.11	0.03	0.01	0.17	1.30	0.81	1.14	1.80	0.39	0.00	0.00	26.39

Note: NOAA = National Oceanic and Atmospheric Administration

*Estimated by the St. Johns River Water Management District
†Estimated by NOAA

Source: Rao et al. 1997

Table 3. Maximum rainfall total data (in inches) reported at the Melbourne station (NOAA 5612) for various rainfall events

Year	1-Day Event	2-Day Event	3-Day Event	4-Day Event	5-Day Event	10-Day Event
1939	6.36	7.64	8.13	8.31	8.95	9.24
1940	2.36	3.07	3.27	4.19	4.83	6.70
1941	3.60	4.36	4.62	4.64	4.64	5.72
1942	2.12	3.05	3.28	3.32	3.82	4.34
1943	1.97	3.10	3.34	3.37	3.79	7.09
1944	3.66	4.43	5.14	5.64	5.66	7.23
1945	6.08	7.64	8.38	8.69	8.76	8.89
1946	2.40	3.30	3.82	3.85	4.65	5.76
1947	3.34	4.29	4.52	5.01	5.92	8.62
1948	7.42	8.21	8.46	8.47	8.49	11.87
1949	7.19	7.44	7.44	7.47	7.50	8.60
1950	5.39	7.94	9.48	9.95	10.02	10.10
1951	3.76	4.09	4.09	5.35	6.07	6.09
1952	3.19	5.15	6.09	6.49	7.20	9.33
1953	3.91	4.18	4.22	4.87	5.42	7.64
1954	3.90	4.23	4.37	4.49	4.54	8.46
1955	1.64	2.66	3.10	3.36	3.48	4.58
1956	8.28	10.99	12.24	12.84	13.04	13.34
1957	1.98	2.23	2.65	2.65	3.78	4.32
1958	3.41	3.59	3.60	3.77	3.78	3.78
1959	3.92	5.28	6.19	6.43	6.43	6.74
1960	4.08	7.02	7.78	7.78	7.78	9.94
1961	4.13	4.75	5.14	5.44	5.52	5.52
1962	4.24	5.08	6.15	6.92	7.18	7.47
1963	6.05	6.71	7.06	9.30	10.44	13.15
1964	5.17	5.17	6.47	6.47	8.11	8.19
1965	2.31	2.81	2.81	2.81	3.69	4.86
1966	4.46	4.71	5.14	7.63	8.42	9.19
1967	3.66	4.08	4.39	4.60	4.77	8.61
1968	3.00	4.50	4.96	5.00	5.26	5.70
1969	5.19	5.27	5.35	5.35	5.38	9.59
1970	5.15	5.20	5.31	5.41	6.68	7.86
1971	2.34	3.11	3.52	3.56	3.56	3.56
1972	3.76	4.51	4.57	4.60	4.61	6.58
1973	4.35	4.39	4.43	4.46	5.30	5.80
1974	2.31	3.52	3.81	3.94	4.85	5.70

Table 3—*Continued*

Year	1-Day Event	2-Day Event	3-Day Event	4-Day Event	5-Day Event	10-Day Event
1975	3.66	3.70	3.70	3.79	5.97	7.21
1976	6.59	8.44	8.82	8.86	8.86	12.68
1977	5.48	5.50	5.50	5.50	5.52	6.46
1978	4.47	5.07	5.11	5.11	5.24	6.48
1979	6.37	7.29	7.32	7.60	7.79	7.97
1980	2.50	2.90	3.14	3.14	3.16	3.78
1981	2.28	2.63	3.71	4.01	4.09	6.26
1982	2.49	2.51	3.11	3.44	3.52	5.20
1983	4.15	4.18	4.23	4.27	4.96	5.88
1984	5.04	6.53	7.82	8.05	8.05	8.07
1985	4.83	5.13	6.70	6.88	6.98	7.47
1986	2.70	2.96	3.36	4.70	4.87	5.62
1987	3.84	5.06	6.96	7.12	7.62	10.61
1988	2.37	2.40	2.40	2.92	3.01	5.41
1989	5.44	6.48	7.19	7.19	7.19	7.20
1990	1.73	1.98	1.98	2.14	2.14	2.26
1991	3.51	4.09	4.09	4.68	5.44	6.41
1992	2.39	2.55	2.62	3.07	3.23	4.68
1993	2.74	2.74	2.96	3.98	4.12	6.91
1994	4.56	7.72	7.79	8.22	8.51	8.73
1995	9.06	10.14	10.84	10.84	10.85	12.17
Maximum	9.06	10.99	12.24	12.84	13.04	13.34

Note: NOAA = National Oceanic and Atmospheric Administration

Table 4. Pan evaporation (in inches) recorded at the Vero Beach station (NOAA 9219)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1966	2.23	2.86	5.06	6.21	6.26	6.08	6.76	6.33	4.54	4.20	3.38	2.21	56.12
1967	2.80	3.16	5.05	7.11	8.18	5.99	6.08	6.16	5.06	4.54	3.60	2.48	60.21
1968	2.66	3.95	5.62	6.87	6.46	—	6.53	6.42	5.49	4.49	2.97	2.59	—
1969	3.00	3.61	4.10	5.61	6.47	6.64	6.39	5.80	4.43	3.97	2.84	2.49	55.35
1970	2.47	3.35	4.70	6.20	7.45	7.22	6.18	6.49	6.09	4.58	3.47	2.61	60.81
1971	3.08	4.11	5.74	6.19	7.71	7.08	7.09	6.29	5.58	3.96	3.33	2.55	62.71
1972	2.74	3.55	5.81	6.37	6.53	—	7.64	6.41	5.84	5.22	3.18	2.47	—
1973	2.31	3.36	5.17	7.12	7.15	6.72	6.76	5.61	5.73	5.59	3.58	2.49	61.59
1974	2.69	4.32	6.34	6.46	7.86	6.16	5.43	5.97	5.57	5.20	3.24	2.88	62.12
1975	3.03	3.70	6.19	7.01	7.06	6.61	6.80	6.47	5.12	5.26	3.46	2.97	63.68
1976	3.10	4.06	5.75	6.86	6.14	6.88	6.70	6.81	5.92	5.32	3.02	2.53	63.09
1977	3.21	3.69	5.81	7.72	7.44	7.33	7.03	6.62	5.43	5.17	3.14	2.77	65.36
1978	2.86	3.56	5.12	6.42	7.23	6.39	6.18	6.77	5.04	4.29	3.47	3.29	60.62
1979	3.13	3.27	5.01	6.74	6.72	7.41	7.15	6.58	—	5.53	3.59	2.97	—
1980	3.09	5.81	5.36	5.91	7.99	7.60	7.11	6.34	5.90	4.67	3.93	2.49	66.20
1981	2.80	4.37	5.63	6.71	8.04	8.26	7.73	—	5.32	4.64	3.76	2.89	—
1982	2.93	3.66	5.01	5.84	6.77	5.78	6.96	6.74	6.56	4.97	3.40	3.18	61.80
1983	3.24	4.10	5.94	6.43	7.54	7.06	8.04	6.18	5.87	5.45	3.35	3.18	66.38
1984	—	4.20	5.84	6.95	7.50	6.62	7.43	—	7.71	6.16	4.49	2.75	—
1985	3.64	3.87	5.93	—	9.04	8.61	7.67	7.01	—	5.47	—	3.27	—
1986	—	4.48	6.39	7.65	6.85	8.44	—	5.74	4.50	4.53	2.37	3.28	—
1987	3.05	2.66	4.52	6.92	7.69	—	7.13	7.11	5.08	4.36	3.26	2.94	—
1988	2.87	3.72	5.21	7.11	6.36	6.10	4.63	6.06	5.72	5.60	3.09	2.85	59.32
1989	2.63	3.96	4.49	6.74	7.62	7.01	7.90	6.06	4.66	5.64	3.48	2.04	62.23
1990	4.25	4.06	6.18	7.16	7.64	8.18	8.07	7.62	7.15	5.65	4.69	3.68	74.33
1991	3.33	4.37	6.11	6.95	7.47	6.83	6.69	6.86	5.99	5.45	3.68	2.99	66.72
1992	2.88	3.90	5.66	7.17	7.73	—	8.08	5.61	6.44	5.40	3.63	3.55	—
1993	3.08	3.57	5.47	6.58	8.27	7.71	7.01	7.32	6.70	5.91	4.37	3.10	69.09

Table 4—*Continued*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1994	3.10	4.01	6.15	7.07	7.28	7.16	7.77	6.54	5.91	5.45	6.64	—	—
1995	2.95	4.49	5.77	6.05	8.30	6.93	7.47	7.04	6.34	4.79	3.60	3.43	67.16
Mean	2.97	3.86	5.50	6.69	7.36	7.03	6.98	6.46	5.70	5.05	3.59	2.86	63.24
Maximum	4.25	5.81	6.39	7.72	9.04	8.61	8.08	7.62	7.71	6.16	6.64	3.68	74.33
Minimum	2.23	2.66	4.10	5.61	6.14	5.78	4.63	5.61	4.43	3.96	2.37	2.04	55.35

Note: — = no record
NOAA = National Oceanic and Atmospheric Administration

Table 5. Stage-discharge gaging stations within or near the Melbourne-Tillman Water Control District

Gaging Station	Period of Record	Interval	Latitude	Longitude	Collecting Agency	USGS Station Number
C-1 canal near Red Bud Circle	February 1988 to September 1992*	Hour	28 00 47	80 43 30	USGS	2249950
C-10 canal at Malabar Road	February 1988 to September 1992*	Hour	27 59 56	80 42 47	USGS	2249970
C-69 canal at Palm Bay Boulevard	February 1988 to September 1992*	Hour	28 02 06	80 40 17	USGS	2249990
C-1 canal near MS-1	January 1956 to present†	Day	28 00 45	80 36 09	USGS, SJRWMD, MTWCD	None
Turkey Creek at Palm Bay	February 1981 to present	Hour	28 01 00	80 35 46	USGS	2250030

*June to September 1992 data were not used in analyses in this report.
†January to May 1956 data were not used in analyses in this report. From 1980 through 1995, the MTWCD collected the data.

Note: MTWCD = Melbourne-Tillman Water Control District
SJRWMD = St. Johns River Water Management District
USGS = U.S. Geological Survey

Table 6. Monthly average discharge of temporarily gaged canals within the Melbourne-Tillman Water Control District (in cubic feet per second)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
C-1 Canal Near Red Bud Circle												
1988		29	108	24	7	12	33	72	38	11	13	31
1989	73	62	51	38	27	23	23	45	39	218	64	50
1990	25	22	19	23	27	34	60	149	61	91	18	13
1991	16	41	31	41	37	55	98	91	92	111	24	17
1992	16	24	25	20	14	216	71	112	68			
Mean	33	36	47	29	22	68	57	94	60	108	30	28
C-10 Canal at Malabar Road												
1988		27	89	33	12	16	30	79	40	18	13	14
1989	43	27	42	31	28	16	30	81	50	142	26	15
1990	20	22	20	16	13	15	35	54	33	134	50	19
1991	16	38	37	42	39	60	87	83	80	116	24	17
1992	19	27	24	15	6	113	93	153	80			
Mean	25	28	42	27	20	44	55	90	57	103	28	16
C-69 Canal at Palm Bay Boulevard												
1988		4	10	2	1	1	1	2	1	1	1	1
1989	2	2	2	1	1	2	3	15	2	10	4	4
1990	3	3	2	1	0	0	1	4	3			
1991			4	4	6	6	17	5	6	8	2	2
1992	2	2	2	3	1	17	6	4	5			
Mean	2	3	4	2	2	5	6	6	3	6	2	2

Note: Blank cells indicate no record

Table 7. Monthly average discharge of the C-1 canal near MS-1 (in cubic feet per second)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1956	43	35	29	37	43	42	56	58	145	930	366	135
1957	105	52	107	81	103	85	119	154	194	134	41	63
1958	352	161	249	104	40	32	44	57	55	87	51	41
1959	66	85	274	93	52	326	147	120	171	310	112	64
1960	41	97	478	101	135	395	516	208	769	655	81	43
1961	66	48	42	52	31	38	105	43	57	40	35	31
1962	30	27	35	23	18	31	108	297	435	104	56	35
1963	40	128	106	33	34	66	71	85	336	196	186	91
1964	167	205	54	30	39	58	34	179	483	135	55	58
1965	38	49	51	43	22	114	123	72	35	76	107	44
1966	133	232	136	38	51	477	207	282	151	330	57	48
1967	44	67	42	34	28	132	375	284	85	70	36	43
1968	42	42	39	37	91	1,015						
1977			74*	38*	41	166	96	126	312*	230*	238	370
1978	175	216	226	79	87	197	270	384	127	153	131	89
1979	340	112	70	34	181	108	118	161	621	219	114	92
1980	128	174	109	87	94	65	76	60	80	72	65	88
Mean	113	108	125	56	64	197	154	161	254	234	108	83

Note: Blank cells indicate no record. No data were collected from July 1968 through February 1977.

*Incomplete record

Table 8. Monthly average discharge of Turkey Creek at Palm Bay (in cubic feet per second)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981		75*	76	69	57	53	61	74	141	68	87	50
1982	50	46	55	71	90	345	477	165	152	110	118	67
1983	113	211	256	111	53	127	64	176	180			
1987	88*	63	104	103	125	67	120	195	327	128	329	84*
1988	79	130	319*	88	52	51	98	173	202*	72	46	54
1989	165	97	180	126	115	66	123	139	116	521		
1990	72*	75	44	41	39	61	138	319	193	306	96	64
1991	74	133	105	135	98	137	264	290	268	495	148	92
1992	97	118	116	125	120	394	272	298*		215*		74
1993	156	158	319	188	64*	43	51	57	78	114*		53
1994	63	78	68	43	40*	473*	446*	437*	506*	505	544	386
1995	186	157	148	103	65	87	229	725	489	700	84	75
Mean	104	112	149	100	77	159	195	254	241	294	182	100

Note: Blank cells indicate no record. No data were collected between October 1983 and September 1986; no data were reported until January 1987.

*Incomplete record

Table 9. Highest mean discharge for various discharge events within the hydrologic year ending May31 (in cubic feet per second)

Year	1-Day Event	7-Day Event	14-Day Event	30-Day Event
C-1 Canal at Red Bud Circle				
1988	320	201	154	113
1989	275	163	125	94
1990	800	475	351	248
1991	314	256	229	155
1992	241	183	173	119
Maximum	800	475	351	248
C-1 Canal at Malabar Road				
1988	351	177	128	93
1989	207	119	103	88
1990	705	398	258	149
1991	236	201	176	139
1992	258	195	183	123
Maximum	705	398	258	149
C-69 Canal at Palm Bay Boulevard				
1988	66	23	17	11
1989	11	5	4	3
1990	119	42	29	16
1991	54	23	18	10
1992	143	38	24	17
Maximum	143	42	29	17
C-1 Canal Near MS-1				
1957	2,500	1,707	1,454	1,028
1958	1,000	614	408	363
1959	1,060	756	500	298
1960	1,540	1,250	950	533
1961	1,580	1,497	1,411	1,123
1962	213	150	137	114
1963	1,180	958	676	436
1964	1,170	880	759	465
1965	1,120	962	782	603
1966	1,250	772	521	292
1967	1,140	796	643	561
1968	732	678	595	403
1978	732	522	415	392
1979	914	604	486	429
1980	1,357	915	820	656
Maximum	2,500	1,707	1,454	1,123

Year	1-Day Event	7-Day Event	14-Day Event	30-Day Event
Turkey Creek at Palm Bay				
1981*	105	93	88	79
1982	436	209	181	144
1983	895	776	651	493
1984	577	293	250	204
1987	367	260	187	136
1988	1,220	549	441	339
1989	942	507	327	210
1990	1,970	1182	838	570
1991	757	529	461	339
1992	1,310	770	753	521
1993	1,210	704	585	482
1994	180	135	126	115
1995	2300	936	793	574
1996	3,530	1,901	1,188	730
Maximum	3,530	1,901	1,188	730

Note: No data were collected between 1968 and 1978 and between October 1983 and September 1986. The 1984 entry consists of data collected from June to October 1983; the 1987 data collection began in October 1986.

*Data available for March, April, and May 1981

Table 10. Highest mean stage for various stage events within the hydrologic year ending May31 (in feet, National Geodetic Vertical Datum)

Year	1-Day Event	7-Day Event	14-Day Event	30-Day Event
C-1 Canal Near Red Bud Circle				
1988	10.83	9.03	8.32	7.72
1989	10.19	8.38	7.66	7.01
1990	17.02	14.61	13.21	11.78
1991	11.84	11.37	11.11	10.31
1992	13.62	12.63	12.47	11.34
Maximum	17.02	14.61	13.21	11.78
C-10 Canal at Malabar Road				
1988	10.94	9.29	8.73	8.28
1989	9.68	8.70	8.57	8.31
1990	16.75	13.97	12.53	11.15
1991	12.54	12.12	11.82	11.41
1992	12.68	11.66	11.44	10.50
Maximum	16.75	13.97	12.53	11.41
C-69 Canal at Palm Bay Boulevard				
1988	21.82	21.07	20.93	20.71
1989	20.87	20.71	20.65	20.63
1990	22.94	21.23	20.89	20.61
1991	22.77	22.18	21.95	21.62
1992	23.26	21.95	21.62	21.45
Maximum	23.26	22.18	21.95	21.62
C-1 Canal Near MS-1				
1978	6.59	5.15	4.26	4.04
1979	7.43	5.68	4.80	4.34
1980	8.81	7.29	6.89	5.94
1981	8.88	8.67	8.62	8.27
1982	8.80	8.64	8.55	8.43
1983	8.42	8.33	8.26	8.22
1984	8.50	8.14	7.98	7.43
1985	8.80	8.10	8.04	7.94
1986	8.70	8.36	8.21	7.99
1987	8.70	8.13	8.07	7.68
1988	9.40	8.09	7.99	7.81
1989	8.90	8.26	8.14	8.01
1990	9.90	8.51	8.47	7.57
1991				
C-1 Canal Near MS-1—*Continued*				
1992				
1993	8.28	7.92	7.77	7.33
1994	8.61	7.82	7.72	7.48
1995	9.50	6.85	6.05	5.43
1996	10.57	8.16	7.72	7.65
Maximum	10.57	8.67	8.62	8.43
Turkey Creek at Palm Bay				
1981	0.96	0.74	0.69	0.51
1982	1.88	1.48	1.44	1.24
1983	2.90	2.25	1.82	1.55
1984	2.27	1.75	1.65	1.55
1985	3.24	2.58	1.95	1.59
1986	4.36	3.02	2.63	2.22
1987	1.78	1.57	1.43	1.14
1988	4.02	2.55	2.23	2.01
1989	2.62	1.68	1.32	1.21
1990	4.42	3.24	2.57	2.01
1991	2.11	1.85	1.62	1.45
1992	3.47	2.67	2.60	2.10
1993	3.73	2.73	2.44	2.11
1994	1.59	1.42	1.40	1.31
1995	5.42	3.74	2.99	2.23
1996	6.24	4.41	3.26	2.58
Maximum	6.24	4.41	3.26	2.58

Note: Blank cells indicate incomplete record

Table 11. (A) Subbasin areas before and after construction of the L-74N levee and (B) the impact on the Upper St. Johns River Basin restoration efforts

A.

Subbasin	Pre-Construction Area (acres)	Percent of Pre-Construction Area	Area Removed (acres)	Post-Construction Area (acres)	Percent of Post-Construction Area
C-2	3,916	5.63	160	3,756	6.54
SW C-1A	5,120	7.36	4,160	960	1.67
C-1A	15,424	22.17	7,802	7,622	13.27
C-38	5,062	7.28	0	5,062	8.81
C-9R	3,101	4.46	0	3,101	5.40
C-10	8,787	12.63	0	8,787	15.30
C-61	6,053	8.70	0	6,053	10.54
C-69	3,896	5.60	0	3,896	6.78
C-37	8,384	12.05	0	8,384	14.60
C-1	3,055	4.39	0	3,055	5.32
C-82	1,890	2.72	0	1,890	3.29
TC South*	4,875	7.01	0	4,875	8.49
Total	69,563	100.00	12,122	57,441	100.01

*TC South is not within the Melbourne-Tillman Water Control District but contributes runoff to the flow gaged in Turkey Creek at Palm Bay

B.

Restoration Area	Pre-Construction Area (acres)	Post-Construction Area (acres)
Three Forks Marsh Conservation Area	0	8,640
Sawgrass Lake Water Management Area	0	2,240
C-1 Retention Area	0	1,242
Total	0	12,122

Table 12. Area of soils by type in the Melbourne-Tillman Water Control District

Soil Name	Area (acres)	Percent
EauGallie sand	12,027	19
Pineda sand	8,788	14
Malabar, Holopaw, and Pineda soils	7,360	11
Felda sand	5,899	9
Micco peat, frequently flooded	4,588	7
Myakka sand	4,381	7
Winder loamy sand	3,671	6
Wabasso sand	3,442	5
Canova peat	2,096	3
Montverde peat, frequently flooded	1,977	3
Malabar sand	1,485	2
Floridana, Chobee, and Felda soils, frequently flooded	1,480	2
EauGallie, Winder, and Felda soils, ponded	1,392	2
Basinger sand	843	1
Immokalee sand	819	1
Oldsmar sand	533	1
Quartzipsamments, smoothed	481	1
Satellite sand	470	1
Pomello sand	355	1
Felda sand, bedded	327	1
Anclote sand, depressional	295	0
Water	233	0
Electra fine sand	213	0
Myakka-Urban land complex	199	0
Myakka sand, depressional	199	0
Floridana sand	176	0
Swamp	161	0
Anclote sand	124	0
Chobee sandy loam	112	0
Pompano sand	89	0
Basinger sand, depressional	89	0
St. Johns sand	87	0
Urban land	83	0
Tomoka muck	35	0
Valkaria sand	34	0
St. Johns sand, depressional	33	0
Chobee sandy loam, frequently flooded	29	0
Orsino fine sand	21	0
Copeland complex	19	0
Anclote sand, frequently flooded	6	0
Micco peat	5	0
Palm Beach sand	4	0
Submerged marsh	3	0
Holopaw sand	2	0
Total	64,665	97

Source: USDA 1974

Table 13. Area of land use, by category, in the Melbourne-Tillman Water Control District

ID	Land Use Description	Area (acres)	Percent
100	Urban and built-up	26,942	42
110	Residential: low density	1,417	
120	Residential: medium density	17,246	
130	Residential: high density	287	
140	Commercial and services	427	
160	Extractive	10	
170	Institutional	557	
180	Recreational	271	
190	Open land	6,727	
200	Agriculture	9,694	15
210	Crops and pasture	8,974	
220	Tree crops	667	
240	Nurseries and vineyards	19	
250	Specialty farms	34	
300	Rangeland	9,477	15
310	Herbaceous	6,931	
320	Shrub and brush	996	
330	Mixed rangeland	1,549	
400	Upland forest	8,126	13
410	Upland coniferous forest	7,360	
420	Upland hardwood forest	754	
430	Upland mixed coniferous/hardwood	7	
440	Tree plantations	4	
500	Water	1,251	2
510	Streams and waterways	825	
530	Reservoirs	422	
540	Bays and estuaries	4	
600	Wetlands	6,592	10
610	Wetland hardwood forest	468	
620	Wetland coniferous forest	112	
630	Wetland forest mixed	83	
640	Vegetated nonforest wetland	5,929	
700	Barren land	1,477	2
730	Exposed rocks	57	
740	Disturbed land	1,420	
800	Transportation, communication, and utilities	1,130	2
810	Transportation	658	
820	Communications	1	
830	Utilities	472	
Total		64,689	100

MODEL SELECTION, CALIBRATION, AND VERIFICATION

This section describes the selection, calibration, and verification of the models used to simulate the hydrology and hydraulics of the MTWCD.

Two different types of simulations are used to assess the hydrology of the MTWCD: continuous simulations and event simulations. Continuous simulations evaluate the MTWCD response to rainfall for extended periods of time for the purpose of computing the annual, seasonal, and monthly water budgets. The HSPF model was selected to perform the continuous simulation because of its excellent water budgeting and long-term simulation capabilities. Event simulations evaluate the MTWCD flood response to specific storm events, such as the hypothetical 10-yr, 25-yr, and 100-yr, 24-hour storms. SWMM was selected as the model to perform event simulations because its dynamic wave routing module, EXTRAN, is especially suited to accurately computing flood stages. Flood stages are of particular interest for storm-event simulations.

HYDROLOGIC SIMULATION PROGRAM—FORTRAN MODEL

Watershed data were used to develop an HSPF model representative of the MTWCD. Subbasins were assigned parameter values based on area, soil type, land use, and topography. Discharge routing was developed from channel geometry, Manning's roughness estimates, and backwater analyses. The HSPF model was then calibrated to observed and cumulative discharge data collected over a 24-month period. The model was verified using data from a 22-month period immediately following the calibration period. Finally, additional comparisons were made to previous long-term data.

HSPF Calibration

The period January 1, 1988, to December 31, 1989, was used to calibrate the HSPF model. This period was selected for model calibration for two reasons: (1) more gaged hydrologic data were available for comparison than in other periods and (2) the rainfall data for this period represented a range of conditions, including a significant storm event. The 4-day rainfall depth for the October 1989 storm event was

7.45 in. over the MTWCD, which falls somewhere between the amount from a mean annual storm event and a 10-yr storm event.

Initial conditions for stage and discharge values were set in the model to the existing values known for the gage locations. Other initial conditions, such as soil moisture, were first estimated and then adjusted to obtain simulated and cumulative discharges that best fit the observed data.

The model was calibrated from upstream subbasins to downstream subbasins. Parameters from subbasins with observed runoff data and similar runoff characteristics were used to assign parameters to subbasins without observed runoff data. The subbasin parameters that were not gaged were adjusted as a group to gaged data in Turkey Creek at Palm Bay.

The gage in the C-1 canal near Red Bud Circle was used to develop distinct hydrologic parameters for subbasins C-2, SW C-1A, and C-1A. The gage in the C-10 canal at Malabar Road was used to develop distinct hydrologic parameters for subbasins C-38, C-9R, and C-10. The C-69 canal was not useful for calibration because of the hydrologic inconsistencies that resulted from construction on Palm Bay Boulevard and Emerson Boulevard. The small basin size and small peak discharge in the C-69 canal allowed the use of approximate results from this subbasin.

The model results were graphically compared with the gaged discharge and cumulative discharge after each simulation of the model. If the simulated results did not match the gaged data, the appropriate parameters were adjusted and the model was run again. This process continued until the best fit was achieved between the simulated and observed data.

Hydrograph Comparison. A comparison of simulated discharges to gaged discharges in Turkey Creek at Palm Bay (Figure 8) shows that the hydrographic trend was well represented by the model. Evaluation of the hydrograph can be separated into three categories: peak discharge, recession rate, and low flow.

<u>Peak Discharge.</u> Comparison of peak discharges showed that three of the four discharge event peaks compared well. March 1988, January

1989, and October 1989 peak discharges matched. The October 1989 peak discharge was gaged as 1,970 cfs and simulated as 1,995 cfs.

Recession Rate. The recession rate compared well for three of the four events. September 1988, January 1989, and October 1989 compared well. The recession rate of the March 1988 storm was overestimated.

Low Flow. The low flow, on average, compared well. However, the variations in the observed low flow were smoothed out by the model. The variability in the low flow may have been the result of direct runoff into the C-1 canal. No attempt was made to perform detailed modeling to establish discharges from these areas.

Cumulative Discharge Comparison. Comparison of cumulative discharges is a method of checking simulated runoff volumes with observed runoff volumes. A good fit occurs if the cumulative simulated discharge lies on the match line. Departures from the match line indicate overestimation of the runoff (when the simulation is above the match line) or underestimation of the runoff (when the simulation falls below the match line). At any point when the slope of the cumulative discharge curve is 1, the simulated runoff rate equals the observed runoff rate; when the slope is less than 1, the rate of runoff is underestimated; when the slope is greater than 1, the rate of runoff is overestimated.

The slope of the simulated cumulative discharge in Turkey Creek at Palm Bay (Figure 9) was approximately 1 to 1 over the majority of the curve. The only exception occurred for the March 1988 period, when the recession rate of the storm hydrograph was overestimated.

HSPF Verification

In general, three requirements should be met in selecting a period for model verification:

1. The verification period must cover a different time span than the calibrated period.

2. The verification period should be approximately as long as the calibration period.

3. The watershed should be unchanged from the calibration period.

The verification period used for the HSPF model development immediately followed the calibration period. The 22-month period extended from January 1990 through October 1991. The watershed had not changed from the calibration period, with two exceptions: Maintenance dredging had been performed in the C-2 and C-1 canals, and the water level had been maintained at 4 ft NGVD instead of 8 ft NGVD for extended periods.

Hydrograph Comparison. Simulated and gaged discharge hydrographs for Turkey Creek at Palm Bay (Figure 10) were compared using the three categories established in the calibration section: peak discharge, recession rate, and low flow.

<u>Peak Discharge.</u> Although none of the peak discharge events matched, the verification results were generally consistent with the calibration results. The March 1988 simulated discharge peak of 820 cfs resulted from a 1-day rainfall of 2.88 in. (Figure 8). For the period July through October 1990, there was no daily rainfall event greater than 2 in. Only in October 1991, when the daily rainfall was 2.56 in., was the simulated peak discharge comparatively significant. (Although the October 1991 peak discharge did not match the observed peak discharge, it did rise above 800 cfs.)

<u>Recession Rate.</u> The recession rate from the October 1990 storm was overestimated by the model. The simulated recession rates for both August and October 1991 compared well.

<u>Low Flow.</u> There are two low-flow periods: March to June 1990 and January to June 1991. Both periods were approximately represented. The simulation of the 1990 low-flow period began above and gradually fell below the observed flow. Overall, the simulation of the 1991 low flow was above the observed low flow. Again, as with the calibration, the variation of the low flow may have resulted from direct runoff into the C-1 canal that was not accounted for in the simulation.

Cumulative Discharge Comparison. Comparison of the cumulative discharge shows that, overall, the simulated runoff volume was close to the observed runoff volume (Figure 11). Only for the period July to November 1990, when several discharge peaks were underestimated, was the slope of the curve less than 1. In the January to July 1991 period, the slope was greater than 1, in accordance with the overestimation of the low flow for that period. Finally, after September 1991, the curve quickly dropped below the match line. This drop occurred because the simulation failed to match one of the discharge events in October. Overall, the simulated volume of runoff is close to the gaged volume of runoff during this period.

Comparison to Other Recorded Hydrologic Time Series

Measured rainfall data were available from the Melbourne station (NOAA 5612) for the period January 1938 to the present. Hydrologic simulations were performed for 1939 through 1991 and available discharge data for the C-1 canal near MS-1 (from January 1977 to December 1980) were compared to simulated discharges (Figure 12). This comparison was made with the knowledge that, at the time the measurements were taken, the hydrologic character of the watershed was different from the conditions under which the model was calibrated. However, given the discrepancies between simulated and gaged discharge for the verification period, additional comparisons were deemed useful. Thus, these additional checks were made to provide reassurance of the model's ability to simulate the hydrology of the MTWCD.

The impacts of increased urbanization can be evaluated by this simulation because the MTWCD was relatively less developed during 1977 through 1980. The urban area has grown since 1980. The impervious surfaces of roadways and rooftops associated with urban areas increase runoff rates and volumes. If a historical rainfall were to occur under existing watershed conditions, then greater peak discharges would be expected because of urbanization. However, the simulated results should generally have the same hydrograph patterns as those measured.

Peak Discharge. As might be expected, the high simulated discharges represent, in part, the change in land use and the increased urban development in the area. The simulated discharge hydrograph for Turkey Creek at Palm Bay from January 1977 to December 1980 (Figure 12) closely resembles the observed hydrograph. However, the model overestimated the peak discharge events of November 1977, August 1978, January 1979, and September 1979 by 100%, 48%, 52%, and 30%, respectively. Observed peak discharges from 1-day rainfall amounts of 3 to 7 in. ranged from 700 to 1,200 cfs for the same rainfall events. The model produced peak discharges of 1,000 to 1,800 cfs. This overestimation in peak discharges is due to urbanization, and the results are consistent with calibration of the model, in which a 1-day rainfall of about 6 in. produced a peak discharge of 2,000 cfs for October 1989.

Recession Rate. The recession rates following each storm event are close to the observed recession rate, except for the August 1978 event. This overestimation can be attributed to the overestimate of the entire storm hydrograph.

Low Flow. On average, for all but the April to July 1980 period, the base of the simulated flow is close to the observed flow. Again, as in the previous comparison, the variation in the low flow is not represented by the model.

Cumulative Discharge. Overall, the simulated volume of water compares well to the measured volume of water (Figure 13). From April 1977 to July 1978, the simulated volume of water underestimates the measured volume of water by approximately 17%. This underestimation is due primarily to missing small discharge events that range from 200 cfs to 700 cfs. From August 1978 to September 1979, the simulated volume of water rises to the match line. From this point, the simulated curve remained close to the match line.

Discharge-Duration Relation

The discharge-duration curve shown on Figure 14 characterizes the daily average discharge from January 1939 to October 1991. Flows from MS-1 into Turkey Creek were greater than 35 cfs 90% of the time, greater than 90 cfs 50% of the time, and greater than 250 cfs 10% of the time.

Summary of HSPF Performance

The hydrologic model of the MTWCD was calibrated, verified, and compared to extended periods of observed discharge and runoff volume data. The model represents the hydrologic character of the

MTWCD for 1990 conditions. Long-term data generated by the model for 1939 through 1991 showed peak discharges that were higher by 30% to 100% compared to the observed peak discharges for 1977 through 1980. This overestimation of peak discharges reflects that the model has taken into account the urbanization that took place in the MTWCD between the 1970s and the 1990s.

Storm Water Management Model

SWMM was calibrated to peak stage, peak discharge, timing, and storm volume for a single storm event. The model was verified using another larger storm event. Whereas the HSPF model produces daily average results that are compared to daily average observations, the SWMM results are displayed for each hour and compared to hourly observed values.

SWMM Calibration

The October 1989 storm event was selected for model calibration. More gaged data were available for this event than for other storm events. Thus, more data could be used to match model results. Model results were compared to discharge gaged in Turkey Creek at Palm Bay, to stage gaged in the C-10 canal at Malabar Road, and to stage gaged in the C-1 canal near Red Bud Circle.

Rainfall data for the October 1989 storm were obtained from the Melbourne station (NOAA 5612) and the USGS C-69 station at Eber Road. Only these two rain gages were collecting hourly rainfall at that time. Because of the proximity of the two stations and because some NOAA records were missing, the data from the C-69 gage were used to supplement the NOAA data. Thus, only one rainfall time series was used as input.

To establish appropriate antecedent conditions, data were input for a 1-month period prior to the storm event. Base flow observed before the October 1989 storm was entered as a constant inflow into the canals.

SWMM was calibrated first to the discharge in Turkey Creek at Palm Bay. To match the discharge, infiltration parameters were proportionally adjusted throughout all of the subbasins to approximate the gaged discharge. Once the simulated discharge matched the gaged discharge, parameter adjustments were made to individual subbasins to match the gaged stage inside the MTWCD. While matching the gaged stages within the MTWCD, care was taken not to alter the match to the discharge hydrograph in Turkey Creek.

The simulated discharge hydrograph for Turkey Creek at Palm Bay exhibits a two-peaked feature similar to the hydrograph of the gaged discharge (Figure 15). The first simulated peak, at 2,635 cfs, was comparable to the first gaged peak (2,640 cfs); the second simulated peak, at 2,477 cfs, was also close to the second gaged peak (2,530 cfs).

The recession of the simulated hydrograph fell more rapidly than that of the gaged hydrograph. One main reason for this may be the limited data available to represent the rainstorm. The 96-hour rainfall total for the October 1989 storm was determined to be 6.18 in. using the NOAA and USGS data. This total differs from the 96-hour depth of 7.45 in. used to calibrate the HSPF model, where a weighted average from five stations was used.

The peaks matched for the total simulated stage and gaged stage for the C-10 canal at Malabar Road (Figure 16). However, the recession rate of the simulated stage hydrograph was slower than the gaged stage. The difference in recession rates can be explained by the gate operation of the MS-1 structure. The model approximated the MS-1 gate operation by assigning a specific discharge to a given elevation. However, in reality, the gate operator opens the MS-1 gates in reaction to a storm to quickly lower the flood stage.

The gaged peak stage was approximately a half foot higher than the simulated peak stage for the C-1 canal near Red Bud Circle (Figure 17). This difference was not necessarily caused by the model—it may have resulted from the shifting of the gage.

The gaged peak stage in the C-1 canal was also approximately a half foot higher than the C-10 peak stage. Comparison of the two stages gaged on October 8, 1989, reveals that the C-1 stage was also approximately a half foot higher than the C-10 stage preceding the storm.

However, subsequent water surface profile analysis using the HEC-2 model did not support this result. For low-flow and high-flow conditions using surveyed cross-sections, and accounting for the proximity of the gages and the discharge rate, the analysis verified that the water surface elevations should have been approximately level before and during the storm. To achieve the half-foot water elevation difference at high flows would require raising Manning's roughness coefficient in the C-1 canal above 0.08, a level well above the acceptable value for this open channel.

This discrepancy raised a question concerning the accuracy of the datum for each gage. The gages in the C-1 and C-10 canals were removed before this discrepancy was discovered. For this reason, a verification of the data could not be made. However, information about the gates themselves was used to determine which data set was likely to be the most accurate.

The C-10 gage was attached to the Malabar Road bridge (a reinforced concrete bridge). The C-1 gage was attached to a temporary wooden platform constructed from the bank out into the channel. The Malabar Road bridge is a permanent and stable structure, less susceptible to shifting or settling, and its surveyed datum is probably more reliable. For these reasons, the peak stage in the C-10 canal at Malabar Road was accepted as the more accurate gage of stages in the C-10 and C-1 canals. Based on this information, we concluded that the half-foot discrepancy between simulated and gaged stages in the C-1 canal was not the result of simulation deficiency.

SWMM Verification

SWMM produced discharge and stage results that matched the hydrologic character of the MTWCD during storm events. Two possible biases must be mentioned. First, the recession of the stage was slower than the gaged stage. Second, the model may overpredict peak flood stages for storm events approximately equal to or greater than the 25-yr event.

The model was verified using data from Hurricane Erin, which occurred in August 1995. This event was larger than the October 1989 event. The 96-hour rainfall depth was 8.44 in. over the MTWCD compared to 7.45 in. in October 1989.

Note that more rainfall stations were used as input for verification than for calibrating (the Palm Bay Sewage Treatment Plant had been converted to hourly collection by this time). The use of additional rain gages for the August 1995 storm event improved the representation of the areal rainfall distribution over the MTWCD. Also, as was done for calibration, one time-series input was used from the Melbourne station (NOAA 5612) and the USGS C-69 station at Eber Road due to the proximity of the stations and the consistency of the data.

The simulated peak discharge in Turkey Creek at Palm Bay was 5,530 cfs compared to the gaged discharge of 5,140 cfs, an overestimation of 7.6% (Figure 18).

Figure 19 shows the simulated stage in the C-10 canal at Malabar Road. The X marks the estimated time and elevation of a water surface observation at the Port Malabar bridge over the C-10 canal. The observed stage of 17.8 ft NGVD was not necessarily the peak stage, but it proved useful for setting the minimum acceptable stage which the simulated stage hydrograph needed to match. The simulated peak flood stage was 18.6 ft NGVD, a reasonable result. For this larger storm event, the modeled result was a greater discharge and a higher flood stage than for the calibrated event.

Comparison to Previous Studies

For additional verification, the 10-yr, 25-yr, and 100-yr storm events were simulated using SWMM and compared with the results from previous studies. Flood discharges into Turkey Creek from the smaller storm events (10-yr storm events) calculated in this study were not as high as in previous analyses (FEMA 1989a) (Table 14). However, for larger storm events (100-yr storm events) the flood discharges were comparable.

One possible explanation for the differing results for the 10-yr storm events may be that the model used to generate the FEMA results was not calibrated to gaged stage and discharge. The 10-yr, 24-hour rainfall depth used by FEMA was 8.0 in. compared to 7.5 in. used by SJRWMD. This greater rainfall depth also contributed, in part, to FEMA's higher 10-yr storm-event results. The reason the 100-yr storm-event peak discharges show better agreement is that the 24-hour rainfall depth used to calculate the FEMA results was 11.0 in. (as reported in U.S. Department of Commerce 1961), whereas the SJRWMD results were calculated using 12.5 in. (as reported in Rao 1991). This lower rainfall, in combination with the higher runoff rate (assumed from comparison of the 10-yr storm event), produced comparable peak discharge results.

Figure 20 shows the SJRWMD 100-yr flood stage along the C-1 canal and the flood stage determined by FEMA (1989b). SJRWMD flood stages are lower.

There are two reasons for the difference in flood stages. First, within the City of Palm Bay, the SJRWMD 100-yr flood stage was calculated using the channel geometry of the improved canals. The canal improvements have increased storage and conveyance in the C-1 canal and lowered the flood stage. Second, west of the City of Palm Bay, the flood stage calculated by SJRWMD was the result of the hydrologic and hydraulic simulation within the MTWCD. The FEMA flood stages were obtained from two independent analyses. The flood stage from MS-1 to 1 mi west of the C-10 inflow was the result of a storm-event simulation for the City of Palm Bay. The flood stage calculation ended at the city limits. West of the City of Palm Bay, the flood stage that FEMA reported was determined from the flooding in USJRB in this vicinity. FEMA must have assumed that the western levee defining the MTWCD boundaries would fail during the USJRB flood.

FEMA does not appear to have evaluated flooding contiguously inside and outside the city limits. The scope of the current study did not allow for calculation of flooding in the MTWCD resulting from flooding in USJRB. Also, the L-74N levee is designed to hold back the USJRB 100-yr flood stage. When the levee is completed in December 1999, the 100-yr flood stage will result entirely from the 100-yr storm rainfall occurring within the MTWCD.

SWMM Results

Flooding in the MTWCD from the 10-yr, 25-yr, and 100-yr storm events is shown using flood stage profiles in the six major canals: C-1, C-2, C-10, C-61, C-37, and C-69. Flooding in the area west of the C-9R canal and south of Malabar Road is shown for each event using stage hydrographs. The flood stage at a particular location is the highest computed stage during the event.

Flood stage profiles include channel invert, location identification, and top of bank. The channel invert is the bottom of the channel or culvert as determined by the existing channel geometry. The location identification marks road overpasses and tributary inflows. The top of bank represents the lower elevation of either the right or left bank.

Some of the canals have levees along both sides. Levees occur along some reaches in canals C-1, C-2, C-61, and C-37. The top of bank for these canals is the crest of the lower levee. When the water level in the canal rises above the levee crest, the flow is represented as weir flow over the levee onto the surrounding land. The surrounding land is represented as a storage area that fills up as water pours onto the land. As the water in the canal recedes, the water stored on the surrounding land is released into the canal at the nearest downstream tributary inflow.

Flood stages in the C-1 and C-2 canals for the 10-yr, 25-yr, and 100-yr events are shown on Figure 21. Flooding in the northwest area of the MTWCD along the C-2 canal occurred during all storm events. This land is undeveloped open land and flooding causes little structural damage.

Flood stages decline slightly upstream of the C-10 canal and C-61 inflow. There are two reasons that the stages are lower in the western area: There is a large amount of storage from open land in the western area, and there is significant inflow into the C-1 canal from the C-37, C-10, C-69, and C-61 canals. This combination of storage upstream of these significant inflows creates a transitory mounding effect.

The flood stages in the C-10 canal for all storm events are shown in Figure 22. Flooding occurred for the 25-yr and 100-yr storm events.

The flood stages in the C-61 canal are shown in Figure 23. The culverts at Pace Drive and Emerson Drive restricted the flow, significantly increasing the flood stage for all events. Flooding occurred at the north end of the C-61 canal for the 10-yr, 25-yr, and 100-yr storm events.

The flood stages in the C-37 canal are shown in Figure 24. Flooding occurred at the south end of the C-37 canal for the 25-yr and 100-yr storm events.

The flood stages in the C-69 canal are shown in Figure 25. Again, flooding occurred in the north end of the C-69 canal for the 25-yr and 100-yr storm events.

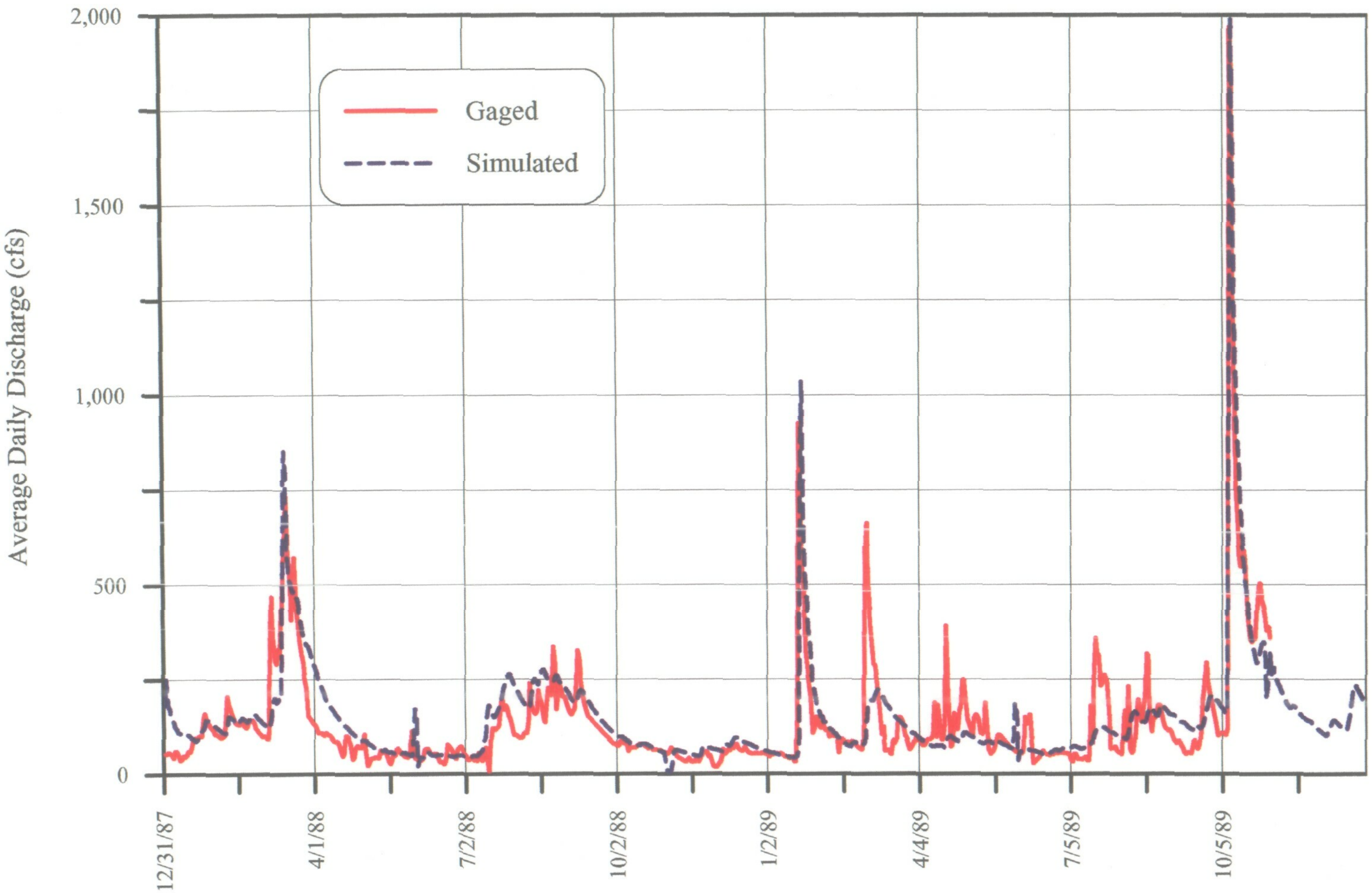


Figure 8. Comparison of simulated to gaged discharge in Turkey Creek at Palm Bay for the calibration of the Hydrologic Simulation Program—Fortran model

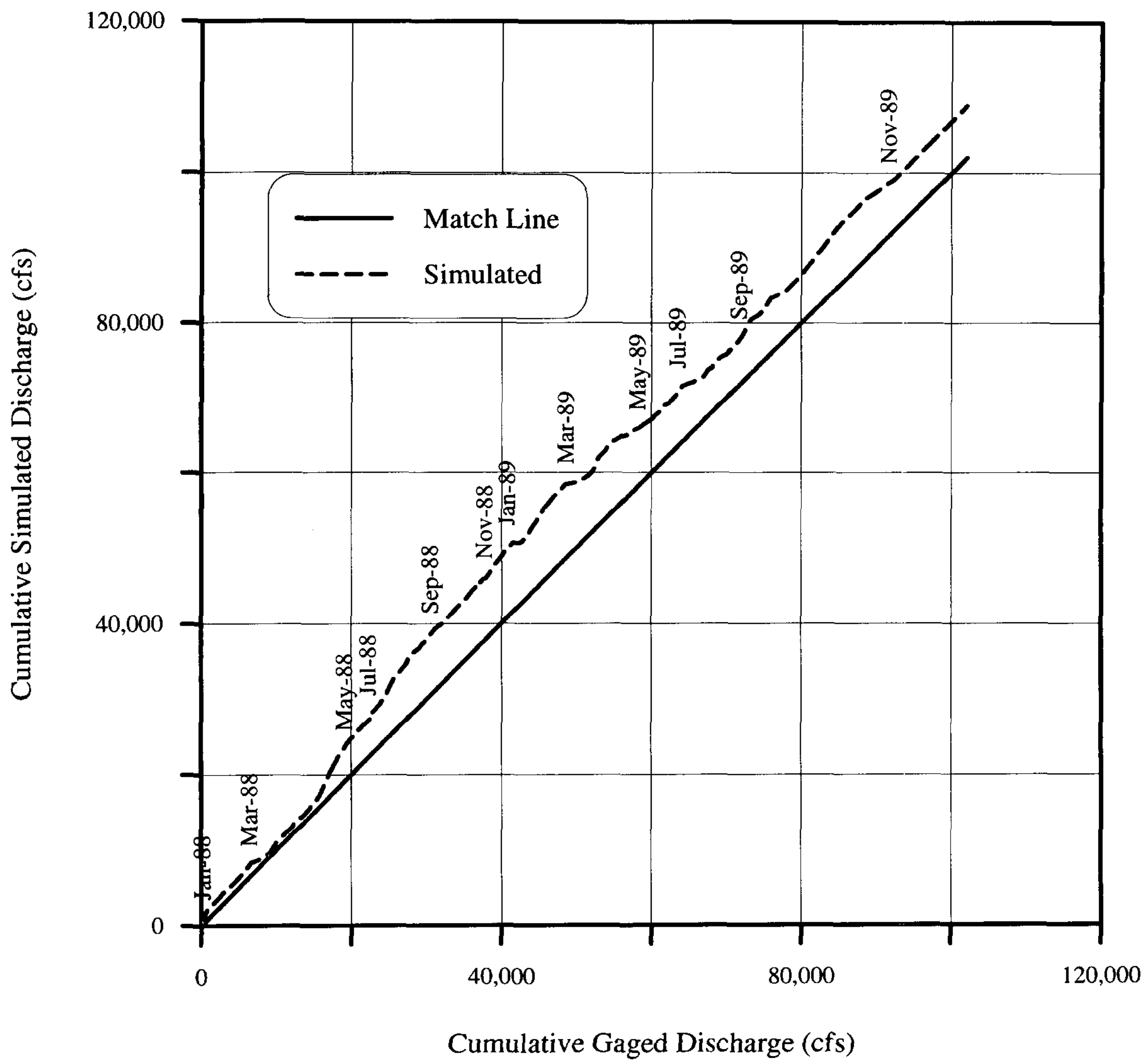


Figure 9. Cumulative simulated versus cumulative gaged discharge in Turkey Creek at Palm Bay for the calibration of the Hydrologic Simulation Program—Fortran model

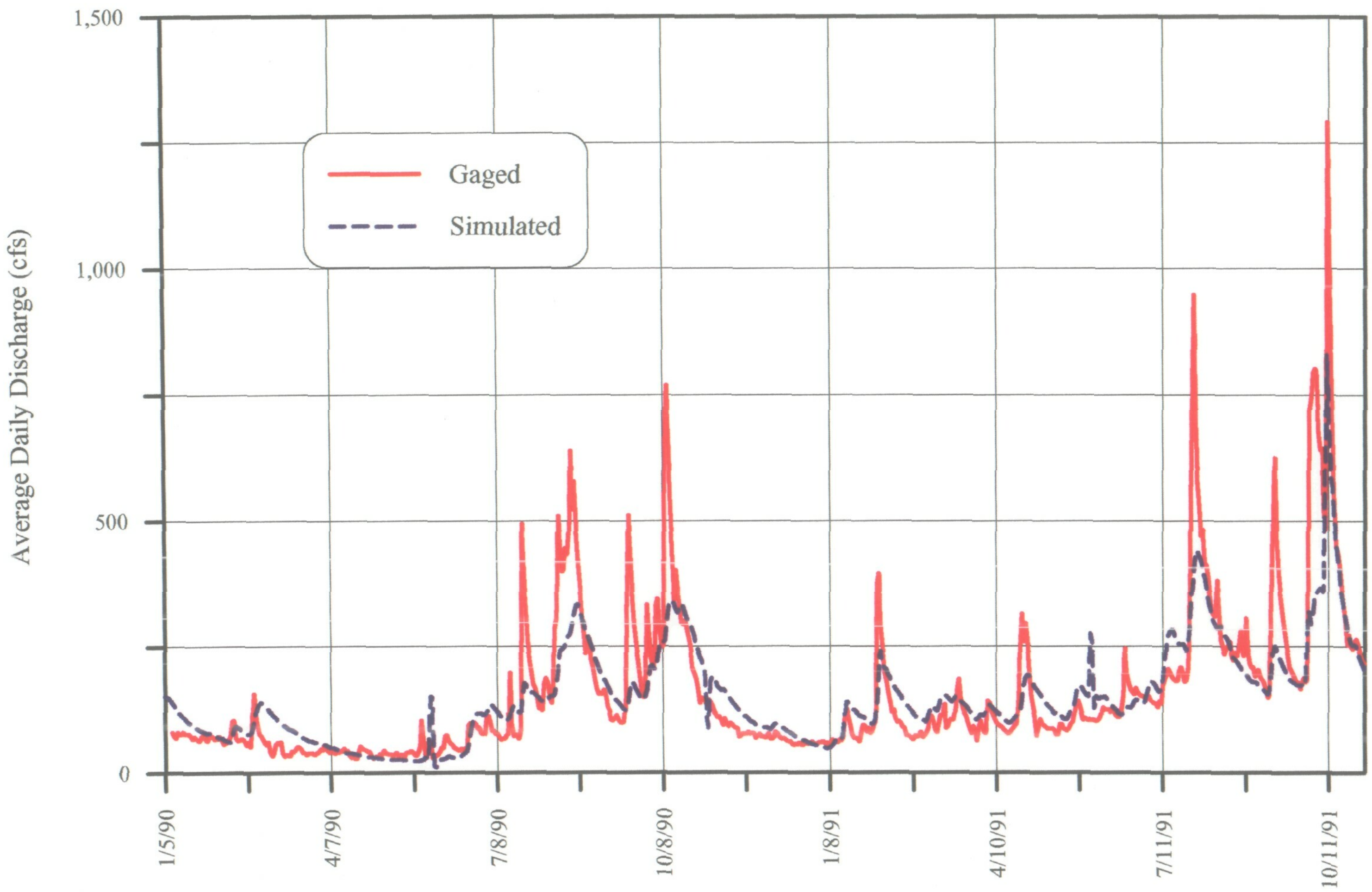


Figure 10. Comparison of simulated to gaged discharge in Turkey Creek at Palm Bay for the verification of the Hydrologic Simulation Program—Fortran model

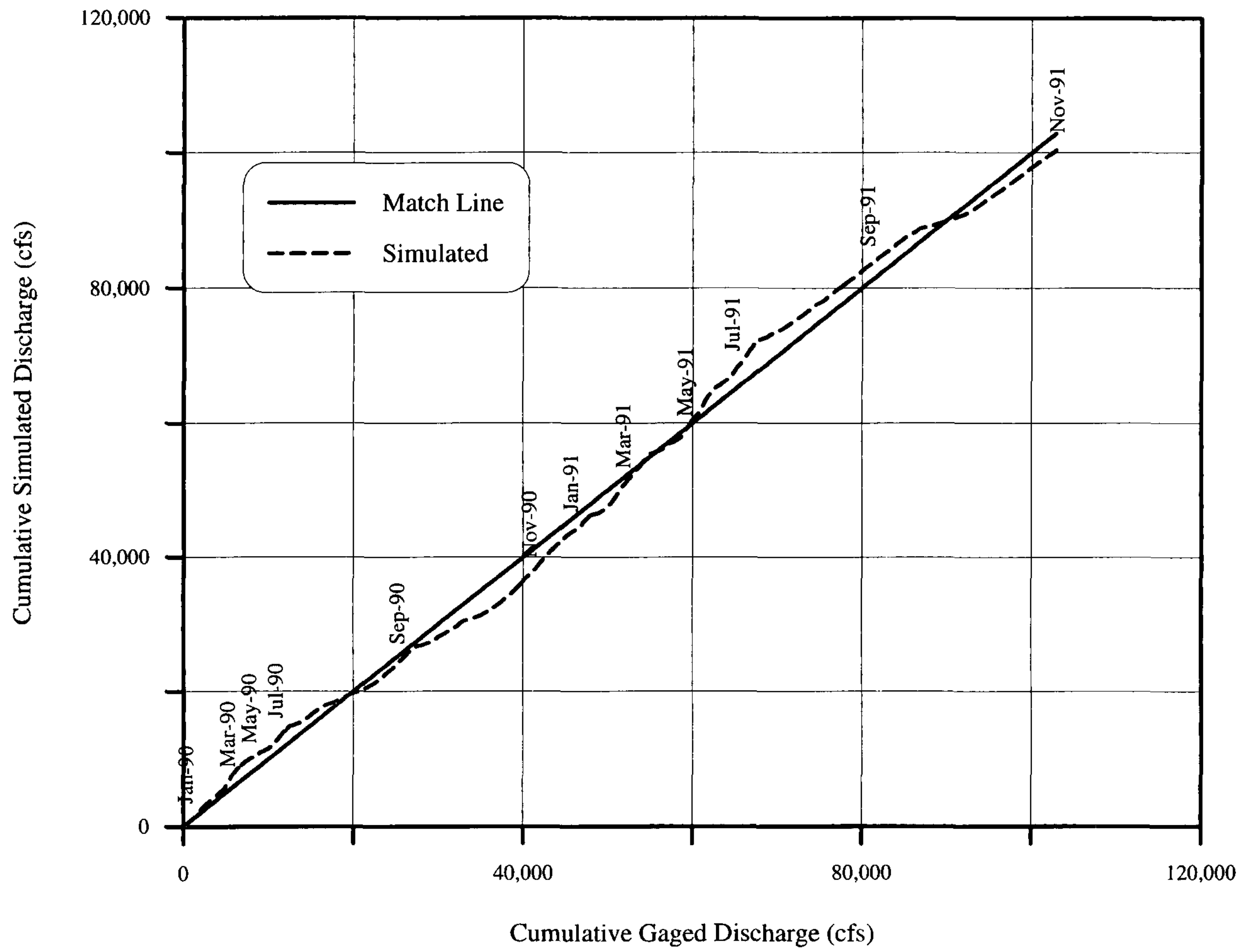


Figure 11. Cumulative simulated versus cumulative gaged discharge in Turkey Creek at Palm Bay for the verification of the Hydrologic Simulation Program—Fortran model

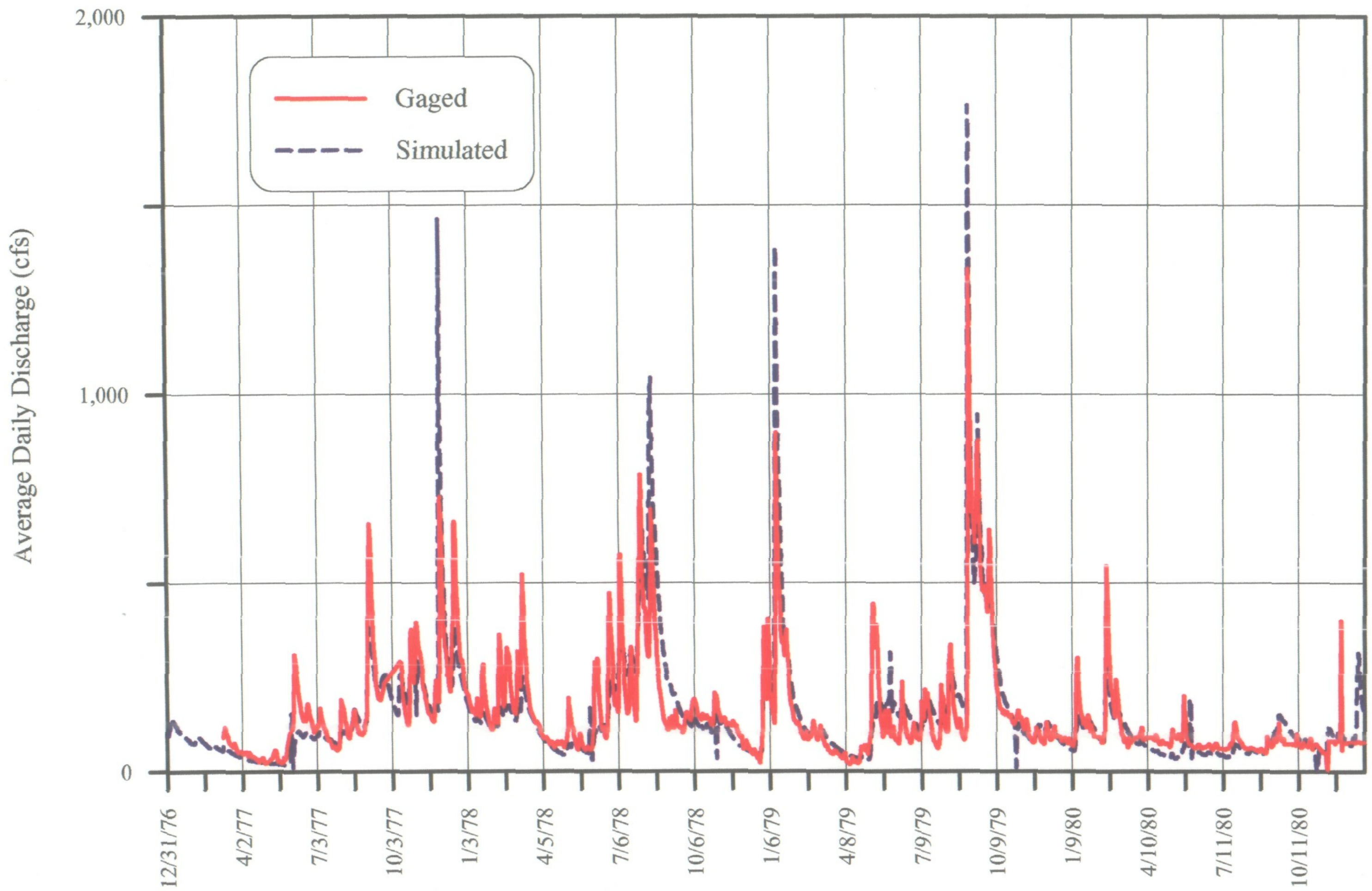


Figure 12. Comparison of simulated to gaged discharge in Turkey Creek at Palm Bay from January 1977 to December 1980 (Hydrologic Simulation Program—Fortran model)

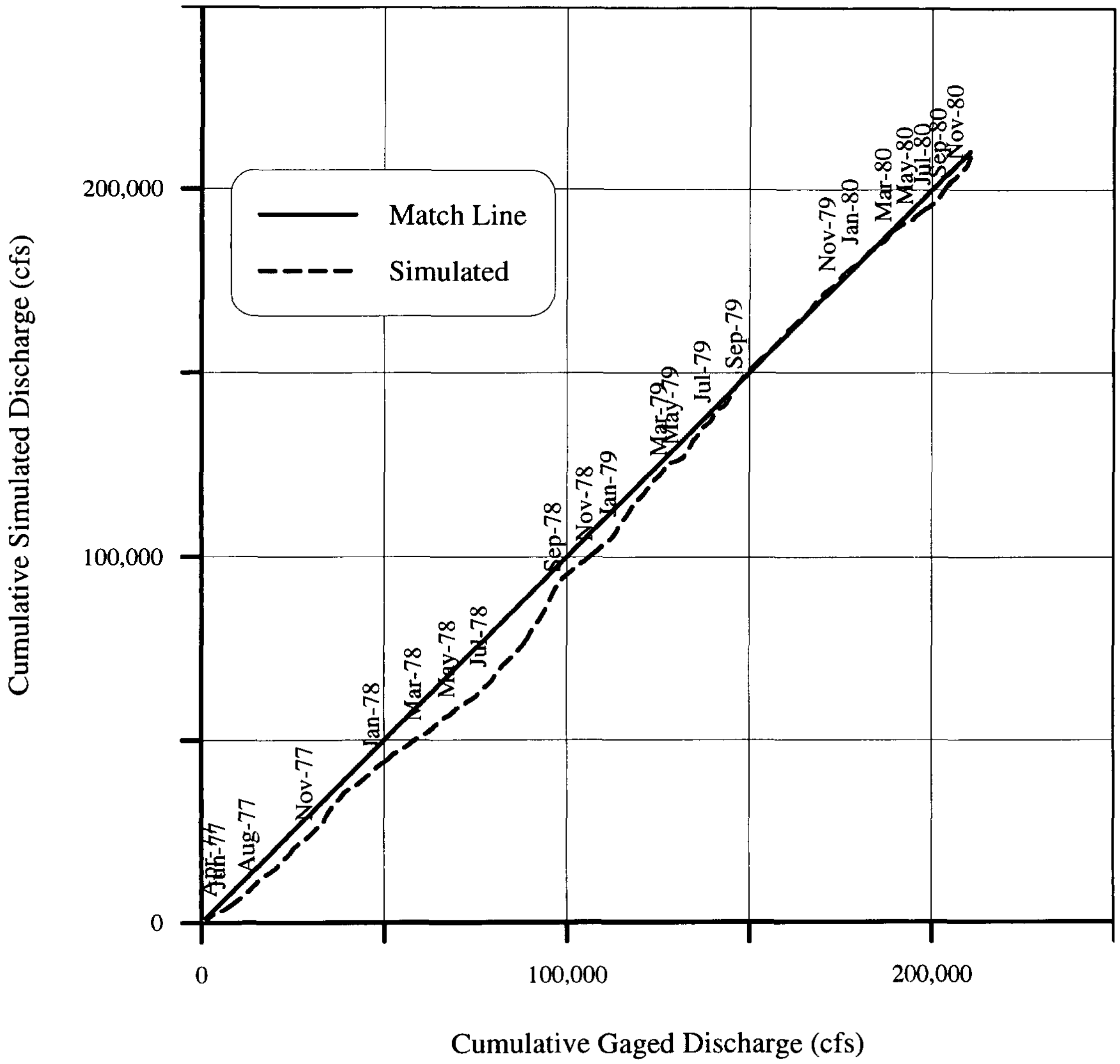


Figure 13. Cumulative simulated versus cumulative gaged discharge in Turkey Creek at Palm Bay from January 1977 to December 1980 (Hydrologic Simulation Program—Fortran model)

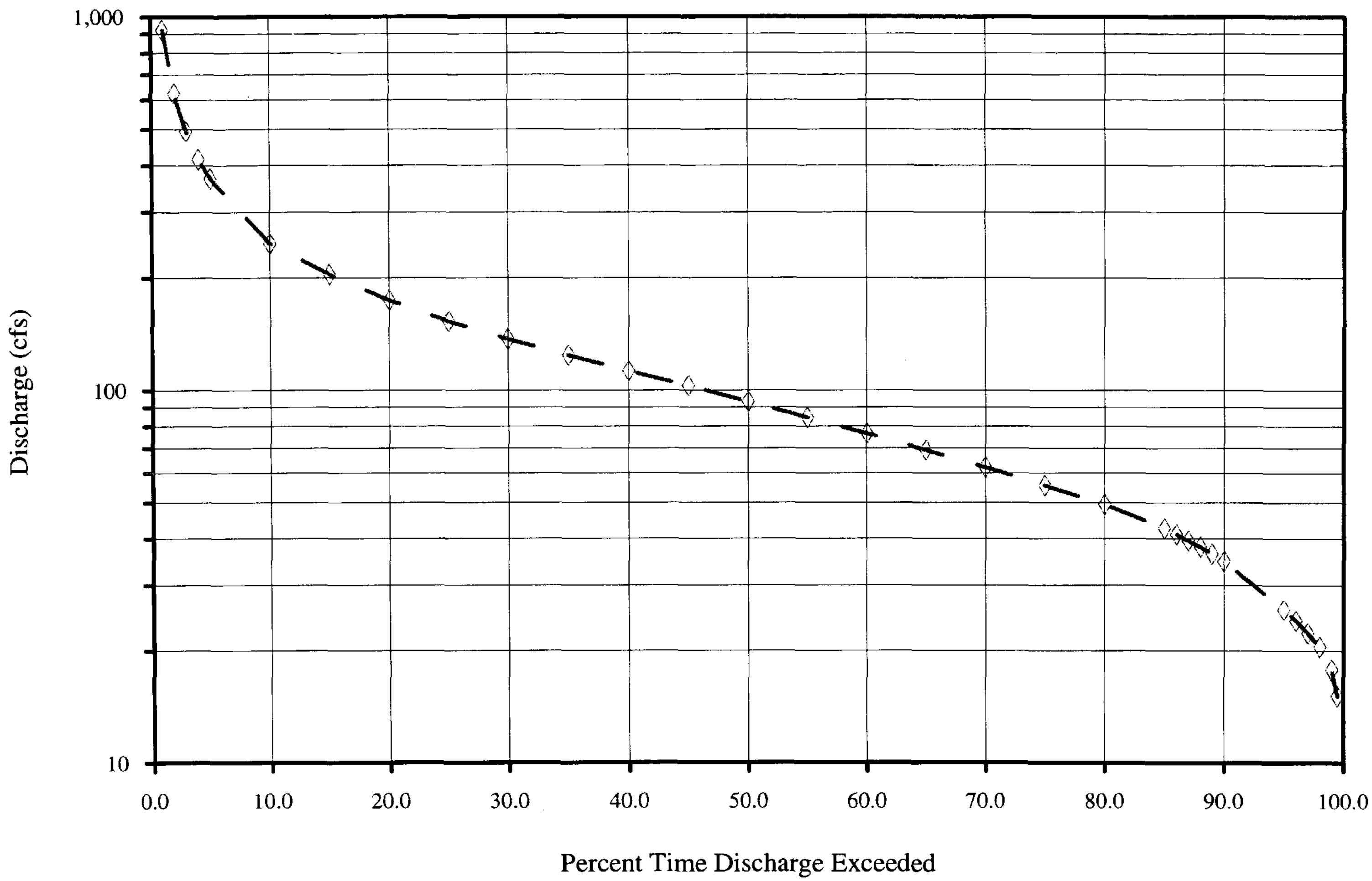


Figure 14. Discharge-duration results from the Hydrologic Simulation Program—Fortran model

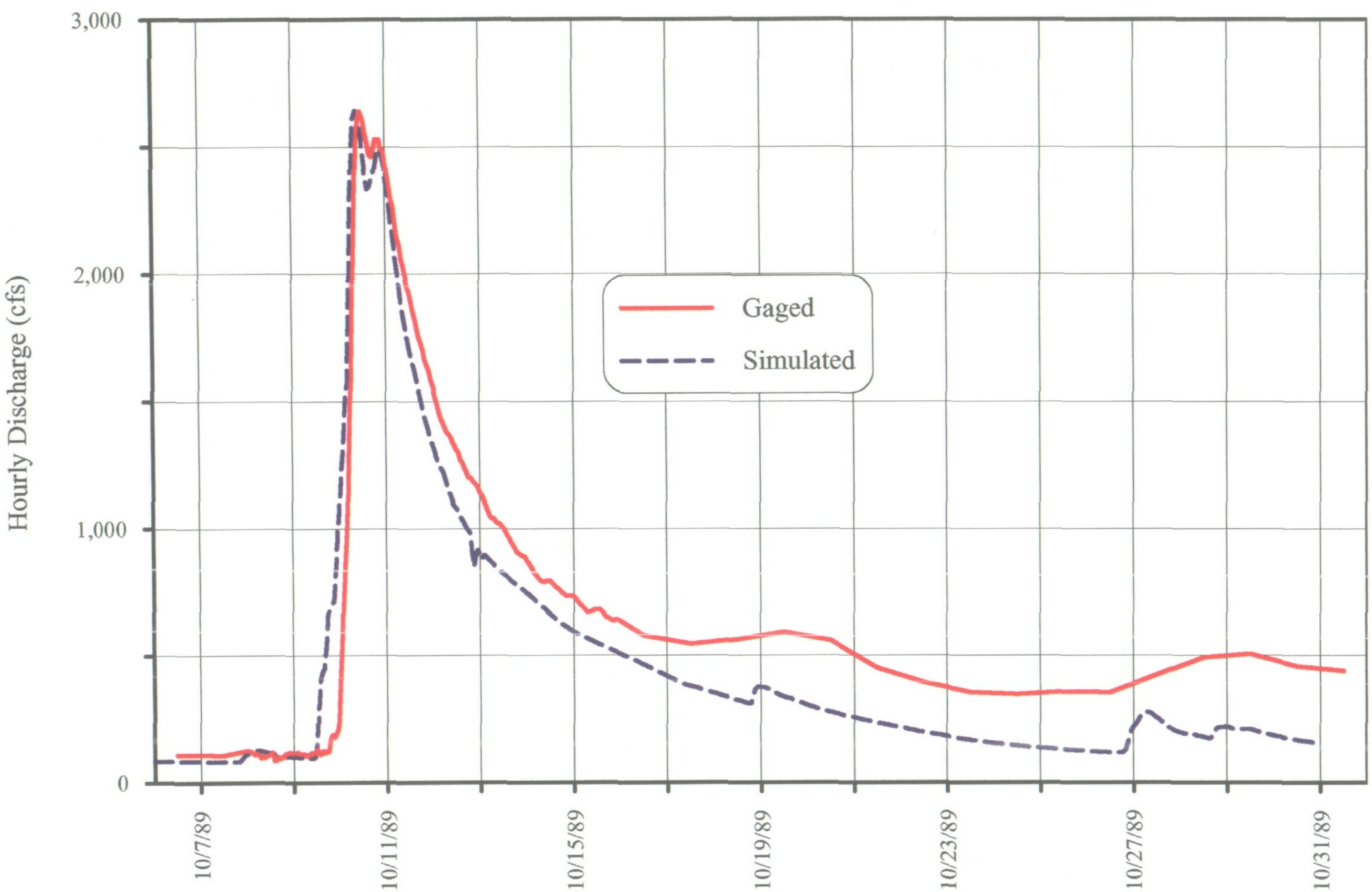


Figure 15. Comparison of simulated to gaged discharge in Turkey Creek at Palm Bay for the calibration of the Storm Water Management Model

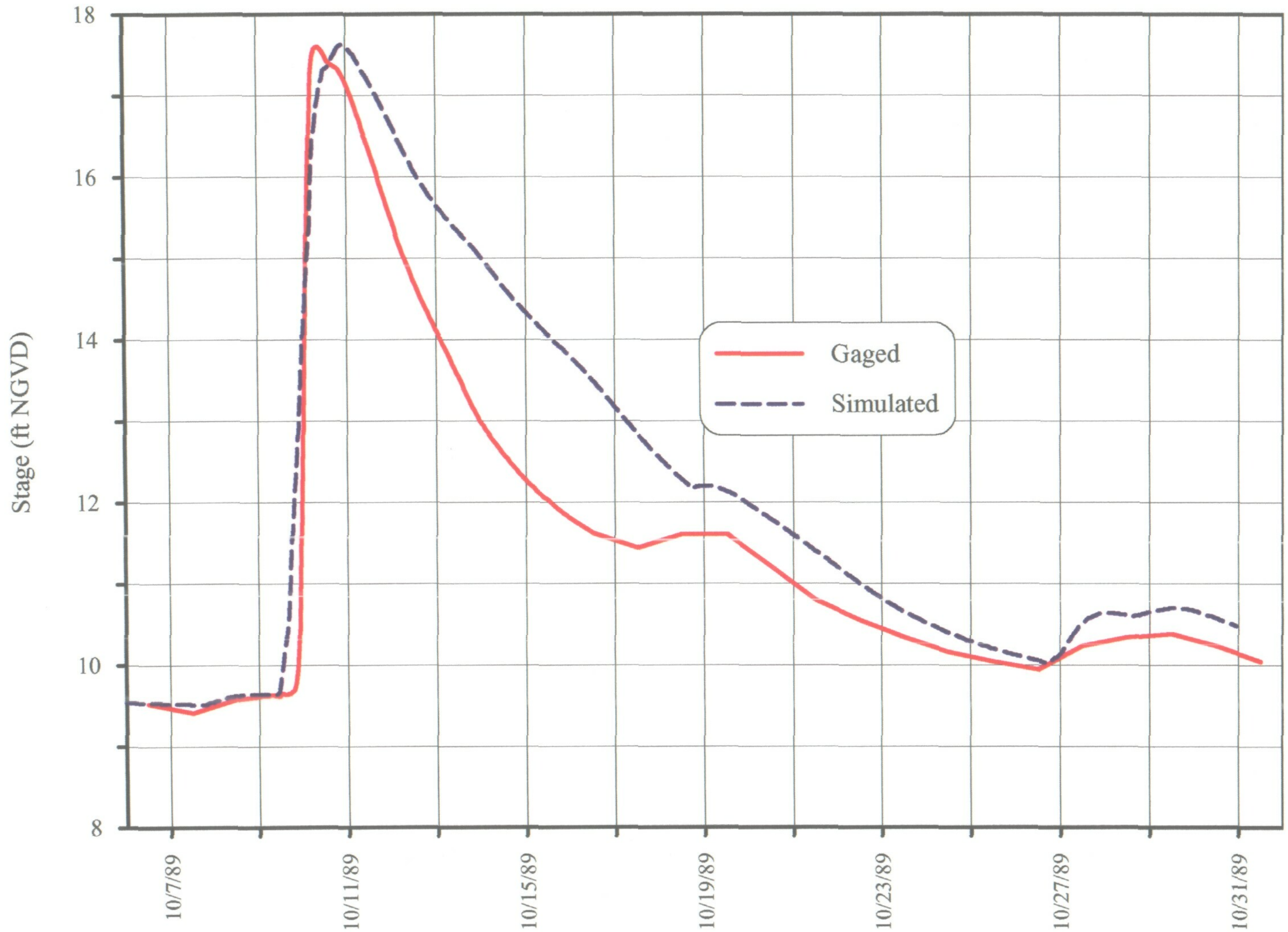


Figure 16. Comparison of simulated to gaged stage in the C-10 canal at Malabar Road for the calibration of the Storm Water Management Model

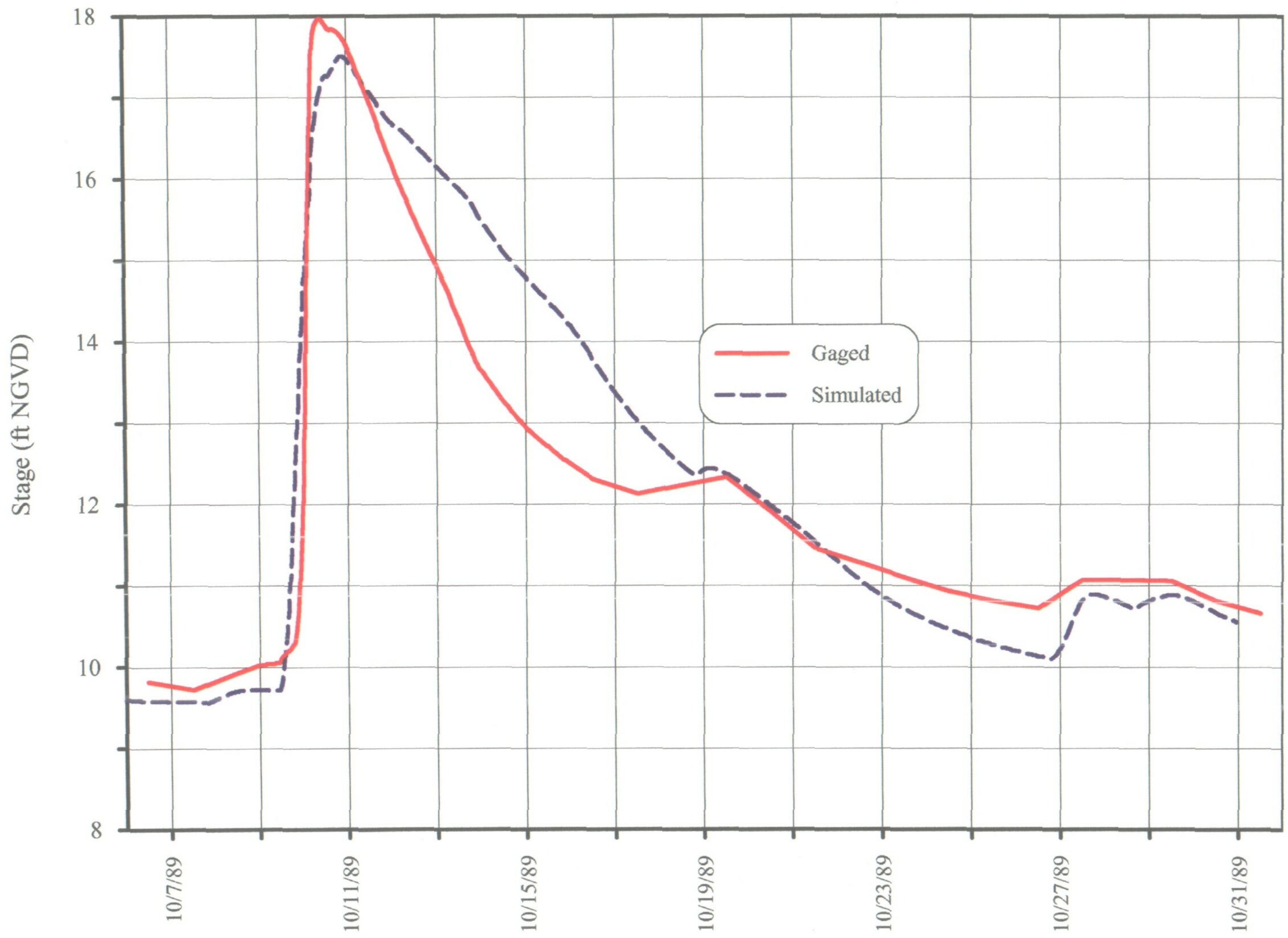


Figure 17. Comparison of simulated to gaged stage in the C-1 canal near Red Bud Circle for the calibration of the Storm Water Management Model

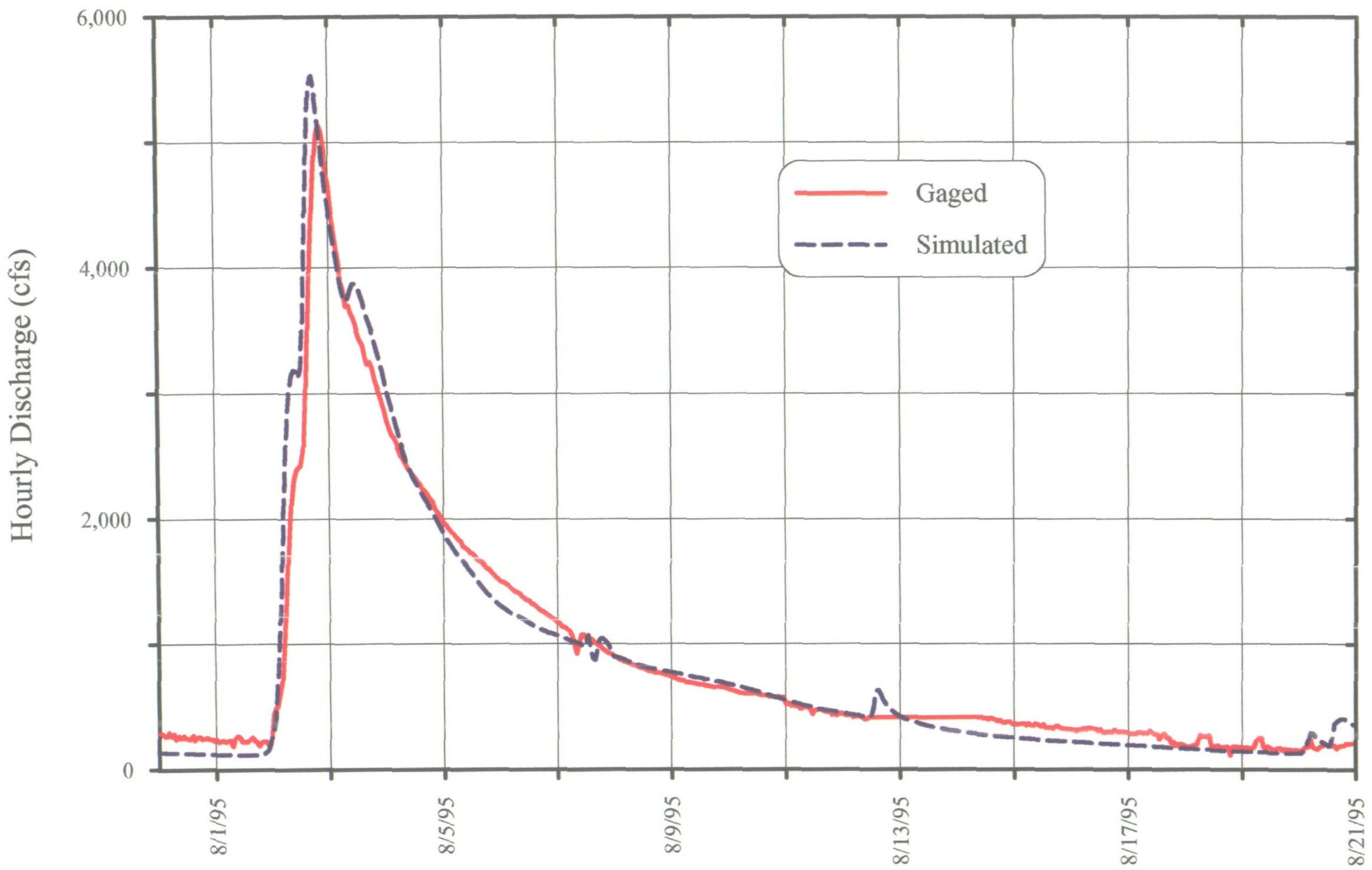


Figure 18. Comparison of simulated to gaged discharge in Turkey Creek at Palm Bay for the verification of the Storm Water Management Model

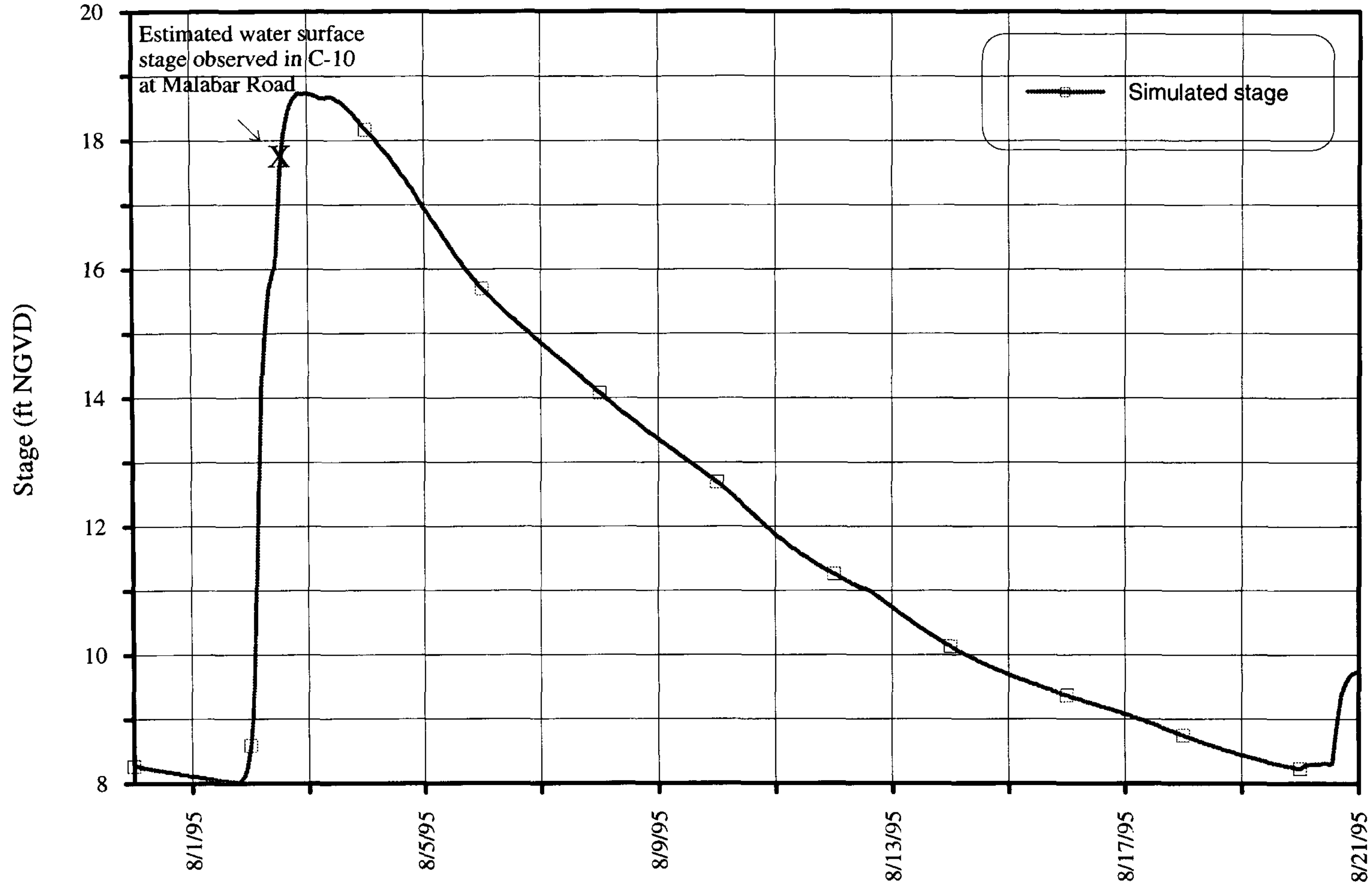


Figure 19. Comparison of simulated peak stage to an observed stage in the C-10 canal at Malabar Road for the verification of the Storm Water Management Model

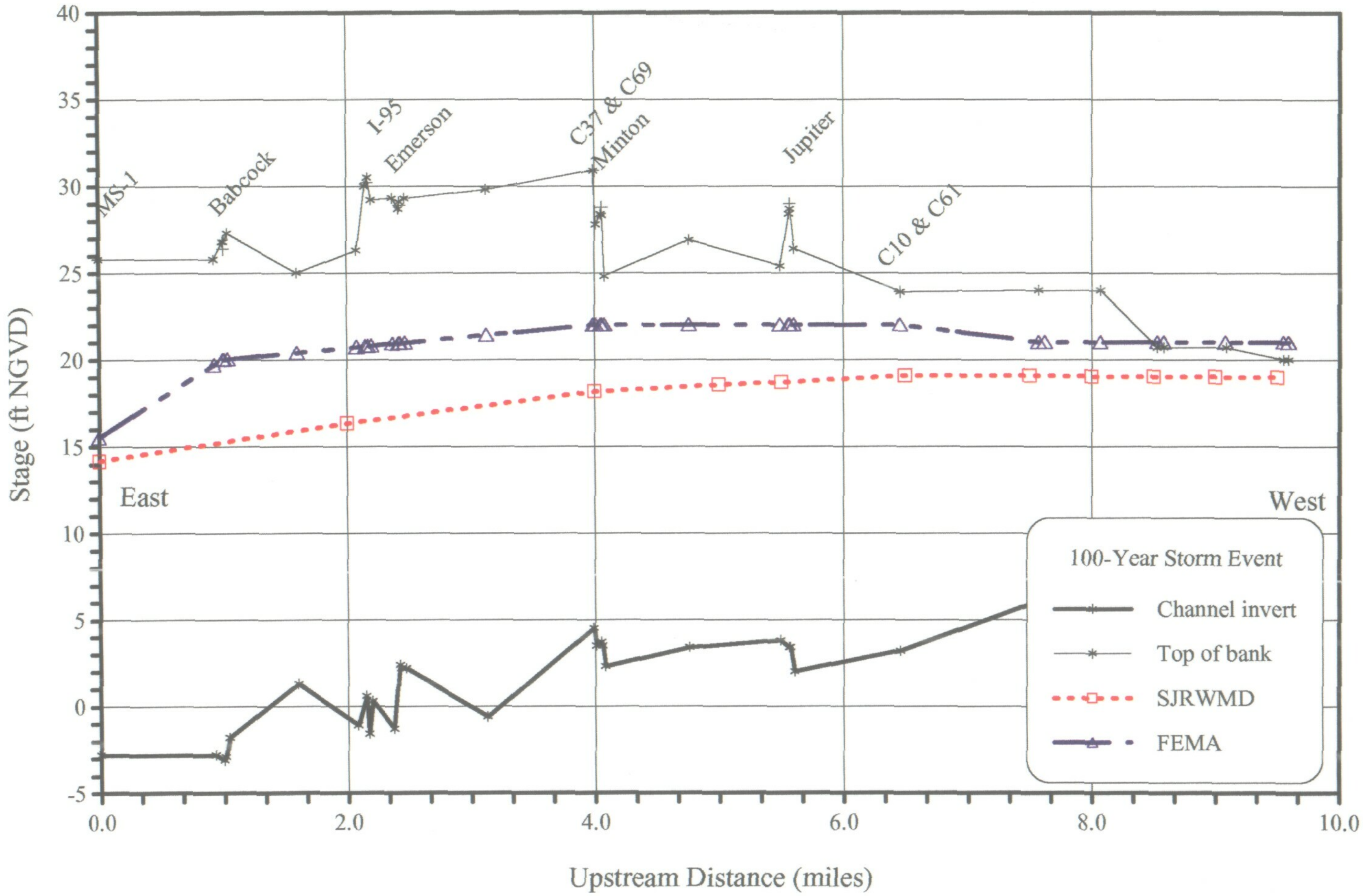


Figure 20. Comparison of the Federal Emergency Management Agency (FEMA) to the St. Johns River Water Management District (SJRWMD) 100-year flood profile along the C-1 canal

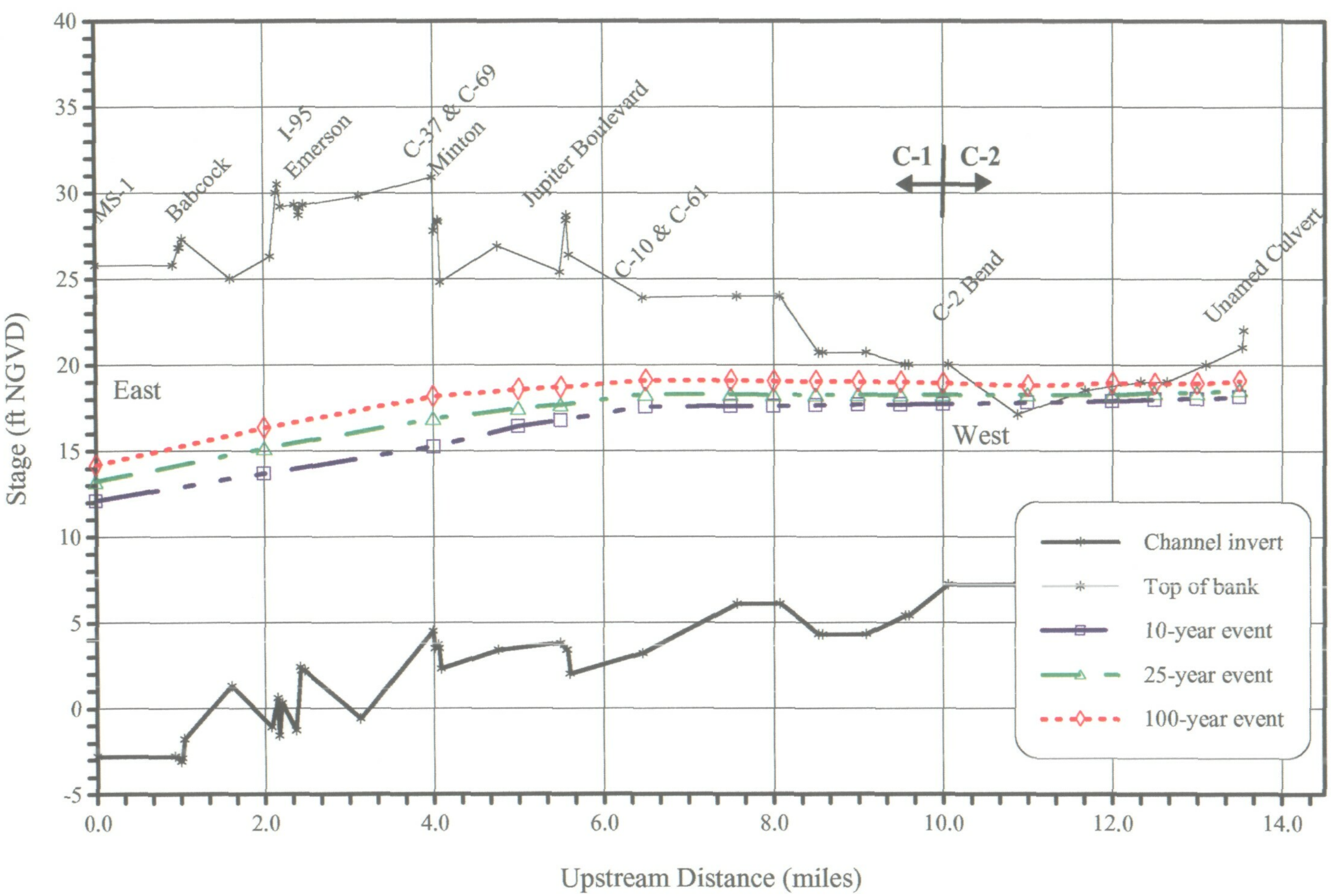


Figure 21. Flood stages in the C-1 and C-2 canals from MS-1

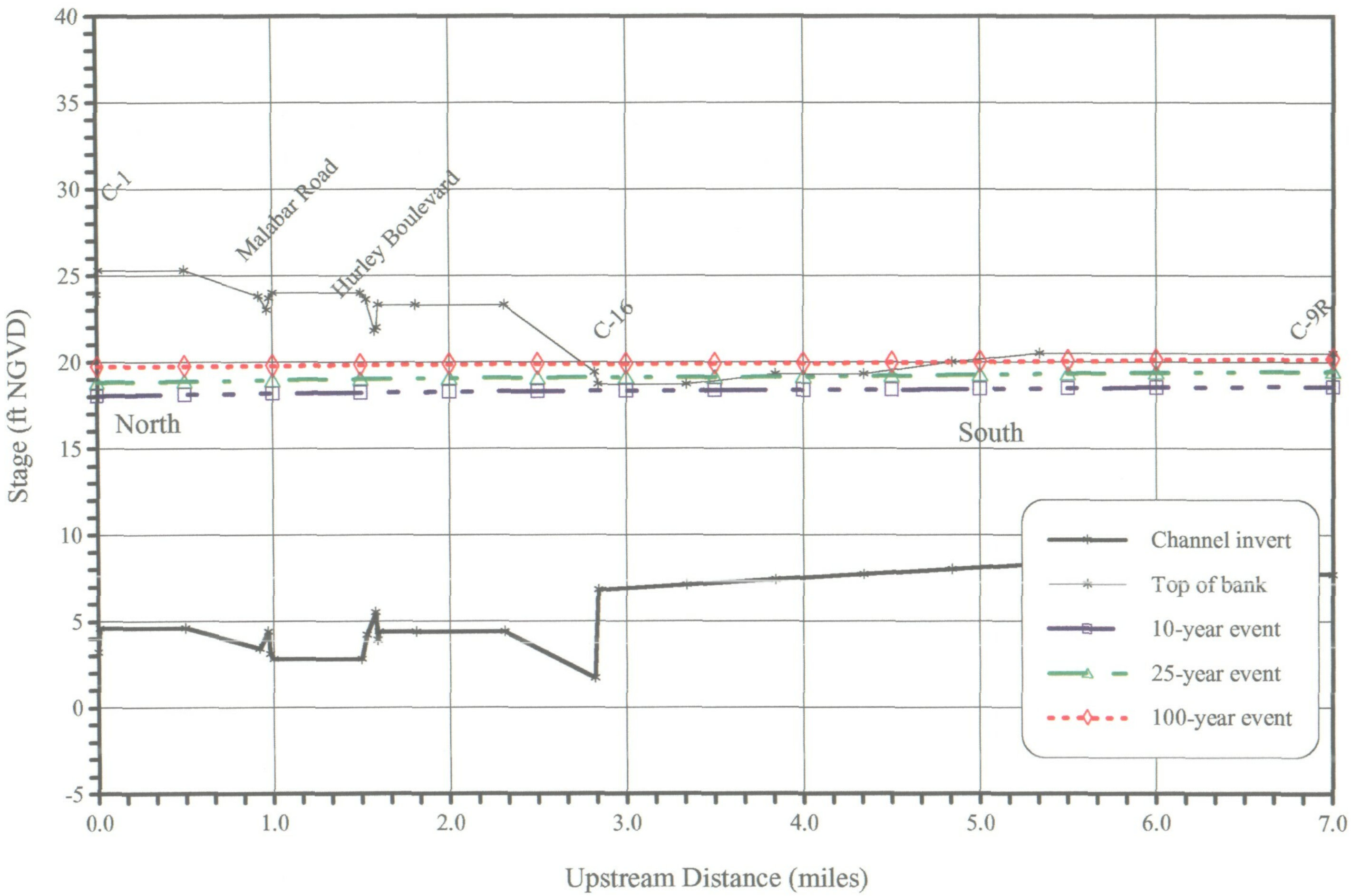


Figure 22. Floods stages in the C-10 canal from the C-1 canal to the C-9R canal

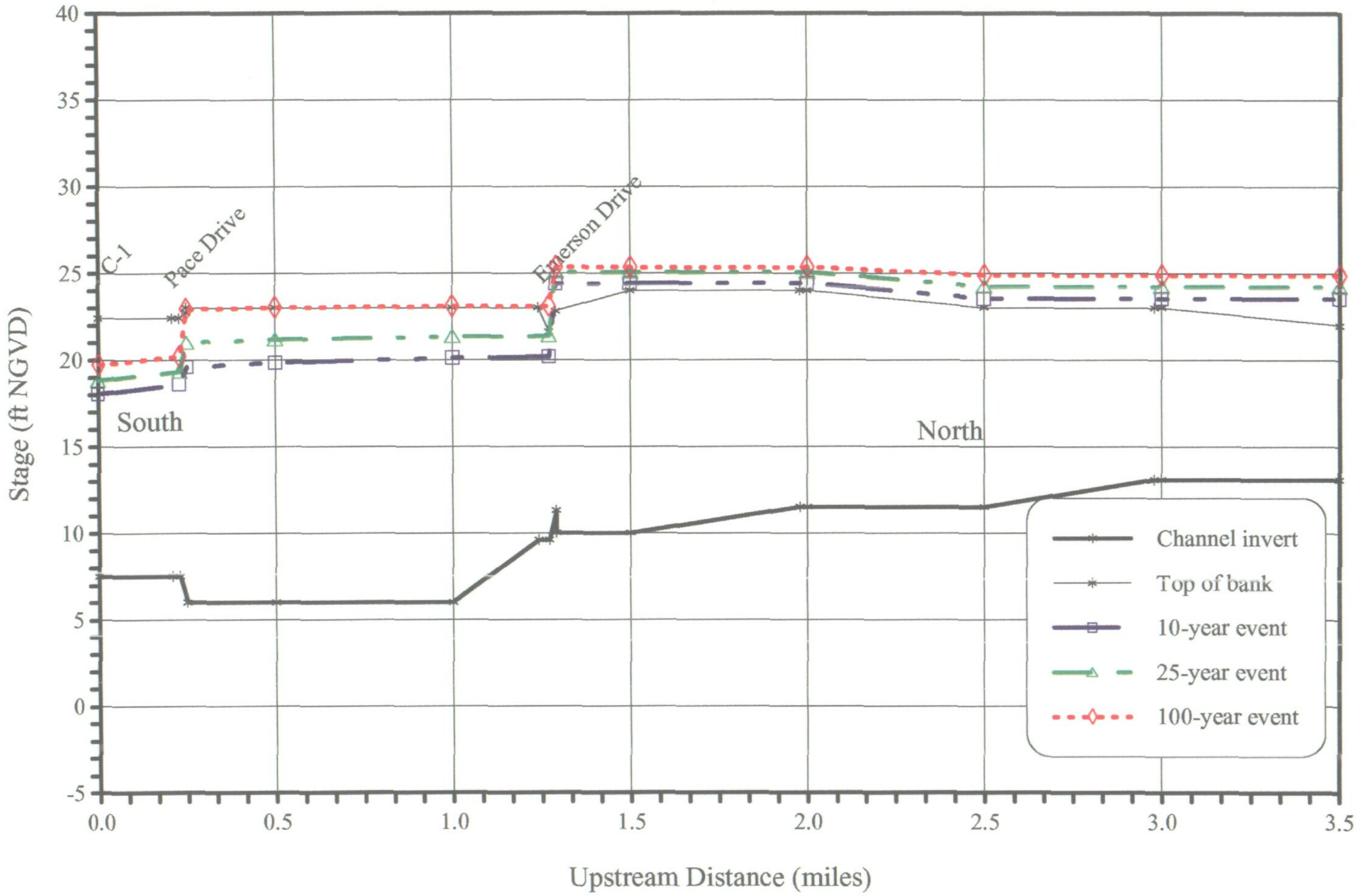


Figure 23. Flood stages in the C-61 canal from the C-1 canal

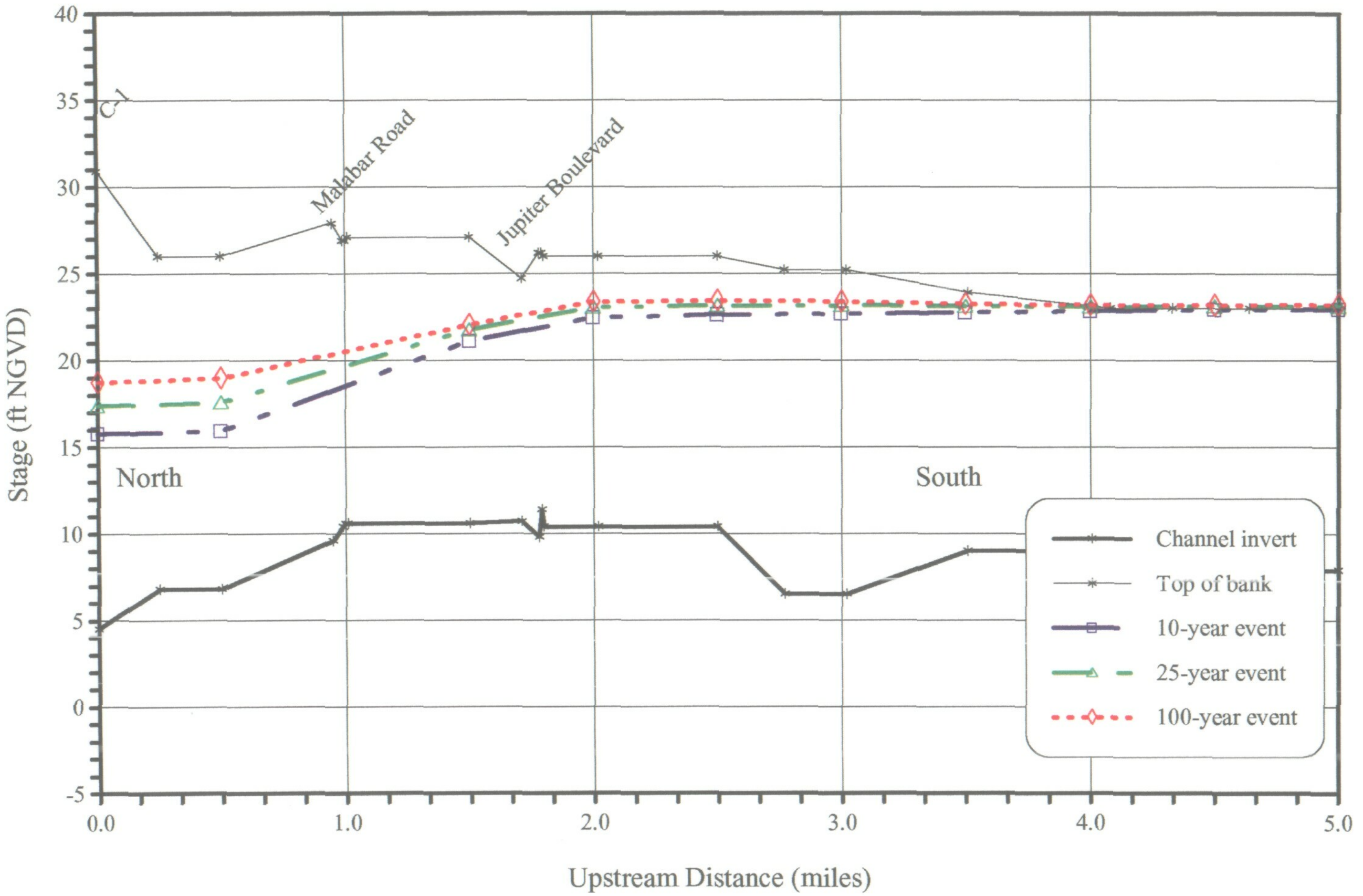


Figure 24. Flood stages in the C-37 canal from the C-1 canal

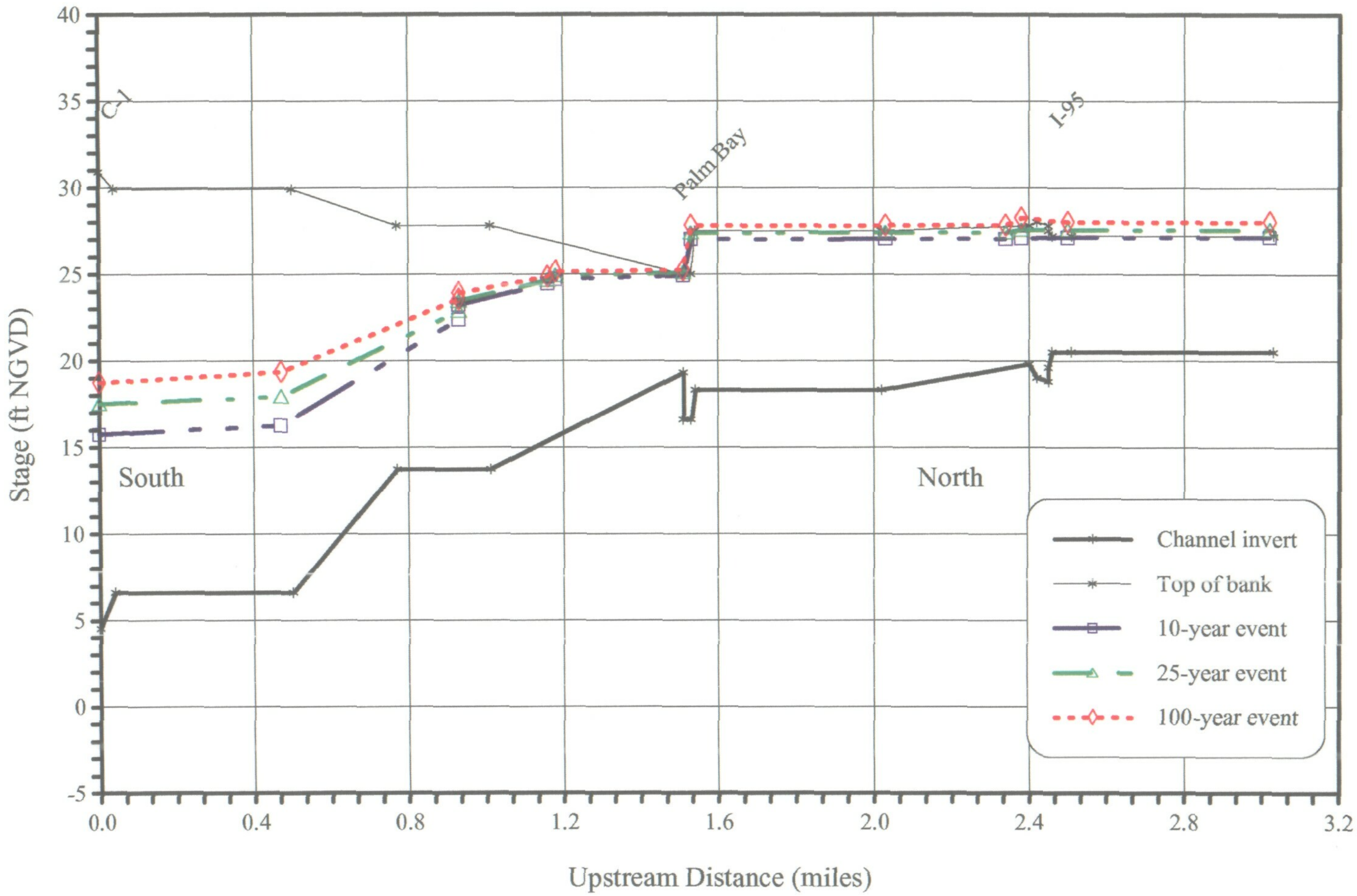


Figure 25. Flood stages in the C-69 canal from the C-1 canal

Table 14. Comparison of flood discharges (in cubic feet per second) calculated by the St. Johns River Water Management District (SJRWMD) and the Federal Emergency Management Agency (FEMA)

Frequency (years)	FEMA at Port Malabar Boulevard	SJRWMD at Port Malabar Boulevard	FEMA at MS-1	SJRWMD at MS-1
10	7,400	5,160	6,200	4,260
25		7,420		5,890
50	8,800		7,400	
100	9,450	10,000	8,000	7,580
500	10,800		9,000	

Note: Blank cells indicate no computed result

SUMMARY AND CONCLUSIONS

This report presents the development of two models to simulate the hydrological and hydraulic character of the MTWCD. The MTWCD drainage will soon be modified as a result of the USJRB restoration project, and surface water management improvements are planned to reduce freshwater discharge and pollution load into the Indian River Lagoon. These models are needed to evaluate various results for the planned activities.

One of the models, HSPF, performs continuous simulations for extended periods. The data generated by the model will be useful for evaluation of environmental concerns in Turkey Creek and the Indian River Lagoon. The strong data management and water budget accounting in the HSPF model make it highly suitable for continuous simulation.

The other model, SWMM, performs storm-event simulation to predict flood stages. The dynamic wave routing module of SWMM, EXTRAN, is capable of accurately calculating the flood stage in this near-level topography where tailwater is a significant influence.

The HSPF model was calibrated for discharge and discharge volume (cumulative discharge) in the MTWCD for the period January 1988 to December 1989. Overall, the trend of gaged hydrographs was represented by the simulation. Three of the four discharge event peaks compared well. The recession rate compared well for three of the four events. The low flow, on average, also compared well. However, the variations in the observed low flow were smoothed out by the model. Over the 2-yr period used for calibration, the model slightly overestimated the runoff volume. This discrepancy is primarily the result of an overestimated recession rate for the March 1988 discharge event.

The HSPF model was verified for discharge and discharge volume at the same location as was used in the calibration. The period January 1990 to October 1991 was used to verify the model. Deviation from normal operations and excavation of the canal at MS-1 altered the conditions for verification. The discrepancies between simulated and observed discharges were more pronounced during verification than during calibration. However, the results were consistent with the calibration. Over the 22-month period, the runoff volume was slightly underestimated.

An additional comparison of discharge and discharge volume was made for the period January 1977 to December 1980. The simulated discharge hydrograph was close to the observed hydrograph with the exception of the overestimated peak discharge events. The urban area has grown since 1980. The impervious surfaces of roadways and rooftops associated with urban areas increase runoff rates and volumes. These overestimates occurred because of urbanization of the MTWCD and were consistent with calibration of the model, in which a 1-day rainfall of about 6 in. produced a peak discharge of 2,000 cfs for October 1989. Over the period of comparison, the simulated discharge volume closely matched the measured discharge volume.

SWMM was calibrated for the October 1989 storm event and verified with data from Hurricane Erin, August 1995. The simulated peak discharge matched the October 1989 peak discharge in Turkey Creek at Palm Bay. However, the recession rate of the simulated discharge hydrograph underestimated the gaged recession rate. The simulated peak stage matched the gaged peak stage in the C-10 canal.

In the verification run, the simulated peak discharge overestimated the gaged peak discharge in Turkey Creek at Palm Bay by 7.6%. The simulated peak stage in the C-10 canal at Malabar Road was 18.6 ft, compared with an estimated single observed stage of 17.8 ft. The single observed stage is not necessarily the peak stage.

In general, both models, HSPF and SWMM, represent the hydrologic and hydraulic character of the MTWCD for the intended purpose. The continuous simulation model produces extended periods of freshwater discharge data to evaluate the environmental concerns of Turkey Creek and the Indian River Lagoon. The storm-event simulation model produces flood stage results to evaluate flooding concerns within the MTWCD. Both models will be used to evaluate the impacts of USJRB restoration activities and the proposed surface water management plan.

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