STRUCTURE S-12 WATER DISTRIBUTION TO EVERGLADES NATIONAL PARK

Report T-650

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INTRODUCTION

The complex maze of water control works now in place in central and south Florida (Figure 1) exemplifies the degree to which man, in a short time, can alter a drainageway formed over millenia. Once a truly dynamic system responding to the cycles of flood and drought common to subtropical Florida, this waterway is now fully controlled by water management schedules and structures designed to meet the varied needs of man.

Historically, the Everglades region was dominated by a very slowly-moving sheetflow system extending from the headwaters of the Kissimmee River, down the center of the state, and emptying into the Gulf of Mexico and Florida Bay (Figure 1). Surface water from the northern reaches of the basin flowed southward into Lake Okeechobee where it was impounded. During wetter years when Lake Okeechobee stage was over 15 feet msl, water would overflow low points in the lake's banks, contributing surface flow to the immense Everglades marsh to the south. Overflow of the southern banks became general when lake stage reached 18 feet msl (Parker, 1955), combining with rainfall upon the Everglades basin to become inputs into the Shark River Slough.

Completion of a shallow canal connecting Lake Okeechobee with the Caloosahatchee River in 1883 marked the beginning of significant human impact upon this drainageway. Increasing population in south Florida in the early 20th century brought more extensive drainage to allow urban and agricultural development south of the lake and along the Atlantic coast. By the 1930's, the surface connection between Lake Okeechobee and the Everglades was eliminated by dikes and drainage canals (Leach, 1972). Waters which once supplied surface flow to the Shark River Slough, Taylor Slough, and numerous smaller slough systems were being diverted to the sea farther north, causing water supply problems, saltwater intrusion in coastal areas, and widespread ecological damage.

The conflicts in water needs between urban, agricultural and environmental interests intensified in the 1940's and the need for a unified water management program for central and south Florida became apparent. In response, Congress passed the Flood Control Act of 1948 (PL 80-853) which established the Central and South Florida Flood Control District as the state agency responsible for water management. Planners for this agency concluded shortly thereafter that construction of reservoirs was necessary to store water from the rainy season for use in the dry season. Construction of the Conservation Areas (Figure 1) soon began, and with the completion of L-29 and the S-12 flood gates in 1962, complete regulation of surface flow into Shark Slough was possible.

Shark Slough, which prior to 1962 had flowed relatively unimpeded past Tamiami Trail (U.S. 41) to the estuaries along Florida's southwest coast, was severely threatened by this flood control plan. This 240,000 acre marshland supports numerous unique plant and animal communities, all dependent upon proper timing, distribution, and magnitude of discharge, as well as good water quality for their perpetuation. Flow through the slough must provide sufficient fresh water head to

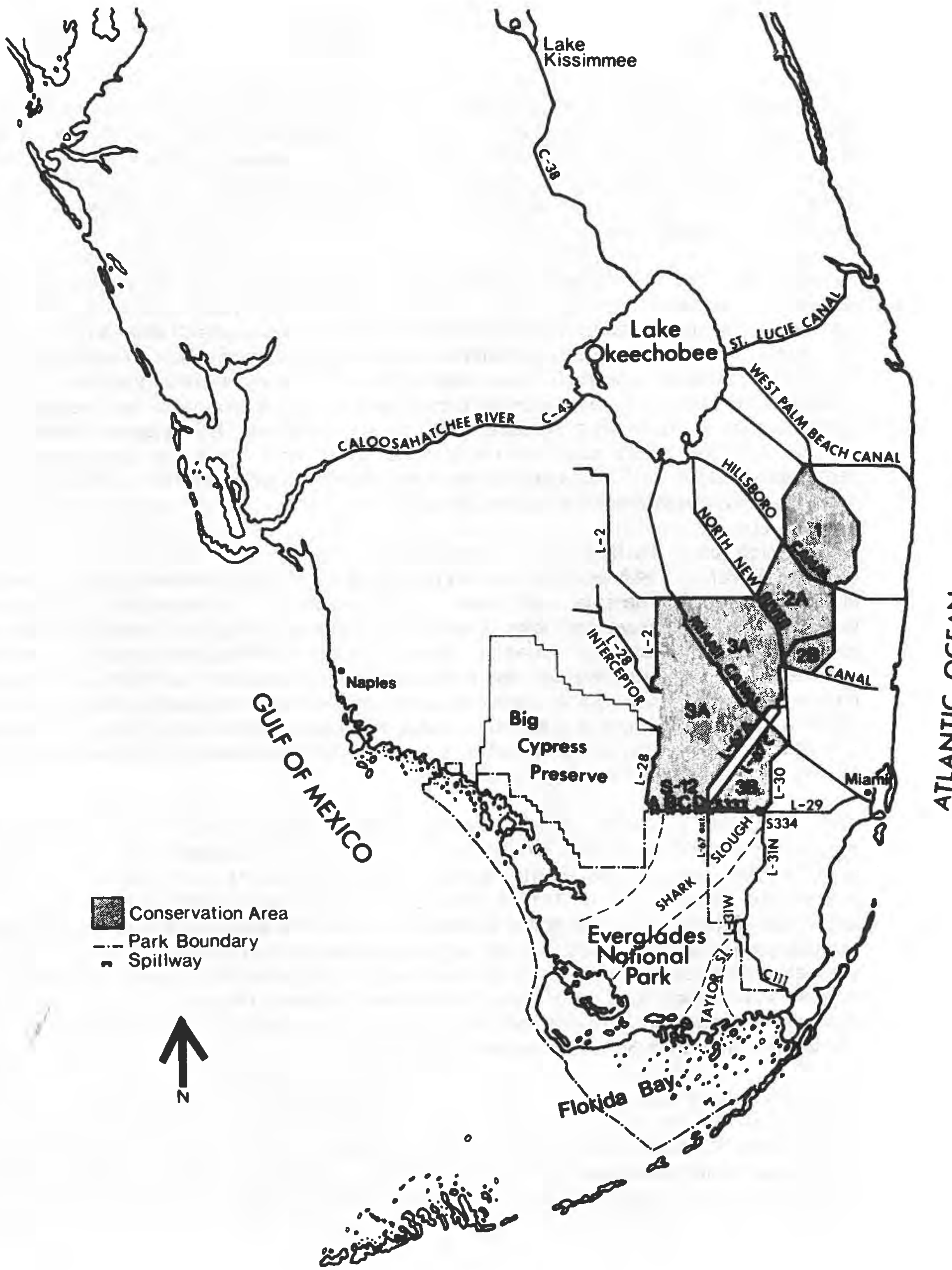


Figure 1 . Major drainage canals in South Florida.

maintain estuarine salinities in streams and bays to the southwest. Still, the S-12 structures were closed in December, 1962, remaining closed throughout 1963 followed by only minimal openings for one month in 1964 (Nix, 1966). This cutoff in surface flow, in conjunction with the unusually late onset of the rainy seasons in 1963 and 1964 caused severe drought conditions in Shark Slough, threatening significant long-term damage to the ecosystem.

64-70 = 6yrs

The National Park Service called for surface water delivery guarantees to remedy this situation, and six years of negotiations between the Department of Interior, Department of the Army, and the Central and South Florida Flood Control District followed. Finally, Congress passed the Monetary Authorization Act of 1970, (PL 91-282) which expedited construction of water conveyance facilities and established the current guaranteed deliveries from the Conservation Areas to the Park. Minimum delivery to Shark Slough was set at 260,000 acre-feet annually, to be distributed monthly as shown in Table 1. A more thorough discussion of the development of the current delivery schedule may be found in Wagner and Rosendahl (in preparation).

With the current water management system, collectively referred to as the Central and South Florida Project, it is possible for surface water destined for the Everglades and Shark Slough to flow from Lake Kissimmee into the Kissimmee River and Canal System and then into Lake Okeechobee. Waters from Lake Okeechobee can be released into the Miami Canal, from the Miami Canal into the L-67 canal, and then into the L-29 borrow canal just north of the park border. Waters may then be delivered to Shark Slough through the four S-12 structures as scheduled. It is the purpose of this report to further our understanding of the distribution of scheduled surface deliveries through the S-12 delivery system to improve Shark Slough surface water management.

STRUCTURE S-12 AND OTHER SURFACE WATER DELIVERY SYSTEMS TO SHARK SLOUGH

The Delivery Systems

Water moving southward past new Tamiami Trail (U.S. 41) between L-30 and 40-Mile Bend may be distributed to Shark Slough through the numerous structures, canals, and culverts illustrated in Figure 2. The various options for delivery are discussed below, however this section concentrates on delivery through the S-12 structures.

1) The S-12 System

Currently, the most frequently used option for delivering surface water to Shark Slough is release from Conservation Area 3A through four identical "S-12 structures" (Figure 2) located along U.S. 41 between the L-67 canal and 40-Mile Bend, just north of the park boundary. These deliveries cause a rise in the tailwater area immediately south of each structure (Figure 3), forcing gradients toward Shark Slough and in either direction down the old Tamiami canal. A portion of the

Table 1. Minimum Monthly Surface Water Schedule of Deliveries to Shark River Slough

Month	Ft^3/Sec	Acre-Feet
January	358	22,000
February	162	9,000
March	65	4,000
April	29	1,700
May	28	1,700
June	84	5,000
July	120	7,400
August	198	12,200
September	655	39,000
October	1,090	67,000
November	992	59,000
December	520	32,000
Total		260,000

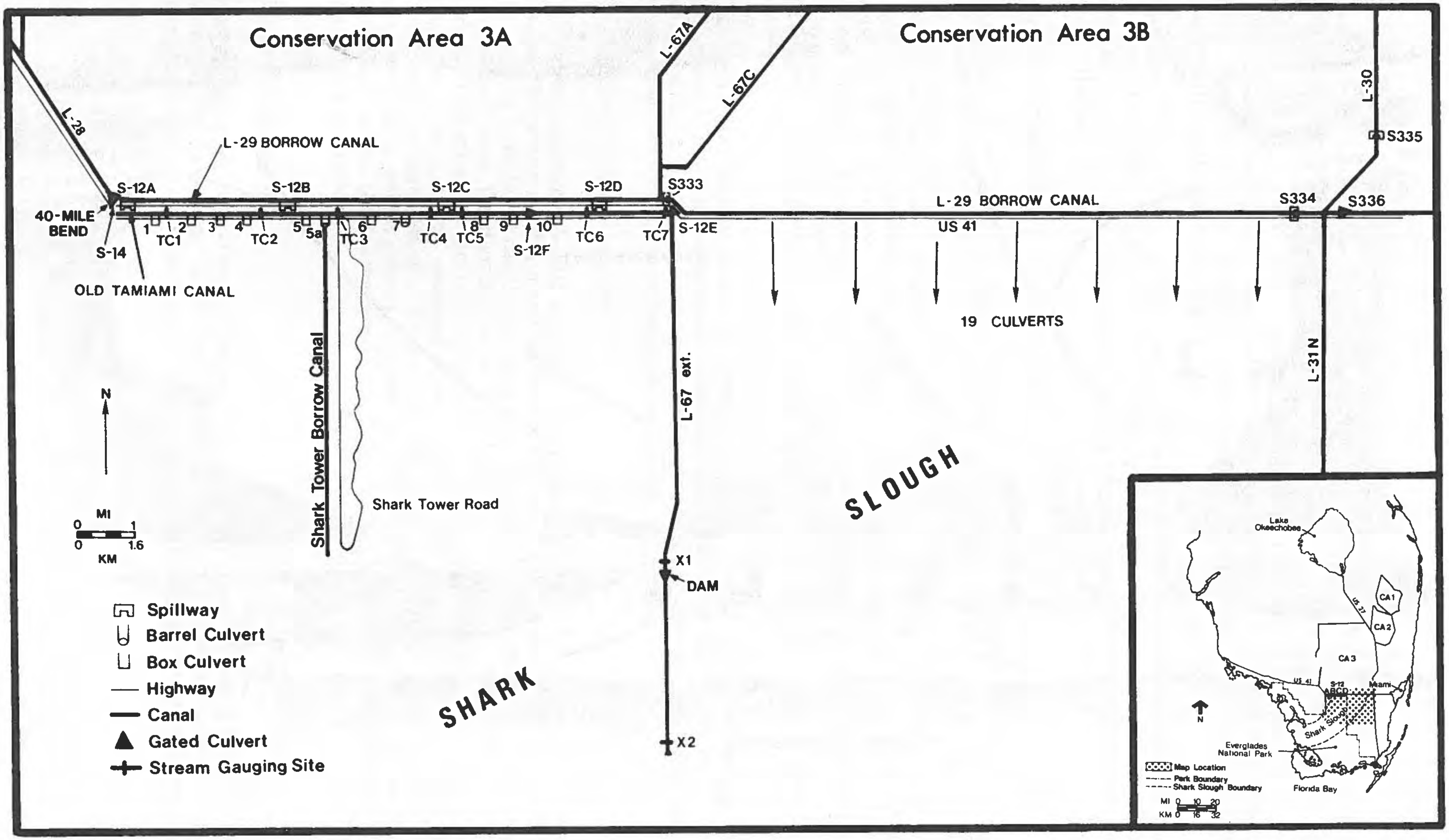


Figure 2. Options for surface water delivery to Shark Slough.

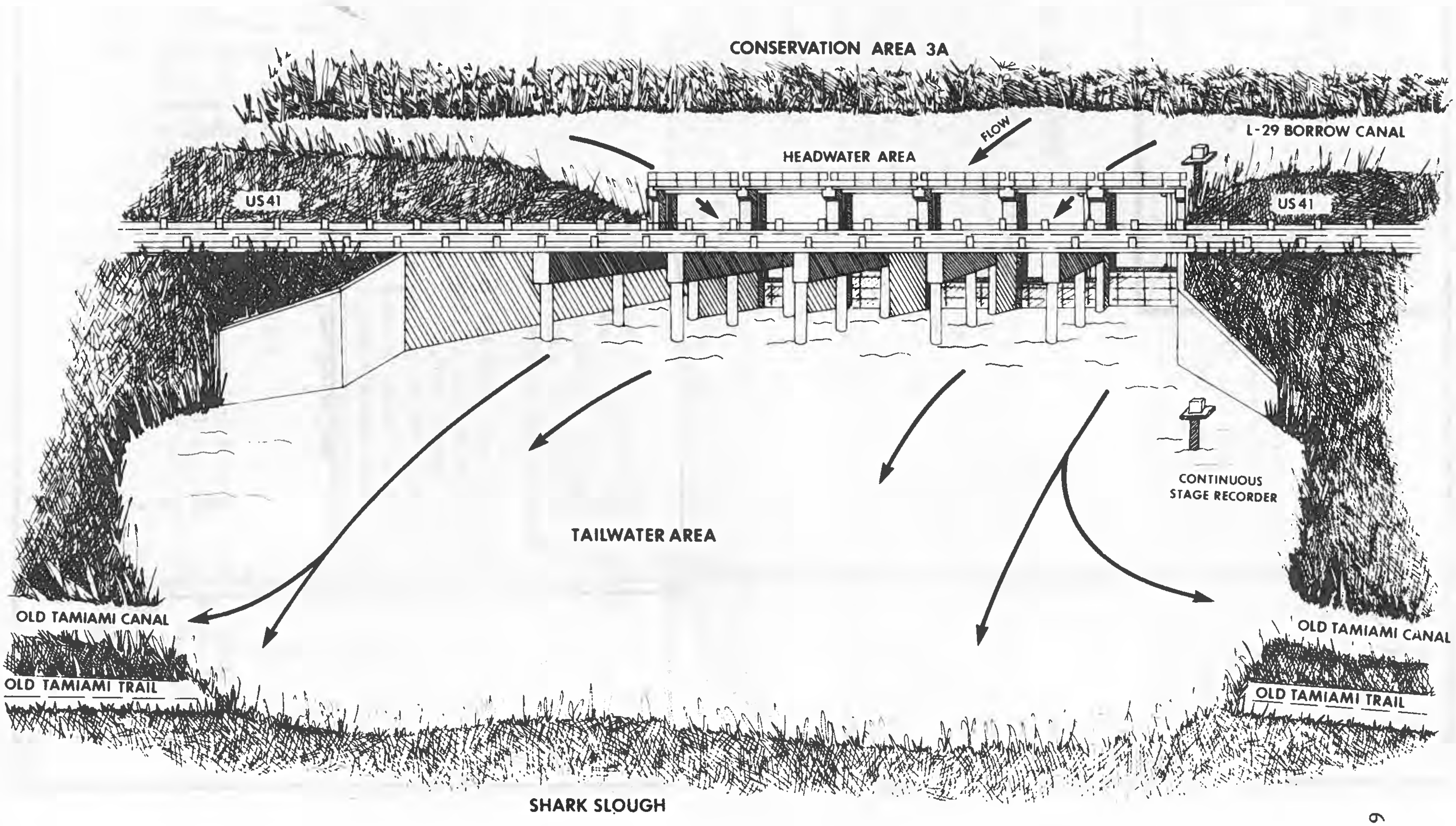


Figure 3. Structure S-12 schematic.

deliveries are distributed directly to the slough through the cutouts in old Tamiami Trail while the rest flows east or west through the canal for distribution through the series of the culverts shown in Figure 2. Portions of deliveries through S-12C and S-12D entering the L-67 extension canal are distributed to the slough at low points along the length of the canal and at its terminus 9.5 miles south of U.S. 41. Small amounts of water may also enter the Shark Valley Tower Road borrow canal and be distributed along its length.

Structure S-12 F in the old Tamiami canal and a structure in the L-67 (ext.) canal are culverted dams with removable stoplogs. These structures provide some additional control over distribution and will be discussed in the section on flow distribution patterns.

2) Northeast Shark Slough Delivery

Water may be delivered to the park through discharge into Northeast Shark Slough. To accomplish this, structure S-333, a weir-type, gated spillway is opened, allowing water from the L-67 canal, Conservation Area 3A, and the L-29 borrow canal to follow gradients eastward through this structure. Closing structure S-334, a similar spillway located just west of L-30 along the L-29 borrow canal, causes water levels in this canal to rise, thereby forcing distribution into Northeast Shark Slough through 19 culverts under Tamiami Trail. Water entering Northeast Shark Slough then follows gradients to the southwest, eventually flowing south of L-67 (ext.) and into the park, or under some conditions seeping westward through the levee.

This option was briefly tested in 1980 but is not currently used for meeting park requirements since existing Indian dwellings limit allowable stage heights in L-29 borrow canal and such deliveries would have to pass through the privately owned lands within Northeast Shark Slough to reach the park boundary.

3) Other delivery options

Two other structures, S-12E and S-14 provide other options for deliveries to Shark Slough. Structure S-12E, a four-barrel box culvert located just east of S-333 at the head of L-67 (ext.) canal may be opened to divert S-333 inputs directly into the L-67 (ext.) canal for distribution to the slough. If S-333 is closed and S-12E is opened, this structure provides a means for regulating stage in the L-29 borrow canal east of L-67 by draining these waters into the L-67 (ext.) canal for distribution to Shark Slough. Structure S-14, a two-barrel box culvert, located just west of S-12A provides gravity drainage from the L-28 borrow canal into the Park. This allows water originating west of L-28 to contribute to direct surface inflow to the Park if desired.

<u>S-12 Structure Design</u>

Each of the four "weir-type" spillways S-12 A through D is composed of six 25 foot wide vertical-lift gates. Gate openings and closings are achieved via mechanically operated cable hoists. Because water normally follows the north to south gradient of the land surface in this area, closing the S-12 gates creates a hydraulic head differential between Conservation Area 3A and the park. Raising the structure gates then allows water to follow this gradient into the park through a distribution system of culverts, cut-outs and canals (Figure 2). Each S-12 structure is designed for a maximum 8000 cfs discharge, a maximum headwater stage of 12.4 feet msl and a tailwater maximum of 11.9 feet msl. These levels are considerably above the recorded extreme maximums of 4810 cfs discharge for all four structures combined, 10.52 feet msl headwater stage above S-12 C, and 10.36 feet msl tailwater stage in old Tamiami canal below S-12C (USGS, 1979). The design "critical static condition" for each structure is a headwater stage of 10.5 feet msl and a tailwater stage of 5.0 feet msl.

Provisions are made for dewatering each of the six structure bays separately by use of aluminum posts and timber stoplogs upstream as well as structural steel needle beams and timber needles downstream of the gates. Both are utilized during maintenance operations and are available for emergency temporary closures.

S-12 Structure Management and Operation

1) Determination of Deliveries to be Made

S-12 water deliveries to Everglades National Park are determined by the interplay of federal and state regulations, physical capabilities and constraints, and management decisions. As discussed earlier, federal law mandates that the S-12 minimum delivery schedule (Table 1) be followed, with provisions for drought conditions. While it is the South Florida Water Management District's responsibility to provide sufficient water for delivery to the park, it is the U.S. Army Corps of Engineers, Jacksonville District, that is responsible for the operation and maintenance of the S-12 structures to ensure that the required minimum deliveries are met. To accomplish this, the Corps must determine the discharge rate needed to meet the regulations for stage in Conservation Area 3A as well as meet the minimum monthly delivery schedule to the park. Once the required total discharge rate is determined, the Corps of Engineers interacts with the National Park Service to choose the optimal combination of structure openings, within physical limitations, to achieve the desired rate.

2) National Park Service Input

Park input for S-12 structure opening strategies is based upon ecosystem requirements as they relate to water quality, amount, timing, and patterns of distribution to Shark Slough.

Regarding water quality, Flora and Rosendahl (1981) showed that waters in the L-29 borrow canal just above S-12D, which have been conveyed by canal and thus bypassed the marsh systems, have high specific conductance and high sodium: calcium ratios typical of water near Lake Okeechobee. Waters above the other structures, however, are a mixture of both canal water and the ground and surface waters which have flowed through the marsh in Conservation Area 3A. Waters delivered through structures west of S-12D are therefore more desirable inputs in that they more closely resemble marshwater quality.

Amount and timing decisions are presently based upon studies by Dunn (1961) and Hartwell, Klein, and Joyner (1963), as incorporated into the Monetary Authorization Act of 1970, (see Table 1). These amounts are minimums, however, and there are no specific laws governing amounts and timing of deliveries in excess of the schedule. Higher than scheduled water levels in Conservation Area 3A may result in large flood releases through the S-12 structures, with magnitude and timing often being dictated as much by urban and agricultural water supply needs as by natural climatic events. Under these conditions, decisions for determining flow to Shark Slough may be totally outside the control of park officials.

Preferences for structure opening combinations with regard to patterns of distribution to Shark Slough are discussed in detail in following sections.

3) The Delivery Process

Once the S-12 structures to be used have been chosen, specific gate openings at the structures required to meet delivery goals must be determined. The head differential-discharge rating curve shown in Figure 4a is used for this purpose. As an example, a 350 ft^3/sec (cfs) discharge may be desired through structure S-12C at a time when a 1.5 foot head differential exists across this structure. The curve shows that a 1.5 foot head differential corresponds to a 175 cfs discharge when one gate is open one foot. Therefore, two gates at S-12C may be opened one foot each, or one gate at two feet and so on to reach the 350 cfs goal.

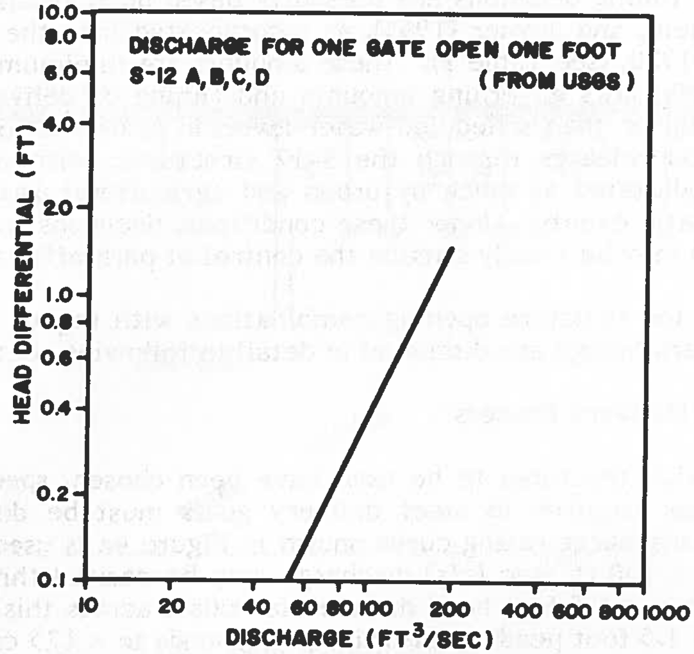
Once the necessary gate openings have been determined, the actual delivery process is begun by opening the gates to approximate the desired discharge. As the water level rises at the downstream side of the structure, the head differential changes to some degree, but soon becomes relatively stable. As this change occurs, less water is discharged than at the time of the initial gate openings and gates may be adjusted as needed to maintain the desired discharge rate.

4) Documentation of S-12 Deliveries

The U.S. Geological Survey (USGS), Miami, is reponsible for recording and publishing the discharge through the S-12 structures. Continuous stage recording devices upstream and downstream of each structure (Figure 3), provide a complete record of head differential across the structures. When this differential is 0.1 feet or greater, the gate openings and upstream and downstream stage records are continuously applied to the curve in Figure 4a to determine discharge rates, and thus total discharge. Using this method, a 1-2% error is expected in the applicable range (personal communication, John Warren, USGS).

The percentage of error when discharge is calculated in the above manner increases when the head differential falls below 0.1 feet. This often occurs during flood releases when the gates are fully out of the water or during drought conditions. For this range, the USGS has developed a tailwater-discharge rating curve for each structure (Figure 4b) by plotting measured discharge through the structure versus the downstream gauge height. The tailwater-discharge relationship is less consistent than the head differential-discharge curve since factors

(a)



(b)

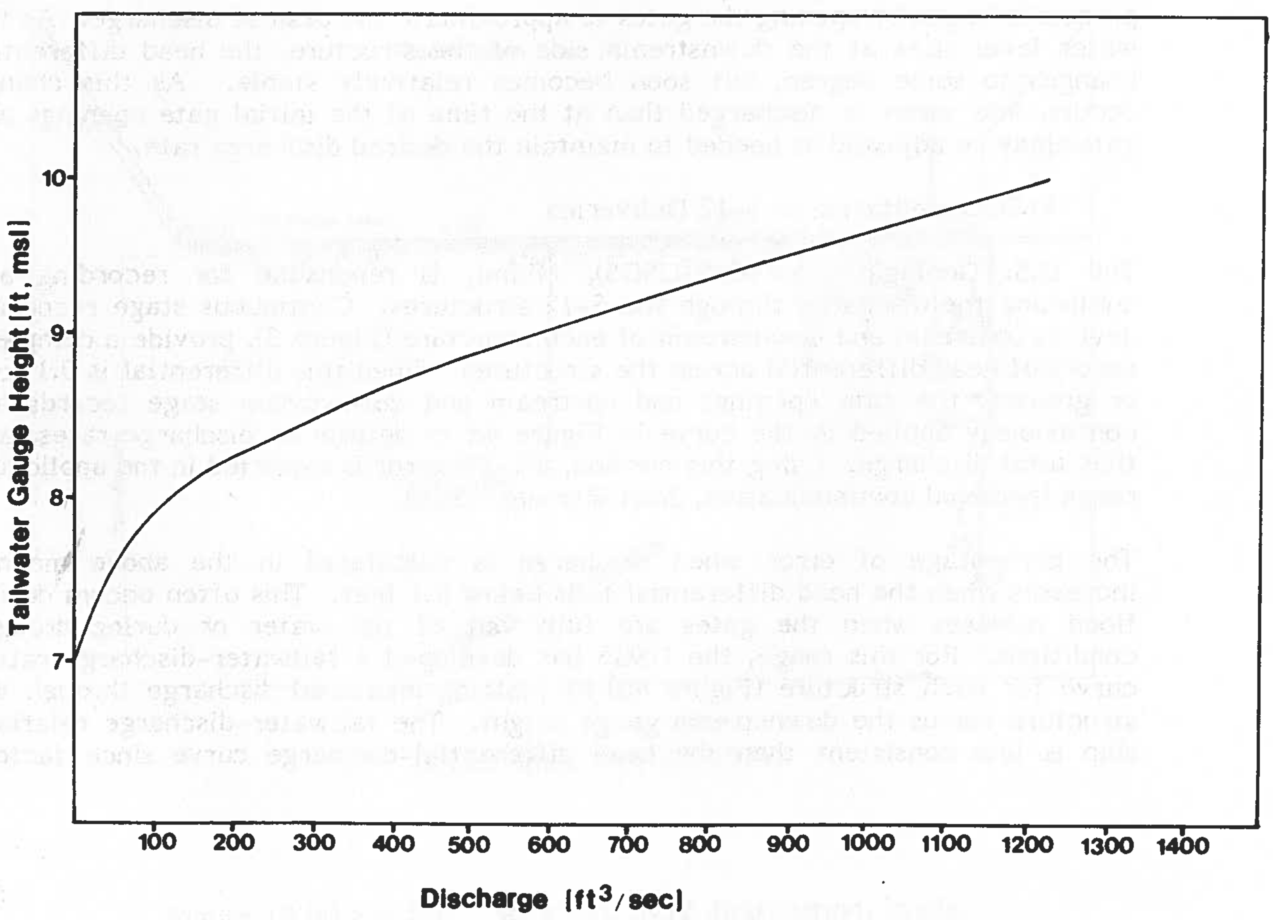


Figure 4. (a) Head differential vs. discharge for structures S-12 A through D.
(b) Tailwater stage vs. discharge at S-12 C.

including changing backwater conditions or vegetation in the tailwater area constantly change the relationship between discharge and downstream gauge height. For this reason, the USGS measures discharge through the structures bi-weekly to apply an appropriate "shift" to the rating curve. This shift is merely a change in the Y-intercept of the curve in order to reflect current tailwater stage-discharge conditions. Discharge through a structure is then computed by pro-rating the shift of the curve over the preceding two week period to account for changing hydrologic conditions near the structures.

Discharges computed by incorporating these two methods are then published in USGS "Water Resources Data for Florida" annual reports as "Surface Water Discharge, Tamiami Canal Outlets, L-67 to 40-Mile Bend, near Miami, Florida".

FACTORS AFFECTING S-12 DELIVERY DISTRIBUTION TO SHARK SLOUGH

Distribution patterns of water delivered to Shark Slough through the S-12 structures are ultimately dependent upon water level gradients throughout the delivery system and the slough. In the broadest sense these gradients are controlled by the placement of these structures and the distribution canals with respect to the basin geometry and configuration of the slough. The gradients at any one time, however, are also affected by such factors as structure opening schemes, size of deliveries and vegetation patterns. Placement of structures and canals with respect to the slough geometry and configuration are discussed below, while the additional factors are discussed in conjunction with distribution monitoring in the section on flow distribution patterns.

Slough Geometry and Configuration

Historically, slough drainage followed contours of the rock floor of the Everglades as shown in Figure 5. This map, developed by Parker (1944) shows a distinct valley starting well to the northeast of the park boundary and moving southwest across L-67 (ext.). It also shows distinct ridges in the northwest portion of Shark Slough and to the southeast along the Atlantic Coastal Ridge.

Shark Slough is a "pulsating" system, with variation in slough configuration within the basin depending upon surface inputs and rainfall. The National Park Service monitored slough water depth over a two year period along a transect perpendicular to flow in the slough (Figure 6a), resulting in the wet season and dry season inundation profiles shown in Figure 6b. During this period, slough width varied from 17 miles during the wet season to 8 miles during the dry season. Determining the border configurations of Shark Slough under these changing conditions, especially the western slough border, is important for understanding the location of the S-12 structures with respect to the slough. Such information is useful in determining probable distribution patterns of deliveries through each structure and in turn may be used in choosing structure opening strategies.

Work by Parker (1955) placed the western boundary at 50-Mile Bend along Tamiami Trail (Figure 7). While north-south drainage may indeed follow Parker's flow

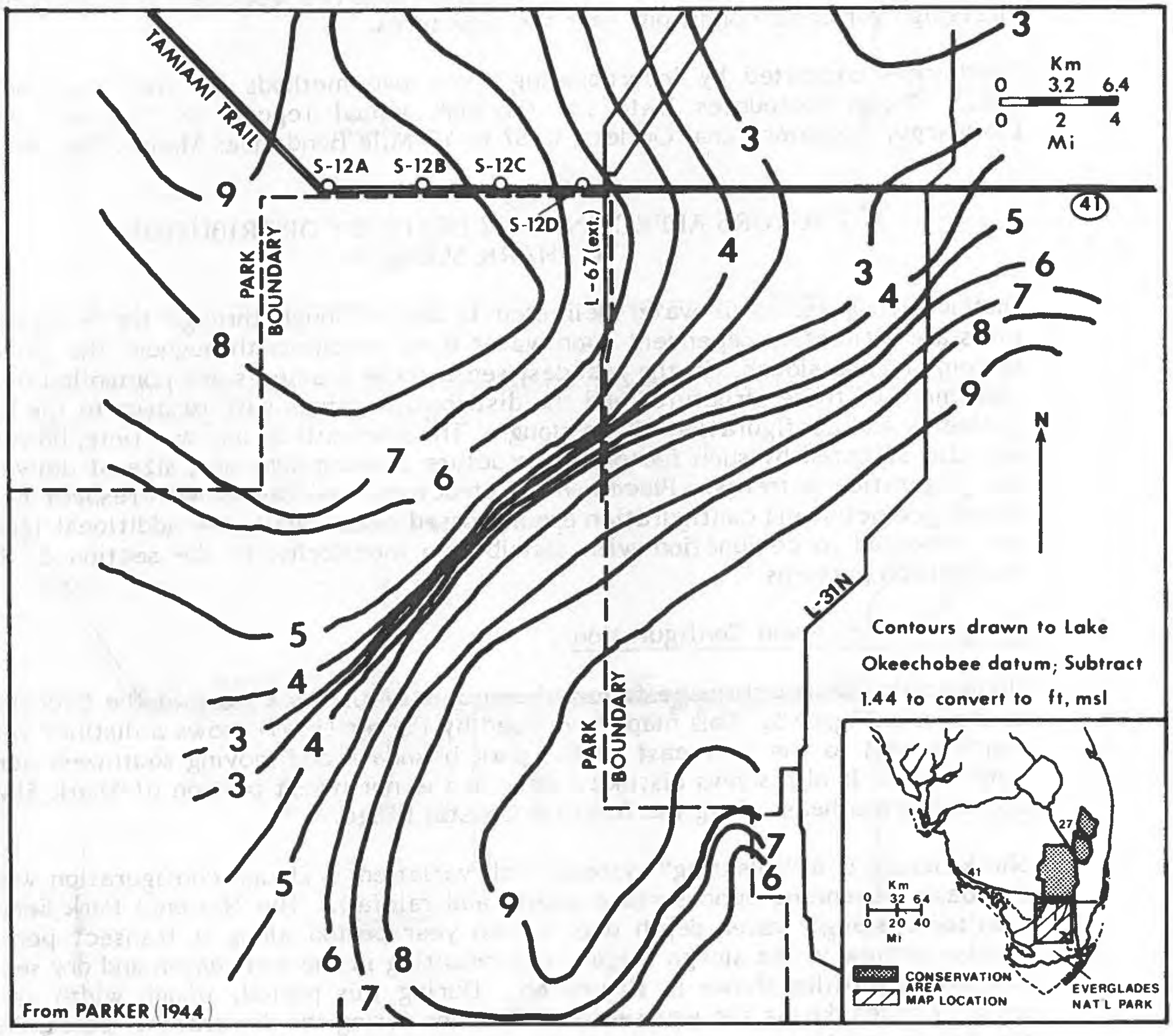
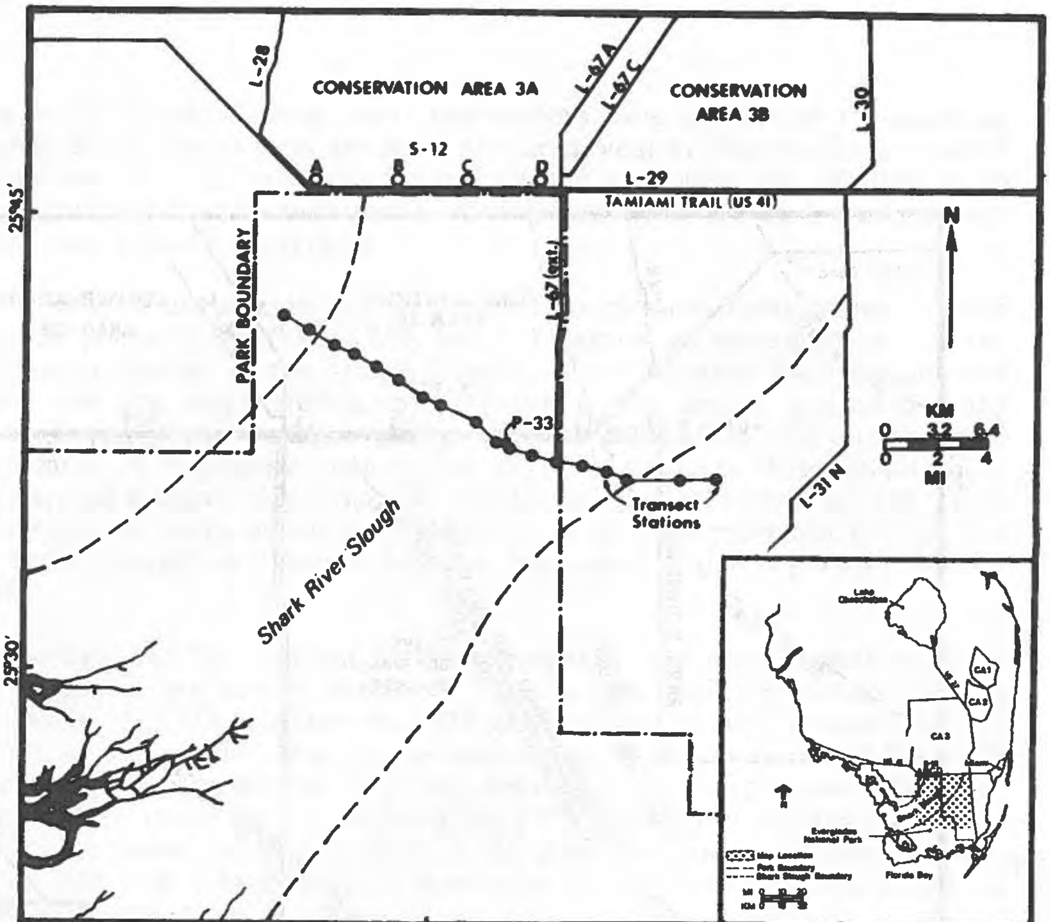


Figure 5. "Rock Floor" elevation in Shark River Slough.

(a)



(b)

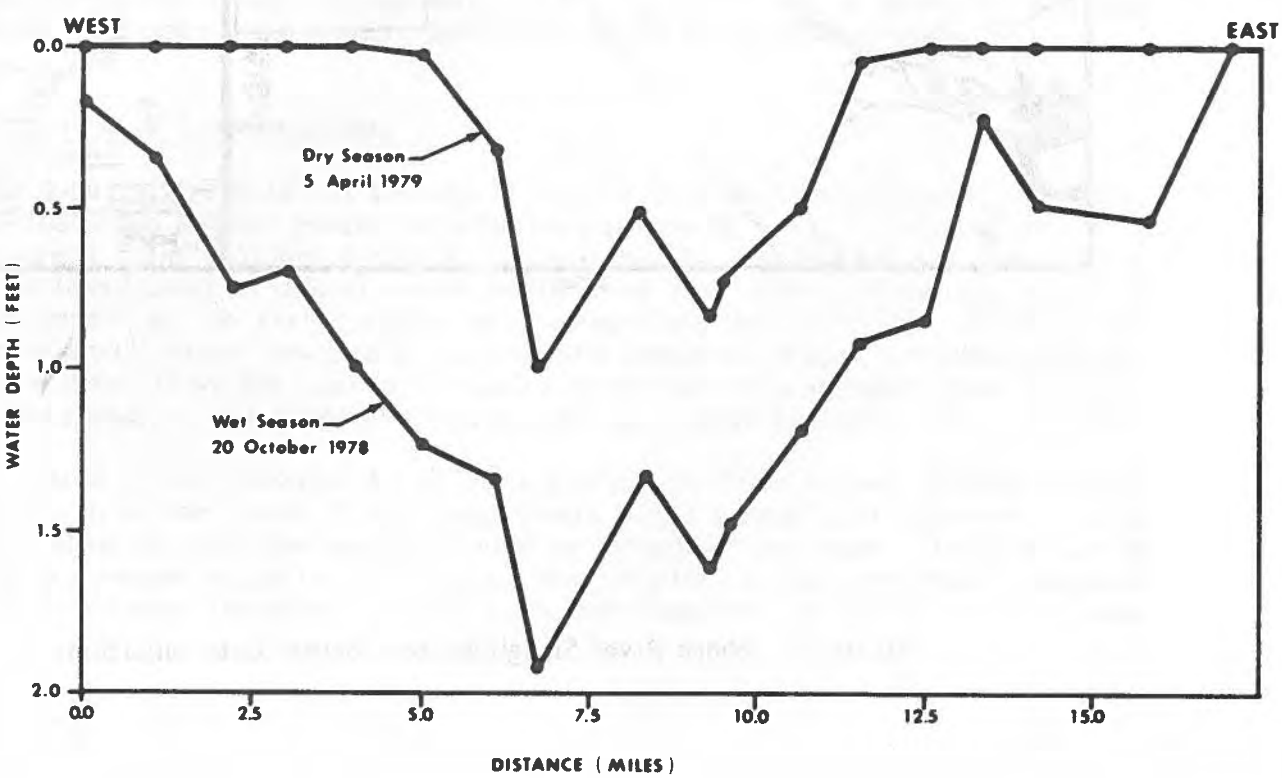


Figure 6. (a) Shark River Slough depth profile monitoring transect.
(b) Shark River Slough wet season and dry season depth profiles.

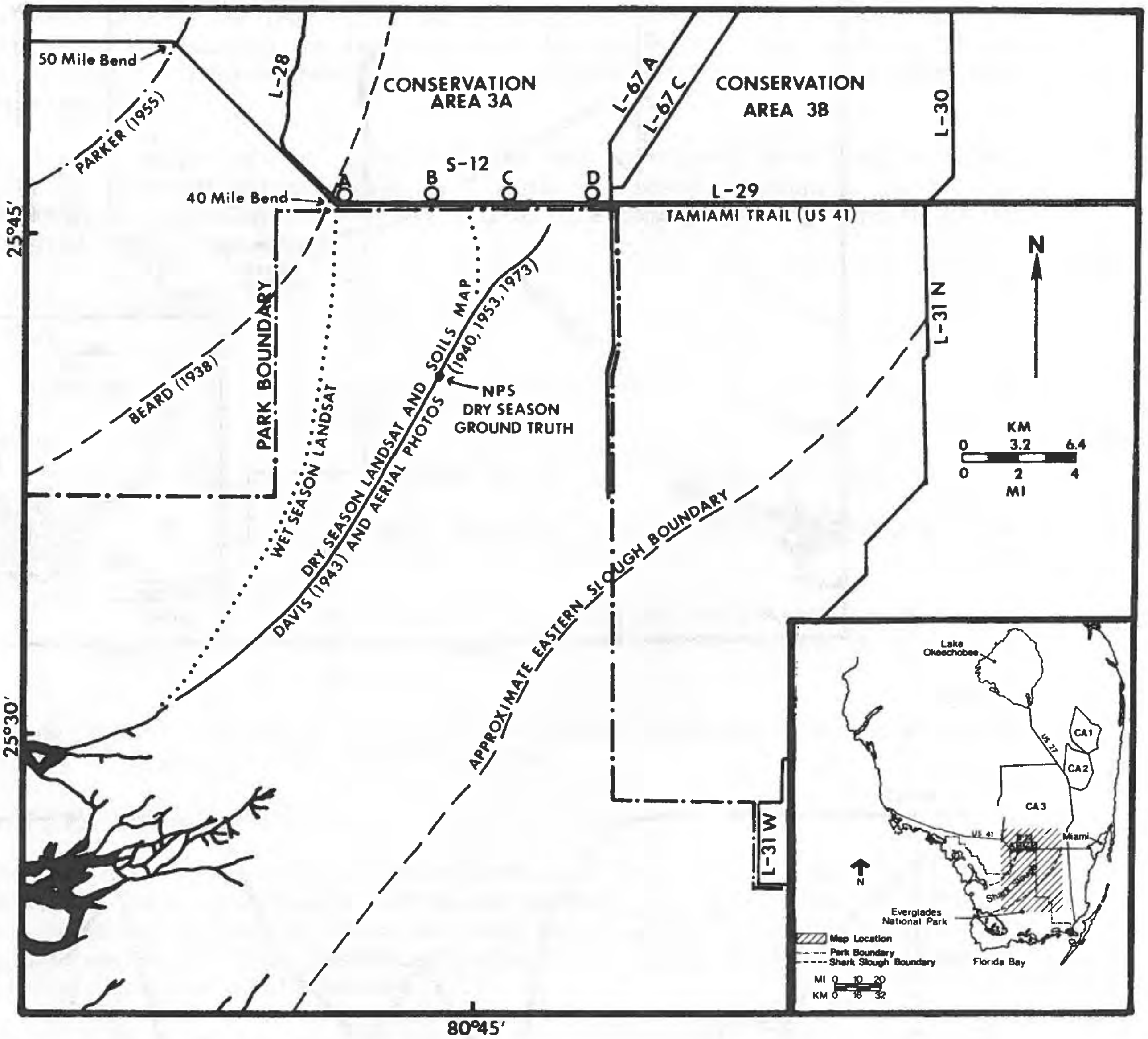


Figure 7. Shark River Slough western border determinations.

distributions in the broadest sense, most researchers have subdivided the drainage areas such that Shark Slough does not drain the area west of 40-Mile Bend. Beard (1938) locates the western border of the "glades" just west of 40-Mile Bend; however, it is doubtful that he intended to specifically note this as a Shark Slough border, rather just "glades" ecosystem.

Further refinement of dry season and wet season borders has been achieved more recently. Aerial photos from 1940, 1953, and 1973 agree on the placement of the dry season western border of the slough (Figure 7) and National Park Service dry season ground-truthing supports this configuration. Wet season ground-truthing showed the border to be more obscure, with continuous wet areas extending west of the park boundary. A vegetation map by Davis (1943) supports these aerial photo determinations, and a soils analysis of the area by the National Park Service found that the limits of peat soils, which are indicative of long hydroperiods such as the area within Shark Slough's dry season borders, approximate this dry season border configuration.

Rose and Rosendahl (1979) analyzed Landsat images in the most recent study of Shark Slough wet and dry season borders. Their analysis of dry season Landsat images from April 28, 1978 and May 16, 1978 generally agree with the aerial photo determinations, with some deviation to the west below S-12C as shown in Figure 7. This extension may, in part, be due to S-12C deliveries occurring at the time these Landsat images were taken (45 cfs on April 28, 1978 and 40 cfs on May 16, 1978), however, a similar extension of peat soils in the area consistent with the contours of the rock surface map does indicate a depression that historically was slower to dry down than adjacent areas.

The wet season western border, as determined from Landsat images during maximum inundation conditions on October 19, 1974, also is shown in Figure 7. In this case, most of the ridge extending along the western park border was still dry. Except for the slough strands which cut across the ridge in times of very high water, this ridge is the western limit of the Shark Slough drainageway.

Placement of S-12 Structures

The locations of S-12's A through D with respect to basin geometry and slough configuration suggest general distribution patterns of S-12 delivery waters. It is apparent from contours shown in Figure 5 that S-12D, located just west of the L-67 (ext.) canal on U.S. 41, would be the most direct route for delivery water to the center of the slough where long hydroperiods are desireable. Most of this water would either flow straight through the cutout and follow contours southward or be drawn down the L-67 (ext.) canal and overflow at low points along its length as discussed in the following section on flow distribution patterns.

Structure S-12C is located 3.4 miles west of the L-67 (ext.) canal. Though situated farther from the center of the slough basin, inputs through this structure are still very likely to enter the slough by following contours to the south. The extension of the dry season slough boundary below this structure as discussed herein supports this conclusion. In addition, under some conditions the L-67 (ext.) canal may also draw a portion of S-12C deliveries for distribution in the center of the slough, as discussed in the following section.

Distribution of S-12B and S-12A delivery waters into the park is less obvious from the contours in Figure 5. Structure S-12B is located 6.2 miles west of the L-67 (ext.) canal. In this area of more gentle contours, water may flow to the southwest as well as into Shark Slough. The ultimate distribution of waters delivered through S-12A, located 9 miles west of the L-67 ext. canal, is similarly unclear. This structure is located well out onto the rock shelf in an area where waters may flow to the southeast toward Shark Slough or southwest into the headwaters regions of the Broad, Lostman's or Harney River systems. It is most probable that during the dry season, the portion of S-12B deliveries flowing to the west and all of the S-12A deliveries never reach Shark Slough, but rather are drawn more to the southwest through smaller drainage systems. However, during times of high water when the areas south of S-12A and S-12B are inundated and are continuous with Shark Slough, i.e. the wet season configuration, gradient regimes may exist which draw a portion of these deliveries into the Shark Slough drainage system.

FLOW DISTRIBUTION PATTERNS IN THE S-12 DELIVERY SYSTEM

Measurement Sites

To determine the distributions of S-12 delivery waters, a series of nine canal gauging stations was established by the National Park Service throughout the system, identified as TC 1 through 7 in the old Tamiami canal and X1 through 2 in the L-67 (ext.) canal (Figure 2). The TC sites were located just east and west of the S-12 structures to measure flow in either direction along the old Tamiami canal, while the X sites were located to determine gains or losses along the length of the L-67 (ext.) canal.

Discharge measurements were also performed at the barrel and box culverts numbered 1 through 10 in Figure 2. These culverts, which are the bridges originally constructed to channel flow through old Tamiami Trail, now serve as distribution points for S-12 delivery waters.

Measurement Techniques

Gauging methods used for measuring discharges depended upon the nature of the site. All methods, however, rely upon determining the cross-sectional area of the water in the channel and measuring velocities in the channel. That is:

$$Q = AV \qquad \text{EQN 1}$$

where: Q = discharge (ft^3/sec, or cfs)

A = area (ft^2)

V = velocity (ft/sec).

The "moving boat method" of stream gauging adapted from Chow (1964) and Smoot and Novak (1969) and illustrated in Figure 8a was used at TC sites 2, 4, 5, 6, and 7 and at the X sites. At these sites, a tag line marked off in 2-foot intervals was strung tightly between two posts. The tag line was then fitted through eyehooks on the gunwales so that the boat could be hand drawn from shoreline to shoreline while remaining perpendicular to and facing the direction of flow. To determine the discharge at these sites, the entire cross-section of the canal is divided into partial areas, each of which is multiplied by its average velocity to obtain a partial discharge. The partial discharges are then summed to arrive at the total discharge at the site. That is:

$$Q_T = \sum_{i=1}^{n} q_i \qquad \text{EQN 2}$$

where: Q_T = total discharge at a gauging site

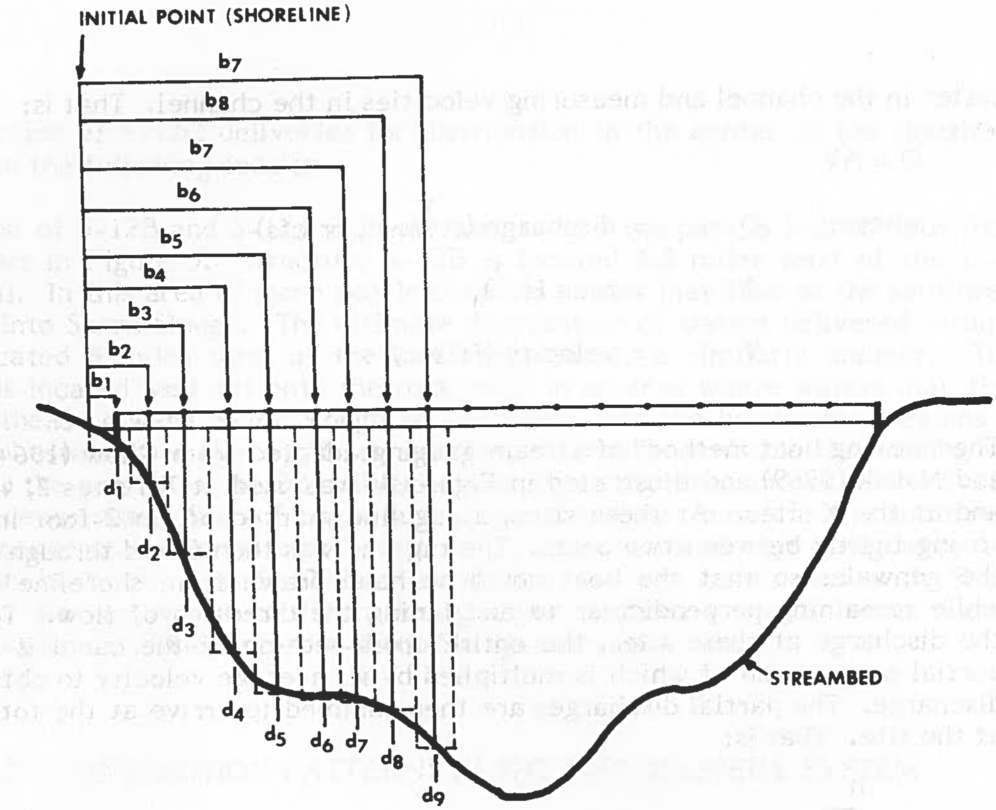
q_i = discharge through any partial section

n = number of partial sections

Partial discharges are determined via the process illustrated in Figure 8a. In this method, depths (d_i) from the surface to the canal bottom are measured at generally not less than 15 intervals across the stream, the actual number of intervals varying mainly with the regularity of the bottom contours and the distribution of flow in the channels. Where bottom contours or velocity change rapidly, measurements were taken at 2-foot intervals, while 4-foot intervals were used for more regular contours and flow distributions.

Using a Price-type water current meter, the velocity was determined at each interval by averaging readings at 0.2 depth and 0.8 depth when water was greater than 1.5 feet deep. When water was less than 1.5 feet deep, one 0.6 depth velocity

(a)



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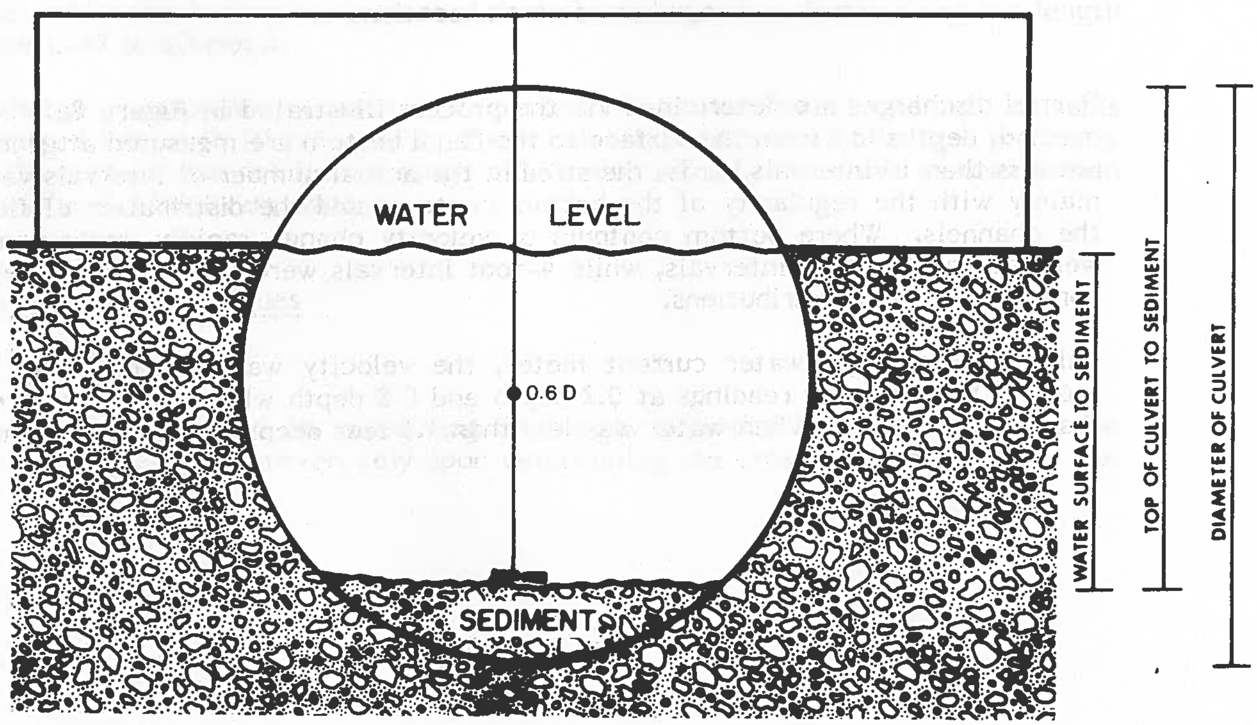


Figure 8. (a) Canal discharge measurement technique.
(b) Barrel culvert discharge measurement technique.

measurement was used (Chow, 1964). Partial discharges, q_i, were then calculated by the following equation:

$$q_i = v_i a_i \qquad \text{EQN 3}$$

where: q_i = discharge through a partial section

v_i = average velocity in a partial section

a_i = cross-sectional area of a partial section

The partial cross-section corresponding to any interval, i, is defined as follows:

$$a_i = \left(\frac{b(i+1) - b(i-1)}{2}\right)(d_i) \qquad \text{EQN 4}$$

where: a_i = cross-sectional area of a partial section i

b(i+l) = distance from the "initial point" to the next interval

b (i-l) = distance from the "initial point" to preceding interval

d_i = depth at interval i

Substituting Equation 4 into Equation 3 results in:

$$q_i = v_i \left(\frac{b(i+1) - b(i-1)}{2}\right)(d_i) \qquad \text{EQN 5}$$

Then, by summing the partial discharges as in Equation 2, the total discharge for the canal at a gauging site is calculated.

Box culverts (culverts 1-5, 6, 8-10 as shown in Figure 2) were gauged somewhat differently than the canal gauging sites, although the basic guidelines outlined above still apply. A pygmy-type velocity meter attached to extension rods was lowered from above these culverts at 3-foot intervals across the width of the culvert. Depths and velocities were measured and cross-sectional areas were determined as at the TC and X sites, and discharge was calculated via the equations outlined above.

Barrel culverts (culverts 5a and 7 in Figure 2) and TC sites 1 and 3 were also gauged from above using the pygmy-type meter on extension rods. At these sites, depths from the water surface to the sediment and from the sediment to the top of the pipe were measured, and the diameter of the culvert was determined (Figure 8b). These measurements were then applied to a table of coefficients for pipes of circular section flowing partly full (Bodhaine, 1968) to calculate cross-sectional area of the pipe below the surface, and the area of the sediment was subtracted to ascertain the effective area through which water flowed. A 0.6 depth velocity measurement was then multiplied by this area to determine discharge.

Since the nature of the cutouts below the structures precluded measurement of discharge directly into the slough via standard gauging methods, a mass-balance approach was adopted to determine cutout discharge directly to the slough at any S-12 structure:

$$Q_C = Q_S - (\Sigma TC + \Sigma C) \qquad \text{EQN 6}$$

where:

Q_C = discharge through a particular cutout directly into the marsh

Q_S = S-12 release rate at the structure under study

TC = measured discharge through the TC sites both east and west of the S-12 structure

C = measured discharge through any culverts which lie between the S-12 structure and the TC site to the east or west

For purposes of this study, seepage from the old Tamiami canal before water reached TC sites or culverts was disregarded.

Distribution Monitoring Results

The S-12 distribution system was monitored on 20 dates between May 22, 1979 and October 3, 1980 to document distribution patterns during a variety of structure opening schemes, delivery rates, and slough water levels. In all cases, monitoring was performed well after gate changes were made in order to allow the system to stabilize under new input schemes.

Station P-33, a continuous stage recording device located in central Shark Slough (Figure 6a) is a reference station for establishing relative slough water levels during monitoring. Period of record stage at P-33 (1953-1981) has ranged from 2.20-7.80 feet msl. During the study period, P-33 remained in a comparatively narrow range (6.10-6.96 ft. msl) due to much larger than scheduled discharges during the 1979-1980 dry season. However mean monthly stage at P-33 has been between 6-7 feet msl 62% of the time since the current delivery schedule has been in effect. Patterns of distribution discussed below therefore should be viewed from this perspective.

1) Individual Structures

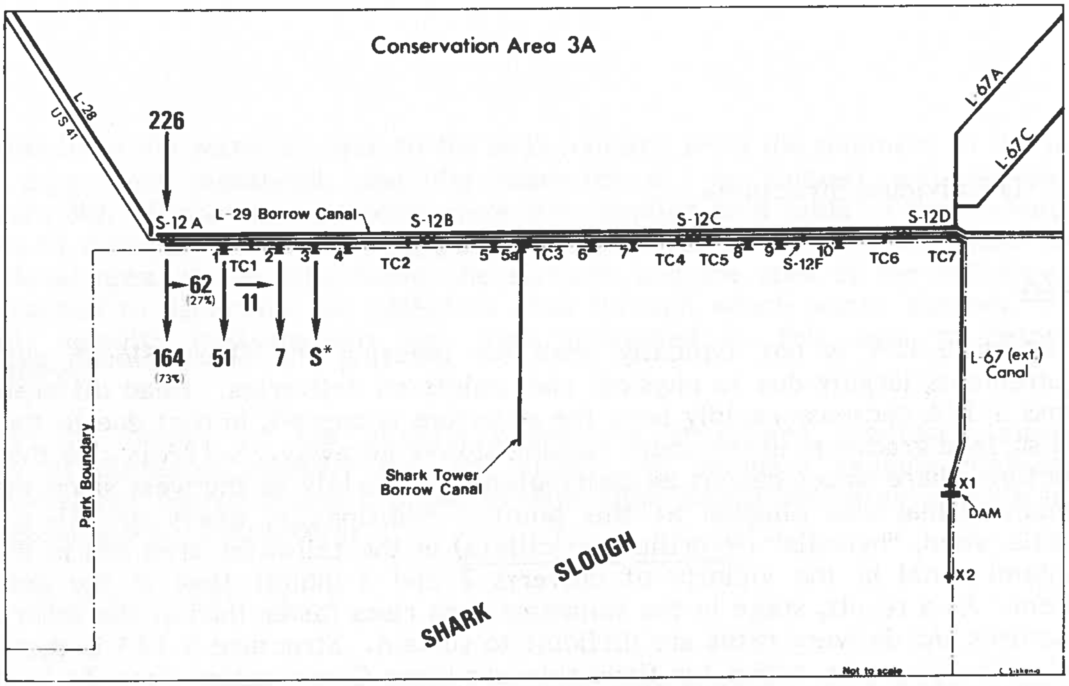
S-12A

Structure S-12A is not typically used for meeting the Shark Slough delivery requirements largely due to physical constraints on deliveries. Head differentials across S-12A decrease rapidly once the structure is opened, in part due to the flat land surface gradients to the south causing slower getaway. S-12A is also the only structure where water cannot be distributed immediately to the west since the old Tamiami canal was plugged at this point. Additionally, heavy growth of the aquatic weed, "hydrilla" (Hydrilla verticillata) in the tailwater area and in the old Tamiami canal in the vicinity of culverts 2 and 3 inhibit flow in the delivery system. As a result, stage in the tailwater area rises faster than at the other S-12 structures and delivery rates are difficult to sustain. Structure S-12A is therefore used primarily as an outlet for flood releases when Conservation Area 3A is above regulation stage, but is also used when it is determined that conditions for a sustainable discharge exist.

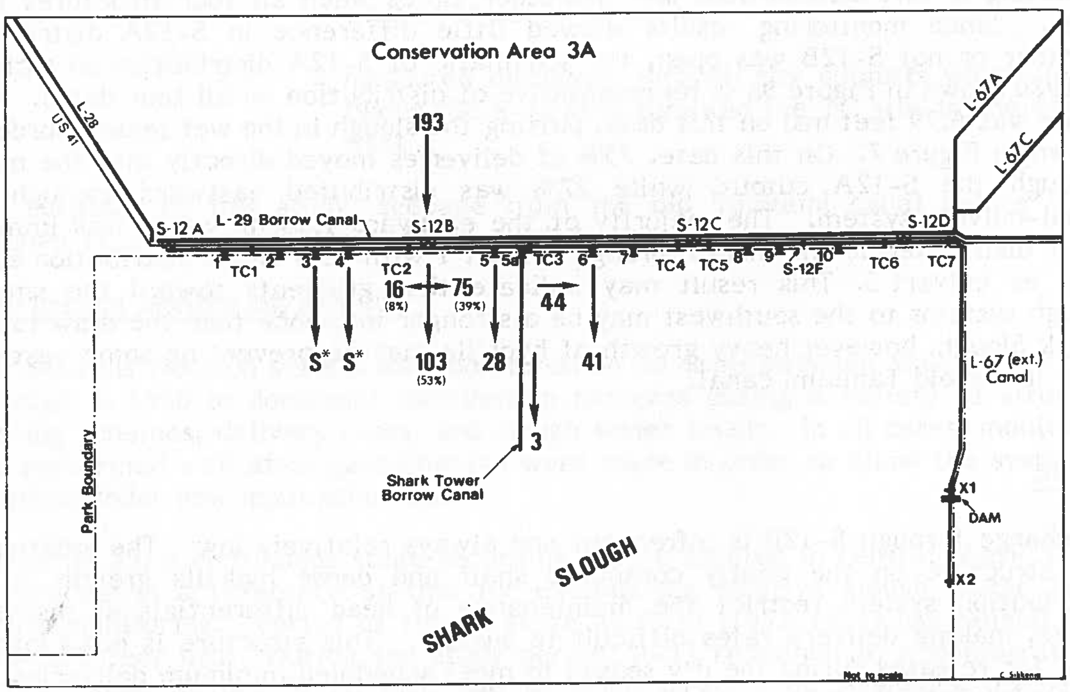
Deliveries through S-12A were monitored on four dates during the study period, once on October 3, 1980 when structure S-12B was closed and therefore not affecting S-12A distribution, and the other times when all four structures were open. Since monitoring results showed little difference in S-12A distribution whether or not S-12B was open, the schematic of S-12A distribution on October 3, 1980 shown in Figure 9a is representative of distribution on all four dates. P-33 stage was 6.79 feet msl on this date, putting the slough in the wet season border as shown in Figure 7. On this date, 73% of deliveries moved directly into the marsh through the S-12A cutout, while 27% was distributed eastward through the canal-culvert system. The majority of the eastward flowing water was immediately distributed to the marsh through culvert 1 with very slight distribution as far east as culvert 3. This result may indicate that gradients toward the smaller slough systems to the southwest may be a stronger influence than the draw toward Shark Slough, however heavy growth of hydrilla may be preventing some eastward flow in the old Tamiami canal.

S-12B

Discharge through S-12B is infrequent and always relatively low. The location of the structure on the gently contoured shelf and dense hydrilla growth in the distribution system restrict the maintenance of head differentials as discussed above, making delivery rates difficult to sustain. This structure is not typically used for releases during the dry season to meet scheduled minimum deliveries, but rather is generally only opened during the wet season when large S-12 releases are scheduled, when flood releases are necessary, or when constraints at other structures leave no other options.



(a) S-12A open, October 3, 1980. Asterisk (*) indicates direction of flow when below threshold of current meter.



(b) S-12B open, September 12, 1979. Asterisk (*) indicates direction of flow when below threshold of current meter.

Figure 9 (a) and (b). Structure S-12 distribution, in cfs.

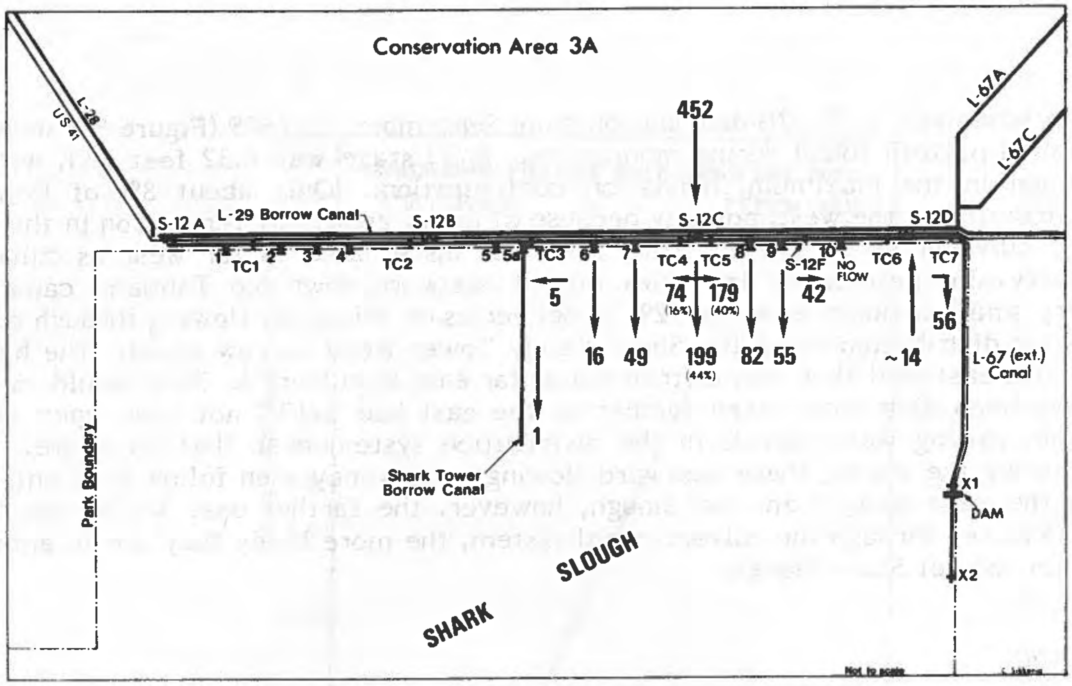
The schematic of S-12B distribution from September 12, 1979 (Figure 9b) shows the typical pattern found during monitoring. P-33 stage was 6.32 feet msl, with the slough in the maximum inundation configuration. Only about 8% of flow was distributed to the west, possibly because of heavy growth of vegetation in the canal and culverts to the west. Still, flow was discernable as far west as culvert 3. Thirty-nine percent of deliveries flowed eastward down old Tamiami canal with very small amounts of water (2% of deliveries on this date) flowing through culvert 5a for distribution along the Shark Valley Tower Road borrow canal. The balance of this eastward flow was distributed as far east as culvert 6. Flow would no doubt have been distributed even farther to the east had S-12C not been open at this time, raising water levels in the distribution system near that structure. Upon entering the marsh, these eastward flowing waters may then follow gradients back to the west away from the Slough, however, the farther east S-12B waters are distributed through the culvert-canal system, the more likely they are to enter the main body of Shark Slough.

S-12C

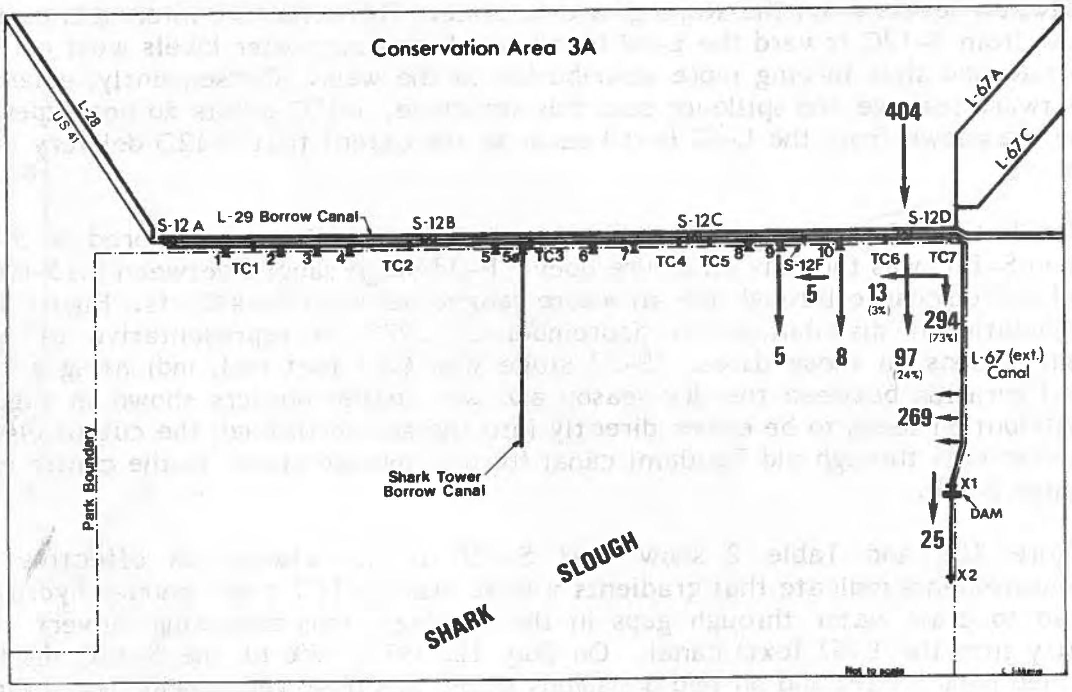
Structure S-12C is a primary point of surface water delivery to the park throughout the year. Head differentials across this structure are easier to maintain than at structures to the west, since steeper ground surface contours toward the center of Shark Slough contribute to faster tailwater drainage. As a result, larger sustained deliveries are possible. Structure S-12F, the stoplog dam in old Tamiami canal between S-12C and S-12D (Figure 2) exerts an influence on tailwater levels when the stoplogs are in place. This structure interrupts eastward flow from S-12C toward the L-67 (ext.) canal, causing water levels west of S-12F to rise and thus forcing more distribution to the west. Consequently, except for eastward leakage and spillover past this structure, S-12C inputs do not experience the drawdown from the L-67 (ext.) canal to the extent that S-12D delivery waters do.

Distribution of surface water deliveries through S-12C was monitored on 5 dates when S-12C was the only structure open. P-33 stage ranged between 6.15-6.47 ft. msl and discharge through the structure ranged between 84-452 cfs. Figure 10a, a schematic of distribution on September 5, 1979, is representative of S-12C distributions on these dates. P-33 stage was 6.19 feet msl, indicating a slough configuration between the dry season and wet season borders shown in Figure 7. Distribution tends to be either directly into the slough through the cutout (44%) or farther east through old Tamiami canal for distribution closer to the center of the slough (40%).

Figure 10a and Table 2 show that S-12F is not always an effective dam. Measurements indicate that gradients toward station TC7 exert enough hydrostatic head to draw water through gaps in the stoplogs, thus bypassing culvert 10 for entry into the L-67 (ext) canal. On July 12, 1979, 57% of the S-12C discharge spilled past S-12F, and on two occasions water was observed flowing north through culvert 10, adding inputs through station TC7. This may indicate that a portion of the S-12C discharge circumvented S-12F through the culverts to the west but then re-entered the old Tamiami canal, following the strong gradient into the L-67 (ext.) canal.



(a) S-12C open, September 5, 1979.



(b) S-12D open, May 22, 1979.

Figure 10 (a) and (b). Structure S-12 distribution, in cfs.

Table 2. S-12C Distribution into L-67 ext. canal, in cfs.

Date	(1) Spillage Past S-12F	Culvert 10	TC7
7/12/79	48	N(2)	21
7/18/79	46	0	50
8/17/79	52	0	36
9/5/79	42	0	56
9/12/79	47	N	72
1/2/80	28	0	73

(1) Computed via mass balance.

(2) Represents direction of flow when discernible but well below the water current meter threshold.

S-12D

Structure S-12D was used extensively for surface water delivery to the park during the study period, both in terms of frequency of opening and magnitude of deliveries. The relatively vegetation-free L-67 (ext.) canal can transport delivery waters away from the tailwater area much faster than water can flow through the slough. Head differentials may therefore be maintained more easily, allowing larger, more sustained deliveries at S-12D.

Stoplog dam S-12F influences waters delivered through S-12D by causing water levels in the old Tamiami canal to rise within the reach between S-12F and S-12D, thus flattening the gradients toward the west and forcing more delivery to the east and south.

Deliveries when S-12D was the only structure open were monitored on four dates during the study period. The schematic of the distribution on May 22, 1979 shown in Figure 10b is representative of this delivery scheme. Stage at P-33 was 6.18 ft msl, indicating a slough border configuration between the wet season and dry season Landsat determined borders shown in Figure 7. The strong influence of the L-67 ext. canal is apparent, with 73% of discharge drawn into the canal. Distribution along this canal will be discussed further below. Flow westward was minimal, but slight leakage through S-12F was evident. Twenty-four percent of discharge was distributed into the slough through the S-12D cutout.

2) Combinations of S-12 Openings

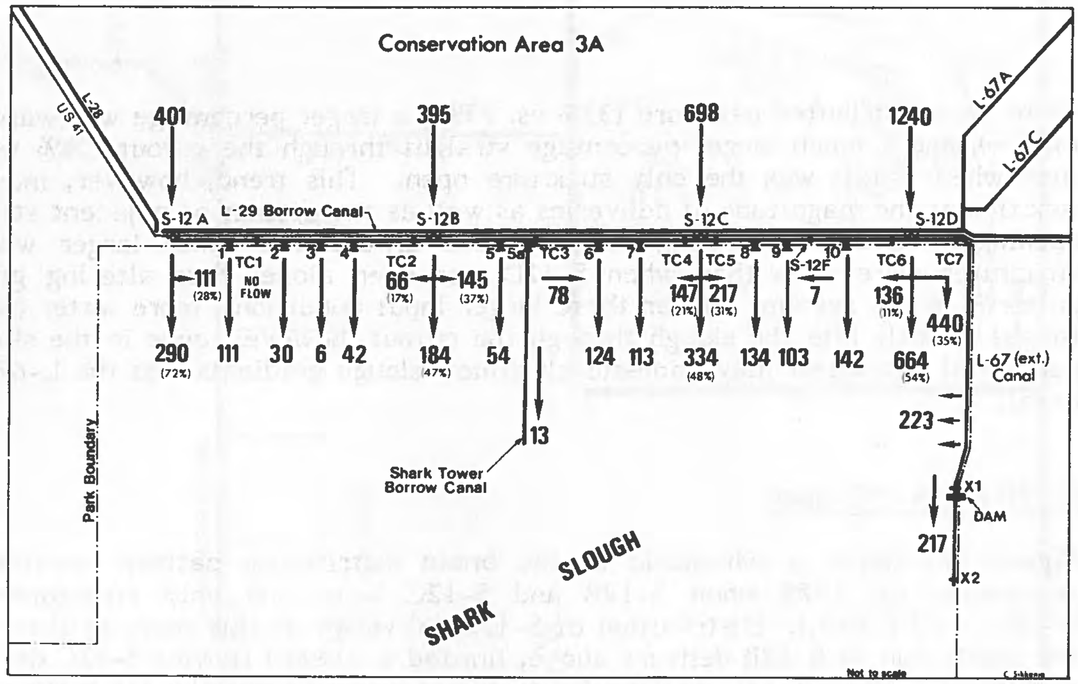
It is often necessary to open the S-12 structures in combination to meet scheduled deliveries and distribution needs. During the study period, flow was monitored under several combinations of structure openings at varying delivery rates.

All Structures Open

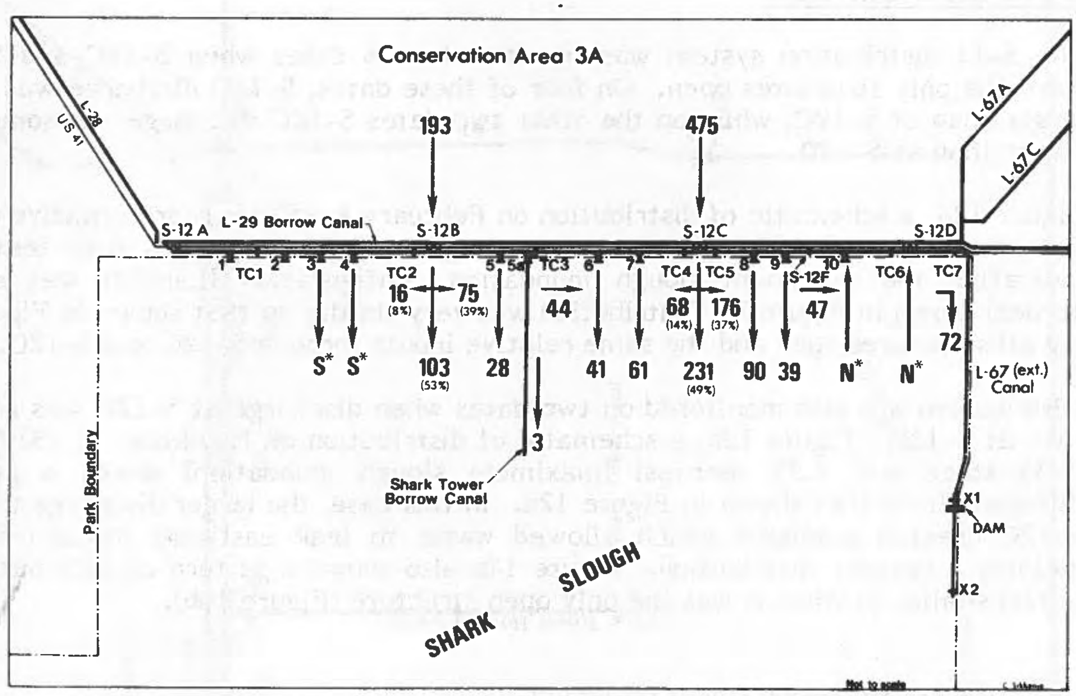
The distribution system was monitored on three dates when all structures were open. Figure 11a, a schematic of distribution on March 4, 1979 is representative of these monitoring dates. P-33 stage was 6.93 ft msl on this date, indicating that the slough had a wet season configuration similar to that shown in Figure 7 as determined by Landsat studies. Patterns of deliveries through S-12A and S-12B as discussed previously do not appear to be significantly different in this structure opening scheme than that discussed above and will not be discussed further here.

Delivery patterns of water from S-12C, as depicted in Figure 11a, show significant changes from when S-12C is the only structure open (Figure 10a). Westward flowing waters from the large S-12D delivery leak past S-12F and reduce the eastward distribution from S-12C. Deliveries through S-12C tended to move into the slough near that structure on March 4, rather than flowing all the way to the L-67 (ext). canal as occurred on September 5.

Distribution patterns at S-12D when all structures were open differed significantly from when S-12D was open alone (Figure 10b). A much smaller percentage of



(a) All four structures open, March 4, 1980.



(b). S-12B and S-12C open, September 12, 1979. Asterisk (*) indicates direction of flow when below threshold of current meter.

Figure 11. (a) and (b). Structure S-12 distribution, in cfs.

water was distributed eastward (35% vs. 73%), a larger percentage westward (11% vs. 3%), and a much larger percentage straight through the cutout (54% vs 24%) than when S-12D was the only structure open. This trend, however, may be a function of the magnitude of deliveries as well as the effects of adjacent structure openings. Deliveries through S-12D were always 2-3 times larger when all structures were open than when S-12D was open alone, thus altering gradient patterns in the system. Under these larger input conditions, more water could be forced directly into the slough through the cutout, however, once in the slough, a portion of this water may immediately follow slough gradients into the L-67 (ext.) canal.

S-12B and S-12C Open

Figure 11b shows a schematic of the broad distribution pattern monitored on September 12, 1979 when S-12B and S-12C were the only structures open (P-33 = 6.32 ft msl.). Distribution of S-12B deliveries on this date, as discussed in the subsection on S-12B delivery above, limited westward flowing S-12C deliveries to culvert 7, while S-12C distribution to the east was essentially the same as when it was the only structure open. Flow from S-12C reached as far east as the L-67 (ext). canal for eventual distribution along the canal banks. Percentages of flow distributions at S-12C were almost identical to when S-12C was open alone.

S-12C and S-12D Open

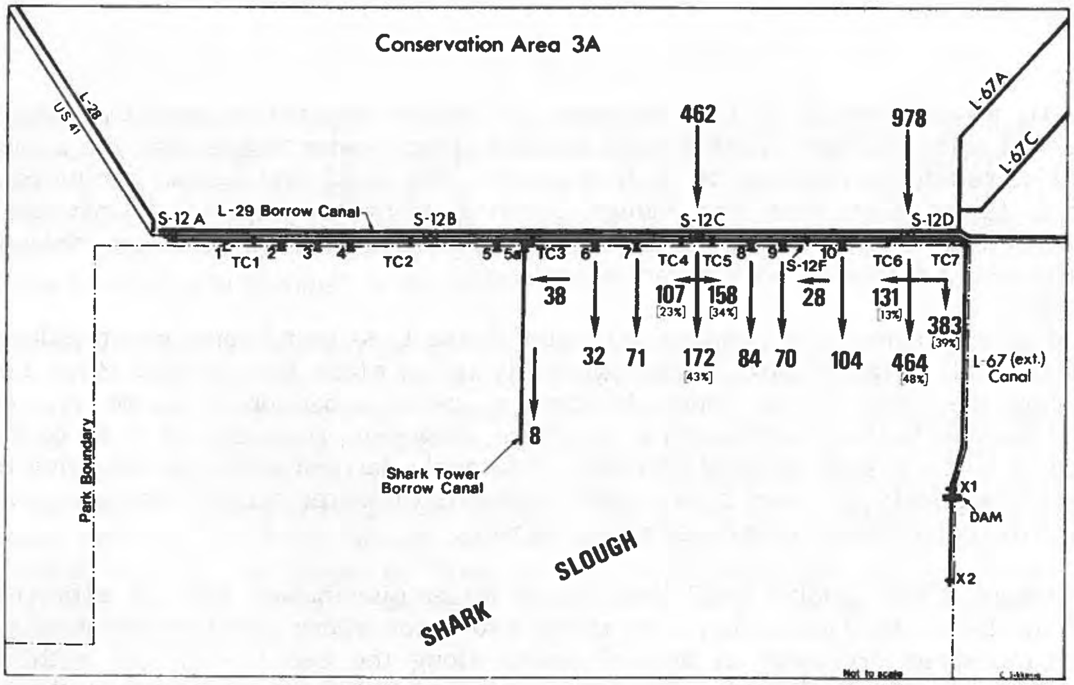
The S-12 distribution system was monitored on 6 dates when S-12C and S-12D were the only structures open. On four of these dates, S-12D discharge was much larger than at S-12C, while on the other two dates S-12C discharge was somewhat larger than at S-12D.

Figure 12a, a schematic of distribution on February 8, 1980 is representative of the four dates when S-12D deliveries were larger. P-33 stage was 6.40 feet msl, indicating the maximum slough inundation configuration (Landsat wet season border) shown in Figure 7. Distribution was very similar to that shown in Figure 11 for all structures open and the same relative inputs through S-12C and S-12D.

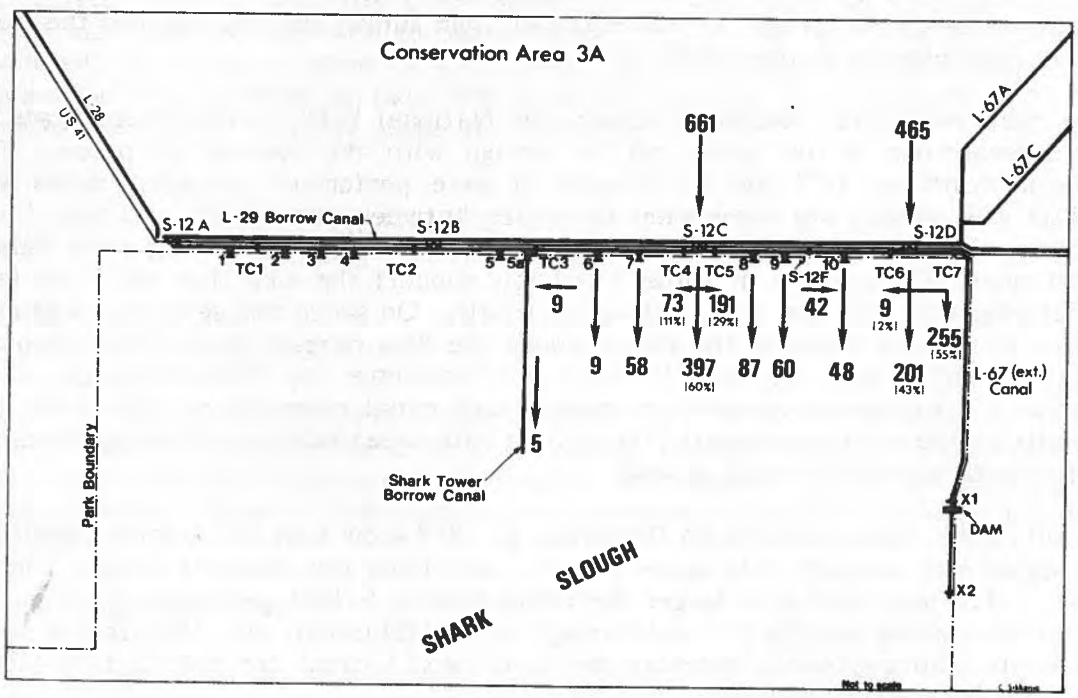
Distribution was also monitored on two dates when discharge at S-12C was greater than at S-12D. Figure 12b, a schematic of distribution on November 6, 1979 when P-33 stage was 6.73 feet msl (maximum slough inundation) shows a pattern different from that shown in Figure 12a. In this case, the larger discharge through S-12C created gradients which allowed water to leak eastward through S-12F, yielding a broader distribution. Figure 12b also shows a pattern of distribution at S-12D similar to when it was the only open structure (Figure 10b).

3) L-67 Extension Canal Dynamics

The L-67 (ext.) canal reaches southward 9.5 miles from U.S. 41, paralleling and just inside the eastern park boundary (Figure 2). The canal, which is directly linked to the old Tamiami canal, was designed to facilitate movement of surface water



(a) S-12C and S-12D open, larger delivery through S-12D, February 8, 1980.



(b). S-12C and S-12D open, larger delivery through S-12C, November 6, 1979.

Figure 12 (a) and (b). Structure S-12 distribution, in cfs.

inputs away from the S-12 structures. Extensive vegetation causes resistance to flow of water through Shark Slough, causing slough water levels near the structures to rise rapidly in response to surface inputs. The L-67 (ext.) canal conducts water at a faster rate than the slough, moving tailwater rapidly downstream and distributing it to the slough as discussed below. The adjacent levee was designed to retain S-12 deliveries within Park boundaries.

A dam with removable stoplogs is located in the L-67 (ext.) canal seven miles south of U.S. 41. The stoplogs, which were always in place but allowed some leakage during the study period, were designed to cause a backup of water to increase distribution to the slough north of the dam. However, this appears to be of limited utility since a well-scoured channel, apparently formed after construction of the canal, regularly conducts considerable amounts of water around the dam and back into the canal directly south of this structure.

Hartwell (1968) studied L-67 (ext.) canal water distribution and the effectiveness of the L-67 (ext.) canal dam. He chose two dates where canal inputs were similar and measured discharge at several points along the canal, with and without the stoplogs in place. Though he found a significant difference in loss to the slough (102 cfs with the stoplogs in place versus 4 cfs 11 days later without stoplogs), Hartwell noted that a flattening of the hydraulic gradient toward the slough in the period between measurements was probably the major cause of the reduction of overflow into the slough, and not the presence or absence of the stoplogs. Though his results were inconclusive, he did establish that water is distributed to the slough along the length of the canal rather than simply spilling out into the slough at the southern end of the canal.

In a more extensive monitoring effort, the National Park Service concentrated on the interactions of the canal and the slough with the stoplogs in place. Flow measurements at TC7 and X1 (Figure 2) were performed on seven dates when S-12D was open. Net movement of water between the slough and the 7 mile section of the canal north of the dam was then determined using mass balance techniques. Data shown in Table 3 strongly support the idea that the L-67 (ext.) canal interacts with the slough along its length. On six of the seven dates studied, the canal showed losses to the slough above the dam ranging from 11%-92% of the measured TC7 input. On June 15, 1979 and September 19, 1980, discharge through station X2 was also measured to study slough-canal interactions below the dam. Results of these measurements (Table 3) on both dates show a net loss to the slough in this segment of the canal as well.

Results from measurements on December 6, 1979 show that under some conditions, the canal may actually gain water (+30 ft^3/sec) from the adjacent slough. On this date, S-12C was open with larger deliveries than at S-12D, perhaps suggesting that water distributed near S-12C and through the S-12D cutout may then follow slough gradients southeastward, entering the L-67 (ext.) canal for distribution farther south as discussed previously.

Table 3. L-67 extension canal dynamics (all discharge in ft^3/sec).

			Distribution of Slough North of Dam[(1)]				Distribution to Slough[(1)]		
Date	TC7 Discharge	X1 Discharge	Discharge	%TC7	X2 Discharge	Between X1 & X2	% TC7	At Southern Terminus	% TC7
5/22/79	294	25	269	92%	-	-	-	-	-
5/31/79	329	45	284	86%	-	-	-	-	-
6/11/79	209	83	127	60%	-	-	-	-	-
6/15/79	93	82	11	11%	47	35	38%	47	51%
12/6/79	169	199	-30	118%	-	-	-	-	-
3/4/80	440	217	223	51%	-	-	-	-	-
9/19/80	410	127	283	69%	74	53	13%	74	18%

(1) Determined via mass balance.

4) Northward Loss of Water Out of the Park via the S-12 Distribution System— A Special Case.

In response to May, 1981 drought conditions in south Florida which threatened to allow saltwater contamination of Miami-area drinking water supply wellfields, the South Florida Water Management District routed water from Lake Okeechobee and the Conservation Areas toward Miami via the C-4, Miami, L-29 borrow canal and other canals. On May 6, 1981, structures S-333 and S-334 were open as a part of this routing scheme, moving water from the L-67 canal and Conservation Area 3A toward Miami. At the same time, structure S-12D was open one gate at one foot, with delivery to the park estimated by the U. S. Army Corps of Engineers to be 37 ft3/sec.

During routine hydrologic monitoring by National Park Service personnel on May 6, 1981 northward flow in the L-67 (ext.) canal was noted, indicating a reversal in the usual north-to-south gradient in this canal. This reversal also may have indicated a reversal of the normal gradient across structure S-12D, causing northward drainage out of the Park toward Miami via the L-29 borrow canal.

On May 7, 1981, National Park Service personnel monitored the S-12 distribution system using rhodamine tracer dye to investigate possible northward drainage out of the Park. Figure 13 is a schematic of the flow pattern observed on this date at 1400 hours. This schematic shows that a significant portion of Shark Slough was affected, with water not only draining from the slough into the L-67 (ext.) canal, then flowing north toward structure S-12D, but also flowing northward through culverts 8, 9, and 10, and then east down the old Tamiami canal toward the structure. A head-differential of 0.03 feet from south to north was observed across S-12D at this time, and northward flow out of the Park was verified via rhodamine tracer dye. Subsequent examination of strip charts from upstream and downstream stage recorders at S-12D further verified the existence of the observed reversal in head-differential.

CONCLUSIONS

1) During typical dry season slough conditions, discharges through S-12A and portions of discharge through S-12B are not likely to flow into Shark Slough, but rather through the smaller sloughs in that area into the headwaters of the Broad, Harney or Lostman's Rivers. Under wet season conditions when surface water in that area is continuous with Shark Slough, greater portions of deliveries through these structures are likely to enter the slough. Deliveries through these structures should be continued to approximate natural drainage through the area.

2) Relatively slow tailwater drainage below S-12A and S-12B limit the size of deliveries through these structures. S-12A distribution tends to be very narrow, with most of the water distributed either straight through the cutout or through

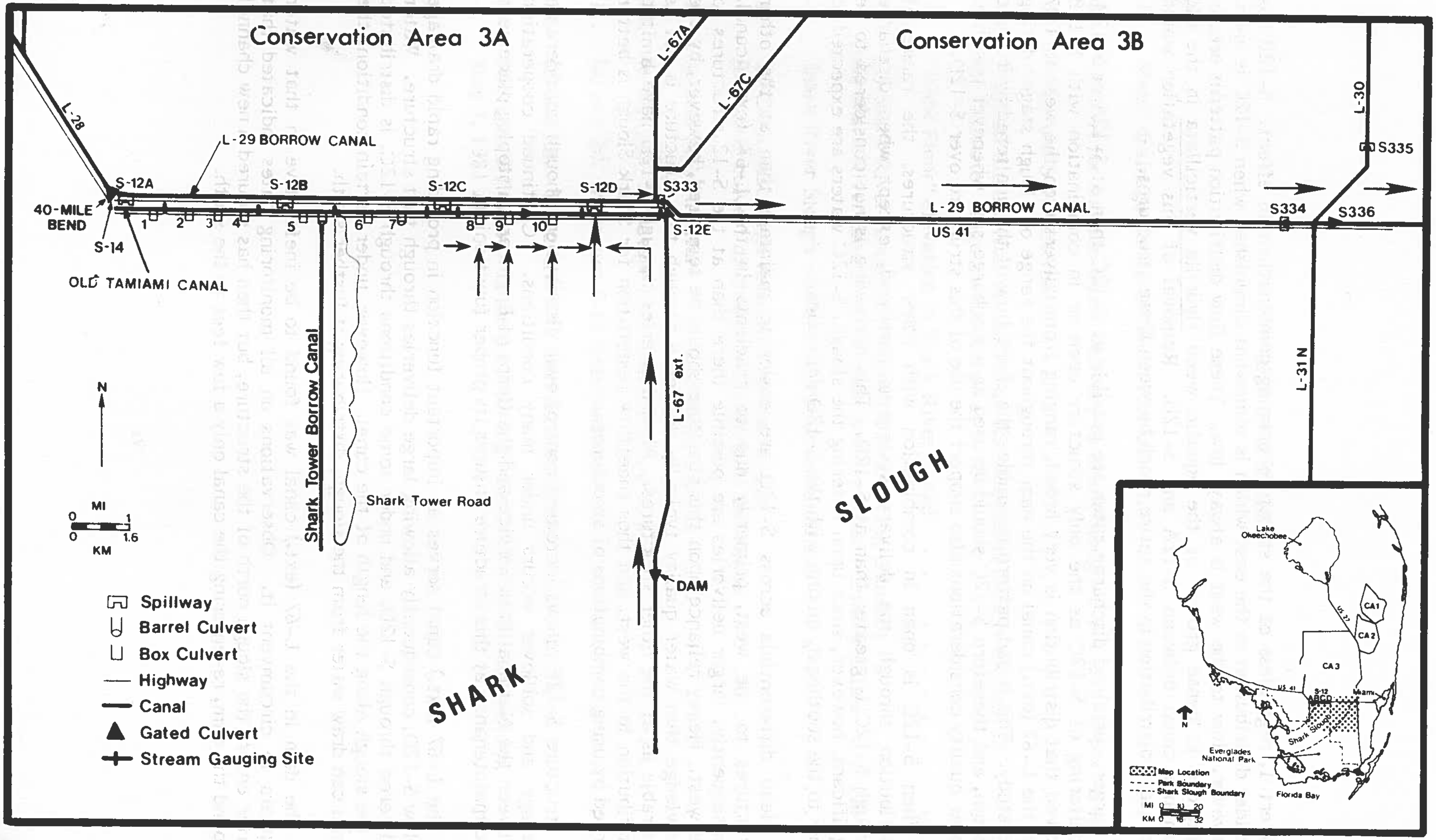


Figure 13. Northward flow out of the Park through the S-12 distribution system, May 7, 1981.

culvert 1, regardless of the structure opening combinations in effect. S-12B has broader distribution to the east which is somewhat diminished when S-12C is open. However, flow to the west is always low. These flow distribution patterns are, in part, due to dense growth of the aquatic weed Hydrilla verticillata in the old Tamiami canal between S-12A and S-12B. Removal of this vegetation would facilitate distribution in the entire reach between these structures.

3) Larger, sustained discharge rates are possible at S-12C than at S-12A or S-12B. Monitoring of S-12C as the only structure open or in combination with S-12B showed that distribution is very broad, ranging from culvert 6 on the west to TC7 and the L-67 (ext.) canal on the east throughout the range of slough stages during the study. This broad pattern resembles the sheet flow of the unaltered hydrologic system, and therefore S-12C should be used as a discharge site whenever possible. Water quality considerations also support the use of this structure over S-12D.

4) When S-12C is open in combination with other structures, the range of distribution through the delivery system is narrowed, except when discharge through S-12C is greater than at S-12D. This narrowing is not considered to be significant, however, since upon entering the slough, S-12C waters are expected to flow to the southeast, mixing with the S-12D deliveries.

5) Head differentials across S-12D are easier to maintain than at the other structures to the west, primarily due to gradients in the L-67 (ext.) canal. Consequently, larger deliveries are possible there than at the S-12 structures to the west. Heavy reliance upon this structure should be tempered, however, by the knowledge that water quality typically delivered through this structure is not as desirable as at the other structures. Also, deliveries through S-12D have limited distribution to the west, and thus sheetflow restoration for Shark Slough is better served by using combinations of structures.

6) Structure S-12F allows increased control over distribution, though considerable leakage and spillover occurs under many conditions. Continued cooperation between the National Park Service and the Corps of Engineers in stoplog placement and maintenance at this structure ensures its proper functioning.

7) The L-67 (ext.) canal serves an important function in providing rapid drainage below S-12D, consequently allowing large deliveries through that structure. Water delivered through S-12D, and under some conditions through S-12C, is distributed to the slough along the length of the canal. However, under certain conditions the canal can draw water from the slough, distributing it further south.

8) The dam in the L-67 (ext.) canal was found to be ineffective in that water appears to circumvent it. Observations on all monitoring dates indicated that water enters the slough north of the structure, but then has scoured a new channel around the dam, re-entering the canal only a few feet to the south.

9) The S-12 distribution system should be monitored when south Florida water management practices could cause slough drainage northward out of the Park. Early discovery of gradient reversal conditions such as occurred May 6-7, 1981 would help assure prompt remedial action.

ACKNOWLEDGEMENTS

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Appendix A. Flow distribution through the S-12 delivery system, all structures open, in ft.^{3}/sec.

Date	S-12 Discharge A	S-12 Discharge B	S-12 Discharge C	S-12 Discharge D	S-12A(1) Cutout	Culvt. 1	TC1	Culvt. 2	Culvt. 3	Culvt. 4	TC2	S-12B(1) Cutout	Culvt. 5	Culvt. 5a	TC3
10/11/79	182	191	470	840	138	36	8	4	0	6	13	152	3	4	18
10/24/79	209	188	451	945	156	46	8	1	0	7	14	143	17	5	9
3/4/80	401	395	698	1,240	240	111	0	30	6	42	66	184	54	13	78
10/3/80	226	0	304	911	164	51	11	7	S(2)	Not Measured					

Date	Culvt. 6	Culvt. 7	TC4	S-12C(1) Cutout	TC5	Culvt. 8	Culvt. 9	S-12F(1)	Culvt. 10	TC6	S-12D(1) Cutout	TC7	X1	X2
10/11/79	28	69	86	221	163	108	86	46(W)(2)	99	159	299	382	-	-
10/24/79	33	79	85	188	178	111	90	31(W)(2)	113	153	404	388	-	-
3/4/80	124	113	147	334	217	134	103	7(W)(2)	142	136	664	440	217	223
10/3/80	Not Measured													

(1) Determined via mass balance.

(2) Direction (N, S, E, W) of flow observed.

Note: Flow through cutouts, culverts, X1, and X2 is south. Flow through TC1, TC3, TC5, and TC7 is east. Flow through TC2, TC4, TC6, and S-12F is west, unless otherwise noted. When only a letter is shown, flow in that direction was discernible but below the threshold of the water current.

Appendix B. Flow distribution through the S-12 delivery system, S-12C open alone, in ft^3/sec.

Date	S-12 Discharge A	S-12 Discharge B	S-12 Discharge C	S-12 Discharge D	Culvt. 5a	TC3	Culvt. 6	Culvt. 7	TC4	S-12C(1) Cutout	TC5	Culvt. 8
7/12/79	-	-	84	-	S(2)	0	2	6	8	34	50	2
7/18/79	-	-	173	-	S(2)	0	S(2)	22	8	93	80	28
8/17/79	-	-	226	-	4	6	1	31	35	82	109	37
9/5/79	-	-	452	-	1	5	16	49	74	100	179	82
1/2/80	-	-	391	-	8	16	29	67	87	142	161	82

Date	Culvt. 9	S-12F(1)	Culvt. 10	TC6	S-12D(1) Cutout	TC7
7/12/79	0	E(2)	N(2)	-	N(2)	22
7/18/79	7	46	0	-	N(2)	50
8/17/79	19	52	0	-	N(2)	36
9/5/79	55	42	0	-	N(2)	56
1/2/80	51	28	0	-	N(2)	73

(1) Determined via mass balance.

(2) Direction (N, S, E, W) of flow observed.

Note: Flow through culverts and cutouts is south unless otherwise noted. Flow through TC3 and TC4 is west, flow through TC5, S-12F, and TC7 is east. When only a letter is shown, flow in that direction was discernible but below the threshold of the water current meter.

Appendix C. Flow distribution through the S-12 delivery system, S-12D open alone, in ft^3/sec.

Date	S-12 Discharge A	B	C	D	S-12F[1]	Culvert 10	TC6	S-12D[1] D	TC7	X1	X2
5/22/79	-	-	-	404	5	8	13	97	294	25	-
5/31/79	-	-	-	558	17	41	58	172	329	45	-
6/11/79	-	-	-	291	7	5	11	70	209	83	-
6/15/79	-	-	-	87	E[2]	0	2	N[2]	93	82	36

(1) Determined via mass balance.

(2) Direction (N, S, E, W) of flow observed. Flow through all cutouts, culverts, and X1 and X2 is south unless otherwise noted. Flow through S-12F and TC6 is west and through TC7 is east unless otherwise noted. When only a letter is shown, flow was discernible but below the threshold of the water current meter.

Appendix D. Flow distribution through the S-12 delivery system, S-12C and S-12D open, in $ft^3/sec.$[1]

Date	S-12 Discharge A	B	C	D	Culvt. 5a	TC3	Culvt. 6	Culvt. 7	TC4	S-12C[2] Cutout	TC5	Culvt. 8	Culvt. 9	S-12F[2]	Culvt. 10	TC6	S-12D[2] Cutout	TC7
11/6/79	-	-	661	465	5	9	9	58	73	397	191	87	60	42E[3]	48	9	201	255
11/20/79	-	-	324	1,180	5	15	14	67	76	153	96	88	80	59	156	201	604	376
12/6/79	-	-	332	251	7	15	16	61	84	110	139	70	53	16E[3]	16	82	169	199
2/8/80	-	-	462	978	8	38	32	71	107	197	158	84	70	28	104	131	464	383
2/14/80	-	-	429	1,280	10	51	41	80	123	180	126	84	81	45	142	187	647	446
9/19/80	-	-	678	987	10	38	52	100	175	240	263	146	125	25	131	158	419	410

(1) Distribution in the L-67 (ext.) canal is shown in Table 3.
(2) Determined via mass balance.
(3) Direction (N, S, E, W) of flow observed.

Note: Flow through culverts and cutouts is south. Flow through TC3, TC4, and TC6 is west. Flow through TC5 and TC7 is east. Flow through S-12F is west unless otherwise noted.

Appendix E. Flow distribution through the S-12 delivery system, S-12B and S-12C open in ft^3/sec.

Date	S-12 Discharge A	S-12 Discharge B	S-12 Discharge C	S-12 Discharge D	Culvt. 3	Culvt. 4	TC2	S-12B[1] Cutout	Culvt 5	Culvt. 6a	TC3	Culvt. 6	Culvt. 7	TC4	S-12C[1] Cutout
9/12/79	-	193	475	0	S[2]	S[2]	16	103	28	3	44	41	61	68	231

Date	TC5	Culvt. 8	Culvt. 9	S-12F	Culvt. 10	TC6	S-12D Cutout	TC7
9/12/79	176	90	39	47	N[2]	-	N[2]	72

(1) Determined via mass balance.

(2) Direction (N, S, E, W) of flow.

Note: Flow through culverts and cutouts is south unless otherwise noted. Flow through TC2 and TC4 is west. Flow through TC3, TC5, S-12F and TC7 is east. When only a letter is shown, flow was discernible but below the threshold of the water current meter.