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SOUTH FLORIDA WATER MANAGEMENT DISTRICT

TECHNICAL REPORT

July 1985

A WET SEASON FIELD TEST OF EXPERIMENTAL WATER DELIVERIES TO NORTHEAST SHARK RIVER SLOUGH AUGUST - NOVEMBER, 1984

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A Wet Season Field Test of Experimental Water Deliveries to Northeast Shark River Slough August -- November, 1984

Thomas K. MacVicar, P.E.
Data Management Division
Resource Planning Department
South Florida Water Management District

July 12, 1985

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The analysis of this field test was made possible by the conscientious effort of a large group of people associated with the collection and processing of hydrologic data in South Dade County. The Miami office of the U.S. Geological Survey, the South Florida Research Center in Everglades National Park and the Data Management Division of the South Florida Water Management District played a key role in the timely collection and processing of the data.

The staff of the District's Homestead Field Station handled the tedious job of making manual water level measurements seven days a week at a large number of ground and surface water sites throughout the study area in a responsible and professional manner.

Several individuals in the Resource Planning Department gave advice and assistance in analyzing the data. Thomas VanLent is responsible for the development and application of the theoretical groundwater flow analysis presented in Appendix A. Kent Loftin performed the regional groundwater seepage computation summarized in Appendix B. Michael Piper was instrumental in organizing all the hydrologic data associated with the test and preparing many preliminary plots of the data used in the analysis.

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Comments on 90-Day Report by Florida Lime and Avocado Committees

SUMMARY

The second in a series of experimental water deliveries to Everglades National Park (E.N.P.) and Northeast Shark River Slough (N.E.S.R.S.) was conducted from August 1 through November 30, 1984. The first two months of the test period exhibited typical summer rainfall. October and November were much drier than normal with very little rain. Detailed hydrologic monitoring was conducted throughout the region to document the effects of the testing program on the hydrology of southwest Dade County.

The objective of this test was to induce sheetflow in N.E.S.R.S. for up to 90 consecutive days under wet season conditions. The experiment was interrupted twice by rainfall which brought the water table near the developed areas of the East Everglades above the trigger level agreed to for this test. Three separate episodes, lasting 21,11, and 47 days, of water diversion to N.E.S.R.S. were made during the time allotted for the test. A total of 118,000 acre feet was released from WCA-3A into the slough from August through November.

Of particular importance during this test was whether large volumes of water could be added to N.E.S.R.S. in the wet season without increasing the risk of flooding to any residential or agricultural areas west of the L-31N levee. Another goal was to document the importance of N.E.S.R.S. flow to the lower reaches of Shark River Slough in Everglades National Park.

Although the test did not realize the goal of 90 consecutive days of flow, a large amount of water was released into the slough during what were historically the wettest months in terms of overland flow. The data from this test, and previous uses of S-333, along with the large body of knowledge of the surface and groundwater hydrology of the East Everglades, supports the following conclusions concerning the reestablishment of sheetflow in N.E.S.R.S.

CONCLUSIONS

It is possible to use S-333 to divert relatively large amounts of water into Northeast Shark River Slough during the wet season without increasing the flood risk in the developed areas west of L-31N.

Such use of S-333 should be accompanied by a plan to lower the L-31N canal level below the design stage whenever the water table in the developed area adjacent to the slough is above a specified elevation.

The use of N.E.S.R.S. as a flow way, by diverting water away from the S-12 structures, has a significant influence on the water level and overland flow rate within Everglades National Park, near the Tamiami Trail. Hydroperiod changes in the center of the slough, farther to the south, were difficult to distinguish with this test data. A plan that controls flow through the S-12 structures, as well as S-333, would be more valid in determining the importance of N.E.S.R.S. to Everglades National Park.

The trigger wells used in the 90 day test showed no obvious signs of influence by S-333 and were not good indicators of conditions in the developed areas.

Any limits set on the operation of the L-31N canal system must be flexible enough to prevent the unnecessary transfer of groundwater that occurred in the last 6 weeks of this experiment.

INTRODUCTION

This report presents a detailed analysis of a 90-day field test of experimental water deliveries to Northeast Shark River Slough. This is the second test to be conducted under the authority granted by the Supplemental Appropriations Act, 1984 (PL 98-181). The first test, with a duration of 30 days, was conducted during April and May, 1984.

Results of the 30-day test were presented in an Evaluation Report published by the South Florida Water Management District (SFWMD) in July 1984. The 30-day test took place during very dry conditions and, while it was successful in documenting hydrologic behavior in N.E.S.R.S., it was not an accurate reflection of the District's, or Everglades National Park's, long term objective of restoring the natural hydrology of the area. Consequently, the District proposed an additional test to be conducted during the wet season, when sheet flow occurred under the natural system. A test duration of 90 days was suggested to allow more time to observe the slow sheet flow process and to provide a more realistic demonstration of the natural flow system.

On July 24, 1984 a meeting was held at the Tamiami campus of Florida International University to discuss the District's 90-day test proposal. The District, the Corps of Engineers, Everglades National Park, south Dade farmers and East Everglades residents were represented. As with the 30-day test, a formal legal agreement was negotiated outlining the specific requirements associated with the use of S-333 to induce sheet flow in N.E.S.R.S.

THE 90-DAY TEST AGREEMENT

A legal agreement between the SFWMD and the south Dade Farmers was signed on July 27, 1984 allowing the diversion of water from Water Conservation Area (WCA)-3A into N.E.S.R.S. for up to 90 days. It was stipulated that the flow had to occur between August 1 and November 30, 1984. A series of limiting conditions were also imposed which restricted the use of S-333 and altered the normal operating procedures for portions of the south Dade canal network.

There were two major elements of the agreement that dominated hydrologic activity associated with the test.

1. The District agreed to maintain lower water levels in the entire reach of L-31N from S-335 to S-176 for the duration of the test, and
2. Two groundwater monitoring wells were adopted as control points in deciding whether or not water could be diverted to N.E.S.R.S.

The first element was suggested by the District to provide an extra degree of flood protection to the residents and farmers in the East Everglades. Although the District felt that the proposal for using S-333 would not increase the risk to developed land, the fear has been expressed by those living or farming near the L-31N canal that putting water into N.E.S.R.S. would raise their water table and increase flood potential. Lowering the canal level was an obvious way to increase the margin of safety related to floods.

The two trigger wells were suggested by the representatives of the farmers as a means of insuring that S-333 would be closed when the water level near the developed areas reached a certain point, whether or not the rise was in response to local rainfall or the use of S-333. There was neither time, nor sufficient data, for a detailed analysis to choose an ideal trigger level for each site. To avoid delaying the start of the test, it was agreed to close S-333 whenever the water table at wells G-3272 or G-3273 rose above 6.5 ft MSL. The test was interrupted for two extended periods and, even with the below normal rainfall of the 1984 wet season, only 79 days of flow were achieved in the 122 days available for testing.

As with the 30-day test, an extensive water level monitoring network (Figure1) was maintained by the U.S. Geological Survey and the S.F.W.M.D. Two additional groundwater level recorders were installed for this test, one just west of L-31N about one mile south of Tamiami Trail and one about a mile southeast of L-31N near S.W. 222 St.

In addition, the 90 day agreement contained specific language about the sharing of data with the farmers, and the time frame allowable for report preparation. Also stipulated was the requirement to submit a first draft of this report to the farmers engineering consultant for review and comment. Any differences in interpretation which could not be resolved prior to the publication of the final report were to be incorporated as an appendix to this report.

RESULTS AND ANALYSIS

The timing of the 90-day test was appropriate to the goal of reestablishing a more natural hydrology to N.E.S.R.S.. Historically, the highest overland flow rates in the slough were recorded from September through November. Any long term plan for restoring the slough to its former function must include surface flows in the traditional wet season.

The dry conditions which prevailed before and during the 30 day test made it relatively easy to analyze the hydrologic data and isolate the changes in the system as a result of the releases through S-333. Wet season conditions complicate the analysis. The process of introducing flow into N.E.S.R.S. consists of establishing sheetflow across a 10 mile front. The changes in the water level are subtle, but noticeable, in the heart of the slough. On the periphery of the slough it is virtually impossible to relate water level activity with flow through S-333. Stations near L-31N are clearly influenced by operation of the canal system. In all areas, rainfall and evapotranspiration dominate the water budget. The frequent, heavy storms result in rapid increases in the water level and, in many cases, completely overshadow the very gradual changes in the base flow which may be occurring in response to the opening of S-333.

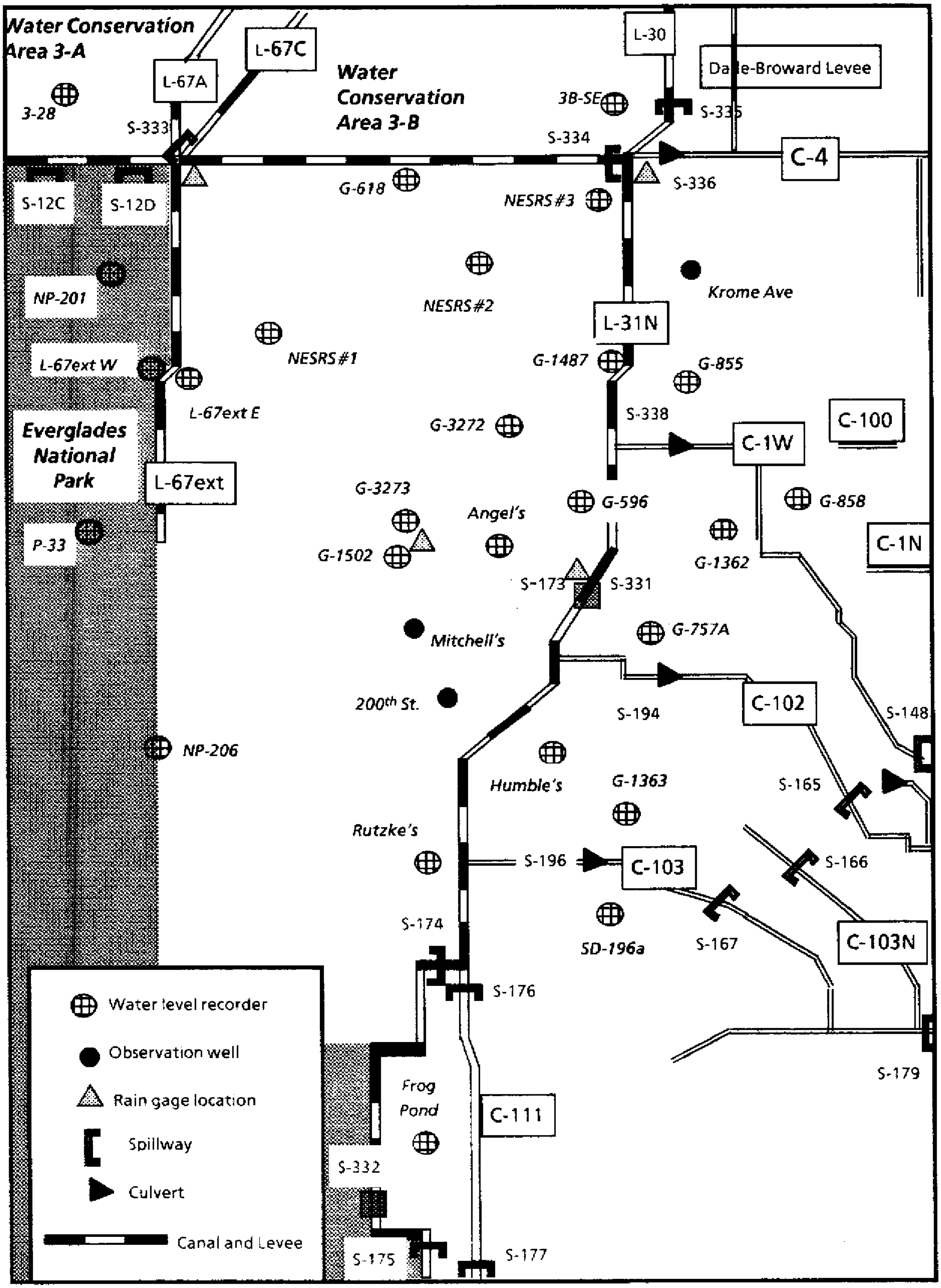


Figure 1. Daily Water Level Monitoring Network.

Hydrologic Conditions

At the start of the test the average water level in WCA-3A was about 10.0 ft above mean sea level (MSL). The S-12 structures, which control flow from WCA-3A into Everglades National Park, had been operated in an experimental mode for the previous 14 months. S-12 A, B, and C had been open full since June 1983. Construction of two plugs in the L-67 extension canal was complete by June 1984 and S-12D was fully opened at that time. As a result of above normal rainfall in 1983 and early 1984, the west side of Shark River Slough experienced high, uninterrupted flow for most of the 14 months preceding the 90-day test.

Based on the data collected during the test, the period can be split into two distinct segments. August and September exhibited typical wet season rainfall and water levels . October and November were unusually dry and conditions during the second half of the test resembled those experienced during the 30 day test. Despite continuous flow into the slough from October 17 through November 30, the groundwater table in the developed areas of the East Everglades showed a steady decline characteristic of the onset of the dry season.

Rainfall was near, or slightly below, normal for most of the study area from June through September. A dry weather pattern became established in October and there was very little rain during the final six weeks of the experiment. Figure 2 is a plot of the average rainfall over N.E.S.R.S. from August through November.

Although authorized to begin the test on August 1, the District was unable to lower the canal levels sufficiently until August 2, despite heavy pumping at S-331. Figure 3 shows the daily flow rates through S-333 during the test. The test was interrupted twice, for extended periods, due to rainfall which was typical for that time of year. There were no major storms during the test and no flooding was reported on any developed property at any time during the test. The two periods when S-333 had to be closed resulted from a general rise in the water table caused by rainfall over the East Everglades, not by surface flow toward the developed area from S-333 . At no time was the District unable to meet the canal water level criteria it had set, although it was necessary to pump S-331 almost daily through August and September to stay below the 4.5 ft level north of S-331.

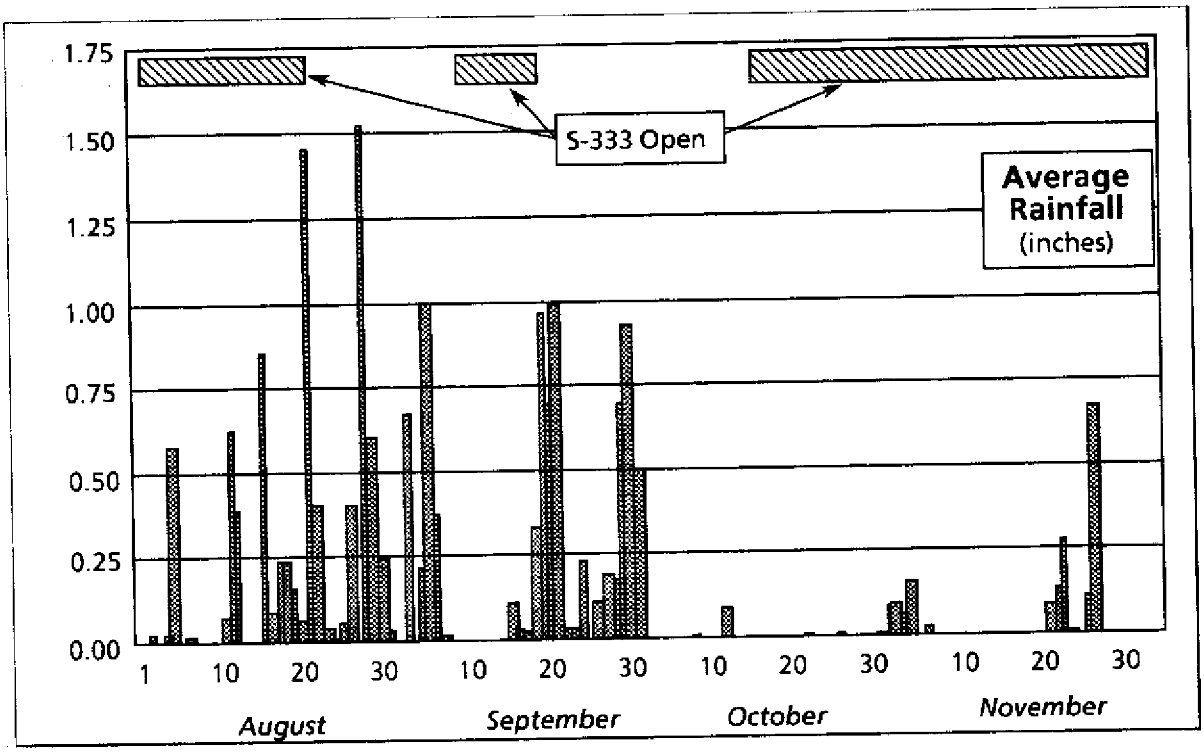


Figure 2. Daily rainfall, Northeast Shark River Slough. Average of four gages (S-333, S-336, S-331, Chekika).

Analysis

The system's response to the introduction of large surface flows into N.E.S.R.S. was documented in the 30-day Test Report. The physical laws which govern the movement of water do not distinguish between wet and dry seasons. The general conclusions of the 30 day test are just as valid when applied to the 90-day test; namely,

(a) Surface water released to N.E.S.R.S. through S-333 is confined for the most part to the slough system and,

(b) Under the conditions developed during the testing program the water table in the developed portion of the East Everglades showed no response at all to the use of S-333, but was very clearly influenced by local rainfall and management of the south Dade canal system.

An attempt was made to estimate surface and groundwater flow rates in, and near, N.E.S.R.S. prior to the test, and after a significant volume of water had been added to the slough. See Appendices A and B for the details of the flow computations used in this analysis.

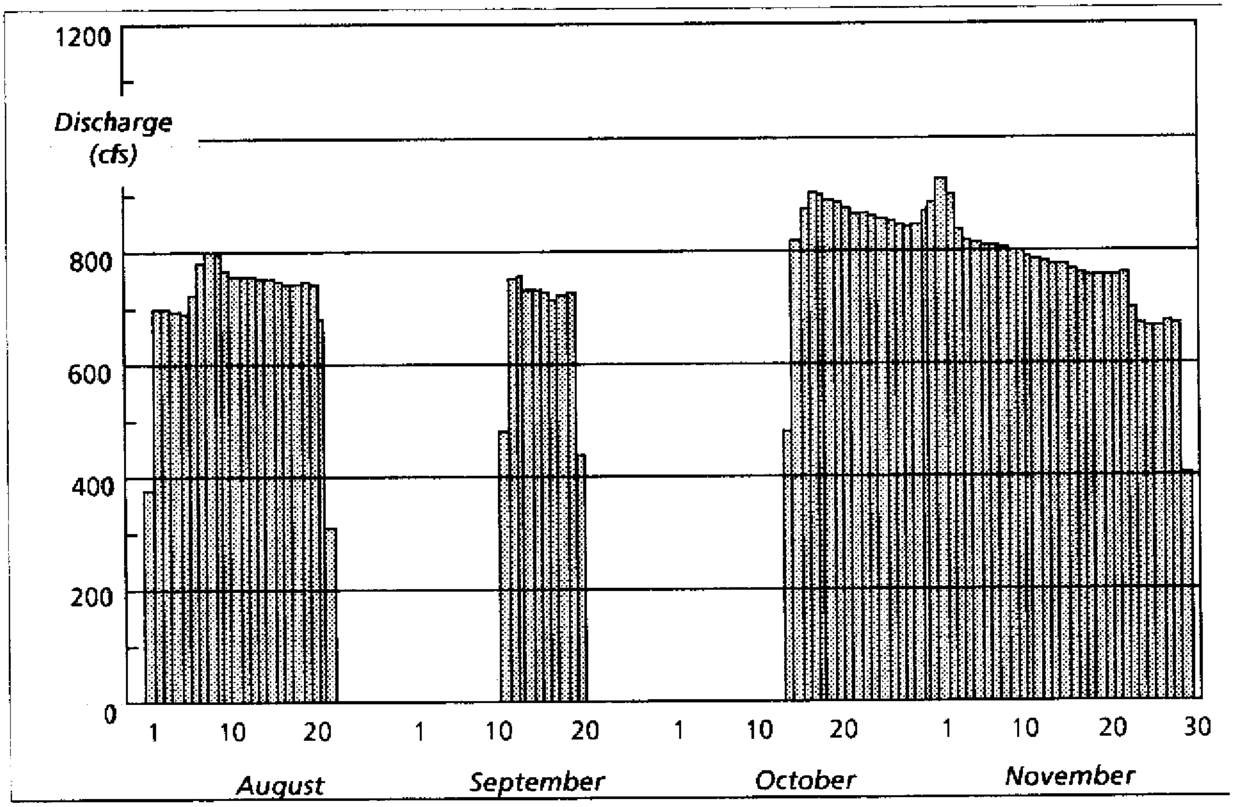


Figure 3. Daily flow rates through S-333 during the 90-day test.

Prior to the use of S-333 there was little surface flow in the slough. Water level gradients in N.E.S.R.S. were slight, and seepage through the L-67 extension levee appeared to be the major non-rainfall input into the system. There was groundwater flow in an easterly direction. The conditions on July 25, prior to the test, result in a groundwater flow estimate of 180 cfs. On August 20, after 19 days of flow through S-333, there was a distinct north to south movement of surface water in the slough (see Appendix A) estimated at approximately 850 cfs. There was also an increase in groundwater flow toward L-31N caused by higher water levels adjacent to the northern reach of the levee, and by lower levels in the canal. The groundwater flow rate, from the areas affected by the use of S-333, was computed to be 313 cfs on August 20, an increase of 133 cfs from the pre test condition. The diversion of water through S-333 and the lowering of the L-31N canal were equally responsible for this increase in seepage.

Rather than perform a detailed analysis of all hydrologic factors in the areas affected by the test, this report will focus on the major issues raised by the use of S-333 and the specific questions relevant to the 90-day test. These are:

1. Is it possible to divert large volumes of water from WCA-3A into N.E.S.R.S. during the rainy season without increasing the flood risk to residential or agricultural land in the L-31N/C-111 canal basin?
2. Does the restoration of sheetflow in N.E.S.R.S. influence the hydrology of the downstream reach of the slough located in E.N.P. ?
3. Did the lowering of the L-31N canal result in unnecessary diversion of large quantities of East Everglades groundwater to areas downstream, or to the coast?
4. Were the trigger wells used during the latest test a reasonable restraint on the use of S-333?

Increased Flood Risk?

The most sensitive issue raised by the 90 day test is whether sheetflow in N.E.S.R.S. can be supplemented during the wet season without increasing the likelihood of flooding in residential areas, or land presently in agricultural production. It is an accepted fact that the surface water in N.E.S.R.S. and the groundwater in the Rocky Glades are continuous. It is the differing flow processes that serve to separate the two areas hydrologically.

The slough itself is characterized by low land elevations with standing water for much of every year. Rainfall and evapotranspiration dominate the water budget. In periods of high water (deeper than 18 inches in the center of the slough), overland flow is the controlling process and the dominant flow direction is to the south and southwest. The developed areas, with higher elevations and their proximity to the canal system, are influenced by groundwater flow almost exclusively. Here the major water movement is groundwater flow to the east and southeast.

Figure 4 shows the approximate water surface contours on July 25, 1984, just before the District began operations to lower the L-31N canal level in preparation for the test. It had been a typical wet season to that point. N.E.S.R.S. had received water from local rainfall, predominantly, and also from seepage through L-67 extension, seepage from WCA-3B, and a small amount of surface

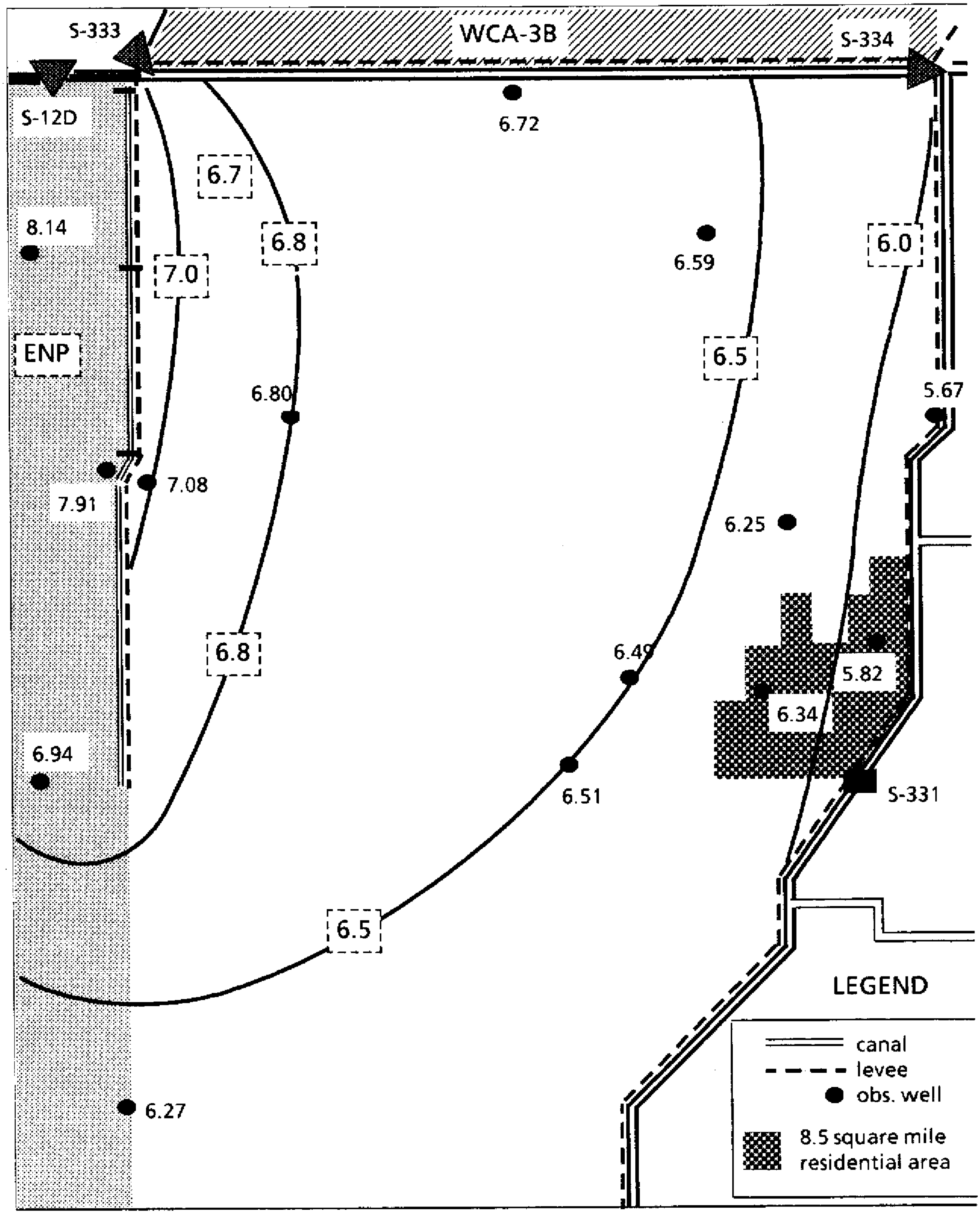


Figure 4. Approximate water surface contours, N.E.S.R.S., July 25, 1984.

flow around the south end of L-67 extension. Water was leaving the area via evapotranspiration, surface flow through the slough to the park, and groundwater flow toward the L-31N canal.

Figure 5 shows the same view on August 20th. This date was selected because it was preceded by the longest uninterrupted flow period achieved under true wet season conditions. It was just prior to the rainfall on the 21st which temporarily halted the use of S-333. Over 27,000 acre feet had been released into the slough through S-333 in the previous 19 days and the L-31N canal level had been held below 4.5 ft since August 2. The water surface contours clearly show the effects of both actions. The use of S-333 had established a significant north to south flow component in the slough while lowering the L-31N canal had lowered the water table in the 8.5 square mile residential area by about a foot. The water table was also lowered beneath the agricultural land adjacent to L-31N south of the S-331 pump station.

At the end of the test (Figure 6), after 47 consecutive days of flow through S-333, the water levels and flow pattern in the slough were almost identical to those established by August 20. The water table in the developed areas continued to recede in response to the lowered L-31N canal level. The groundwater was more than 0.5 ft. lower at Angel's well, located on the western edge of the residential area, compared to August 20. The 200th street well, in an agricultural area 2 miles west of the levee, was 0.8 ft. lower at the end of the test than it was on August 20.

The hydrographs in Figure 7 show the impacts that changes in canal operations can have on groundwater conditions in the residential area. Normal wet season practice is to open S-173, a single 72 inch culvert beside the S-331 pump station, when the upstream canal stage is above 5.0 feet. If there is sufficient difference between upstream and downstream water levels, the pump chambers are also opened for siphoning to allow additional gravity flow to the south. As a result, the canal level upstream of the pump station averages between 5.0 and 5.5 feet during the wet season. By lowering the average canal level and using the pumps to maintain the lower levels the area was afforded an increased level of flood protection during the experiment. The response time in lowering the water table after a storm was reduced with the operational changes used during the test, primarily because of the use of the S-331 pump station. Comparing the water table behavior after the July 21 storm with that

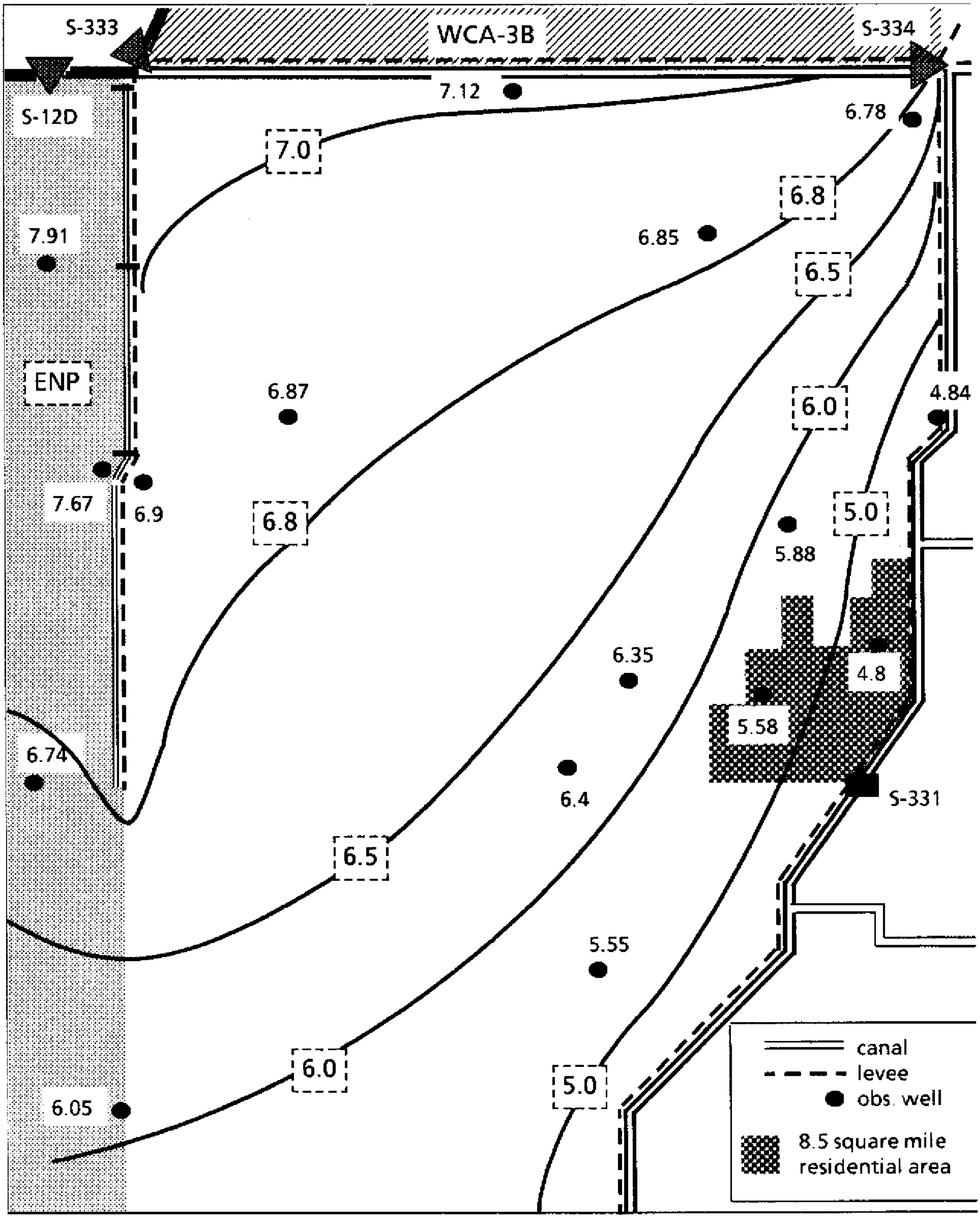


Figure 5. Approximate water surface contours, N.E.S.R.S., August 20, 1984.

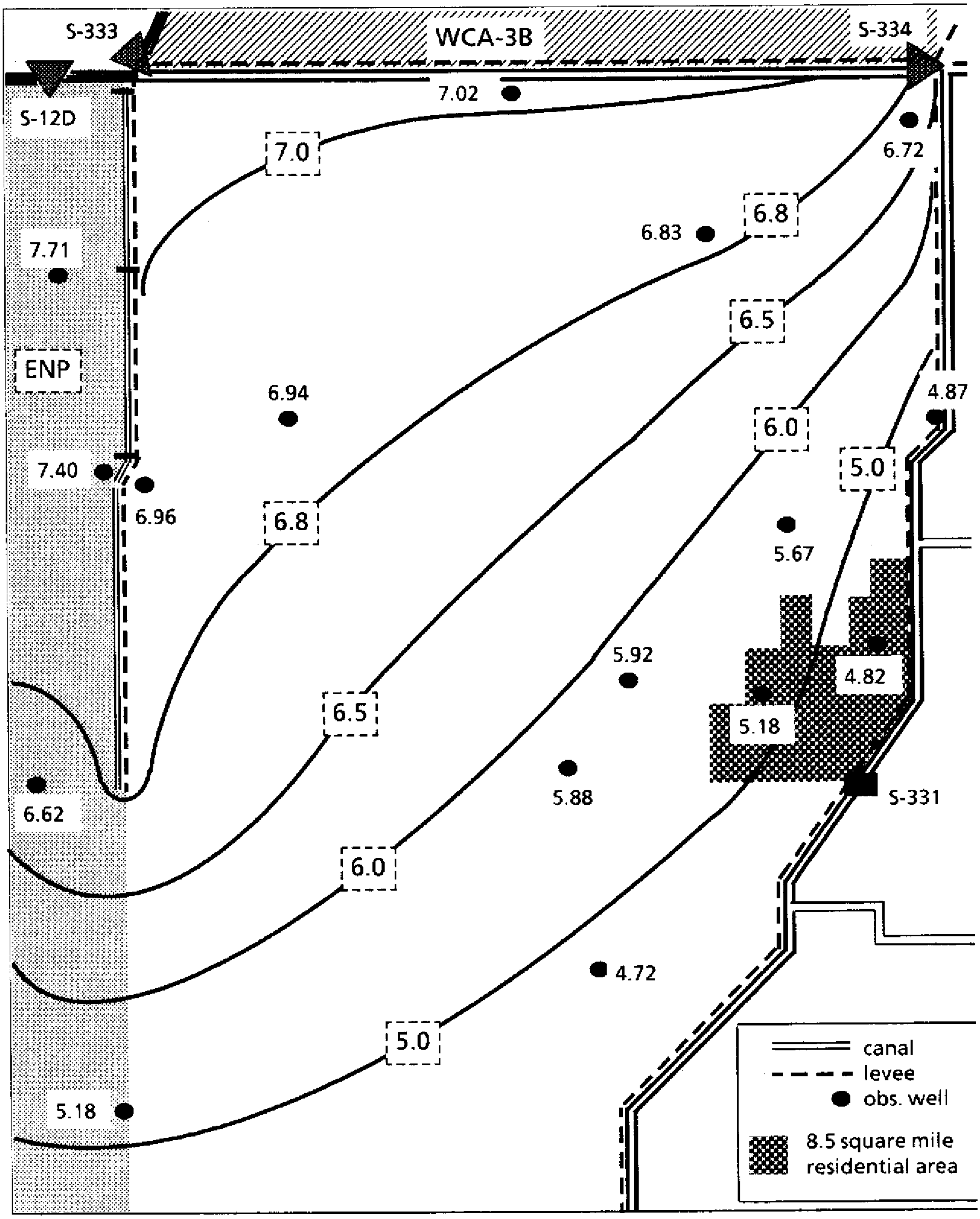


Figure 6. Approximate water surface contours, N.E.S.R.S., November 30, 1984.

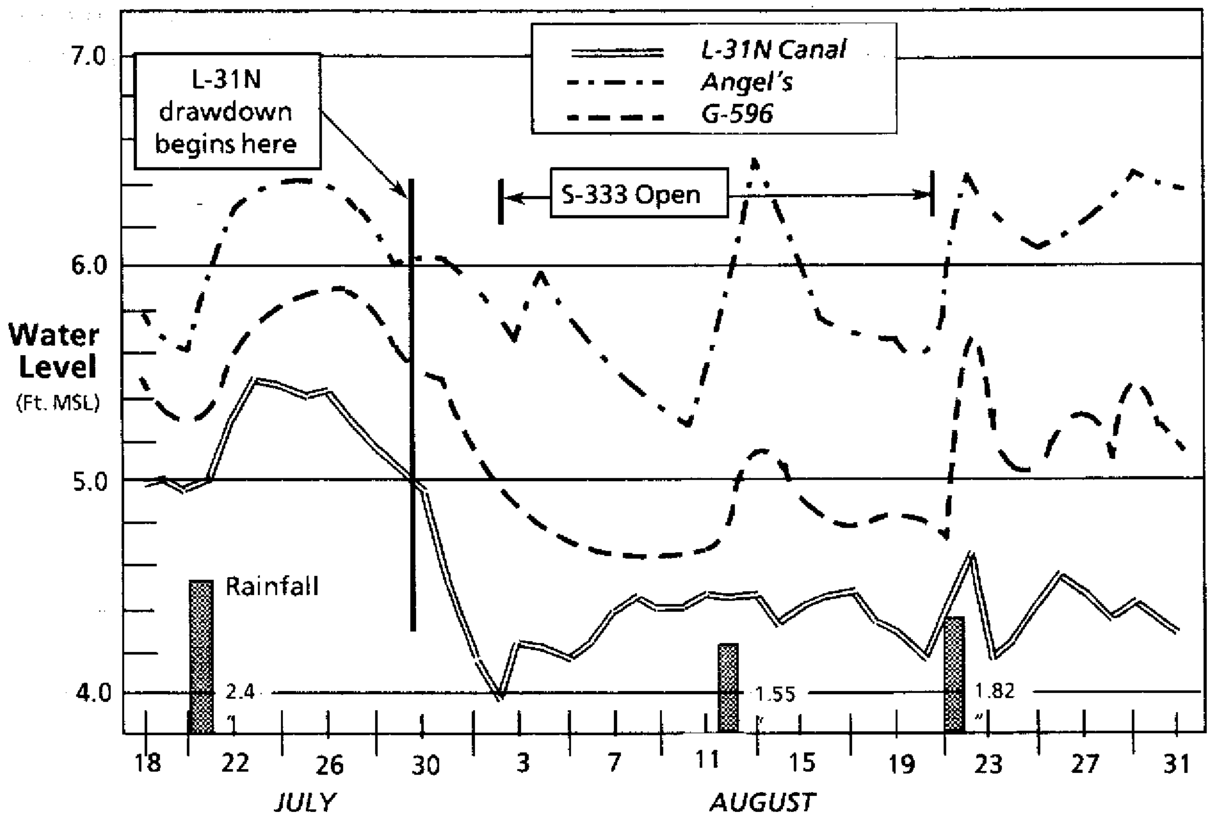


Figure 7. Water table behavior at two groundwater locations in the 8.5 square mile residential area west of L-31N.

shown after the August 12 rainfall (see Figure 7), a faster recession rate is apparent with the canal operation practiced during the test.

In these areas with no direct connection to the flood control canals, the vertical distance from the land surface to the water table is the prime determinant of sensitivity to flooding. By increasing this distance, which increases available soil storage, flood protection was enhanced even though large volumes were being added to the slough . This was not accomplished at the expense of imposing additional risk to any downstream areas. The canal management practices used during this test had the effect of discharging more water between storms. The additional soil storage which this created meant that flood peaks would be lower, for a given amount of rain, than under previous wet season operating procedures.

It must be emphasized that during flood operations the S-331/S-173 complex acts as basin divide for L-31N. This means that the canal system was designed, and must be operated, such that there is no flow through S-331 or S-173 when conditions approaching the design storm are experienced in the C-111 basin. Flood conditions downstream of the pump station must subside before actions can be taken to remove storm runoff from the reach of L-31N north of S-331. This limitation is inherent in the design of the L-31N/C-111 canal system and cannot be waived as a part of any field test. However this does not change the two main conclusions regarding flood risk; namely, that lowering the water table prior to a storm lessens the severity of the flooding, and utilizing the pumps when downstream capacity is available results in a faster recession rate following the storm.

The observed behavior supports the position taken by the District when the 90 day test was first proposed. The operation of the L-31N/C-111 canal system has the most influence on the water conditions in the developed portions of the East Everglades, not the use of S-333. The 90 day test data demonstrate that it is possible to introduce flow into N.E.S.R.S. during the wet season without causing adverse impacts in any residential or agricultural areas.

Effect on Everglades National Park

The primary reason for reintroducing sheetflow into N.E.S.R.S. is to improve conditions in Everglades National Park. While the goal of the experimental program is to induce specific, measureable changes in the hydrology of Shark River Slough, the assumption is that some of the ecological deterioration in E.N.P., which is a result of the altered flow system, will be reversed. This field test did not address total control of surface flow into Shark River Slough. All four S-12 structures had been fully opened since June and they remained open during the test period. As in the 30 day test, S-333 was shown to have a significant effect on the water level in the south end of WCA-3A and on the flow rate through the S-12s. The decline in the S-12 flow rate when S-333 is open is clearly shown in Figure 8. Reducing the flow through the S-12 structures also reduces the water levels in the park south of the structures.

The important question, which was not resolved by the 30 day test, was whether water flowing through N.E.S.R.S. would affect the downstream sections of the slough within the park boundaries. Figure 9 is a plot of some E.N.P.

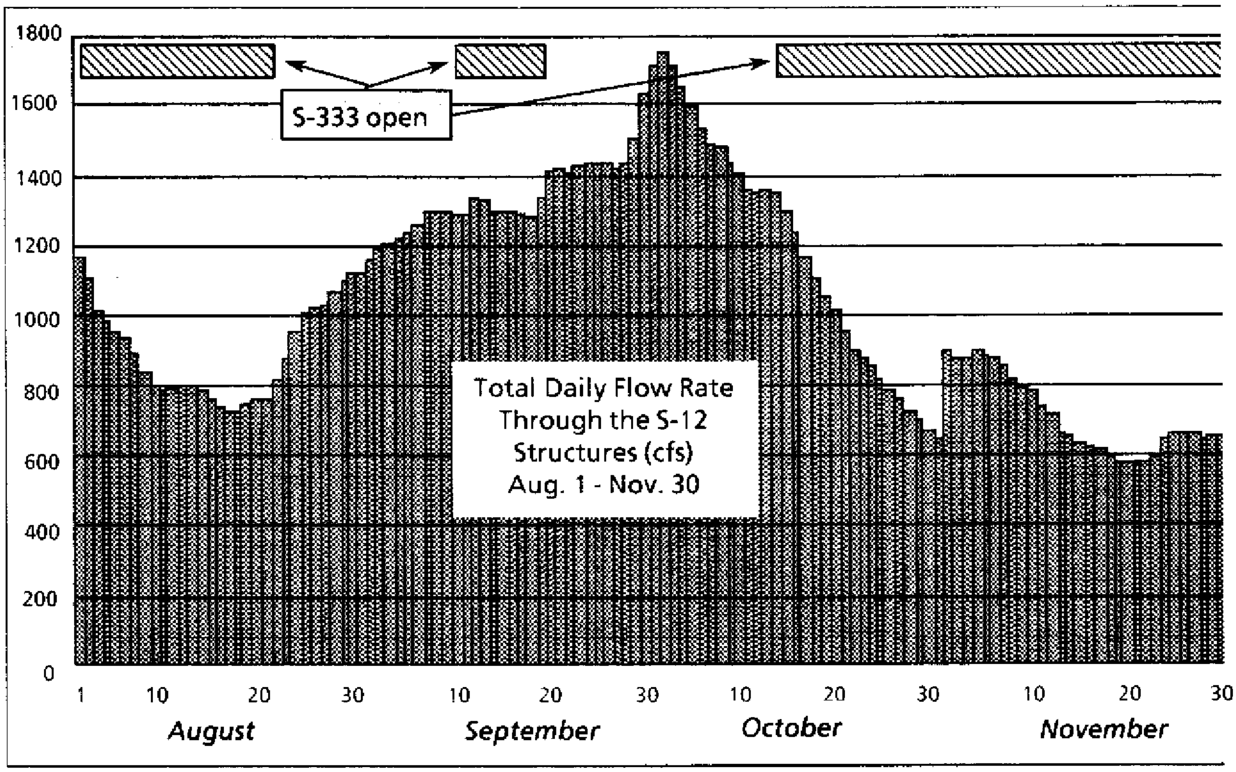


Figure 8. Daily flow through all S-12 structures during 90-day test period. The flow-through operation was in effect throughout the test (all gates open full).

hydrographs for the final 60 days of the test. There is a noticeable increase in the recession rate at NP201 and L-67ext when S-333 is opened, caused by the reduction of flow through the S-12s. The situation seems reversed at the P-33 gage, which is located in the center of the slough about a mile west of the park boundary.

There is a significant net increase in flow to the full width of the slough when S-333 is opened. When the gate was opened on October 17 the flow rate through the S-12 structures was about 1100 cfs. The combined flow to the slough after the gate was opened was 1900 cfs. The level at P-33 did not begin to show a faster recession until early November. The water that had been put into N.E.S.R.S. probably contributed to maintaining higher levels in the center of the slough within the park boundary.

The water level in the center of the slough records its most noticeable vertical fluctuations in response to rainfall and evapotranspiration, processes which affect the entire area. Due to the very slight land slopes, large increases in flow rate are only accompanied by very small rises in the water level. Adding water to

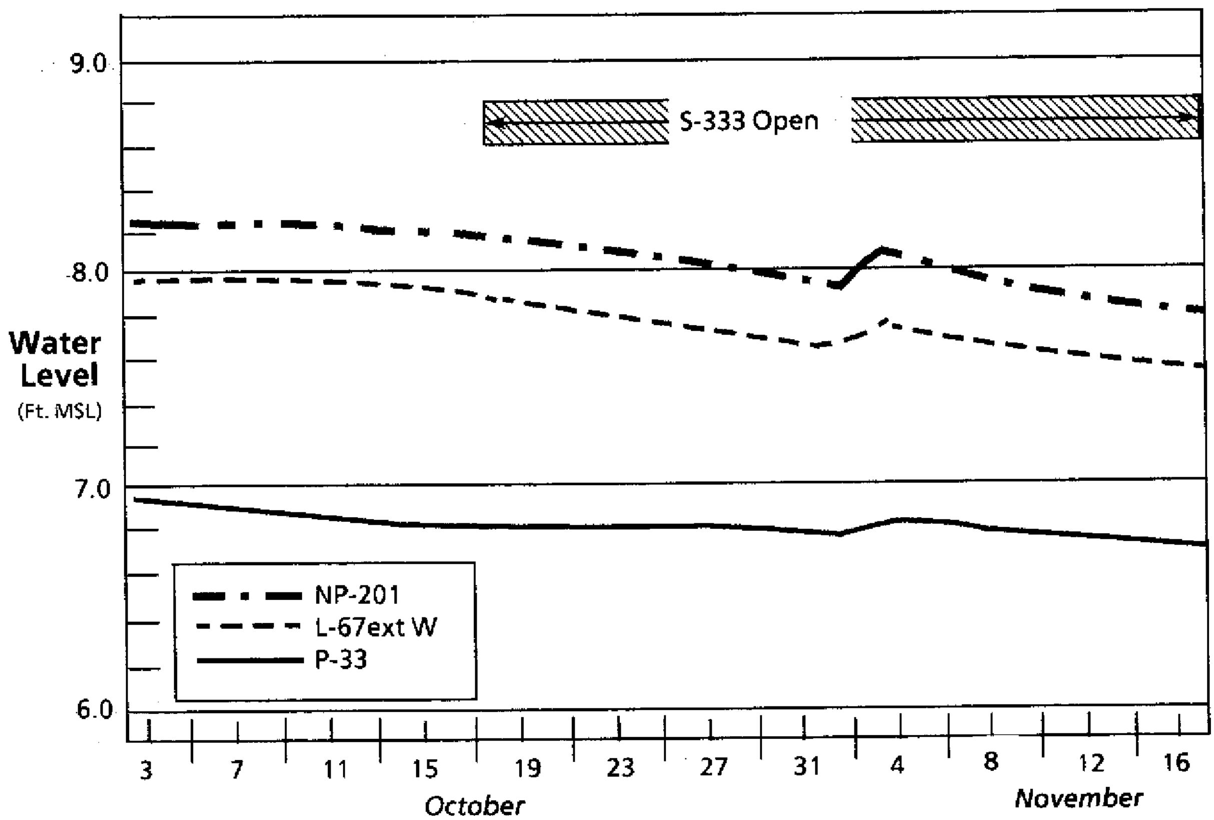


Figure 9. Hydrographs at three Shark River Slough gages within Everglades National Park

the head of the slough will be noticed as a delayed recession in the downstream reaches rather than an obvious rise in the water surface.

With the present gaging network, and the flow rates experienced during this test, it is impossible to state definitively that the center of the slough within ENP was significantly affected by the diversions to N.E.S.R.S.. It is also impossible to quantify the fraction of those diversions which may have crossed the park boundary south of L-67ext.

There is no doubt that the historic flow pattern through N.E.S.R.S. was to the southwest, or that it was a significant part of the slough system prior to the construction of the L-29 levee. The next phase of testing, which proposes to manage the S-12 structures and S-333 to establish a more natural flow distribution across the slough, and which will include additional monitoring near the park boundary, may document the extent of the hydrologic connection between N.E.S.R.S. and the park which can be achieved with the existing canals, levees, and structures.

Groundwater Resource Questions

The 90 day test, overlapping as it did the start of a severe dry season, is subject to criticism for its negative impact on the water supply resource of Dade County. Three factors affected the resource during the test period;

1. The decision to keep all the S-12 structures completely open,
2. The goal of putting as much water as possible through S-333 subject only to a tailwater constraint in the downstream canal (L-29), and
3. The agreement, by the District, to lower the water level in the entire reach of L-31N from S-176 to S-335.

The first factor was a policy decision made in response to a request from Everglades National Park. Park researchers were interested in documenting the behavior of the system in an uncontrolled mode for a complete annual cycle after the completion of the plugs in the L-67 extension canal. The District agreed to this operation as part of the testing program authorized by the Fascell Bill (P.L. 98-181), passed by Congress in November 1983. The guidelines for operating S-333 were selected to allow as much water as possible to be put into N.E.S.R.S. so the wet season flow regimen could be analyzed. These were policy level decisions that were made acceptable by the large volume of water available in Lake Okeechobee at the time. Their effect on water supply will not be analyzed in this report.

The third factor was an operational decision made by the District to insure that the developed areas of the East Everglades would not be adversely impacted by the test. The water level contour map of August 20 (Figure 5) suggests that the use of S-333 should be accompanied by modified operating rules for L-31N canal system whenever there is a possibility of S-333 releases affecting the water table in the developed areas. There is no record of this having occurred but there is the potential of it happening under certain conditions. If large volumes were diverted to the slough for an extended period of time, accompanied by high water levels in the developed areas and in the L-31N canal, the potential for adverse impacts would exist.

The L-31N guidelines adopted during this test required lowering of the canal for the entire duration of the test, regardless of the adjacent groundwater levels. Figure 10 is a plot of hydrographs in the slough and in the rocky glades from October 10 to November 23. The groundwater recession typical of the start of the dry season is clearly shown despite the continued use of S-333 and the stable water level in the slough. From a flood control standpoint it was not necessary to continue with the low canal levels beyond October 15. By doing so, groundwater was shifted to the south, and some may have been unnecessarily passed out of the system through the canals. Figure 11 is a summary of the weekly flow volumes in L-31N and C-111.

The large canal flows in August and September are primarily in response to summer rainfall in the basin. Some of this water could have been retained in the aquifer with a more flexible L-31N operation strategy but it would not have amounted to a significant addition to storage by the time the dry season began. The large flow through S-177 in the first week of October reflects a precautionary lowering of the coastal canals as tropical storm Isidore approached the south Florida coast. Some of the discharge in the second week of October was the result of the District's action, unrelated to this test, to lower the C-111 canal to allow early planting by the vegetable farmers in south Dade. The majority of the L-31N canal flow from mid-October to the end of November was necessary to meet the lowered canal levels required by the test. Most of the water that passed through the S-331/173 complex reentered the aquifer to the south and east. Although it would have been more desirable to keep it upstream, it was not lost from the system and served to recharge the southern reaches of the Biscayne aquifer.

The District is required to make minimum monthly water deliveries to the E.N.P. panhandle area and to Taylor Slough. During dry periods, this water must be conveyed through the L-31N canal. The Taylor Slough discharges are diverted into L-31W through S-174, and are pumped into the park through the S-332 pump station. Deliveries are made to the panhandle via the C-111 canal. The flow through S-176 and S-177 (see fig. 11) from mid-October through the end of November was required to meet the legislated minimum flow into the panhandle.

Some of the water that passes through S-176 recharges the Florida Keys Aquaduct Authority wellfield and is used for irrigation by the farmers in the

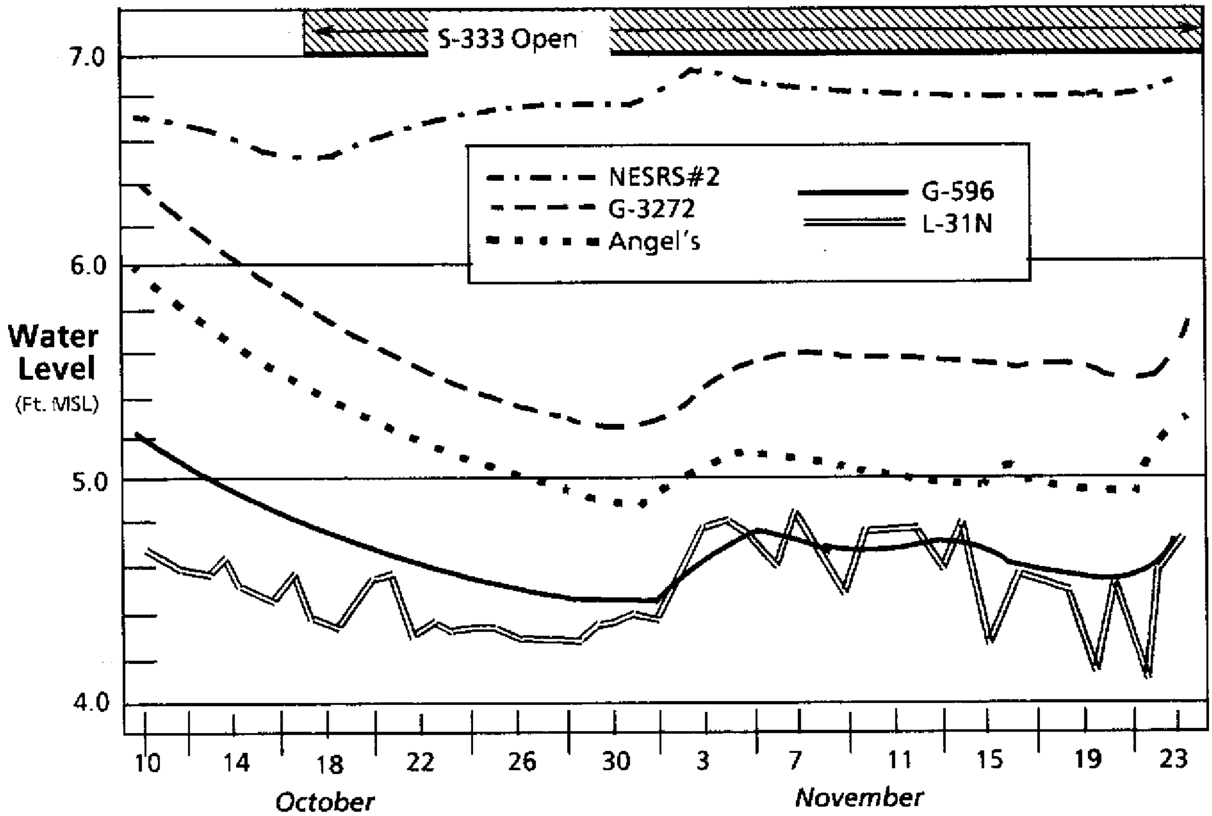


Figure 10. Water level activity in N.E.S.R.S. and the Rocky Glades, October 10 - November 23.

C-111 basin. Once water passes through S-177 it is unavailable for water supply use later in the year. It still serves a useful purpose by suppressing salt encroachment in the southern end of the Biscayne aquifer and by augmenting sheetflow into the panhandle of E.N.P.

This analysis indicates that the canal level constraints adopted for this test were too rigid to allow for the best management of the groundwater resource. As a result, some unwanted transfer of groundwater, and unnecessary lowering of the water table, occurred. No large scale dumping of fresh water to the coast, above what is normally required for flood protection in the wet season, was caused by the canal operations during the test. Future limitations of the operation of the L-31N canal should be tied to water table monitoring in the developed portion of the East Everglades and should call for lowering the water table only when it is above a specified high water threshold.

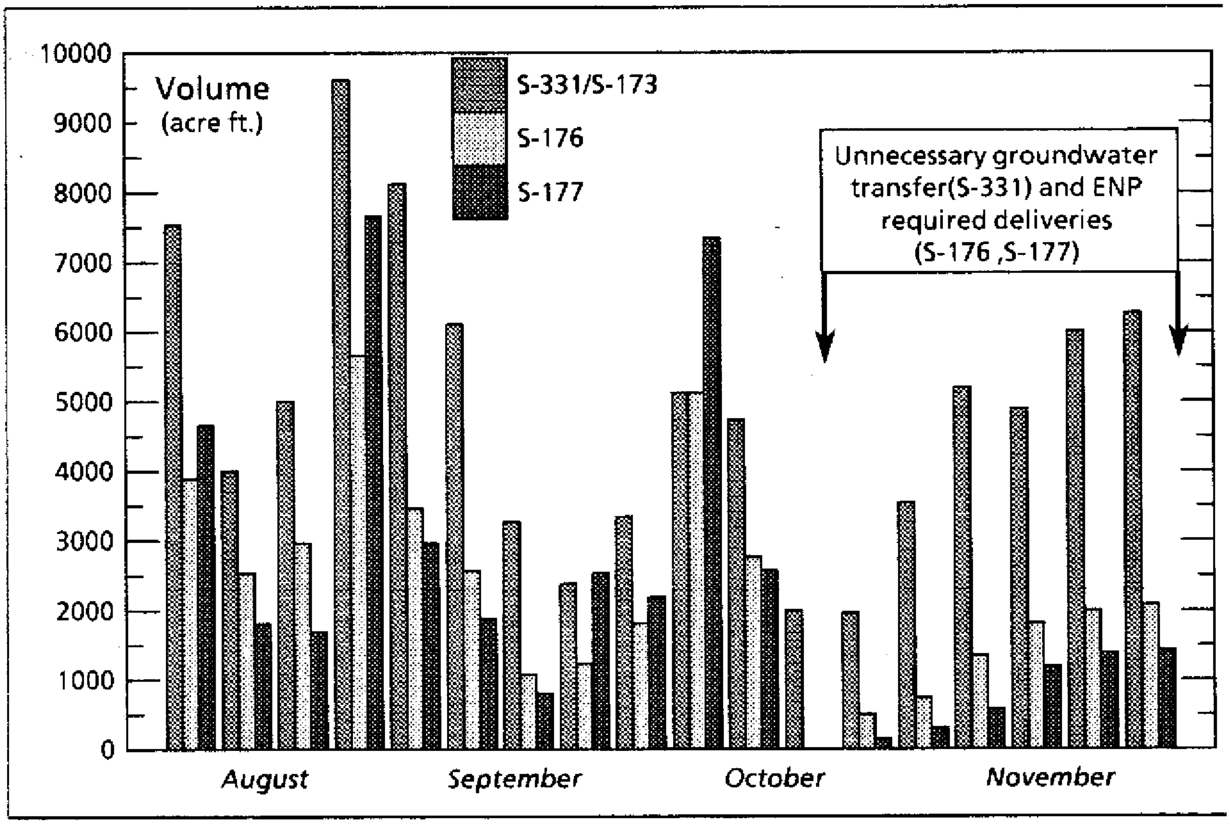


Figure 11. Weekly flow totals at three points along the L-31N / C-111 canal system.

Trigger Wells

The concept of using trigger wells was not part of the District's original proposal for the 90-day test. Two sites were accepted at the last minute in order to reach agreement with the farmers. Both wells, G-3272 and G-3273, are located in the transition zone between the slough and the Rocky Glades. Figure 12 illustrates the water surface fluctuations in the slough, the residential area, and at the trigger wells prior to, and through, the first month of the test. The influence of rainfall is obvious at all locations.

Angel's well and G-3272 are affected by the L-31N canal as evidenced by the decline in response to the canal drawdown. Well G-3273 shows the same behavior as well G-1502, which is located a mile away in Chekika State Park. Both wells record water levels consistently higher than either Angel's or G-3272. They may be influenced by Grossman's ridge, whose highest point is in Chekika State

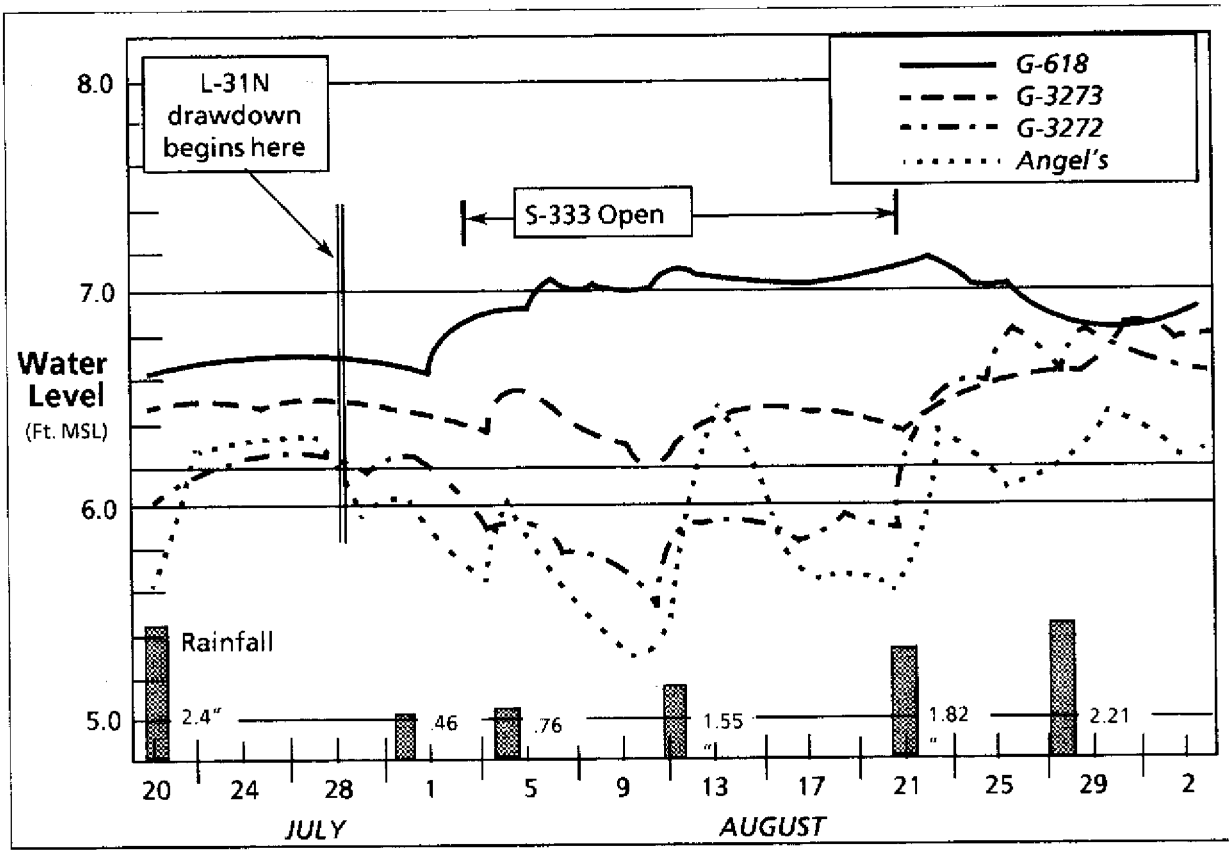


Figure 12. Comparison of slough (G-618), Trigger wells (G-3272 & G-3273), and residential area (Angel's) prior to , and during, the first month of the test.

Park, and the free flowing artesian well which feeds the pond in the park. G-3273 is five miles from the L-31N levee and two miles west of the residential area. It is much less responsive to canal operations and is not at all indicative of conditions in the developed land west of the levee.

With the data from the 30 and 90 day tests it is impossible to definitively state that either well shows a response to the flow through S-333. If there was any response, it was so subtle that it could be considered insignificant. This does not imply that there is no connection between water levels in the slough and in the transition zone which these wells reflect. There undoubtedly is a strong hydrologic relationship between the two areas; however, the L-31N canal operations during the test more than compensated for any possible slough-related effects which may have occurred had the canal measures not been taken.

The concept of a trigger well was put forth as a vehicle to elicit action that would help to alleviate potential high water problems in developed areas. The plan as practiced during the 90-day test had two flaws:

1. Neither of the wells was reflective of conditions in the areas that needed protection. This was especially true of well G-3273.
2. The agreement also called for the wrong action to be taken in response to the trigger level being exceeded. Closing S-333 in response to a water level rise at the trigger wells would not provide any meaningful flood relief in the developed areas.

The trigger well concept is a meaningful one for an area like the Rocky Glades, which has no direct connection to the flood control system. However, to be effective, the trigger well should be located on the outer edge of the residential area (such as Angel's) and the action required by rising trigger well levels should be focused on the L-31N canal, which has been shown to be an effective means of providing some high water relief to the residential and agricultural areas west of the levee.

There should be some criteria for closing S-333 in the event of high water conditions which have the potential to threaten developed property west of L-31N . Deliveries to the slough should be halted whenever there are indications that the canal system is near, or may be approaching, its flood control capacity. This could be indicated by a specific condition in the canal system, or a realistic level at one of the trigger wells that would be indicative of above normal water levels in the region.

Appendix A

Computation of Relative Velocities

Overland and groundwater flow rates were computed for the conditions of July 25 and August 20, 1984 to give additional insight into the change in the slough's hydrology caused by the test. Manning's equation was used to estimate the north to south flow rate in the slough. Prior to the use of S-333 there was very little surface water movement in the slough, as indicated by the contour map of July 25 (Fig. 4). By August 20, after the diversion of 27,000 acre feet of water into the slough, a distinct north to south sheet flow regimen was established, with a flow rate estimated in excess of 850 cfs.

Groundwater seepage calculations were also performed for the same two days to quantify the change in aquifer flow caused by the test. Prior to the test the groundwater gradient west of L-31N was directly east. The flow rate from N.E.S.R.S. toward L-31n was estimated at 180 cfs on July 25. On August 20 the gradient was in a southeasterly direction and reflected higher water levels in N.E.S.R.S. and lower levels in the L-31N canal. The flow rate through the same section of aquifer was calculated at 313 cfs. A two step approach, based on a mathematical technique of solving the theoretical groundwater equation, was used to compute the seepage rates. For areas where surface water was directly adjacent to the levee the equation was used to compute a seepage rate through (and below) the levee to the L-31N canal. For areas to the south, where there was no standing water within several hundred feet of the levee, flow was calculated between two vertical planes in the aquifer.

Overland Flow Velocity in Northeast Shark River Slough

Manning's Equation was used to compute approximate velocities in the slough

$$Q = \frac{1.49}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} A \qquad \text{(A1)}$$

where

Q = velocity (cubic feet per second)
R = hydraulic radius (feet)(equal to the water depth for sheetflow)
S = energy gradient
A = cross sectional area of flow section

n = Manning's "n", for a sawgrass slough, can be defined as [US Army Corps of Engineers, 1955]

$$n = .45R^{-.77} \quad \text{(A2)}$$

Substitution for Manning' s "n" will yield

$$Q = 3.31R^{1.44}S^{\frac{1}{2}}A \quad \text{(A3)}$$

Ten flow sections were superimposed on the contour map of August 20 (see figure A1) and the flow rate was computed in each section. Table A.1 summarizes the values of the variables used with Manning's equation for each flow section.

Estimation of Aquifer Seepage in the Vicinity of L-31N

Flow rates in the aquifer near L-31N were estimated through an application of the fundamental equations of groundwater mechanics. The accuracy of the results is limited by the knowledge of the boundary conditions near L-31N and Northeast Shark River Slough, which determine the direction and magnitude of aquifer seepage, and by assumptions about the physical characteristics of the aquifer. This analytical approach was used to describe the patterns of flow west of L-31N most likely to be altered by the test conditions.

Mathematical Analysis

Darcy's Law defines a discharge vector, Q, for an unconfined aquifer as

$$Q_{x_i} = -k\phi\frac{\partial\Phi}{\partial x_i} \quad i = 1,2 \quad \text{(A4)}$$

where ϕ is the piezometric head, and k is the permeability. A potential function, Φ, can be defined for an unconfined aquifer as

$$\Phi = \tfrac{1}{2}k\phi^2 \quad \text{(A5)}$$

When (A5) is substituted into (A4) and conservation of mass is written around an arbitrary control volume, the result can be expressed as

$$\frac{\partial^2\Phi}{\partial^2 x} + \frac{\partial^2\Phi}{\partial^2 y} = 0 \quad \text{(A6)}$$

This equation is referred to as LaPlace's equation.

When a streamfunction is defined such that

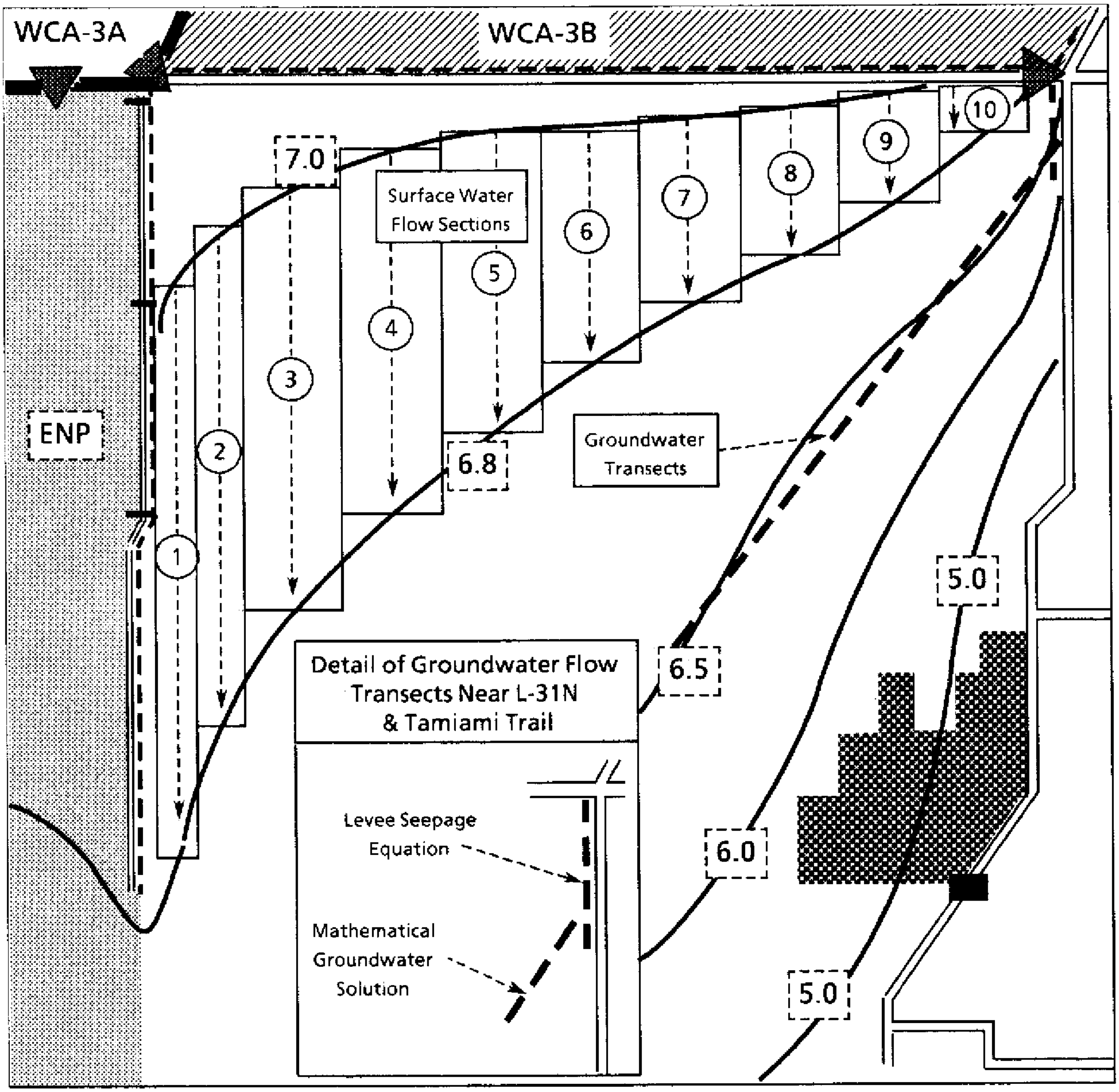


Figure A.1. Surface water flow sections used to compute overland flow, and aquifer transects used in groundwater calculations (data from August 20).

$$Q_x = \frac{-\partial \Psi}{\partial y} \qquad \text{(A7)}$$

$$Q_y = \frac{\partial \Psi}{\partial x}$$

and assuming irrotational flow, it can be shown that this streamfunction also satisfies LaPlace's equation:

$$\frac{\partial^2\Psi}{\partial^2 x} + \frac{\partial^2\Psi}{\partial^2 y} = 0 \quad \text{(A8)}$$

It can also be proven [*Polubarinova-Kochina*, 1962] that the complex potential,

Sec.	R (ft)	S (10^{-5})	Width(ft)	Length(ft)	Flow(cfs)
1	1.25	.48	3,250	42,000	40
2	1.10	.50	3,250	40,000	32
3	1.20	.53	6,500	38,000	78
4	1.30	.58	6,500	35,000	101
5	1.40	.72	6,500	27,600	127
6	1.38	.98	6,500	20,400	143
7	1.20	1.44	6,500	14,000	124
8	1.05	1.90	6,500	10,500	102
9	.85	2.33	6,500	8,500	72
10	.70	4.12	6,500	5,000	59
				TOTAL	**878**

Table A.1. Variables Used in Overland Flow Calculations.

when defined as

$$\Omega(z) = \Phi + i\Psi \quad \text{(A9)}$$

where

$$z = x + iy \quad \text{(A10)}$$

is a solution to both (A6) and (A8). Solving LaPlace's equation for the analytic function Ω will yield both the potential function and the streamfunction. From the potential, the head can be obtained at any point in the domain, while the streamfunction can be used to obtain the seepage in the aquifer between any two points in the domain.

Figure A.2 depicts the boundary conditions on the z plane which would be necessary to approximate the flow in the vicinity of L-31N. Complex variable mapping techniques [*Churchill*, 1975] can be used to define a reference plane, ζ, where

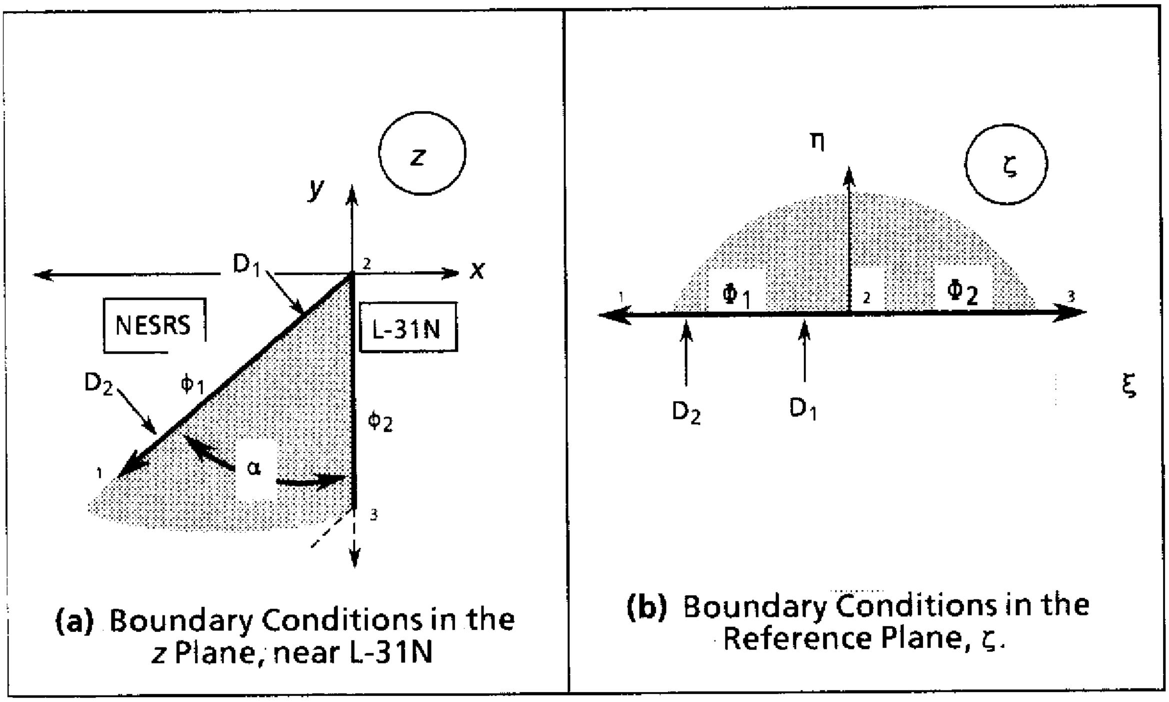


Figure A.2. The small numbers refer to corresponding locations in each plane.

$$\zeta = \left(iz \right)^{\frac{\pi}{\alpha}} \tag{A11}$$

This function maps the domain of interest in the *z* plane onto the upper half-plane in the ζ plane (See Figure A.2b). *Verruijt* [1970] then writes the solution for the complex potential as

$$\Omega(\zeta) = \frac{i(\Phi_2 - \Phi_1)}{\pi} \ln \zeta + \Phi_2 \tag{A12}$$

where the following boundary conditions are applied:

$$\Phi = \Phi_1 \quad when\ \xi < 0\,;\ \eta = 0 \tag{A13}$$

$$\Phi = \Phi_2 \quad when\ \xi > 0\,;\ \eta = 0$$

Substitution of (A6) and (A11) into (A12) yields

$$\Omega(z) = \frac{ki}{2\alpha}(\phi_2^2 - \phi_1^2)\left[\ln z - \frac{i\pi}{2}\right] + \tfrac{1}{2}k\phi_2^2 \tag{A14}$$

With equation (A14), the streamfunction and potential can be found at any point in the domain, which is shaded in Figure A.2. The aquifer seepage between any two points would be the difference in the imaginary parts of (A14), while the head at any point could be found by taking the real part, and applying equation (A5).

These computations were made using the contour maps for July 25 and August 20. Two planes were fitted to the 6.0 foot contour of July 25 and one plane was superimposed on the 6.5 foot contour of August 20. The numbers used in the solutions are shown in Table A.2.

Date	Depth (ft.)	Trans. (MGD)	α	D_1 (ft)	D_2 (ft)	$\phi 1$ (ft)	$\phi 2$ (ft)	Q (cfs)
July 25	60	8.0	11.2	5,000	39,800	66.0	65.3	**101**
July 25	59	8.0	13.5	21,600	54,500	65.0	65.0	**37**
August 20	50	8.0	33.3	4,300	58,500	56.5	54.6	**117**

Table A.2. Variables used in seepage plane calculations.

B. **Levee Seepage**

The analytical description of idealized flow under a levee can be derived with a similar process as above. Equations (1) through (7) are still valid even though the plane of interest is now vertical rather than horizontal.

$$\Omega(z) = \frac{(\Phi_2 - \Phi_1)}{\pi}\left(Sin^{-1}\left[-tanh\left(\frac{\pi}{2H}z\right)\right]\right) + \frac{\Phi_2 + \Phi_1}{2} \qquad \text{(A15)}$$

Figure A.3 shows the streamline distribution through an aquifer below an impermeable barrier which maintains a head difference across a vertical plane above the aquifer. A mathematical solution, equation (A15), is available to compute the flow between any two points in the aquifer. The L-31N levee and canal cross sections were superimposed on a scaled drawing incorporating the actual thickness of the aquifer. The flow rate was computed between the base of the barrier and the furthest point in the canal which could intercept seepage (point P in Fig. A.3). A series of calculations resulted in a seepage rate in the range of 58 - 60 cfs per mile per foot of head. The 60 cfs figure was used in this report for all calculations where this condition was known to occur.

Table A.3 summarizes the calculations that were made using the levee seepage function for July 25 and August 20. The total flow rate, for comparative purposes, is equal to the sum of the groundwater flow computed with equation A14 and that

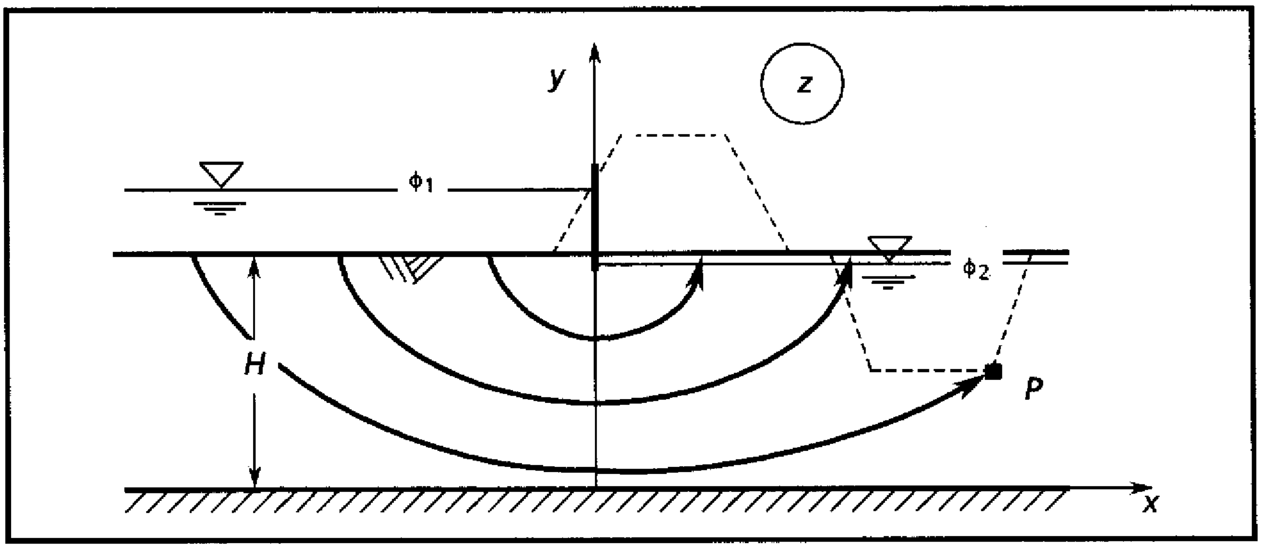


Figure A.3. Idealized flow section used in derivation of levee seepage function

computed using the levee seepage function. This results in a total groundwater flow rate estimate of 180 cfs on July 25 and 313 cfs for August 20.

Date	Head Difference	Distance	Seepage Rate	Flow Rate
July 25	0.7 ft.	5,300	60 cfs/ft/mile	**42** cfs
August 20	1.8 ft.	9,600	60 cfs/ft/mile	**196** cfs

Table A.3 . Variables used in levee seepage component of flow rate estimations.

References used in this section:

Churchill, R.V., J.W. Brown, and R.F. Verhey. *Complex Variables, and Applications,* McGraw Hill, New York, 1976.

Polubarinova-Kochina, P. Ya. *Theory of Groundwater Movement*, Princeton University Press, 1962.

Verruijt, A. *Theory of Groundwater Flow*. McMillan, New York, 1970.

Appendix B

Groundwater Flow Characteristics in the L-31N Basin

In order to estimate regional groundwater movement in the L-31 basin, the area was segmented into five west and five east reaches as shown in Figure B-1.

Daily seepage was estimated for each reach by Darcy's Law

where:

V_x = seepage per unit width of aquifer
T = transmissivity
h = head
x = horizontal flow distance

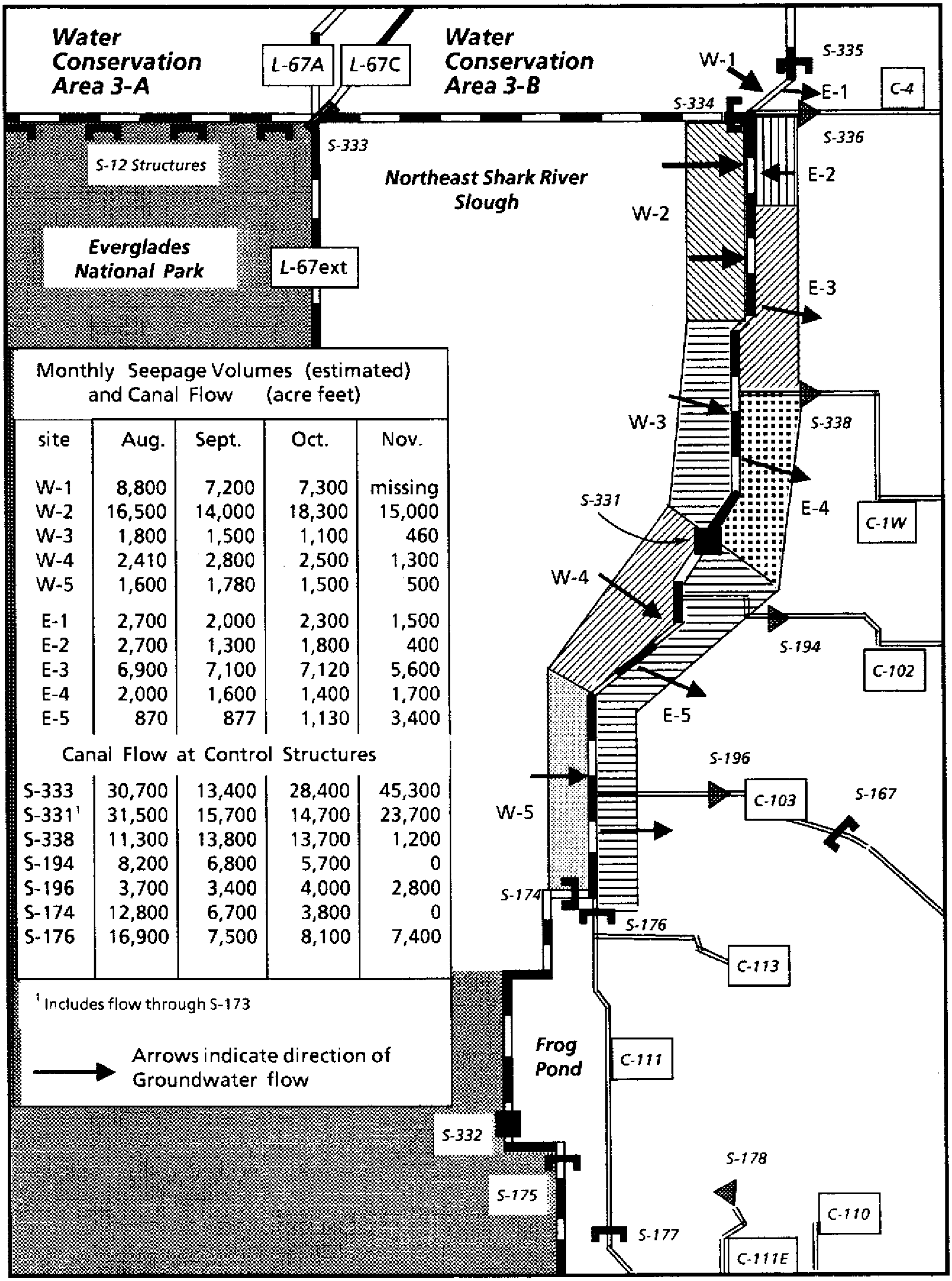
The transmissivities, horizontal flow distances, reach lengths, and water level stations used in this analysis are listed in Table B.1.

$$V_x = T\frac{dh}{dx} \qquad \text{(B1)}$$

A straight line profile between control structures was used to compute the level in the L-31N canal. To compensate for short term fluctuations of canal stages, a three day moving average was applied to computed daily seepage to more closely simulate steady state conditions for the one-day time interval. A canal penetration factor of 0.5 was used to simulate the partial penetration effects of L-31N.

The canal was assumed to be a groundwater head boundary for all reaches. In reaches W1, W2, and E1, where surface water was known to occur for extended periods adjacent to the levee, the seepage rate derived in Appendix A was used to estimate flow. In all other reaches Darcy's equation of one dimensional flow was used. The gage placement allowed the use of at least a 1000 foot flow distance to reduce the error associated with neglecting the two dimensional flow effects.

The monthly total of seepage for each reach is tabulated in Figure B.1. The numbers represent the interaction between the canal and the aquifer. Where the arrows point toward the canal the amounts indicate a volume of water flowing into the canal; where they point away they are estimates of the volume leaving the canal and recharging the aquifer. These numbers should not be interpreted as precise quantifications of the actual flow. They are necessarily rough calculations based on



Monthly Seepage Volumes (estimated) and Canal Flow (acre feet)

site	Aug.	Sept.	Oct.	Nov.
W-1	8,800	7,200	7,300	missing
W-2	16,500	14,000	18,300	15,000
W-3	1,800	1,500	1,100	460
W-4	2,410	2,800	2,500	1,300
W-5	1,600	1,780	1,500	500
E-1	2,700	2,000	2,300	1,500
E-2	2,700	1,300	1,800	400
E-3	6,900	7,100	7,120	5,600
E-4	2,000	1,600	1,400	1,700
E-5	870	877	1,130	3,400
Canal Flow at Control Structures				
S-333	30,700	13,400	28,400	45,300
S-331[1]	31,500	15,700	14,700	23,700
S-338	11,300	13,800	13,700	1,200
S-194	8,200	6,800	5,700	0
S-196	3,700	3,400	4,000	2,800
S-174	12,800	6,700	3,800	0
S-176	16,900	7,500	8,100	7,400

[1] Includes flow through S-173

Figure B.1. Dominant groundwater flow directions and estimated monthly totals of seepage and canal flow during 90-day test.

Sec.	Trans (mgd)	Length (ft)	Distance (ft)	Basis of Canal Water Level	Basis of Surface or Groundwater Level
W1	8.0	6,300	N/A	S-335TW, -S334TW	3BSE
W2	8.0	27,500	N/A	S-334TW, S-331HW	NESS3-G-1487
W3	8.0	28,100	5,000	S-334TW,S-331HW	G-1487,G-596, Angel's
W4	8.0	21,100	5,000	S-331TW,S-176HW	Angel's-Mitchel's-200th St.
W5	8.5	23,900	5,000	S-331TW,S-176HW	200th St., Rutzke's
E1	8.0	6,100	N/A	S-335TW,S-334TW	S-335TW,S-336TW
E2	8.0	14,100	1,000	S-334TW,S-331HW	S-336TW,Krome
E3	8.0	20,200	5,000	S-334TW,S-331HW	Krome,S-338TW
E4	8.5	19,400	5,000	S-334TW,S-331HW	S-338TW,G-1362, G-757A,S-194TW
E5	9.0	47,100	5,000	S-331TW,S-176HW	S-194TW,S-196TW

Table B.1. Parameters used in regional seepage estimates.

the best available data and the limited analytical techniques practical for use in a short term analysis such as this. Nevertheless they are valid comparative tools and can be accepted as accurate, overall descriptions of the groundwater movement in the region.

Appendix C

This appendix contains eight tables which list the hydrologic and meteorologic data associated with the 90-day test collected from August 1 through November 30, 1984.

All flow data, with the exception of the S-12 structures and S-333, were computed by the SFWMD based on water level, gate, and pump information. The data for S-12 and S-333 were supplied by the U.S. Geological Survey. Rainfall data were collected by the SFWMD, Everglades National Park, and several cooperators in south Dade county. Water level information was collected and processed by the SFWMD, the U.S.G.S., the ENP Research Center, and the Corps of Engineers.

Unless otherwise noted, all water level and rainfall data were derived from continuous recording stations. Sites where once-a-day , manual readings were used are indicated by a superscript '*m*' in the table heading. Superscript '*U*' indicates a water level station just upstream of a control structure ; '*D*' indicates a downstream station.

Blank cells in the tables indicate missing data.