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Water Budget Analysis for Stormwater Treatment Area 6, Section 1

(January 1, 1998 to December 31, 1999)

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by

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EXECUTIVE SUMMARY

This report presents a water budget for Stormwater Treatment Area (STA) 6, Section 1, from January 1, 1998, through December 31, 1999. STA 6, Section 1, was the first of six stormwater treatment areas to be built and was substantially completed on October 31, 1997 at a cost of $1.9 million. STA 6 started full operation on December 9, 1997 with the purpose of reducing the phosphorous concentration in runoff from approximately 10,400 acres of agricultural land north of STA 6. Prior to construction, STA 6 was a runoff detention area belonging to US Sugar Corporation.

STA 6, Section 1, is comprised of two bermed, wetland treatment cells, Cell 3 and Cell 5, with a total effective treatment area of 870 acres (245 acres and 625 acres, respectively). Under typical operating conditions, the cells are designed to have water depths of 0.5 to 4.5 feet with a long-term design operating water depth of 2.0 feet. Water flows from west to east across the cells and eventually discharges to the L4 canal.

In 1998 and 1999, STA 6 received 128,287 acre-feet (ac-ft) of water from pumping operations at G600_P. An additional 9065 ac-ft was input to STA 6 via rainfall; 8063 ac-ft was lost through evapotranspiration. Seepage was 17.7 percent of the water budget during this period, losing 24,440 ac-ft to surrounding water bodies and the surficial aquifer. Outflow from STA 6 at G606 was 75.8 percent of the flow entering STA 6 at G600_P or 97,250 ac-ft. This volume entered the L4 canal via the G607 culverts. The amount of water stored in STA 6 was reduced by 665 ac-ft in two years. The error in the biennial water budget was 8,265 ac-ft or 6.0 percent. Cell 3 retained water an average of 4.2 days in 1998 and 1999. The average retention time in Cell 5 was 8.8 days.

There were two unexpected outcomes that resulted from the water budget analysis of STA 6. The first was that estimated seepage constituted a much larger part of the water budget (17.7 percent) than was anticipated. The second was that mean hydraulic retention times were significantly lower than those computed for the Everglades Nutrient Removal project (17 to 25.4 days versus 4.2 days for Cell 3 and 8.8 days for Cell 5).

The water budget for STA 6, Section 1, will improve with additional years of data and improved information about seepage at the site. A better understanding of water movement including retention and seepage should aid in the design and optimization of future STAs used in the restoration of South Florida's water resources.

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INTRODUCTION

This report presents a water budget for Stormwater Treatment Area (STA) 6, Section 1. The budget covers the period of operations from January 1, 1998, through December 31, 1999. During this period South Florida experienced the end of an El Niño weather pattern (January to March 1998), which produced higher than average rainfall, stages and flows (Huebner, 2000), and the onset of La Niña-influenced weather that resulted in drier than average summer months. Another major event, Hurricane Irene, affected the area from October 14 to 17, 1999 (Abtew and Huebner, 2000) resulting in an average of 6.84 inches of rain over the South Florida Water Management District. In general, 1998 was drier than average and specifically the wet season in 1998 (June through October) was drier than average. There was significantly more rain in 1999 than average (66.65 in. versus 53.47 in.); most of the increase occurred during the wet season.

A water budget is an important analytical technique used to assess the relative impact of various hydrologic and hydraulic components (rainfall, flow, seepage, etc.) on the units that make up a hydrologic system (e.g., channels, lakes, etc.). It is one of the simplest forms of hydrologic model and is often used to determine the amount of water available to meet water supply needs. It can also be used to assess the sensitivity of a unit to changes in component inputs, such as changes in rainfall, and to determine the relative impact of each of the components to the overall budget and the error involved with its measurement. Hydrologic analysis is vital to on-going research and evaluation efforts to optimize performance of STAs, a cornerstone of Everglades restoration. The information gives us a better understanding of the physical processes occurring and can be used to target efforts to improve data acquisition and evaluation. Ultimately, it gives the observer a sense of where water is coming from and where it is going and in what quantities.

The analysis presented herein is based upon a daily water budget for hydrologic units in STA 6. Daily results were aggregated to develop monthly, annual and biennial water budgets. The daily water budget accounted for inflow, outflow, rainfall, evapotranspiration, seepage and error. This section of the report presents background information about STA 6, water budget analyses and monitoring at STA 6. Sections describing the operation of STA 6 and the sources of data used for the report follow. The latter of these two presents information on previous studies on areas similar to STA 6. The actual water budget analysis is presented in the next section followed by a summary, recommendations and conclusions.

Background

STA 6, Section 1, was the first of six STAs to be built and operated following the success of the prototype Everglades Nutrient Removal (ENR) project started in August 1994. Construction of STA 6 was substantially completed October 31, 1997, at a cost of $1.9 million. It was funded as part of the Everglades Construction Project (ECP), an element of the Everglades Program established by the Everglades Forever Act

(§373.4592, Fla. Stat.). STA 6 received a discharge permit from the Florida Department of Environmental Protection (DEP) and started full operation on December 9, 1997. Its principal purpose is to reduce phosphorous concentrations in runoff from U.S. Sugar Corporation's (USSC) Unit 2 development (approximately 10,400 acres) north of STA 6. Prior to construction, the stormwater treatment area was a runoff detention area belonging to USSC.

Since the ENR was a prototype wetland treatment area, it was well instrumented and closely observed. Water budgets were completed for the periods 1994-96 (SFWMD, 1996), 1996-97 (Abtew and Mullen, 1997, Guardo, 1999) and 1997-98 (Abtew and Downey, 1998). The form of these analyses and the presentation of the results strongly influenced the methods used in this study. Results from the ENR water budget studies were also used to evaluate and compare water budget errors in this analysis for STA 6.

The water budget at STA 6 involves the following hydrologic/hydraulic components:

- Inflow through pumps and weirs
- Outflow through weirs and culverts
- Rainfall
- Evapotranspiration
- Seepage
- Change in storage
- Water budget error

Each component makes up an important part of the water budget for STA 6. The budget is developed for varying time periods ranging from one day to two years using the following equation:

$$\frac{\Delta S}{\Delta t} = I - O + R - ET \pm G + \varepsilon \qquad (1)$$

where ΔS = change in storage over the time period
Δt = time period
I = average inflow over the time period
O = average outflow over the time period
R = rainfall over the time period
ET = evapotranspiration over the time period
G = levee and deep seepage over the time period
ε = water budget error over the time period

In equation 1, all terms have the same units, acre-feet per unit time (day, month, year). In order to do this for rainfall and evapotranspiration, the values (in inches or millimeters) are converted to feet and multiplied by the effective surface area in acres, (e.g., 245 acres for Cell 3) to get a volume of rainfall or evapotranspiration for a selected time period.

Two years of daily average stage, flow, rainfall and evapotranspiration data were used in this report. The data were analyzed using equation 1 on a daily, monthly and annual basis. For each time period, each of the terms in equation 1 was quantified. Optimization techniques, described in the section titled Seepage, were used to minimize the water budget error term in the equation.

Site Description

STA 6 is in the southwestern corner of the Everglades Agricultural Area (EAA) adjacent to the Rotenberger Wildlife Management Area. STA 6 and its location relative to major canals and roadways are shown in **Figure 1**. It is comprised of two treatment cells, Cell 3 and Cell 5, with a total effective treatment area of 870 acres (245 acres and 625 acres, respectively). The cells are bermed wetlands with structures that control inflow, outflow and stage within the cells.

According to a survey conducted in 1998 (GEONEX, 1999), Cell 3 was dominated by sawgrass (45.0 percent), but other wetland species were present, such as *Sagittaria lancifolia* (12.0 percent), willow (6.5 percent), and cattail (2.0 percent). Mixed shrubs covered 21.0 percent of the cell. Only 3.0 percent was open water and/or submerged algae. The plant community in Cell 5 was dominated (62.0 percent) by miscellaneous grasses, including *Panicum purpurescens* and *Panicum repens*. Cattail made up 4.4 percent of the vegetation and willow about 2.0 percent. Sawgrass and *Sagittaria* were also present, but made up less than 2.0 percent of the plant coverage. At the time of the survey 14.6 percent of the area in Cell 5 was open water and/or submerged algae. **Table A-1** in Appendix A contains a summary of site properties used in the water budget calculations for STA 6.

The treatment cells receive water via a supply canal that is west of the cells (**Figure 2**). Under normal operating conditions, water enters the supply canal from the north through pump station 600_P. During periods of drought, it can also enter the canal through G604, a set of five culverts with upstream flap gates at the southern end of the supply canal. Water entering the supply canal through G604, is used to irrigate USSC's Unit 2 development to the north of STA 6. The stage in the canal is typically below the crest of the inlet weirs under drought conditions.

There is one inflow weir for Cell 3 and two inflow weirs for Cell 5. Water leaves the treatment cells through a series of three outlet weir structures in each cell (G393A though C and G354A through C). Treated water then enters a discharge canal that connects to the L4 canal. The L4 canal runs east-west along the southern boundary of the EAA flowing east during the wet season to the South Florida Water Management District's (SFWMD) S8 pump station and the Miami canal. The two treatment cells, the supply canal and the discharge canal cover a total area of 912 acres.

A full description of STA 6, its design and operation are provided in the Operation Plan Stormwater Treatment Area No. 6, Section 1 (SFWMD, 1997).

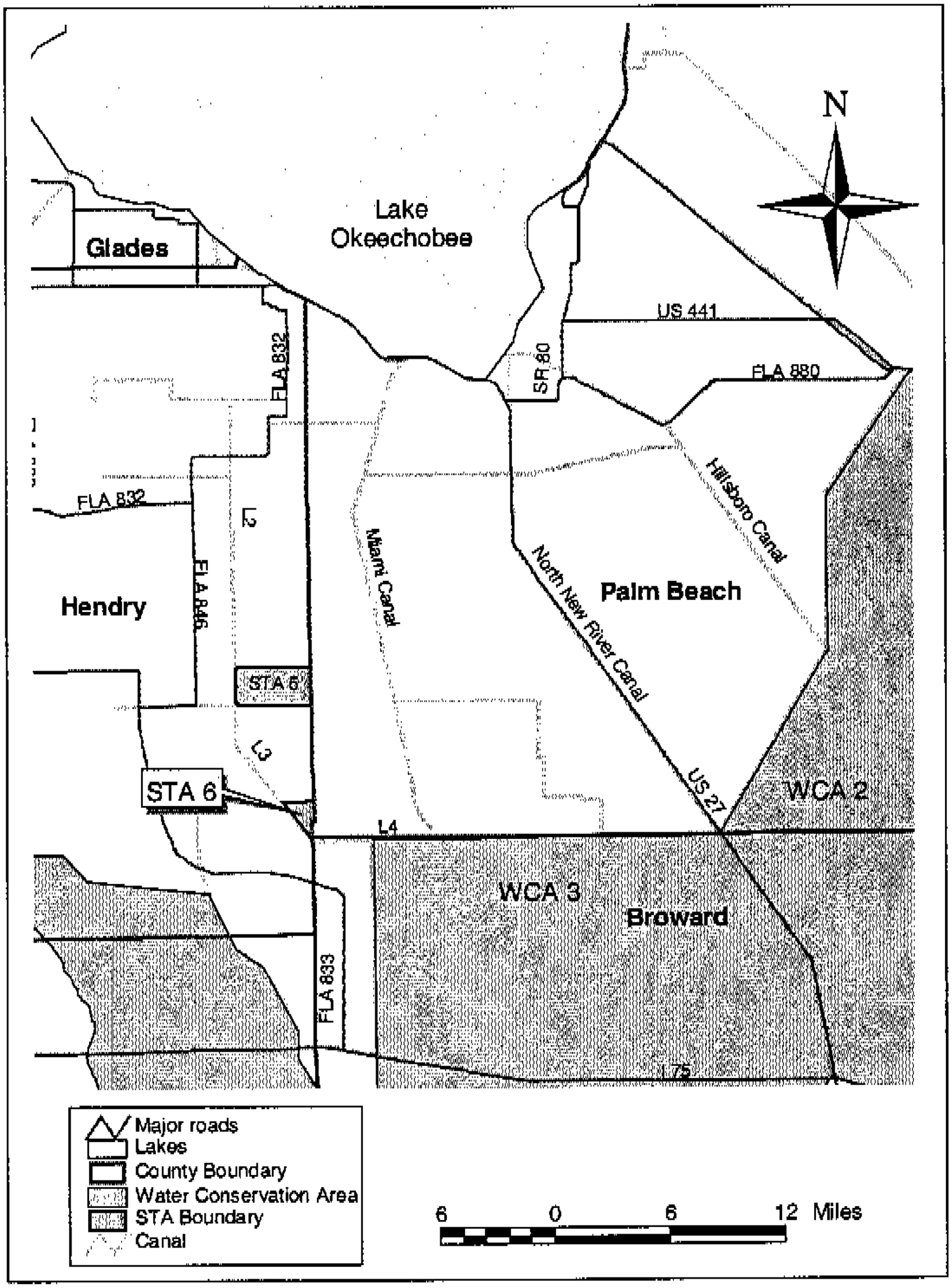

Figure 1. STA 6 Site Map

Monitoring

Three hydrologic parameters were monitored at STA 6, flow, stage and rainfall. The monitoring locations are shown in **Figure 2.** **Table 1** lists the stations where daily average flow data was recorded. Daily average stage (water surface elevation) was recorded at the stations shown in **Table 2.**

The depth of rainfall in inches was recorded at G600_R, located near pump station G600_P. The rainfall data were compared to rainfall amounts at nearby rainfall recording locations to check for potential data errors. The station names, database (DB) keys and station descriptions are shown in **Tables A-2 through A-4** in Appendix A.

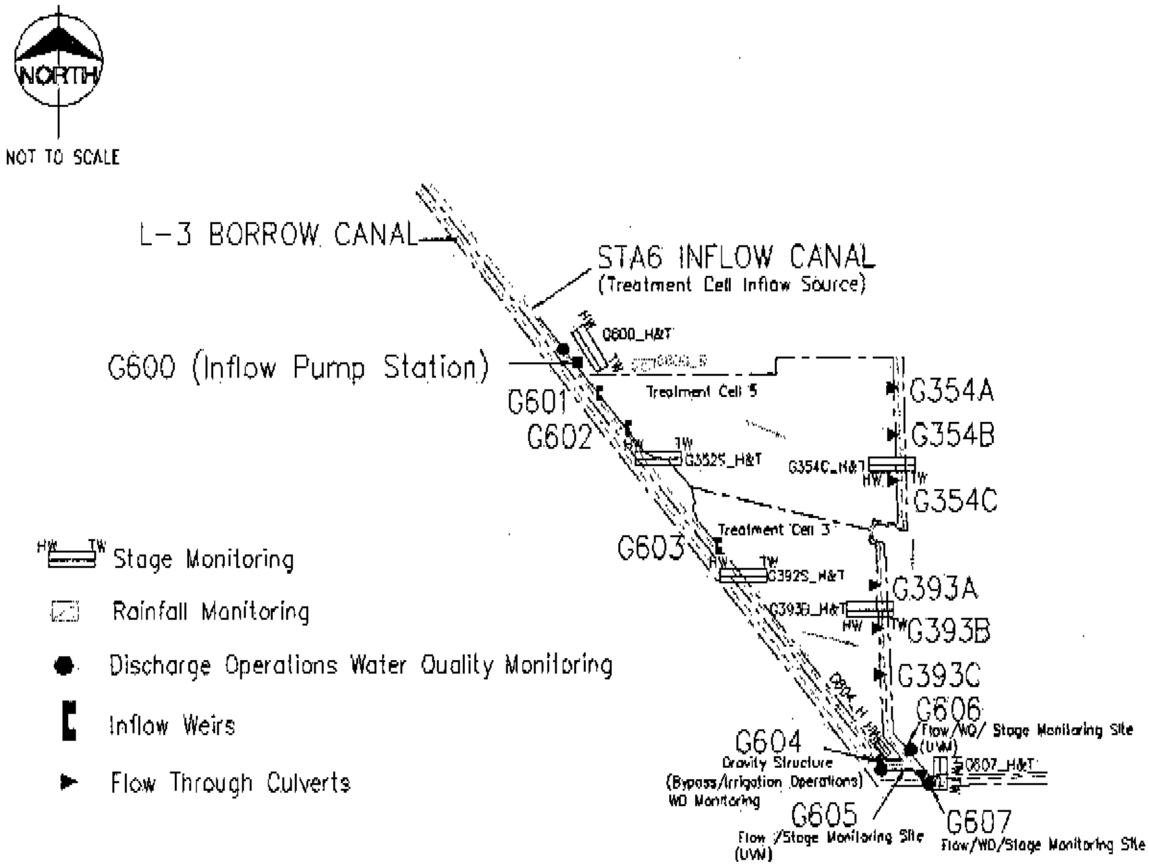

Figure 2. STA 6, Section 1 Structure and Monitoring Locations

Table 1. Flow Monitoring Locations at STA 6

Stations	Description
G600_P	inflow pumps at the northwest corner of STA 6
G601	northern inflow weir to Cell 5
G602	southern inflow weir to Cell 5
G603	inflow weir to Cell 3
G354A, B and C	outflow weir/culverts for Cell 5
G393A, B and C	outlet weir/culverts for Cell 3
G605	ultrasonic velocity meter (UVM) for flow to the supply canal (south of culvert G604)
G606	ultrasonic velocity meter (UVM) for flow out of the discharge canal
G607	flow through culvert G607

Table 2. Stage Recording Locations at STA 6

Stations	Description
G600_H	headwater elevation for the pumps at G600
G600_T	tailwater elevation for the pumps at G600
G352S_H	headwater elevation for the inlet weirs at G601 and G602
G352S_T	tailwater elevation for the inlet weirs at G601 and G602
G392S_H	headwater elevation for the inlet weir at G603
G392S_T	tailwater elevation for the inlet weir at G603
G354C_H	headwater elevation for outlet weirs at G354A, B and C
G354C_T	tailwater elevation for outlet weirs at G354A, B and C
G393B_H	headwater elevation for outlet weirs at G393A, B and C
G393B_T	tailwater elevation for outlet weirs at G393A, B and C
G604	headwater elevation for the culvert at G604
G605	tailwater elevation for the culvert at G604 (water elevation at the UVM at G605)
G606	Water elevation at the UVM at G606
G607_H	headwater elevation for the culvert at G607
G607_T	tailwater elevation for the culvert at G607

Evapotranspiration (ET) is the loss of water to the atmosphere by vaporization (evaporation) at the surface of a water body and/or by respiration of living organisms including vegetation (transpiration). The evapotranspiration data used in this water budget analysis were derived from two sources: 1) ET data for the ENR and STA 1 West; and 2) ET values computed using recorded air temperature and total radiation. The station information for the ET database that was used in this study is listed in **Table A-5**.

STA OPERATION

The five pumps at station G600_P typically run during the wet season in order to drain agricultural fields to the north of STA 6. Each pump has a capacity of 100 cfs. The pumps are cycled on and off depending upon the amount of water that needs to be withdrawn from the fields. This water discharges into the supply canal and creates a hydraulic head on the inlet weirs, G601, G602 and G603 to Cells 3 and 5. There is no inflow control to the treatment cells other than controlling the stage in the supply canal by varying the amount of water pumped at G600_P. Since Cell 3 has a surface area that is 28.0 percent of the total effective treatment area of STA 6 (245 acres vs. 870 acres), it was designed to treat 28.0 percent of the total inflow. The design of the inlet weirs was based upon this division of flow (SFWMD, 1997). The inlet weir crests for G601 and G602 (Cell 5) is set at 14.1 ft NGVD. The crest of the weir at G603 (Cell 3) is set at 14.2

ft NGVD. The maximum total design inflow for both cells is 500 cfs. This value has never been exceeded. The maximum inflow since the start-up of STA 6 was 456.7 cfs recorded at G600_P on October 18, 1999, attributed to runoff caused by Hurricane Irene.

Under typical operating conditions, the cells are designed to have water depths of 0.5 to 4.5 ft. The average ground elevation of each cell is 12.4 ft NGVD. The long-term design operating depth is 2.0 ft (14.4 ft NGVD). The outlet weir boxes at G354A through C and G393A through C control the water surface elevations in each of the treatment cells. The outlet weir crest elevations were set at 13.6 ft NGVD. Sometime during the first two years of operation, the outlet weir boxes at G354 (Cell 5) and G393 (Cell 3) were observed to be no longer level. (In April 2000, weir plates were installed to correct this problem. The crests of the weir plates are now set at 14.0 ft NGVD in Cell 3 and 14.1 ft NGVD in Cell 5). Each of the six outlet weir boxes is connected to gated culverts that allow water to flow into the discharge canal. Normally, all three gates in Cell 5, G354A through C, are open. In Cell 3, only one gate is usually open, i.e., one outlet structure is operating. This means that the maximum flow rate under normal operating conditions in Cell 3 is 140 cfs, 28.0 percent of the total design inflow of 500 cfs. Flow in the discharge canal goes to G607, a set of six culverts that connect the discharge canal to the L4 canal.

All STAs go through an initial start-up phase during which the four-week flow-weighted geometric mean phosphorous concentration at the outlet structure(s) is compared to the same parameter at the inflow to STA 6. The Florida Department of Environmental Protection permits discharges from STA 6 to begin when the value at the outlet is less than the value at the inlet indicating a reduction in phosphorous concentration resulting from treatment within STA 6. STA 6, Section 1, met these conditions and started normal operation on December 9, 1997.

Two other flow conditions affect the operational plan for STA 6. They are extreme storm conditions and drought conditions. During extreme storm conditions, all of the outlet structures for Cells 3 and 5 will be open and operate at maximum capacity (147 cfs at each of the 6 culverts) based on a stage within the cells of 17.6 ft NGVD. Under drought conditions, minimum water levels in the cells should, to the greatest extent practicable, be maintained at 12.4 ft NGVD. This would maintain static water levels above the average ground surface elevation for approximately 50 percent of the treatment area.

HYDROLOGIC AND HYDRAULIC DATA

The following sections describe the data that were used for the water budget computations and any special considerations for using the data. The source for the data was the South Florida Water Management District's corporate database, DBHYDRO. The corresponding database (DB) keys and station names are presented in Appendix A.

Rainfall

Daily rainfall data for STA 6 is collected at G600_P (the inflow pumping station). The data, stored in the DB key for G600_R, is compared to rainfall values at seven nearby rain gage locations to check for data errors. Missing values are filled based upon the best available information usually from nearby rain gages. The data are loaded into a preferred DB key every month. A final QA/QC check of the data is completed on a quarterly basis. The preferred DB key provides a high-quality, continuous record of daily rainfall amounts. **Table B-1** in Appendix B lists the daily rainfall amounts recorded at G600_R.

Evapotranspiration

The majority of the data was taken from a preferred DB key for the ENR project that contains daily values of ET. The data for ET were considered to be of the highest quality available. The period of record for this key ended September 30, 1999. For the remaining period of this study (through December 31, 1999), ET was estimated using equation 2 and air temperature and total solar radiation data from the ROTNWX meteorological station located near G606. **Table C-1** in Appendix C lists the daily ET values used in this study.

$$ET = K_1 \frac{R_s}{\lambda} \qquad (2)$$

where ET = evapotranspiration
K_1 = empirical constant (= 0.53)
R_s = total solar radiation
λ = latent heat of vaporization (varies with air temperature)

Stage

Stage data are collected on an instantaneous basis, averaged and recorded as daily average stage in DBHYDRO. The instantaneous stage data are also used to compute flows at the inlet and the outlet weir structures at STA 6. A headwater stage and a tailwater stage are needed to compute flow at each of the structures. As a result, more than one stage value was available to report average daily stage within each of the treatment cells. In this study, the daily average stage at each of the recording gages within a cell was averaged to generate a daily average stage within the cell.

When the recorded stage in a treatment cell fell below the average ground elevation, a function was used to estimate the volume of water that was available for release or necessary to fill voids in the soils beneath the cells. Equations were developed for a falling and a rising water table from cumulative water gain and water release equations presented by Abtew, et al. (1998). In the case of the falling water table (drying front) a seventh-order polynomial was developed that estimated the volume of water available from a unit volume of soil based on distance below the ground surface (0-62 mm). That was:

$$
V_w = 0.949734 - 0.274805d + 0.0359762d^2 - 0.00237059d^3 + 0.0000851231d^4 - 0.00000169054d^5 + 1.74307E-8d^6 - 7.27834E-11d^7 \quad (3)
$$

where V_w = volume of water available per unit volume of soil (cm^3/cm^3)
d = distance from the ground surface to the water table (cm)

Equation 3 had an adjusted coefficient of determination (r^2) of 0.981. **Figure D-1** in Appendix D shows the function versus the observed values generated from equations given in Abtew, et al (1998).

The expression for the amount of water needed to fill pores that resulted from a rising water table (wetting front) was represented by a cubic equation or third-order polynomial and is shown in equation 4:

$$
V_w = 0.591486 - 0.0329963d + 0.000676337d^2 - 0.00000482634d^3 \quad (4)
$$

where V_w and d are described above.

The adjusted r^2 value for equation 4 was 0.998. **Figure D-2** in Appendix D shows the function versus the observed data for equation 4.

Flow

Daily average flow rates were determined using three methods, weir equations, ultrasonic velocity meters and pump performance curves. At G600_P, average daily flow is computed instantaneously using motor speed, headwater and tailwater elevation data. The daily average flow at G600_P is recorded in DBHYDRO and reviewed on a monthly basis for accuracy and missing data. A complete record of daily average flow is loaded to a preferred DB key in DBHYDRO monthly. A final QA/QC check of the flow data in the preferred DB key is done on a quarterly basis.

Daily average flows at G601, G602, G603 (inlet weirs), G354A through C and G393A through C were computed using weir equations for each structure and were recorded in DBHYDRO. This information was not loaded into preferred DB keys and thus received less scrutiny. Because these flows were based primarily on changes in stage data and the fact that stage data records have relatively few missing values, the daily average flow records at these stations were complete for the period of the study.

Flow at stations G605 and G606 were computed using data from ultrasonic velocity meters (UVM). UVMs rely on the reflection of ultrasonic waves by moving particles in the water. They work well under certain conditions. At low flow conditions however, they tend to overestimate total flow and, instead, represent local flow phenomena such as thermal and wind-driven circulation. Such was the case in this study at G605 and G606. Small flows at G605 into the supply canal during drought conditions were not accurate and thus were not used in the water budget calculations. During the wet season, flow out of the supply canal to G605 was prevented by flap gates and stop logs at G604. Average daily flow data for both stations are maintained in preferred DB keys. For low flows at G606, data recorded were compared to outlet weir flow for Cells 3 and 5. If there was no outflow from the treatment cells, flow at G606 was recorded as zero in the preferred DB key. Likewise at G605, if stage information indicated that flow would be out of the supply canal to G605, the flow was set to zero in the preferred DB key because of the flap gates and stop logs. These changes to the daily average flow data recorded at G605 and G606 have implications with respect to the water budget calculations. The changes made for low flow conditions at these two stations, however, should have improved water budget calculations. Because these occurred at low flow situations, the impact on the water budget has been minimal.

Seepage

No direct measurement of seepage was made at STA 6 during the period of this study. A number of attempts to quantify seepage at sites like STA 6 have been made. The most recent, detailed studies of seepage at a site like STA 6 have been associated with the ENR project and are discussed here.

Prior to the start-up of the ENR, Smith (1990) used MODFLOW to model groundwater flow in Hendry County. STA 6 lies along the southeastern boundary of Hendry County. The model used three layers, the surficial aquifer, the Lower Tamiami aquifer and the sandstone aquifer. The Tamiami confining zone separates the surficial (or water table) aquifer from the Lower Tamiami aquifer. Smith found that there was very little loss from the surficial aquifer to the Lower Tamiami aquifer through the Tamiami confining zone (less than 5.0 percent) and that upflow from the Lower Tamiami was about equal to down flow from the surficial aquifer (3.7 versus 7.0 percent). Therefore, the water budget for STA 6 is based upon seepage from and to the surficial aquifer as well as to surrounding canals and impoundments.

A Brown and Caldwell design team (1996) summarized the results of a number of studies of drainage and seepage in the Everglades Agricultural Area (EAA) as part of the pre-design data gathering process for STA 2. They identified two principal zones in the aquifer underlying the EAA. The upper zone had vertical and horizontal permeabilities of 40 feet per day (ft/d) and 200 ft/d, respectively. The lower zone was 250.0 percent more permeable than the upper zone. Rohrer (1999) also used two principal zones in the area of the EAA to quantify seepage. As the result of pump tests, he found that the transmissivity of the upper zone was 9.4 ft^2/min as opposed to the lower zone that had a transmissivity of 44.9 ft^2/min. The Brown and Caldwell team reported seepage losses on the order of 2 to 3 cubic feet per second per mile of levee per foot of head difference (cfs/mi/ft). They concluded that the "vertical component (of seepage) is significant and probably responsible for the continual residual loss in the water budget." Levee seepage was found to be approximately 0.6 cfs/mi/ft. The report also concluded that "significantly higher values, thought to be in the range of 3 to 4 cfs/mi/ft, include both shallow (levee) and deep-seated seepage flows." The "deep-seated component" of seepage was considered to be comparatively large when the low permeability cap rock layer was penetrated or disturbed. Seepage for STA 2 was estimated to be on the order of 35.0 percent of the inflow pump volume in Brown and Caldwell (1996).

In a 1997 water budget analysis of the Everglades Nutrient Removal (ENR) project, Abtew and Mullen (1997) lumped seepage that could not be quantified into a remainder term in the water budget equation. The remainders for the daily water budget were occasionally in excess of 100.0 percent of the daily inflow or outflow. On an annual basis, the remainders were 3.8 percent of total inflow or outflow for 1996-97. Quantifiable seepage was 26.3 percent of the total inflow or outflow for the same period.

The Detailed Design Report for STA 6 (Burns and McDonnell, 1997) estimated seepage for Cells 2, 3, 4 and 5 to be between 0.1 to 0.8 cfs/mi/ft using the SEEP2D finite element model and hydraulic conductivity ranging from 22 ft/d to 150 ft/d. It advised using the higher value for design purposes and pointed out that flexibility should be incorporated into the design and operation of STA 6 due to the variation in lithology that existed at the site.

Guardo and Prymas (1998) used the FastSEEP/SEEP2D model to develop an equation for seepage from Water Conservation Area 1 (WCA1) into the ENR project:

$$Q_{SS} = 0.42 * [STG_{WCA1}]^{3.06} * [STG_{ENR}]^{-3.57} \qquad (5)$$

where Q_{SS} = seepage into the ENR project from WCA1 (m^3/s)
STG_{WCA1} = mean daily stage in WCA1 (m NGVD)
STG_{ENR} = mean daily stage in the ENR project (m NGVD)

The coefficient of determination for equation 5 based upon 42 observations was 0.962. In a related study, Prymas (1997) found that 23.0 percent of the outflows from the ENR could be attributed to seepage. Guardo (1999) subsequently modified equation 5:

$$SURFSEEP = 0.2158 * (STG_{WAC1} - 4.57)^{1.3121} * (STG_{WCA1} - STG_{ENR})^{2.0246} \qquad (6)$$

where $SURFSEEP$ = surficial seepage into the ENR project from WCA1 (m^3/s)

STG_{WCA1} and STG_{ENR} are described above for equation 5. The coefficient of determination for equation 6 was 0.932. While equations 5 and 6 are the best available equations for quantifying seepage, they are empirical and applicable only to the ENR project. Remainders in the water budget for 1998 were 9.1 percent of the inflow or outflow. Quantifiable seepage was 27.2 percent of the annual inflow or outflow.

Guardo and Rohrer (2000) used data from three test cells at the ENR project and the FastSEEP/SEEP2D model to quantify seepage gains from an adjacent agricultural canal. The three test cells were varied in terms of the bottom of the cells. One cell had an undisturbed bottom of muck 0.65 ft thick. Another had the muck removed down to a cap stone layer. The third had the muck and capstone layer removed. Data presented in the report showed that seepage into the cells occurred at different rates depending upon the difference in hydraulic head between the agricultural canal and the cell. The rate of seepage was also affected by the bottom condition of the cell. Seepage rates varied between 2.4 and 5.56 cfs/mi/ft. There was about a 50.0 percent increase in seepage in the cell where the cap rock layer had been removed.

Choi and Harvey (2000) used water and solute mass balances, seepage meters and groundwater modeling to estimate groundwater recharge in the ENR over a 4-year period (1994-1998). They estimated that net groundwater recharge was between 13 and 14 hectare-meters per day (ha-m/d, 53.1 to 57.2 cfs). They found that approximately 31 percent of the surface water pumped into the ENR was lost to seepage. A portion of that flow, 73 percent, was collected by the seepage canal and returned to the ENR. Seepage that was not captured by the seepage canal occurred when pumped inflow rates to the ENR were relatively high. There was also a 2.8 percent gain due to seepage, primarily from Water Conservation Area 1.

Figures 3 through **6** were developed from surface water and groundwater data in the region surrounding STA 6 to depict subsurface and near surface groundwater flow domains. **Figures 3** and 4 depict groundwater table levels during a wet period (January 1, 1998, to April 15, 1998) and **Figures 5** and **6** show groundwater table conditions during a dry period (April 16, 1998, to June 30, 1998). These two ranges of dates do not represent the usual wet and dry periods for this region. They resulted from the effect of El Niño and La Niña weather patterns during 1998. By examining both sets of figures the impact of STA 6 on ground water and groundwater flows can be visualized. Note the cone of depression in the northwest corner of STA 6 especially during the wet period (**Figure 4**). This is due to the pumping at G600_P that occurs more frequently during the wet season and thus has a more pronounced effect on the surrounding groundwater table. The area of influence of the pump extends back into STA 6 and thus some re-circulation of flow from STA 6 probably occurs as a result of pumping at G600_P. A similar set of closely spaced contours is evident at the southern end of STA 6 in **Figure 4**. The steep groundwater table gradients at the south end of STA 6 are due to two features of the system. In addition to being a point value of higher water surface elevation within STA 6 in comparison to the surrounding groundwater table, water in the L3 canal that drains from the C-139 basin ponds at this point behind weirs at structures G88, G89 and G155 creating a locally high groundwater table.

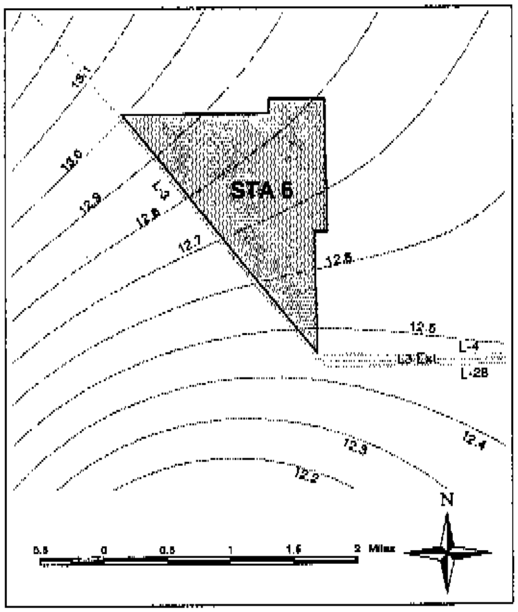

Figure 3. Average Groundwater Table Elevations without STA 6 or the USSC Unit 2 Pump Station at G600 - January 1, 1998, to April 15, 1998

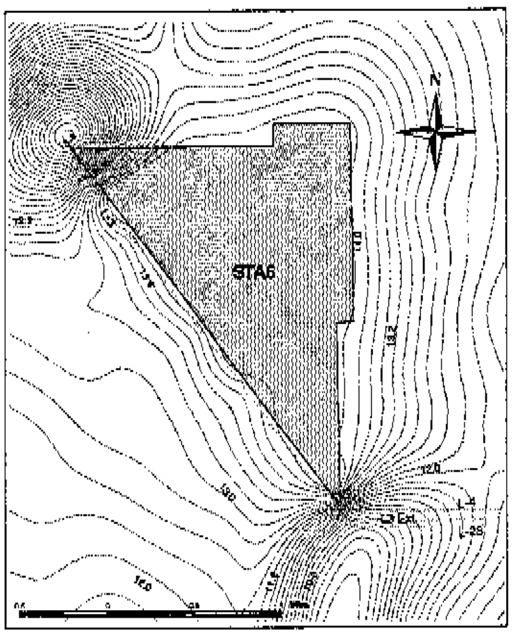

Figure 4. Average Groundwater Table Elevations with STA 6 January 1, 1998, to April 15, 1998

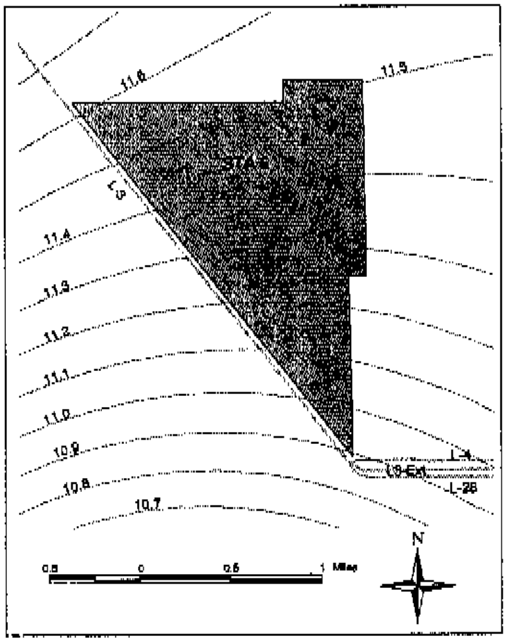

Figure 5. Average Groundwater Table Elevations without STA6 or the USSC Unit 2 Pump Station at G600 - April 16, 1998, to June 30, 1998

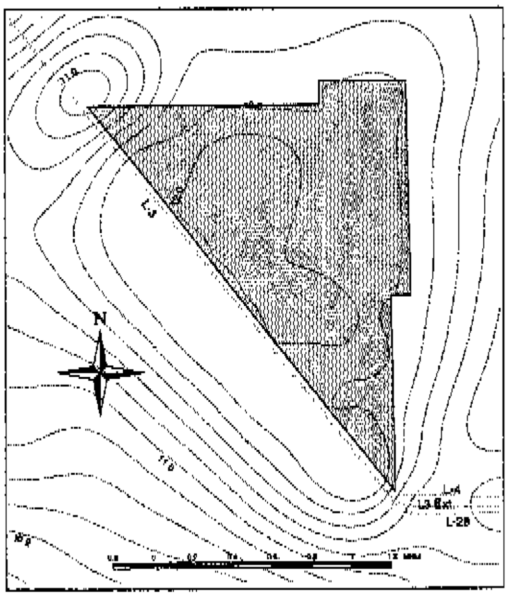

Figure 6. Average Groundwater Table Elevations with STA6 - April 16, 1998, to June 30, 1998

WATER BUDGET

Methodology

For the purposes of a water budget analysis, STA 6 can be divided into four hydrologic units: 1) the supply canal; 2) Cell 5; 3) Cell 3; and 4) the discharge canal. A water budget analysis was performed on each of the units on a daily, annual and biennial basis using equation 1. Monthly water budgets were developed for Cells 3 and 5. A daily, monthly, annual and biennial water budget was also completed for the entire STA using data from all four units. Terms in equation 1 were converted to acre-feet (ac-ft) per unit time (day, month or year depending upon the period being used for the water budget calculations). The discussion of the results in the following section of the report focuses on the biennial water budget. The annual summaries are provided to show the range of values in the data used for the biennial water budget.

In the analysis, seepage was computed as:

$$G = 1.983 * K_{sp} * L * \Delta H \tag{7}$$

where G = seepage, levee and deep (ac-ft/d)
K_{sp} = coefficient of seepage (cfs/mi/ft)
L = length along the seepage boundary (mi)
ΔH = hydraulic head difference between the unit and the boundary (ft)
1.938 = constant to convert from cfs to ac-ft/d

The value of K_{sp} was optimized using a genetic algorithm (New Light Industries, 1995). The optimized coefficient was used in the daily water budget to minimize the net water budget error in the two-year period of study. The results from Guardo and Rohrer (2000) and Brown and Caldwell (1996) were used to compare value of the optimized coefficient. In all cases, the optimized value compared favorably with the range of values presented in both studies. An additional parameter, a surface area coefficient, was also used initially in the optimization runs to account for variations in vegetation and hydrologic unit geometric properties. It was eventually discarded because the change in water budget error was relatively insensitive to reasonable changes in this term.

Results

Supply Canal

Table 3 presents the biennial (1998-99) and annual water budgets for the supply canal. The properties of the canal (width, length, and surface area) are listed in **Table A-1** in Appendix A. **Table 3** also shows summary information for the daily water budget analysis in the section titled Residuals Analysis. A similar table is shown in the corresponding section for the other hydrologic units at STA 6.

In **Table 3**, error in the biennial water budget is 6.5 percent. However, the percentage of days where the daily water budget did not balance within a 0.25 ft (3 in) depth was 94.9 percent. This implies that daily values in the budget were not adequately quantified. Budget residuals are shown in **Figure 7**. Increasing the seepage rate coefficient improved the daily budget, but not considerably. The seepage coefficient was 4.0 cfs/mi/ft, the maximum suggested by Brown and Caldwell (1996) and less than the maximum value found by Guardo and Rohrer (2000). **Figure 8** shows the estimated seepage for the supply canal over the period of the study and **Figure 9** displays the water levels in the supply canal versus surrounding canals and cells. Considering that the supply canal covers a little more than 2.0 percent of the surface area of STA 6 (20 ac vs. 912 ac) and that flows and stages in the canal are highly dependent upon the operation of the pumps at G600_P (**Figure 10**), the variation in the water budget was expected and had a minor impact on the water budget for the entire STA. In addition, STA optimization is a long-term process. Thus, short-term budget variance is not a major concern for operation and optimization. Seepage constituted 5.0 percent of the biennial water budget. Approximately 89.0 percent of the flow from the pumps at G600_P entered the treatment cells at G601, G602 and G603 (~11% loss).

Table 3. Supply Canal Water Budget Summary 1998-99

			Supply Canal			
1998-99	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Pumps	128287	99.85	Outflow Weirs	113551	88.34
	Rain	199	0.15	Seepage	6465	5.03
				ET	177	0.14
				Error	8345	6.49
	Total	128486	100	Total	128537	100
	Storage Chg.	-51				
1998	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Pumps	59365	99.85	Outflow Wiers	53257	89.57
	Rain	88	0.15	Seepage	2429	4.08
				ET	93	0.16
				Error	3681	6.19
	Total	59453	100	Total	59460	100
	Storage Chg.	-7				
1999	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Pumps	68922	99.84	Outflow Weirs	60294	87.29
	Rain	111	0.16	Seepage	4036	5.84
				ET	83	0.12
				Error	4664	6.75
	Total	69033	100	Total	69076	100
	Storage Chg.	-44				

Residuals Analysis				COUNT	1" error	2" error	3"error
Sum =	8344.71	Avg. Error	11.4311	# >	342	335	329
Max =	355.54	St. Dev.	88.03	# <	377	371	364
Min =	-184.67	AvgAbsErr	69.532506	Total	719	706	693
SUM98=	3681.15	St.Dev	55.117421	Percent	98.5	96.7	94.9
SUM99=	4663.56	SumAvgAb	50758.729	Combined Absolute Percent Error			12.94
Seepage Coefficient =	4	Area (ac) =	20	Eff. Area Cofficient =	1.00		

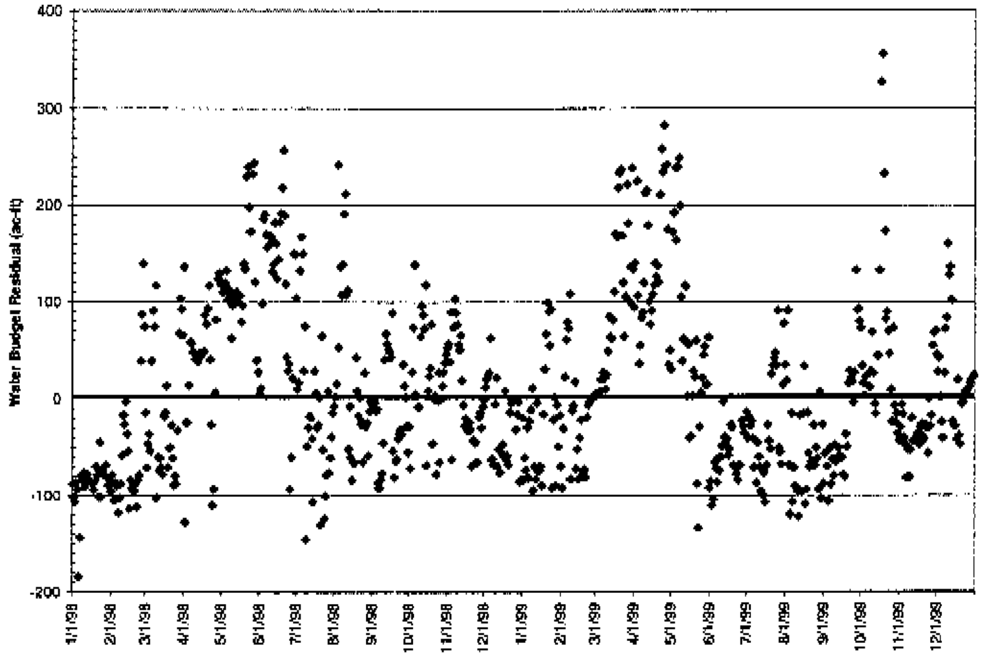

Figure 7. Daily Water Budget Residuals for the Supply Canal 1998-99

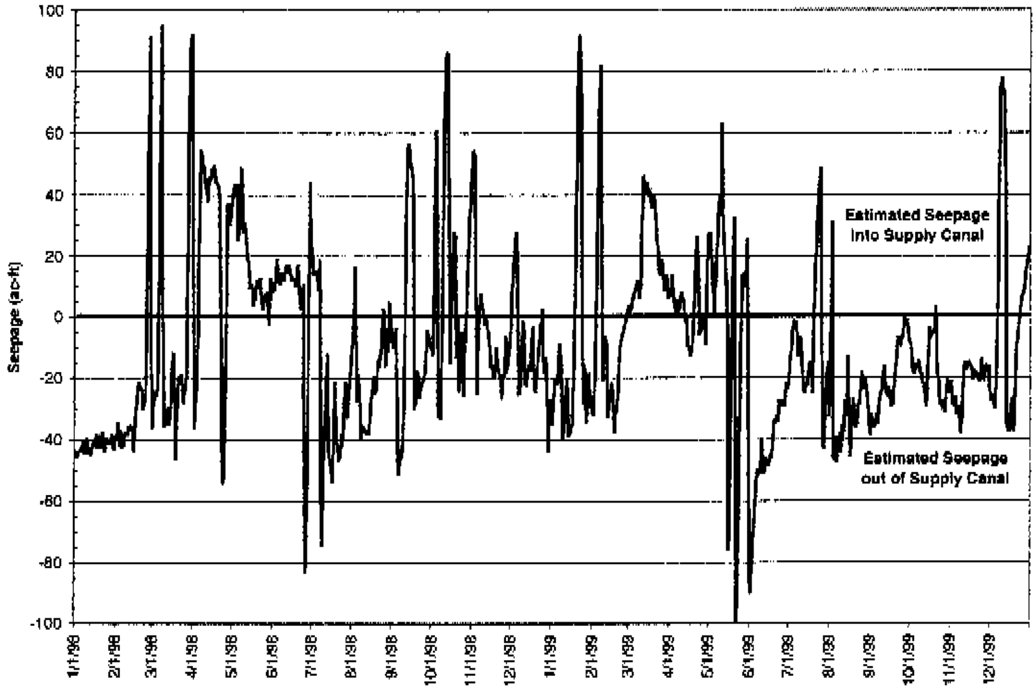

Figure 8. Supply Canal Estimated Seepage 1998-99

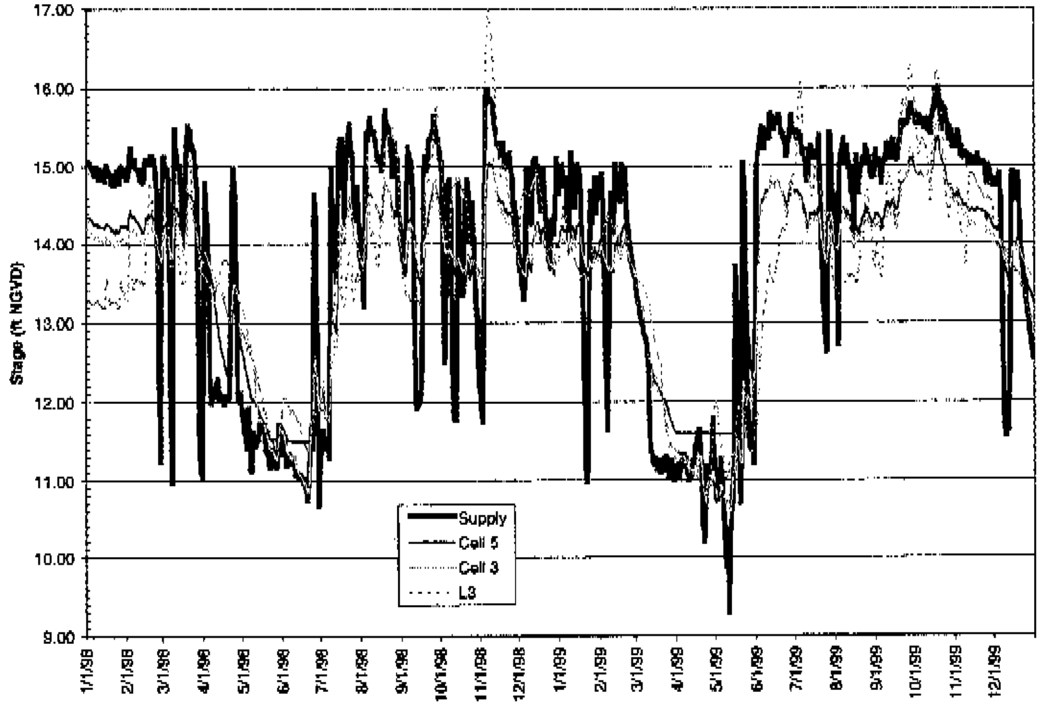

Figure 9. Supply Canal Stage versus Surrounding Water Bodies 1998-99

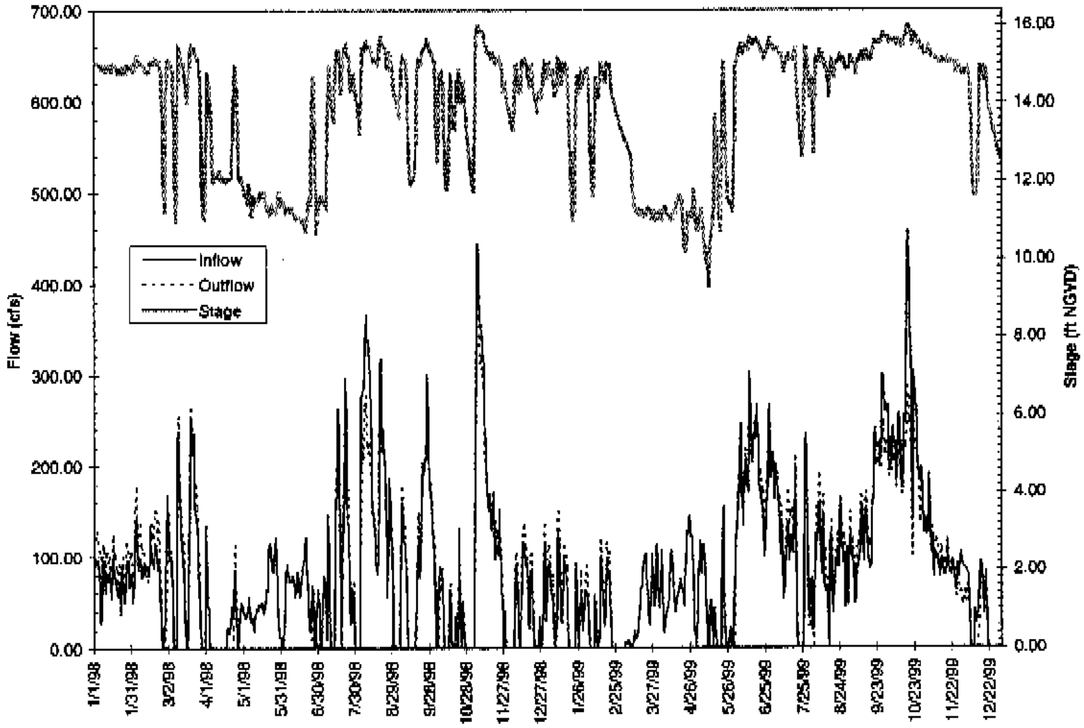

Figure 10. Supply Canal Inflow, Outflow and Stage 1998-99

Cell 5

Table 4 shows the biennial and annual water budget for Cell 5. Cell 5 is the northern cell of the two treatment cells in STA 6. Inflow is measured at G601 and G602; outflow is recorded at G354A, B and C.

As a percentage of the budget, error is less for Cell 5 than for the supply canal. Less than 1.0 percent of the days have errors that are greater than 0.25 ft (3 in) in depth. This was partially due to the fact that the budget is being applied to a unit that has a much larger area (625 ac vs. 20 ac for the supply canal). Also, the error in 1998 is offset by the error in 1999 (outflow is overestimated in 1998 and underestimated in 1999). **Figure 11** shows the residual error plot for the Cell 5 water budget. The seepage coefficient used for the Cell 5 water budget was 1.47 cfs/mi/ft, which agrees well with values from the literature. Seepage constitutes 15.4 percent of the biennial water budget. Seepage into and out of Cell 5 is depicted in **Figure 12**. Note that there was minimal seepage into Cell 5 during 1998-99 even during the periods when the cell dried out. Stage in Cell 5 and in surrounding water bodies is presented in **Figure 13**. 85.1 percent of the inflow to the cell at G601 and G602 leaves the cell at G354A, B and C. **Figure 14** shows the inflow, outflow and stage in Cell 5 for 1998-99.

The monthly water budgets for 1998 and 1999 are shown in **Table 5**. The monthly error in ac-ft/month and the daily average error in inches are given in the right two columns in the table. Except for the first several months of 1998 and June 1999, the average daily errors are exceptionally small. All average daily errors based on the monthly water budget are less than 1.0 in.

Table 4. Cell 5 Water Budget Summary 1998-99

Cell 5						
1998-99	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Weirs	64900	91.26	Outflow Weirs	55227	76.91
	Rain	6213	8.74	Seepage	11042	15.38
				ET	5525	7.69
				Error	9	0.01
	Total	71113	100	Total	71804	100
	Storage Chg.	-691				
1998	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Weirs	31032	91.88	Outflow Weirs	27605	81.02
	Rain	2741	8.12	Seepage	5933	17.41
				ET	2920	8.57
				Error	-2388	-7.01
	Total	33773	100	Total	34070	100
	Storage Chg.	-297				
1999	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Weirs	33868	90.70	Outflow Weirs	27622	73.20
	Rain	3471	9.30	Seepage	5109	13.54
				ET	2606	6.90
				Error	2397	6.35
	Total	37340	100	Total	37734	100
	Storage Chg.	-395				

Residual Analysis				COUNT	1" error	2" error	3"error
SUM =	9.21	Avg. Error	0.01	# >	71	8	0
MAX =	146.36	St. Dev.	47.88	# <	76	17	7
MIN =	-300.26	Avg.Abs.Error	33.58	Total	147	25	7
SUM98=	-2388.20	St. Dev.	34.10638208	Percent	20.14	3.42	0.96
SUM99=	2397.42	Sum Abs.Err.	24516.91	Combined Absolute Percent Error			13.36
Seepage Coefficient =	1.47	Area (ac) =	625	Eff. Area Cofficient =			1.00

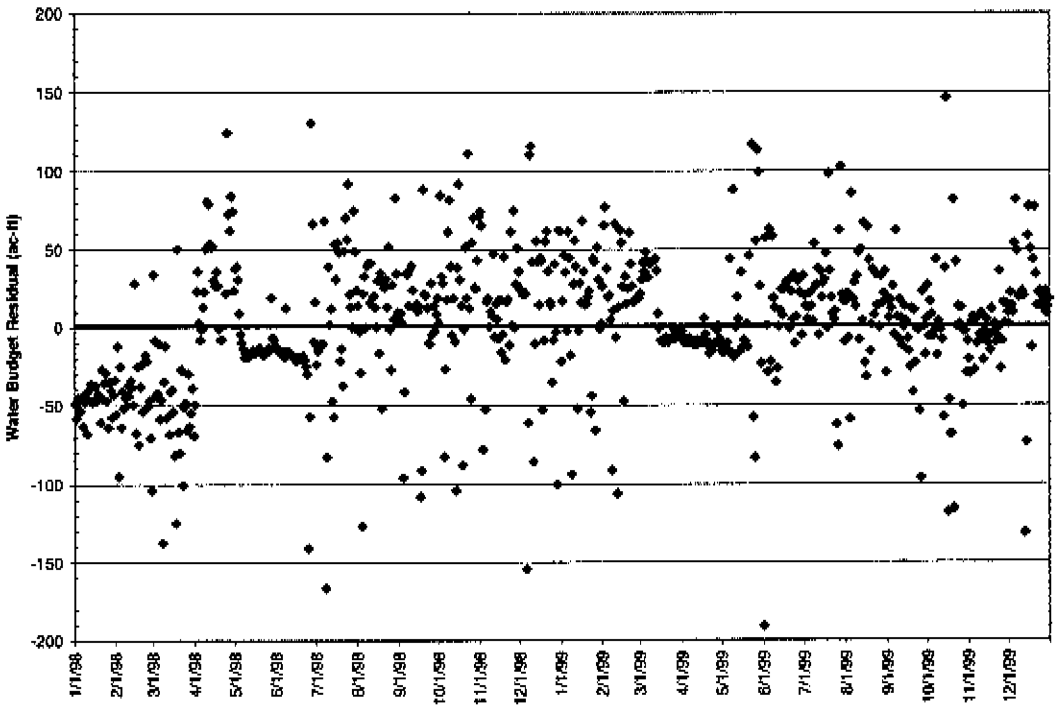

Figure 11. Daily Water Budget Residuals for Cell 5 1998-99

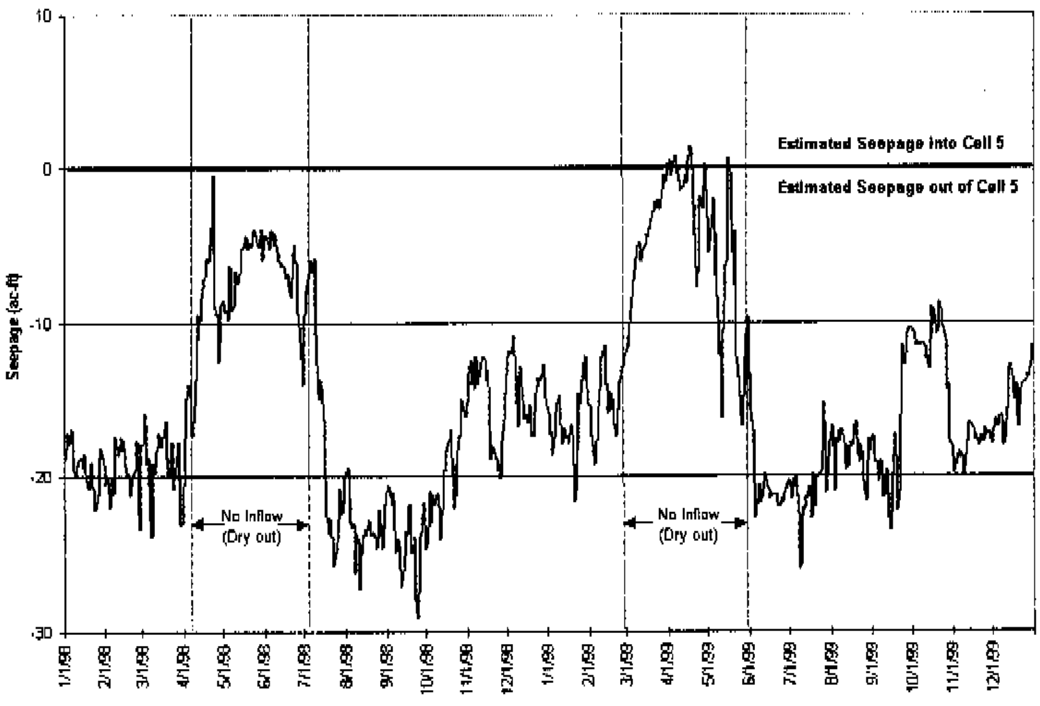

Figure 12. Cell 5 Estimated Seepage 1998-99

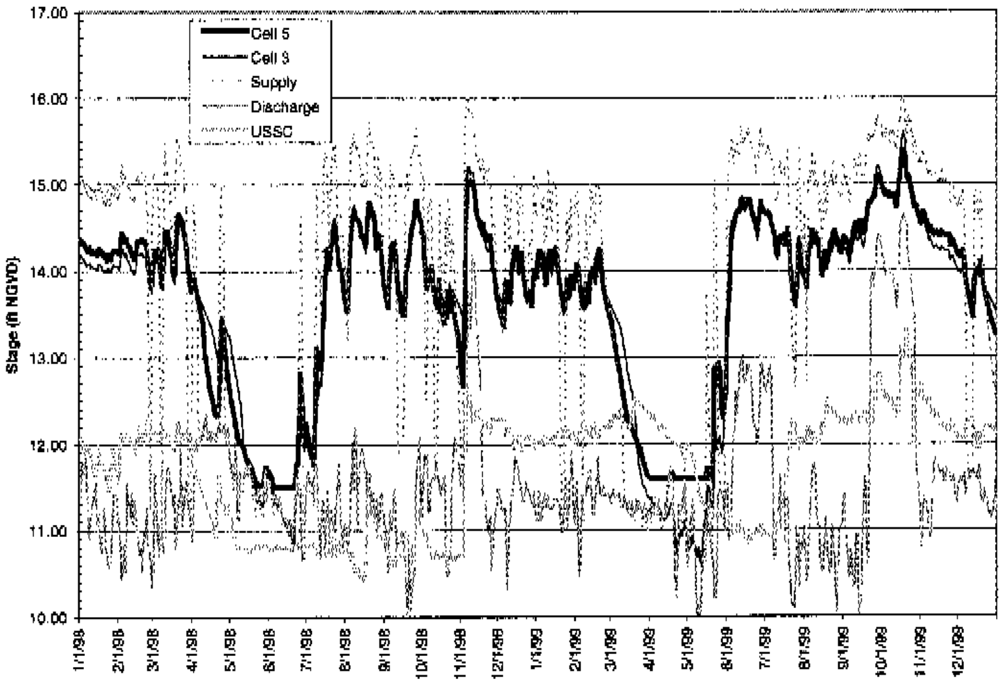

Figure 13. Stage in Cell 5 Stage and Surrounding Water Bodies 1998-99

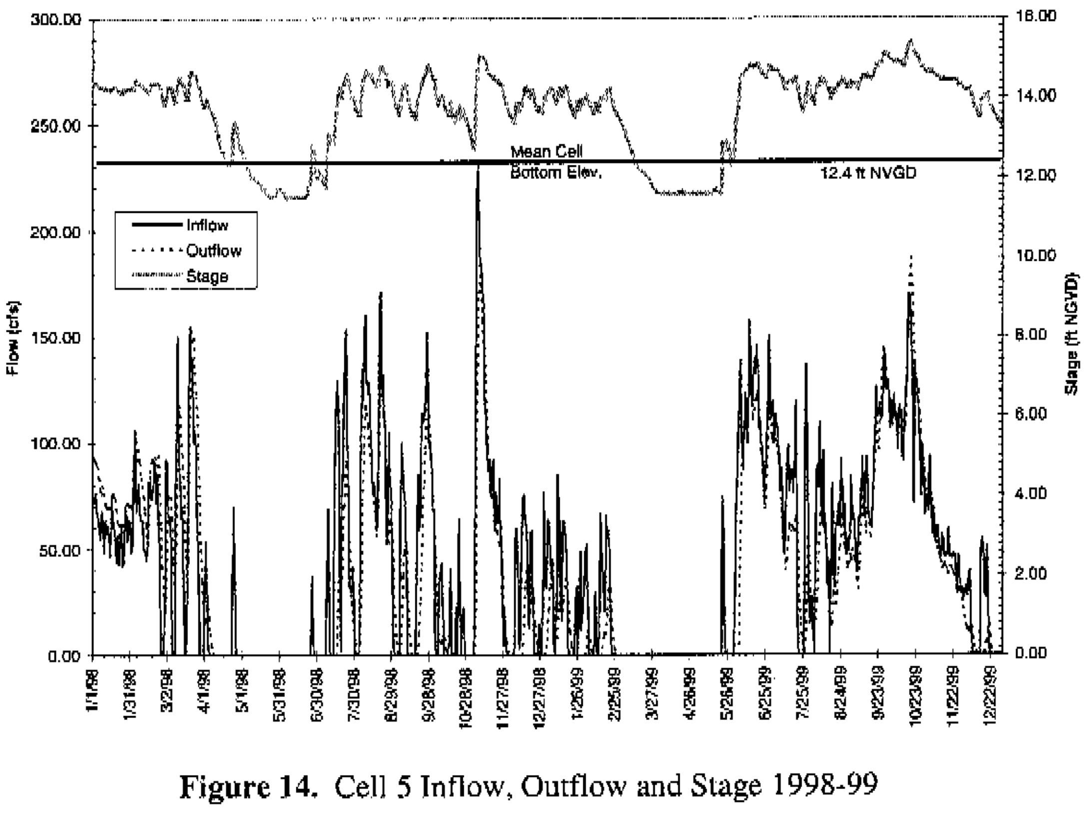

Figure 14. Cell 5 Inflow, Outflow and Stage 1998-99

Table 5. Cell 5 Monthly Water Budget 1998-99

1998 Month	Inflow (ac-ft)	Outflow (ac-ft)	Storage Change (ac-ft)	Rain (ac-ft)	ET (ac-ft)	Seepage (ac-ft)	Monthly Error	Daily Avg. Error (in)
JAN	3671.49	4512.17	-102.19	56.77	153.03	-596.25	-1431.00	-0.89
FEB	3307.66	4238.12	-159.69	241.67	152.31	-549.33	-1230.75	-0.84
MAR	3853.84	4944.03	-100.16	263.54	204.17	-598.63	-1529.29	-0.95
APR	512.45	217.22	-727.65	35.42	264.80	-319.21	474.28	0.30
MAY	0.00	0.00	-246.92	54.69	348.98	-189.79	-237.16	-0.15
JUN	94.11	0.00	47.55	98.44	355.62	-197.59	-408.22	-0.26
JUL	2825.66	1361.97	819.43	444.27	321.36	-518.34	248.83	0.15
AUG	5486.00	4441.90	120.31	506.25	323.86	-725.57	380.60	0.24
SEP	3398.52	2289.27	408.91	358.85	218.93	-724.73	115.54	0.07
OCT	973.65	559.06	-920.94	174.48	234.15	-613.67	662.19	0.41
NOV	5214.37	4463.96	410.31	459.90	182.93	-455.51	161.55	0.10
DEC	1694.20	577.43	154.22	46.88	159.61	-444.59	405.23	0.25

1999 Month	Inflow (ac-ft)	Outflow (ac-ft)	Storage Change (ac-ft)	Rain (ac-ft)	ET (ac-ft)	Seepage (ac-ft)	Monthly Error	Daily Avg. Error (in)
JAN	1859.05	930.90	-3.44	97.92	155.20	-515.63	358.67	0.22
FEB	1181.00	424.91	-297.81	47.40	160.90	-419.82	520.57	0.36
MAR	0.00	0.00	-761.11	13.54	238.09	-144.03	392.53	0.24
APR	0.00	0.00	0.43	41.67	264.35	-38.34	-261.45	-0.17
MAY	236.15	0.00	505.16	570.31	281.60	-264.41	-244.70	-0.15
JUN	6711.99	5373.71	1065.78	776.56	215.02	-618.39	215.66	0.14
JUL	4167.77	3324.38	-447.34	249.48	279.08	-642.09	619.05	0.38
AUG	3535.17	2456.94	224.22	492.71	246.15	-569.62	530.96	0.33
SEP	5234.12	4648.59	443.12	528.13	216.10	-527.55	-73.12	-0.05
OCT	6949.23	7401.62	-259.53	576.04	198.62	-364.77	-180.21	-0.11
NOV	3060.98	2753.83	-261.41	58.85	194.74	-537.40	-104.73	-0.07
DEC	932.96	307.31	-602.66	18.75	155.69	-467.16	624.20	0.39

Cell 3

Table 6 shows the biennial and annual water budgets for Cell 3 for 1998 and 1999. Cell 3 is south of Cell 5. It is the smaller of the treatment cells at STA 6 covering 245 ac. Inflow is measured at G603; outflow is recorded at weir boxes G393A, B and C. **Table 7** contains the monthly water budget for Cell 3. Missing data for flow at G603 in DBHYDRO were supplied by running the FLOWCALC program using archived stage data.

Error in the biennial water budget was 2.8 percent. Of the total number of days in the biennial study, 1.1 percent had a daily water budget residual that represented more than a 0.25 ft (3.0 in) error. The seepage coefficient used for the water budget for Cell 3 was 3.79, which is within the values found in the literature. Using this value, however, resulted in seepage rates that represented 19.6 percent of the water budget for 1998 and 1999. Although this percentage appears high, there is a significant groundwater gradient at the southern end of Cell 3 that may contribute to the increase in seepage losses (**Figures 4** and **6**). Outflow through weir boxes G393A through C was 77.0 percent of the inflow to Cell 3 measured at G603.

The average daily error in the monthly water budget analysis shown in **Table 7** is less than 1.0 inch for all months except October 1999. The monthly volumes in the budget for October 1999 in Cell 5 were also much larger than the average. Hurricane Irene affected flows and stage at STA 6 in October 1999.

Figure 15 presents the residuals in the Cell 3 water budget for 1998-99. **Figure 16** shows the estimated seepage into and out of Cell 3 and **Figure 17** shows the stage in Cell 3 versus that in the supply and discharge canals and Cell 5. The variation in Cell 3 inflow, outflow and stage is depicted in **Figure 18**. Cell 3 displayed the least amount of variation in the water budget residuals because it is the smaller of the two treatment cells and receives less flow. Proportionally, the water budget residuals for Cell 5 were on the same order as those for Cell 3.

Table 6. Cell 3 Water Budget Summary 1998-99

			Cell 3				
1998-99	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent	
	Inflow Weirs	48650	95.23	Outflow Weirs	37479	73.34	
	Rain	2435	4.77	Seepage	10038	19.64	
				ET	2166	4.24	
				Error	1418	2.78	
	Total	51086	100.00	Total	51101	100.00	
	Storage Chg.	-15					
1998	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent	
	Inflow Weirs	22225	95.39	Outflow Weirs	15745	67.54	
	Rain	1075	4.61	Seepage	5014	21.51	
				ET	1145	4.91	
				Error	1410	6.05	
	Total	23300	100.00	Total	23314	100.00	
	Storage Chg.	-14					
1999	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent	
	Inflow Weirs	26425	95.10	Outflow Weirs	21734	78.21	
	Rain	1361	4.90	Seepage	5024	18.08	
				ET	1021	3.68	
				Error	8	0.03	
	Total	27786	100.00	Total	27787	100.00	
	Storage Chg.	-1					
	Residual Analysis			COUNT	1" error	2" error	3"error
SUM =	1418.428668	Avg. Error	1.94305297	# >	140	37	2
MAX =	95.93039581	St. Dev.	24.923803	# <	106	14	6
MIN =	-160.1288359	Avg.Abs.Error	17.60	Total	246	51	8
SUM98=	1410.393926	St. Dev.	17.7424685	Percent	33.70	6.99	1.10
SUM99=	8.034742042	Sum Abs.Err.	12848	Combined Absolute Percent Error		6.08	
Seepage Coefficient =	3.79	Area (ac) =	245	Eff. Area Cofficient =		1.00	

Table 7. Cell 3 Monthly Water Budget 1998-99

1998 Month	Inflow (ac-ft)	Outflow (ac-ft)	Storage Change (ac-ft)	Rain (ac-ft)	ET (ac-ft)	Seepage (ac-ft)	Monthly Error	Daily Avg. Error (in)
JAN	2355.51	1439.38	-44.10	22.25	59.99	-778.91	143.58	0.23
FEB	2179.72	1468.08	-46.92	94.73	59.71	-608.12	185.46	0.32
MAR	2604.71	1958.53	-23.03	103.31	80.03	-585.79	106.68	0.17
APR	315.84	95.85	-128.14	13.88	103.80	-339.19	-80.98	-0.13
MAY	0.00	0.00	-239.36	21.44	136.80	-87.55	36.45	0.06
JUN	57.82	0.00	71.39	38.59	139.40	102.85	-11.54	-0.02
JUL	2010.97	1106.72	368.63	174.15	125.97	-474.20	109.60	0.17
AUG	4109.23	3216.99	33.81	198.45	126.95	-569.63	360.30	0.57
SEP	2632.04	1848.21	122.26	140.67	85.82	-655.01	61.41	0.10
OCT	715.30	589.83	-210.46	68.40	91.79	-320.63	-8.10	-0.01
NOV	3992.42	3414.04	49.00	180.28	71.71	-361.28	276.68	0.45
DEC	1251.67	607.25	33.01	18.38	62.57	-336.37	230.84	0.36

1999 Month	Inflow (ac-ft)	Outflow (ac-ft)	Storage Change (ac-ft)	Rain (ac-ft)	ET (ac-ft)	Seepage (ac-ft)	Monthly Error	Daily Avg. Error (in)
JAN	1386.95	750.88	-17.27	38.38	60.84	-520.10	110.80	0.18
FEB	860.64	438.25	-52.25	18.58	63.07	-382.01	48.12	0.08
MAR	0.00	0.17	-346.08	5.31	93.33	-446.33	-188.44	-0.30
APR	0.00	0.00	33.16	16.33	103.63	88.78	-31.68	-0.05
MAY	198.19	0.00	156.59	223.56	110.39	69.47	224.25	0.35
JUN	5182.82	3836.37	499.62	304.41	84.29	-614.06	452.90	0.74
JUL	3093.93	2425.67	-162.56	97.80	109.40	-541.48	277.73	0.44
AUG	2592.02	1815.20	61.86	193.14	96.49	-789.02	22.60	0.04
SEP	4149.98	3467.27	213.76	207.03	84.71	-517.61	73.65	0.12
OCT	5371.08	6237.77	-139.71	225.81	77.86	-376.42	-955.45	-1.51
NOV	2941.90	2238.68	-131.57	23.07	76.34	-453.58	327.74	0.54
DEC	647.64	523.34	-116.93	7.35	61.03	-541.73	-354.18	-0.56

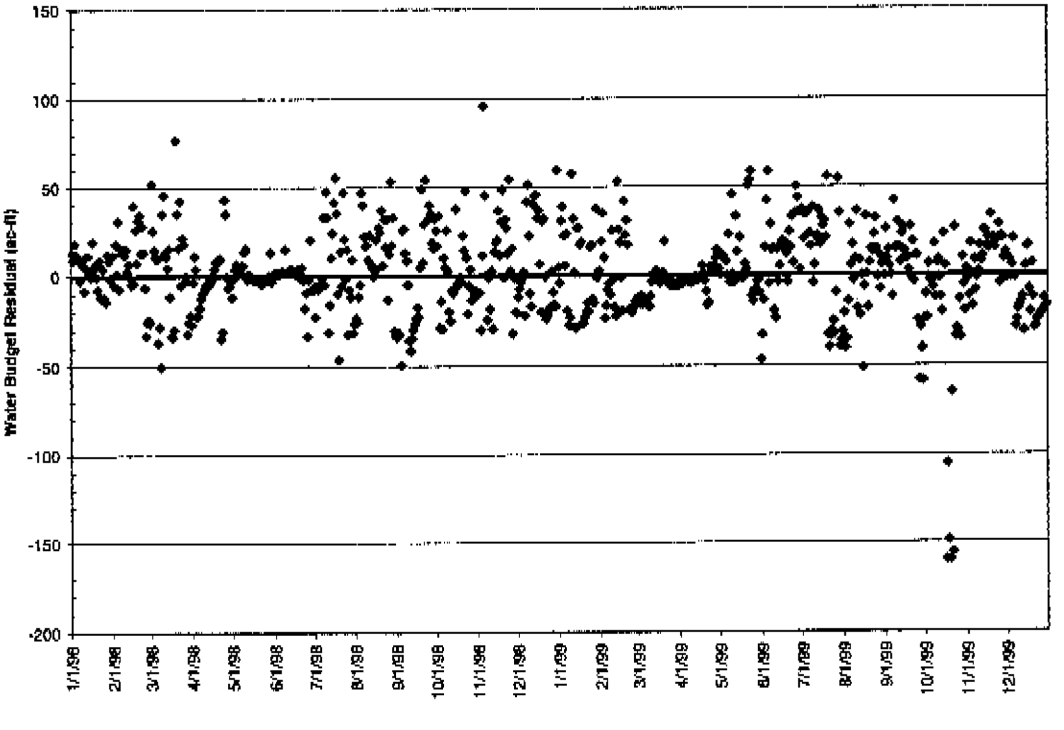

Figure 15. Daily Water Budget Residuals for Cell 3 1998-99

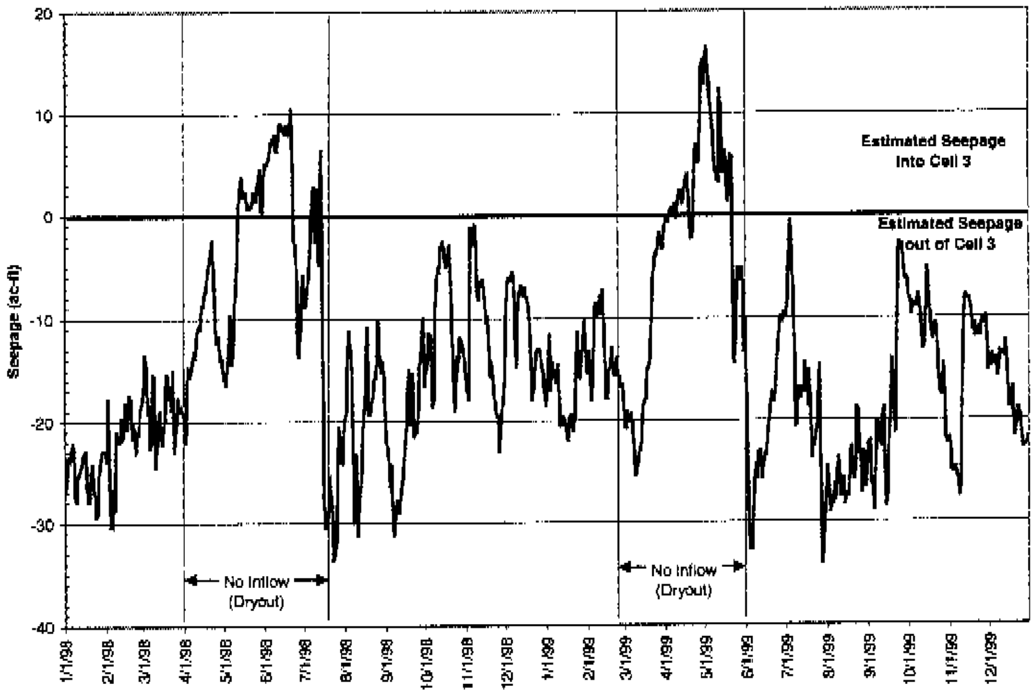

Figure 16. Cell 3 Estimated Seepage 1998-99

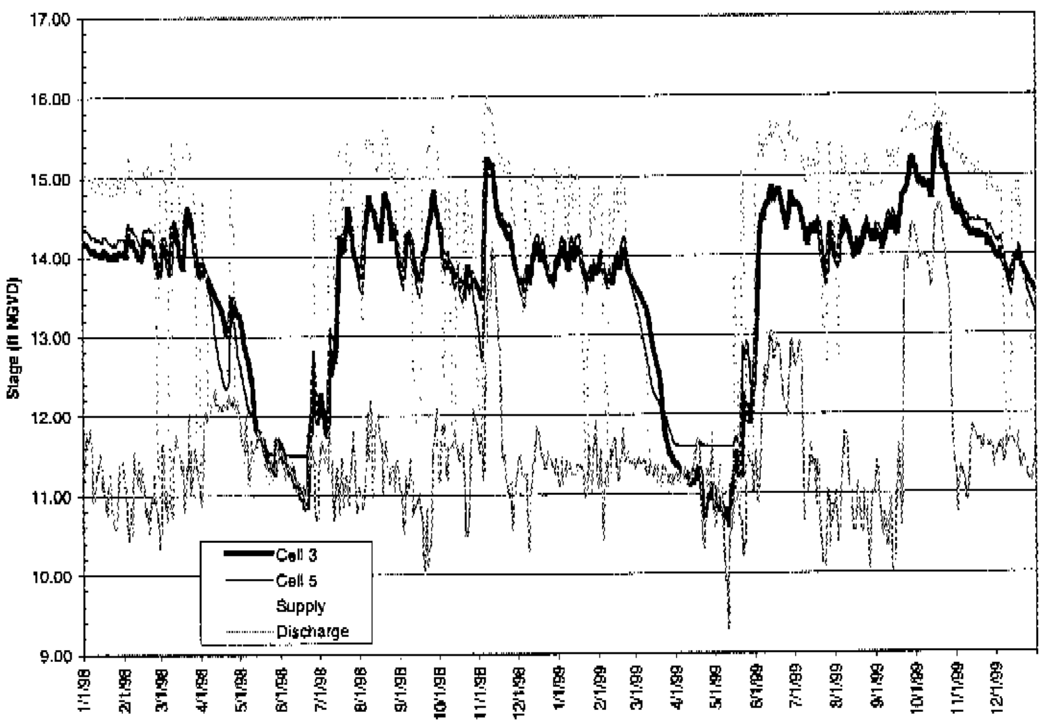

Figure 17. Stage in Cell 3 and Surrounding Water Bodies 1998-99

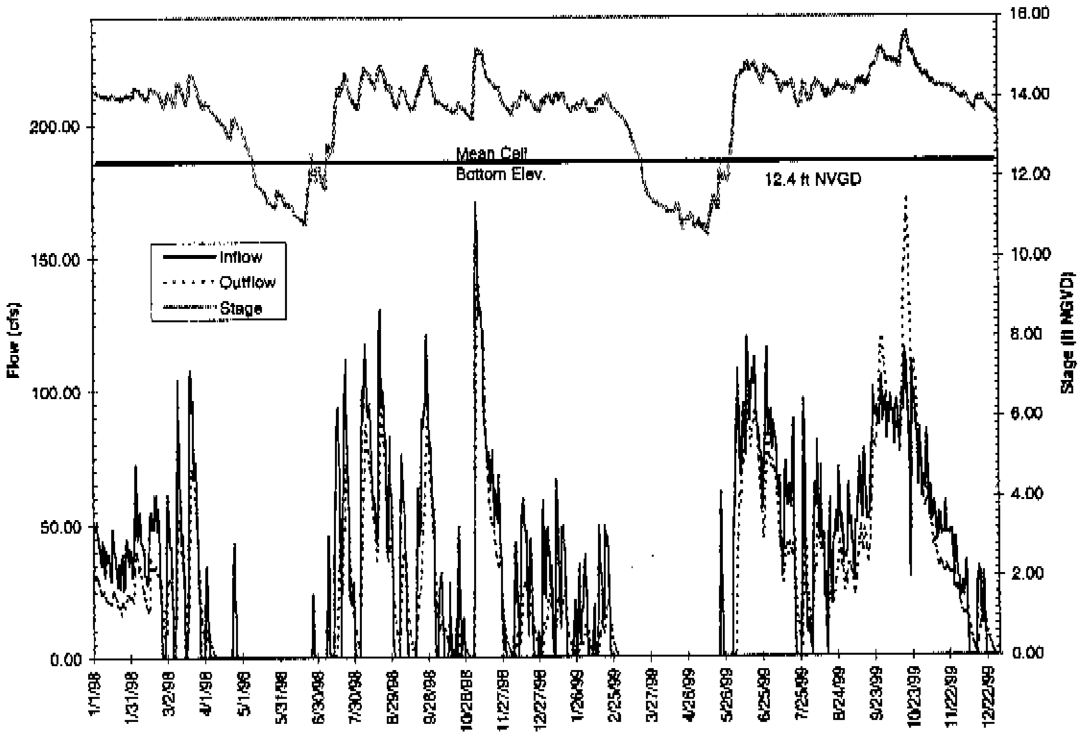

Figure 18. Cell 3 Inflow, Outflow and Stage 1998-99

Discharge Canal

The summary table of the biennial and annual water budgets for the discharge canal is shown in **Table 8**. Implementing a water budget for the discharge canal was difficult. The outflow recorded at G606 in 1999 was greater than the inflow to the discharge canal that year. This may be due to flows that enter the discharge canal from the L-4 canal through the culverts at G607. Never the less, the discharge canal gained water through seepage. The seepage coefficient used for the discharge canal water budget was 0.59 cfs/mi/ft. Increasing it beyond this value reduced the water budget error in 1999 but increased the error in the budget for 1998. This value for the seepage coefficient resulted in the lowest combined error for both years. Seepage was 4.6 percent of the biennial water budget. As was the case for the supply canal, the majority of the daily water budgets, 75.9 percent, had an error that represented more than 0.25ft (3.0 in). The surface area of the discharge canal represents less than 3.0 percent of the total effective area of STA 6, so the errors in the water budget, although large, are not significant with respect to the overall budget for STA 6.

Figure 19 shows the daily water budget residual for the discharge canal for 1998-99. **Figure 20** depicts the estimated seepage for the discharge canal, which is primarily into the canal. The stage in the discharge canal versus those in Cells 3 and 5 and the Rotenberger Wildlife Management Area is shown in **Figure 21**. **Figure 22** shows recorded stage, inflow and outflow for the discharge canal for 1998-99.

Discharge Canal						
1998-99	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Weirs	92706	95.14	Outflow UVM	97250	99.81
	Rain	219	0.22	ET	194	0.20
	Seepage	4520	4.64	Error	-9	-0.01
	Total	97445	100	Total	97436	100
	Storage Chg.	9				
1998	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Weirs	43350	95.18	Outflow UVM	36503	80.15
	Rain	96	0.21	ET	103	0.23
	Seepage	2099	4.61	Error	8940	19.63
	Total	45545	100	Total	45545	100
	Storage Chg.	0				
1999	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Weirs	49356	95.10	Outflow UVM	60748	117.07
	Rain	122	0.24	ET	92	0.18
	Seepage	2421	4.66	Error	-8948	-17.24
	Total	51899	100	Total	51891	100
	Storage Chg.	8				

Residuals Analysis				COUNT	1" error	2" error	3" error
Sum =	-8.88	Avg. Error	-0.0122	# >	404	371	340
Max =	158.90	St. Dev.	61.71	# <	250	224	214
Min =	-274.48	AvgAbsErr	39.356814	Total	654	595	554
SUM98=	8939.67	St.Dev	47.505801	Percent	89.6	81.5	75.9
SUM99=	-8948.45	SumAvgAbsErr	28730.328	Combined Absolute Percent Error			36.87
Seepage Coefficient =	0.59	Area (ac) =	22	Eff. Area Cofficient =			1.00

Table 8. Discharge Canal Water Budget Summary 1998-99

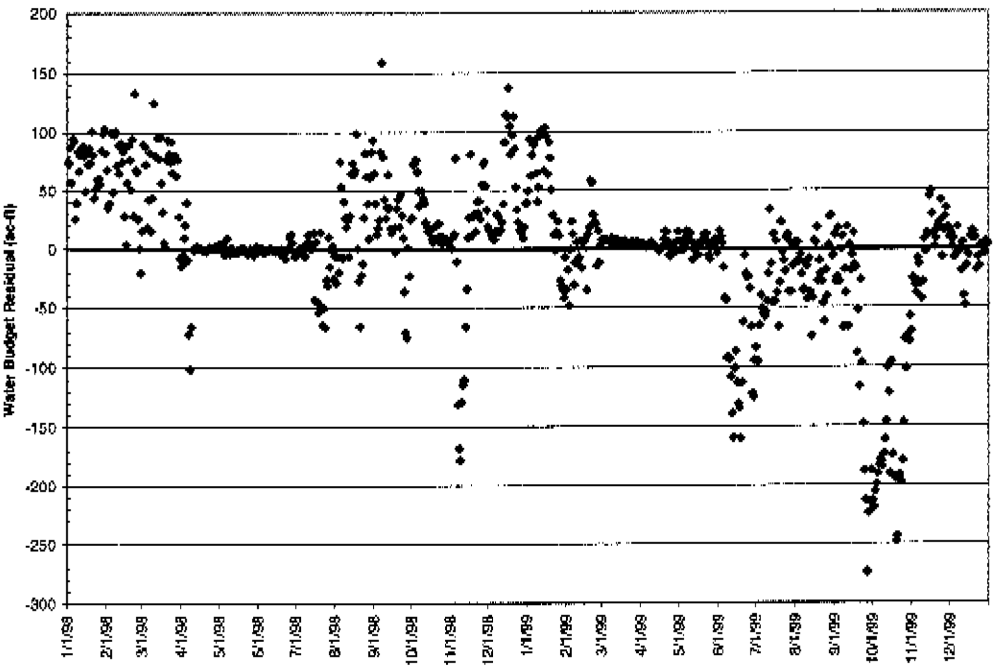

Figure 19. Daily Water Budget Residuals for the Discharge Canal 1998-99

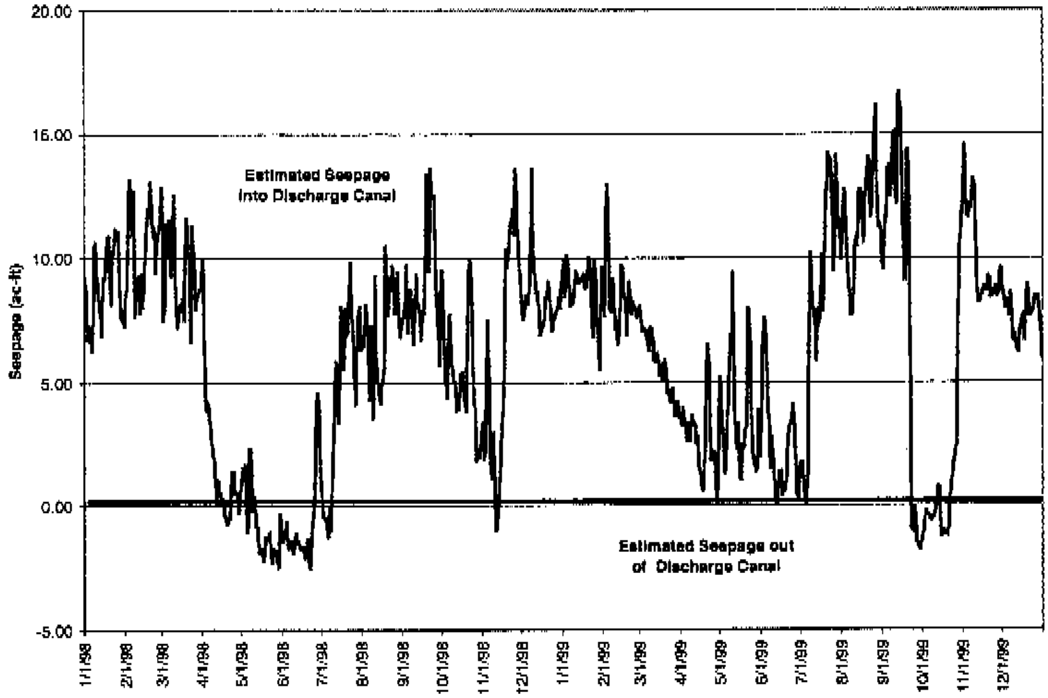

Figure 20. Discharge Canal Estimated Seepage 1998-99

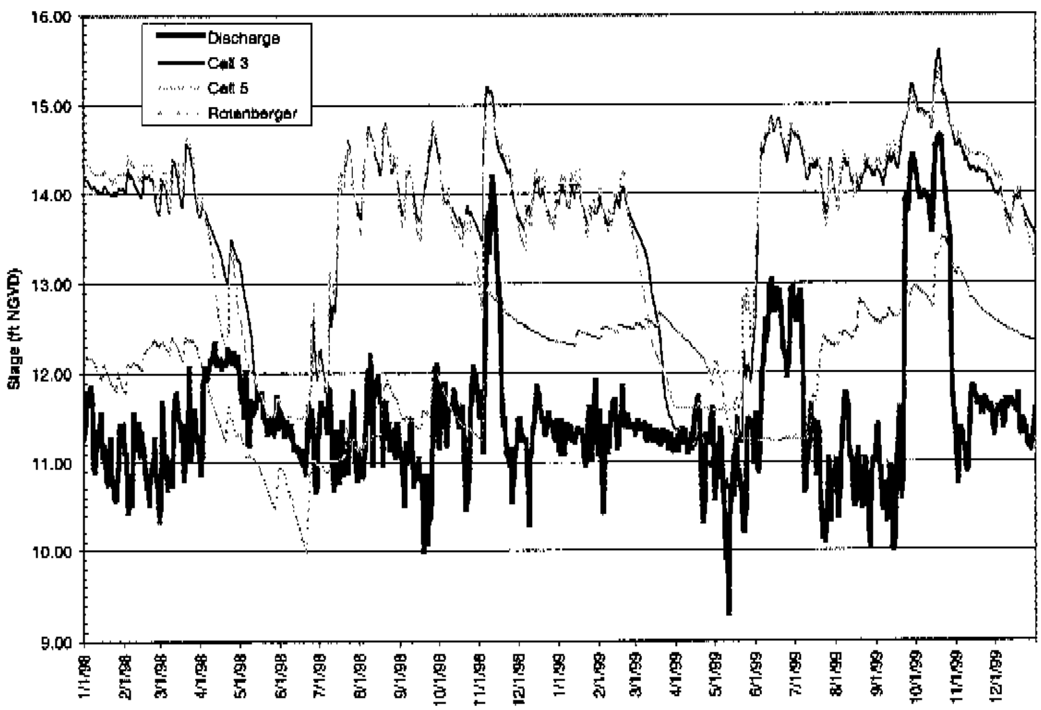

Figure 21. Stage in the Discharge Canal and Surrounding Water Bodies 1998-99

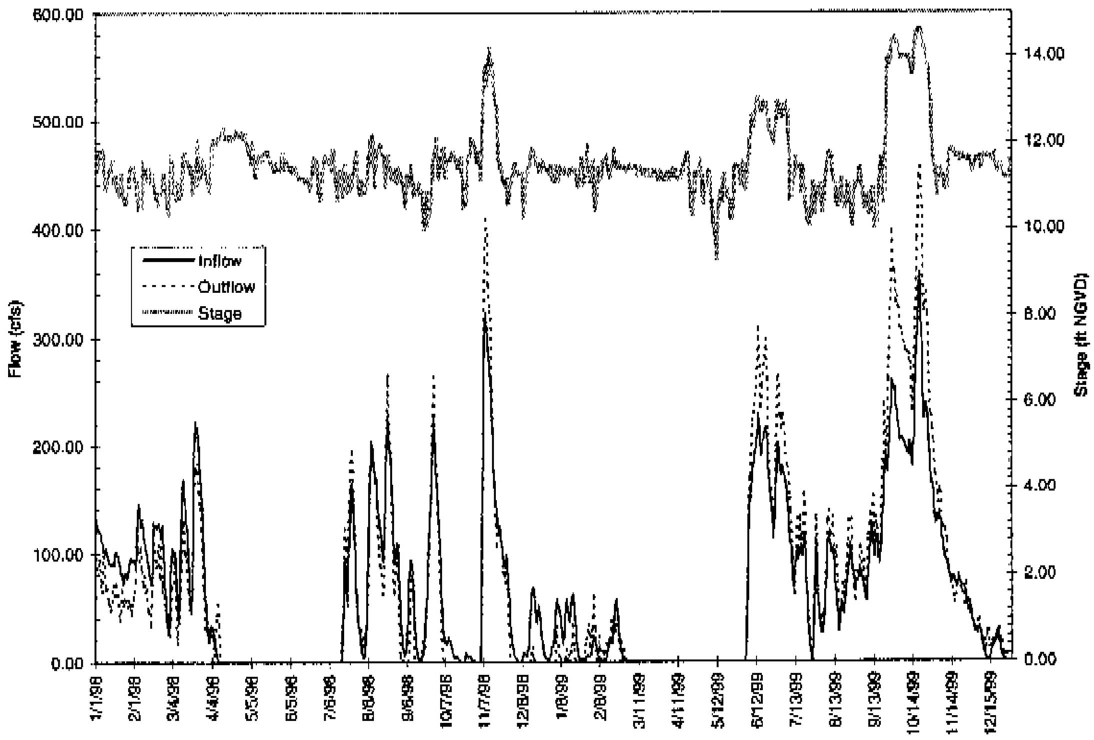

Figure 22. Discharge Canal Inflow, Outflow and Stage 1998-99

STA 6

Table 9 contains the summary of the biennial and annual water budgets for the entire STA, which includes all four hydrologic units, discussed above. The water budget for the entire STA was affected by the apparent problems with outflow measurement for STA 6 at the discharge canal. Seepage was estimated by using stages in Cell 5 along the northern boundary of STA 6, in the supply canal along the western boundary with the L3 canal and the discharge canal along the eastern boundary with the Rotenberger Wildlife Management Area. Using a seepage coefficient of 7.0 cfs/mi/ft, errors for the two years were 6.0 percent of the budget. The value of the seepage coefficient is greater than reported in the literature but it resulted in lower error in the biennial budget. Seepage was 17.7 percent of the water budget. Increasing the seepage coefficient reduced the water budget error but increased the percentage of the water budget attributed to seepage in 1998 to nearly 30.0 percent. This was considered to be unreasonably large. Slightly more than 6.0 percent of the days during the two-year period had errors that were greater than 0.25 ft (3.0 in).

Table 10 shows the monthly water budget summary. Most of the daily average errors are less than 1.0 in. except in June 1998 and six months in 1999. June 1999 was the beginning of a wetter than normal wet season after a drier than normal spring (the signs of the average daily errors reflect these trends). October 1999 was the month in which Hurricane Irene produced unusually large rainfall amounts over southeastern Florida.

Figure 23 shows the residual in the daily water budgets. The peaks in the residual plot occur during periods of high inflow, showing that the daily water budget under these conditions does not accurately quantify all of the hydrologic processes occurring in STA 6. **Figure 24** presents the estimated seepage into and out of STA 6. It shows that there is a net loss of water seeping from STA 6 into the surrounding area. This is consistent with groundwater gradients depicted in **Figure 25, 26 and 27** and **Figures 3** to **6**. Since inflow, outflow and seepage constitute such large portions of the water budget, their values over time are shown in **Figures 28** and **29.**

Figure 30 shows the inflow and outflow volumes for STA 6 as a single hydrologic unit based upon the results of the water budget for 1998-99. The value within STA 6 represents the change in storage from 1998 to 1999. More detailed information about how each of the four hydrologic units, the supply canal, treatment cell 3, treatment cell 5 and the discharge canal, fit into the overall STA biennial water budget is shown in **Figure 31.** It depicts the inflow and outflow volumes in ac-ft for each of the four hydrologic units that make up STA 6. Percentages in parentheses indicate the relationship between flow upstream and flow at that point in the diagram. For instance, the outflow from the discharge canal was 75.8 percent of the inflow to the supply canal. Also, the 64,901 ac-ft of water entering Cell 5 was 57.2 percent of the flow leaving the supply canal (113,551 ac-ft). Inflow to the discharge canal from Cells 3 and 5 was 75.9 percent of the surface flow into the cells (113,551ac-ft plus 8,648 ac-ft from rainfall). The values within each hydrologic unit indicate the change in storage in ac-ft from 1998 to 1999.

Mean Hydraulic Retention Time

Hydraulic retention time is a measure of how long water remains in each cell. It estimates the period of time that water will be treated in a cell. Over this period, physical, chemical and biological processes remove particulate and soluble phosphorous and other contaminants. The mean hydraulic retention time (also referred to as mean cell residence time) was determined using equation 8:

$$t = \frac{V}{Q} \qquad (8)$$

where t = mean hydraulic retention time (d)
V = cell volume (ac-ft)
Q = flow rate (ac-ft/d)

Table 9. STA 6 Water Budget Summary

STA 6						
1998-99	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Pumps	128287	93.40	Outflow UVM	97250	70.46
	Rain	9065	6.60	Seepage	24440	17.71
				ET	8063	5.84
				Error	8265	5.99
	Total	137353	100.00	Total	138017	100.00
	Storage Chg.	-665				
1998	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Pumps	59365	93.69	Outflow UVM	36503	57.33
	Rain	4000	6.31	Seepage	15550	24.42
				ET	4261	6.69
				Error	7356	11.55
	Total	63365	100.00	Total	63669	100.00
	Storage Chg.	-304				
1999	INFLOWS	ac-ft	Percent	OUTFLOWS	ac-ft	Percent
	Inflow Pumps	68922	93.15	Outflow UVM	60748	81.71
	Rain	5065	6.85	Seepage	8890	11.96
				ET	3802	5.11
				Error	909	1.22
	Total	73987	100.00	Total	74348	100.00
	Storage Chg.	-361				

Residual Analysis				COUNT	1" error	2" error	3"error
SUM =	8254.991554	Avg. Error	11.32190624	# >	190	58	22
MAX =	324.6984514	St. Dev.	112.63167	# <	129	59	22
MIN =	-477.8446836	Av.Abs.Err.	86.68	Total	319	117	44
SUM98=	7355.987969	St. Dev.	73.04213404	Percent	43.70	16.03	6.03
SUM99=	909.0035651	Sum Abs.Err.	63278.36	Combined Absolute Percent Error			12.78
Seepage Coefficient =	7.00	Area (ac) =	812	Eff. Area Cofficient =			1.00

Table 10. STA 6 Monthly Water Budget 1998-99

Month 1998	Inflow (ac-ft)	Outflow (ac-ft)	Storage (ac-ft)	Rain (ac-ft)	ET (ac-ft)	Seepage (ac-ft)	Error (ac-ft)	Daily Avg. Error (in)
JAN	4560.00	3944.94	-145.56	82.84	223.30	-2366.23	-1746.07	-0.74
FEB	4603.62	4257.42	-184.64	352.64	222.26	-1009.87	-348.65	-0.16
MAR	5969.67	5266.20	-81.51	384.56	297.93	-616.75	254.87	0.11
APR	1376.33	527.23	-874.12	51.68	386.40	-804.78	583.72	0.26
MAY	3298.85	0.00	-470.21	79.80	509.23	-667.96	2671.67	1.13
JUN	3629.12	0.00	126.52	143.64	518.92	-875.62	2251.69	0.99
JUL	5330.22	3017.40	1139.84	648.28	468.93	-2636.39	-1284.05	-0.55
AUG	10965.60	6998.68	150.33	738.72	472.58	-2612.63	1470.11	0.62
SEP	5783.35	3666.09	510.17	523.64	319.47	-1644.57	166.69	0.07
OCT	1870.89	487.20	-1081.25	254.60	341.67	-1267.69	1110.18	0.47
NOV	9504.26	8290.49	428.62	671.08	266.93	-850.08	339.22	0.15
DEC	2473.49	46.91	177.98	68.40	232.91	-197.49	1886.60	0.80

Month 1999	Inflow (ac-ft)	Outflow (ac-ft)	Storage (ac-ft)	Rain (ac-ft)	ET (ac-ft)	Seepage (ac-ft)	Error (ac-ft)	Daily Avg. Error (in)
JAN	2784.02	495.11	-22.35	142.88	226.47	-556.29	1671.38	0.71
FEB	1665.52	1033.11	-327.97	69.16	234.79	-154.86	639.88	0.30
MAR	2396.25	0.00	-1057.91	19.76	347.42	1534.10	4660.61	1.98
APR	4227.73	0.00	48.19	60.80	385.74	1152.86	5007.45	2.20
MAY	2451.43	0.00	587.93	832.20	410.91	238.24	2523.03	1.07
JUN	11501.38	11457.06	1506.48	1133.16	313.75	-4690.58	-5333.34	-2.34
JUL	6576.50	6970.97	-550.55	364.04	407.23	-1283.95	-1171.06	-0.50
AUG	5430.49	5164.54	267.40	718.96	359.17	-896.02	-537.69	-0.23
SEP	9190.61	10411.99	576.02	770.64	315.34	-967.40	-2309.50	-1.01
OCT	14734.43	18847.22	-324.72	840.56	289.83	-2385.45	-5622.78	-2.39
NOV	5822.26	5231.96	-385.12	85.88	284.16	-644.68	132.46	0.06
DEC	2141.26	1135.54	-678.29	27.36	227.19	-235.61	1248.57	0.53

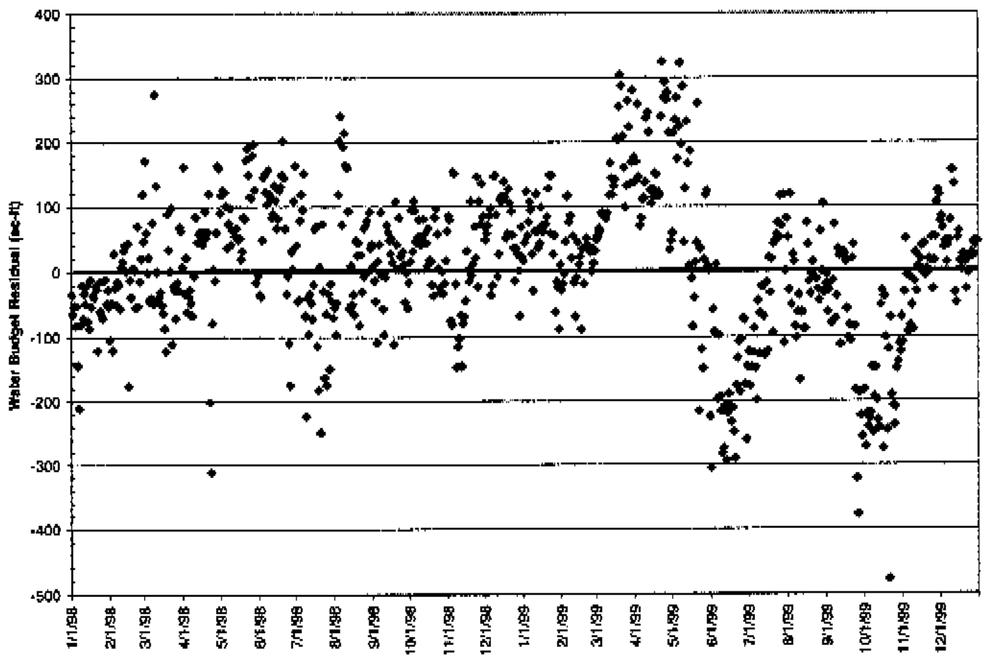

Figure 23. Water Budget Residual for STA 6 1998-99

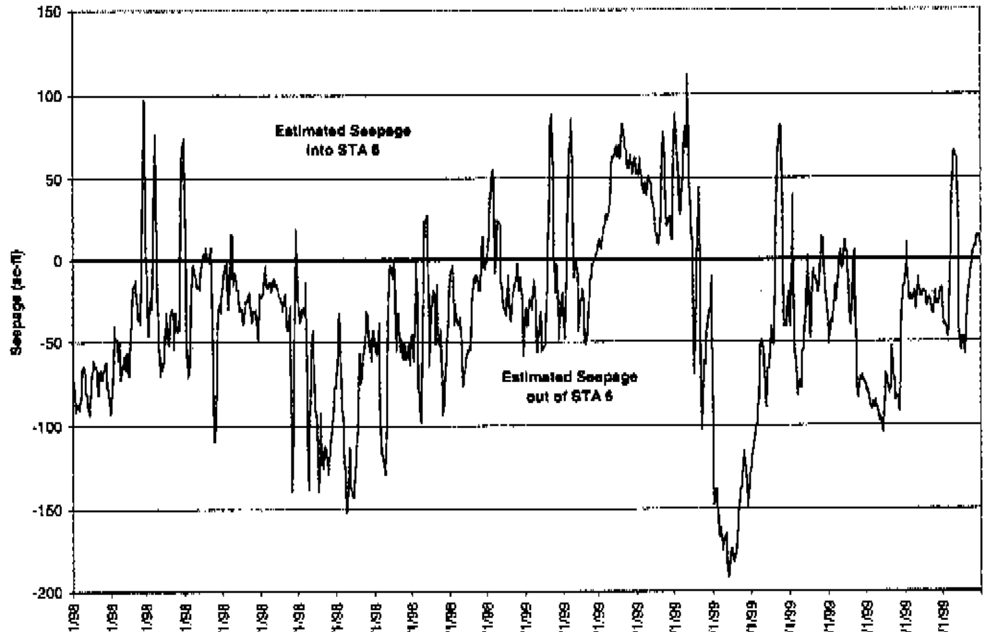

Figure 24. STA 6 Estimated Seepage 1998-99

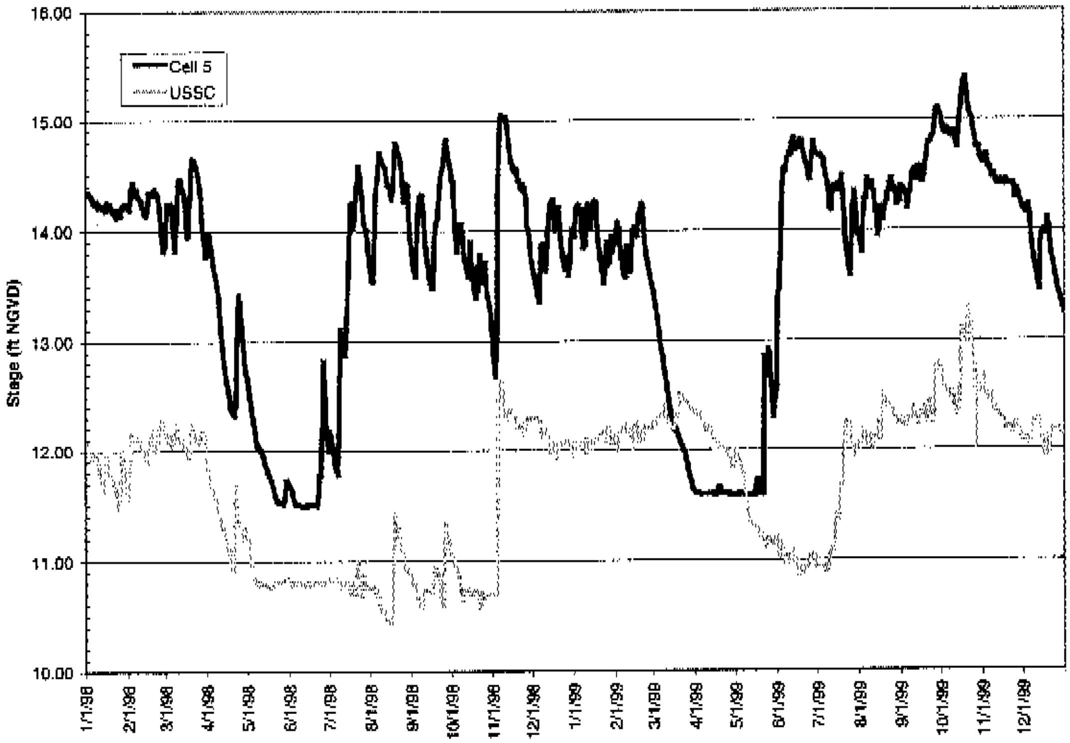

Figure 25. Stage along the Northern Boundary of STA 6 1998-99

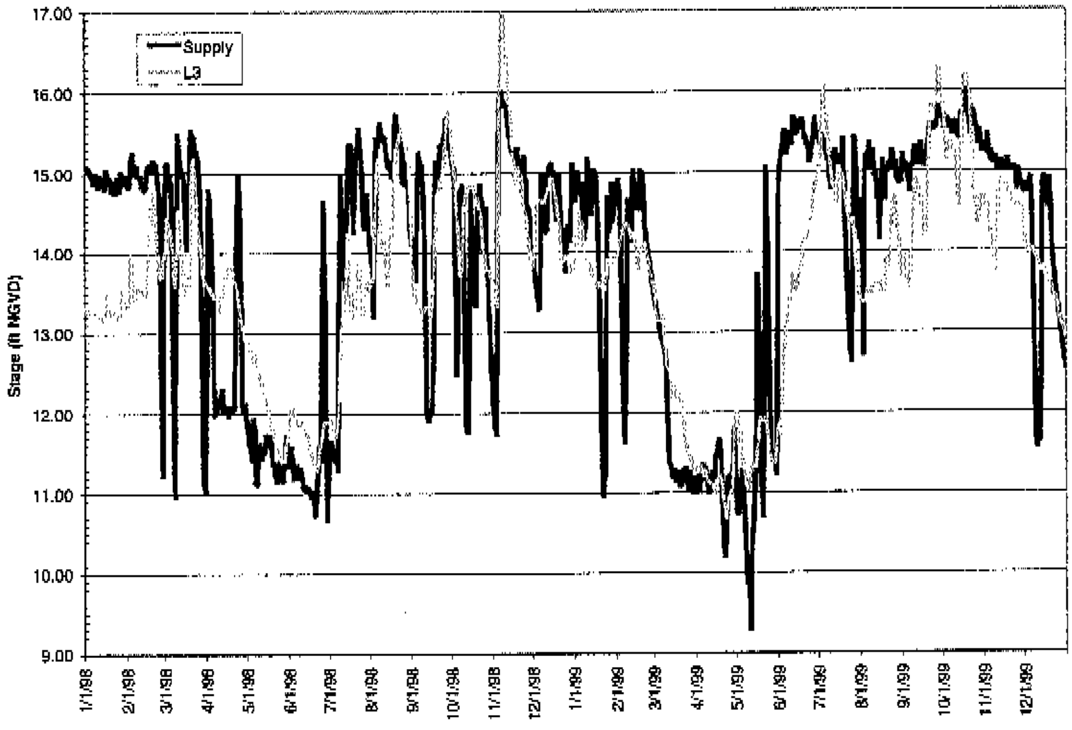

Figure 26. Stage along the Western Boundary of STA 6 1998-99

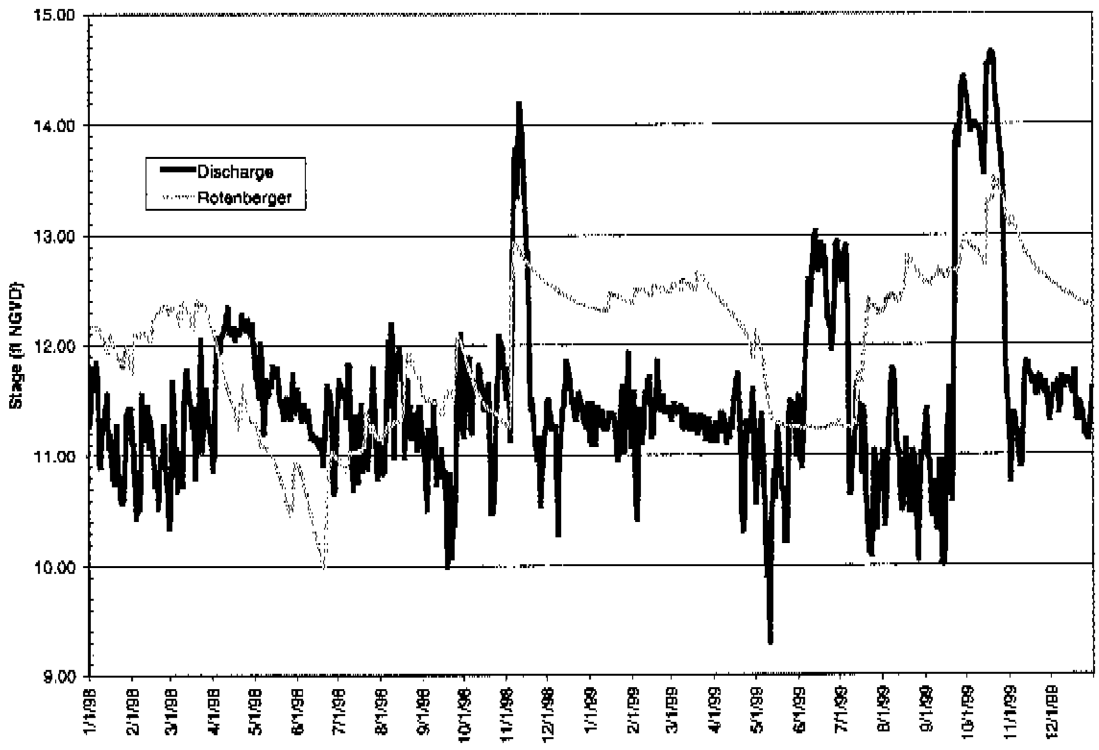

Figure 27. Stage along the Eastern Boundary of STA 6 1998-99

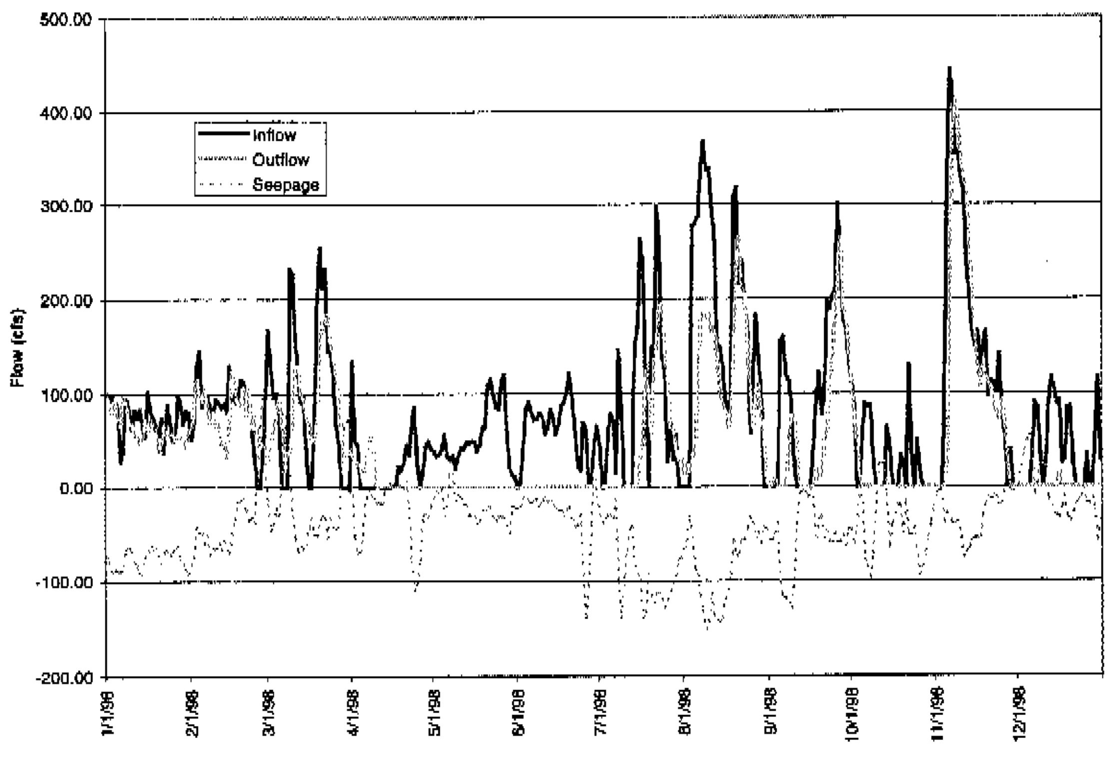

Figure 28. Inflow, Outflow and Seepage for STA 6 1998

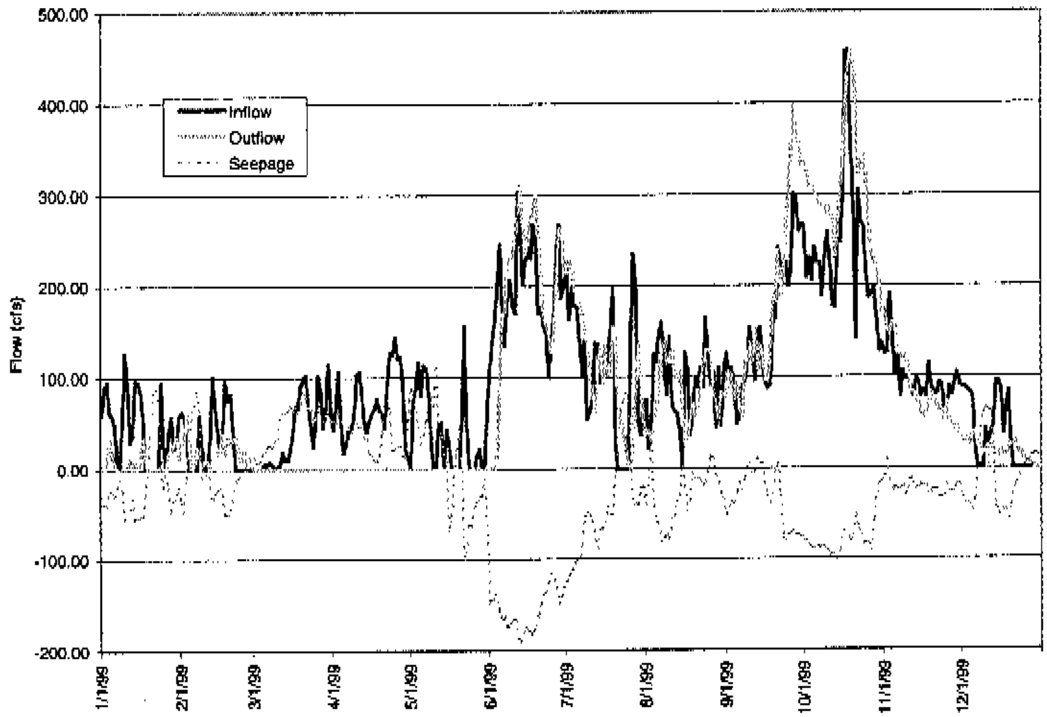

Figure 29. Inflow, Outflow and Seepage for STA 6 1999

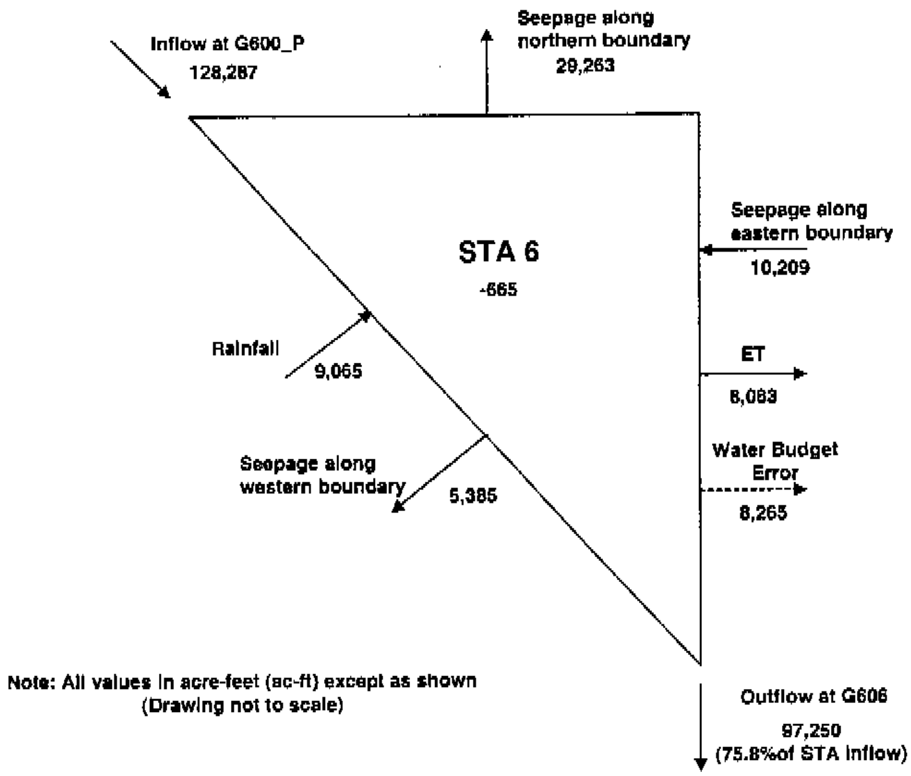

Figure 30. STA 6 Water Budget Inflow and Outflow Volumes 1998-99

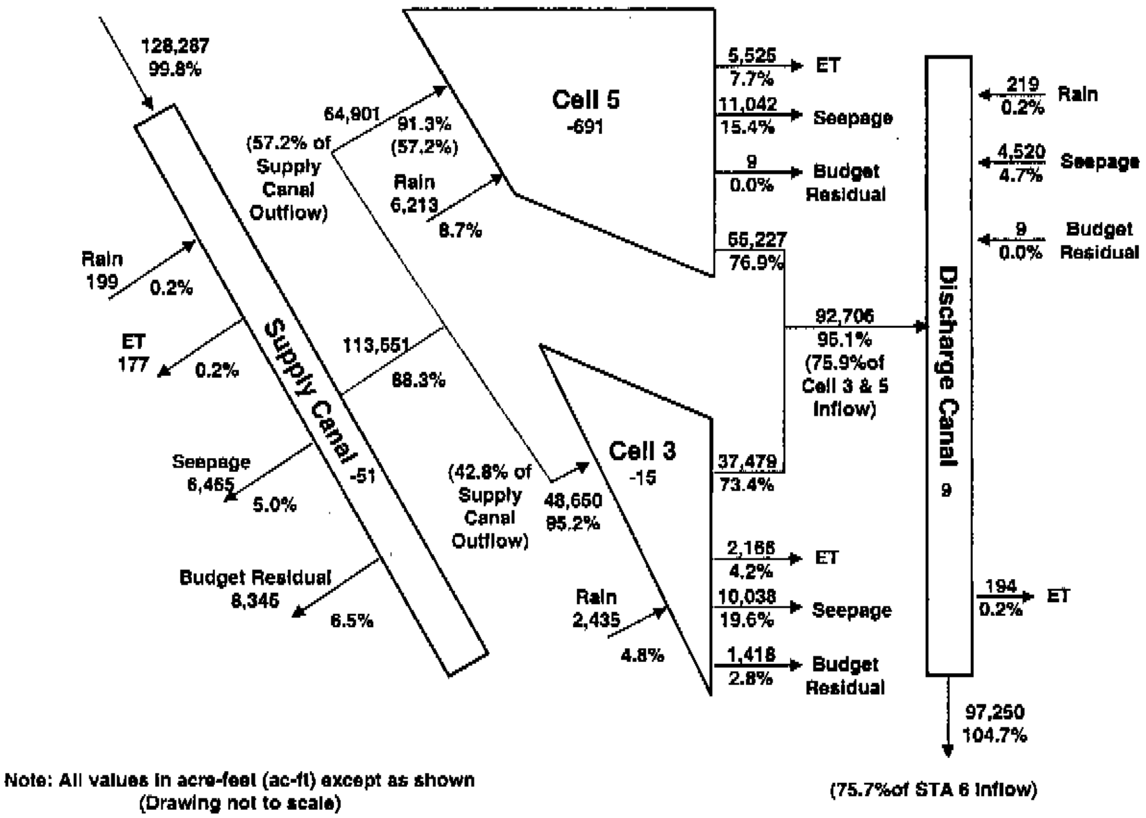

Figure 31. STA 6 Water Budget Volumes 1998-99

Table 11 shows the mean hydraulic retention time in days for Cells 3 and 5. The two-year mean was based upon the average stage during the biennial period (calendar years 1998 and 1999) and the average volume of inflow and outflow including rainfall, evapotranspiration and seepage.

Table 11. Mean Hydraulic Retention Time

Treatment Cell	Average Depth (ft)	Mean Hydraulic Retention Time (days) 2-year Mean
Cell 3	1.20	4.20
Cell 5	1.25	8.79

These retention times are significantly less than those reported for the ENR (17 days in 1994-96, 24.5 days in 1996-97 and 25.4 days in 1997-98). In April 2000, the outlet weir box crest elevations at STA 6 and were increased to 14.1 ft NGVD in Cell 5 (stations G354A, B and C) and 14.0 ft NGVD in Cell 3 (stations G393A, B and C). This should increase the mean hydraulic retention time for each of the cells by several days.

SUMMARY AND DISCUSSION

Over the two-year period, calendar years 1998 and 1999, STA 6 received 128,287 ac-ft of water from pumping operations at G600_P. An additional 9,065 ac-ft was input to STA 6 via rainfall; 8,063 ac-ft was lost through evapotranspiration. Seepage was 17.7 percent of the water budget during this period, losing 24,440 ac-ft to surrounding water bodies and the surficial aquifer. Outflow from STA 6 at G606 was 75.8 percent of the flow entering STA 6 at G600_P or 97,250 ac-ft. This volume entered the L4 canal via the G607 culverts. The amount of water stored in STA 6 was reduced by 665 ac-ft in two years. The error in the water budget was 8,265 ac-ft or 6.0 percent of the budget. Cell 3 retained water an average of 4.2 days in 1998 and 1999. The average retention time in Cell 5 was 8.79 days. STA 6 was a net loser to ground water with significant gradients during the wet season at the southern tip of Cell 3 in STA 6 and the northwestern corner of Cell 5 where the G600_P pumps are located (**Figures 4** and **6**).

There were a number of problems associated with calculating the water budget for STA 6 similar to those encountered for the ENR. The largest source of error may be the values computed for seepage. The seepage and budget residual combined constitute 23.7 percent of the water budget. It should be noted that the seepage coefficients used in this study were calibrated based on minimizing net water budget error. Their values may also reflect other errors. When examining the estimated seepage by year for 1998 and 1999, it appears that seepage was higher during 1998, the drier of the two years. A similar result occurred when analyzing water budget data for the first half of 2000 which was dry in comparison to average.

In addition, there appeared to be an inconsistency between the 1998 and 1999 values of inflow to and outflow from the discharge canal. The end of an El Niño event and the start of a La Niña pattern affected weather in 1998. The latter caused a dry wet season in 1998. The wet season in 1999 had nearly 15 in. more rain than average (50.36 in. versus 35.41 in.). Unfortunately, a review of data from the first half of 2000 did not resolve the discrepancy. In the future, flow measurements from STA 6 should be improved since outflow monitoring is being moved to the outlet weirs from G606. Once calibrated, the outlet weirs should provide more accurate flow information especially for extreme flows.

The water budget residuals for STA 6 shown in **Figures 7, 19** and **23** (residuals for the supply canal, the discharge canal and STA 6 as a whole) are not random, especially for 1999. The residuals increase when flow increases. **Figure 32** shows the residuals for STA 6 plotted with inflow data and seepage data. The largest residuals are observed in 1999 during two consecutive, extended periods of significantly higher inflow. Although seepage also increases during these periods (in response to increased stages in STA 6), the volume of outflow from STA 6 plus the increased seepage and the increase in storage do not equal the volume of water entering STA 6 on a daily basis. Flow measurement error may account for this, but this may also indicate that there is a response to large pulse inflows that is not adequately represented by the traditional equations for levee seepage used in this and other studies.

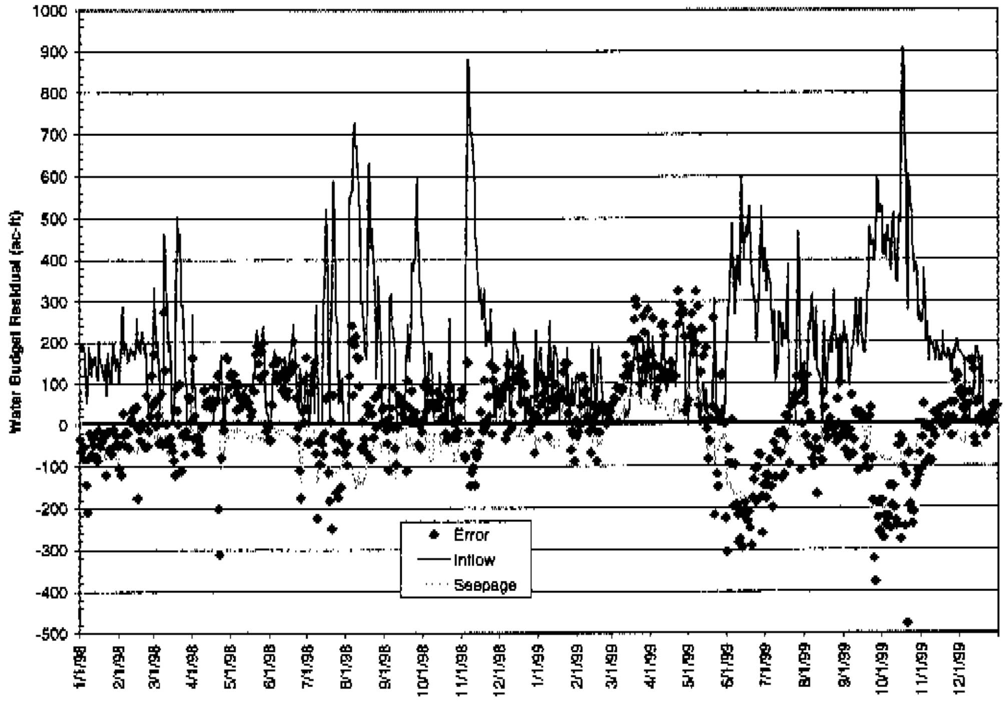

Figure 32. STA 6 Inflow, Seepage and Water Budget Residuals 1998-99

Other possible sources of error in the budget include use of ET values from the ENR located approximately 35 miles to the northeast of STA 6 and using a ground elevation of 12.4 ft NGVD for the bottom of the treatment cells. Both of these should have had a minor impact on the biennial water budget.

RECOMMENDATIONS

Additional study of the geology and the seepage characteristics of the area is warranted at STA 6. Overall seepage constituted the largest single quantifiable unknown at the site. Although the percentage of the water budget attributed to seepage fell within literature values, it is greater than values found in reports for the ENR. The quantity of water lost through seepage has implications for STA design and water quality management in the basin. A previous study (SFWMD, 2000) found that roughly 50.0 percent of the total phosphorous load was dissolved phosphorous in the Northern Everglades. If 17.7 percent of the water entering STA 6 leaves via seepage, 50.0 percent of the phosphorous load is dissolved and the cell is 76.0 percent efficient (based on monthly flow-weighted mean concentrations reported for STA 6, Section 1 January 1998 to February 1999, SFWMD 2000), then 11.6 percent of the removal efficiency of the treatment cell can be attributed directly to dissolved phosphorous removed in seepage water. Seepage also enhances the removal of particulate phosphorous through filtration. Soluble phosphorous in the form of orthophosphate may also be removed by precipitation as it comes in contact with limestone and reacts with calcium and hydroxyl ions

(Hammer, 1986). Further investigation of this aspect of treatment cell dynamics is needed.

A dye study test should be conducted in order to assess flow short-circuiting in Cells 3 and 5. This is important since the retention time of the cells is significantly lower than that reported for the ENR and short-circuiting is likely to have a more pronounced impact on the removal efficiency of the treatment cells.

Observation wells with stage recorders located outside the boundary of STA 6 would have aided the analysis of seepage for this study especially along the northern and eastern boundaries. The ability to calculate seepage into and out of an STA should be a design criterion. Location and installation of observation wells for this purpose should be a design/construction requirement for all STAs.

Consideration should be given to relocating flow measurement at G605 using a ultrasonic velocity meter (UVM) to G604 using a culvert flow equation based on headwater and tailwater elevations. Usually flow only occurs at G604 during dry periods when demand for irrigation water for USSC's Unit 2 fields. The flows are very small and fall within the "noise" level for UVMs. Often the UVM readings at G605 during these periods account for local thermal and wind-driven circulation as opposed to flow through the culverts at G604. During wet periods, water is prevented from flowing southward at G604 by flap gates and stop-logs.

CONCLUSIONS

There were two unexpected outcomes of the water budget analysis. The first was that seepage was a large percentage of the water budget. The biennial and annual water budgets for the Everglades Nutrient Removal (ENR) project did not estimate unknown seepage quantities but included them in the water budget remainder term. If the same were done for STA 6, the aggregated remainders would constitute 23.7 percent of the biennial water budget. This compares with annual water budget remainders of 3.8 to 9.1 percent for the ENR project. The second was that mean hydraulic retention times were significantly less than those computed for the ENR project which ranged from 17.0 to 25.4 days. Cell 3 in STA 6 had a mean hydraulic retention time of 4.2 days and Cell 5 had a mean hydraulic retention time of 8.8 days.

The water budget for STA 6, Section 1, will improve with additional years of data and improved information about seepage at the site. This should aid in the design of future STAs for the Everglades Agricultural Area as well as STAs in other parts of the District's jurisdiction such as the Kissimmee River basin and the Lower West Coast.

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APPENDICES

Appendix A. Site Properties and Monitoring Stations

Table A - 1. STA 6 Site Properties

Surface Area	
Supply Canal	**~20 ac**
Discharge Canal	**~22 ac**
Cell 5	**625 ac**
Cell 3	**245 ac**
Cell 5 Ground Elevation	**~12.4 ft**
Cell 3 Ground Elevation	**~12.4 ft**
Levee Length	
Along Northern Boundary	**7785 ft**
Supply Canal	
Total	**11548 ft**
Along Cell 5	**4412 ft**
Along Cell 3	**7136 ft**
Discharge Canal	
Total	**10596 ft**
Along Cell 5	**6012 ft**
Along Cell 3	**4584 ft**
Between Cells 3 and 5	**4195 ft**
Canal Width	
Supply Canal	**75 ft**
Discharge Canal	**90 ft**

Table A - 2. Stage Monitoring Stations

DBKEY	STATION	STATION_DESC	COUNTY
G6559	G352S_H	STA 6 SECTION 1 (ON SUPPLY CANAL ACROSS FROM CELL 5)	HENDRY
G6560	G352S_T	STA 6 SECTION 1 (IN CELL 5 ACROSS FROM SUPPLY CANAL)	HENDRY
G6563	G354C_H	STA 6 SECTION 1 IN CELL 5 NEAR OUTFLOW C	HENDRY
G6564	G354C_T	STA 6 SECTION 1 IN DISCHARGE CANAL NEAR OUTFLOW C	HENDRY
G6561	G392S_H	STA 6 SECTION 1 (ON SUPPLY CANAL ACROSS FROM CELL 3)	HENDRY
G6562	G392S_T	STA 6 SECTION 1 (IN CELL3 ACROSS FROM SUPPLY CANAL)	HENDRY
G6565	G393B_H	STA 6 SECTION 1 IN CELL 3 AT OUTFLOW B	HENDRY
G6566	G393B_T	STA 6 SECTION 1 IN DISCHARGE CANAL AT OUTFLOW B	HENDRY
G6528	G600_H	STA 6 SECTION 1, INFLOW PUMP STATION, HEADWATER	HENDRY
G6529	G600_T	STA 6 SECTION 1, INFLOW PUMP STATION, TAILWATER	HENDRY
GA117	G604_H	STA 6 SECTION 1 GRAVITY STRUCTURE	HENDRY
GA118	G605	STA 6 SECTION 1 BYPASS CANAL	HENDRY
GA115	G606	STA 6 SECTION 1 DISCHARGE CANAL OUTFLOW	HENDRY
FI260	G607_H	STORMWATER TREATMENT AREA 6, OUTFLOW AT USSC STRUCTURE	BROWARD
FI261	G607_T	STORMWATER TREATMENT AREA 6, OUTFLOW AT USSC STRUCTURE	BROWARD
15794	G88_T	CMP CULVERT IN NW CORNER OF WCA 3A	BROWARD
15795	G89_T	G89 CULVERT AT NW CORNER OF WCA 3A	HENDRY
16745	G89_O	OPEN CHANNEL UVM 500' BELOW G89 CULVERTS	HENDRY
15790	G155_T	WEIR TAIWATER AT NW CORNER WCA 3A	HENDRY
15791	G155_H	WEIR AT NW CORNER WCA 3A	HENDRY
FI321	L3.2	L-3 CANAL NR CLEWISTON MIDWAY BETWEEN DEER FENCE AND L-4 CANALS	HENDRY
16244	L3BRS_O	L-3 CANAL NORTH OF OIL WELL BRIDGE (BORROW CANAL SOUTH), OPEN CHANNEL	HENDRY
16748	USSO_O	U.S. SUGAR OUTFLOW OPEN CHANNEL UVM	HENDRY

Table A - 3. Flow Monitoring Stations

DBKEY	STATION	STATION_DESC	COUNTY
J5569	G393_C	STA 6 SECTION 1 CELL 3 COMBINED OUTFLOW FOR G393A,B,C	HENDRY
J0939	G354_C	STA 6 SECTION 1, DISCHARGE CANAL, COMBINED FLOW FOR G354A,B,C USING G354C+H/TN	HENDRY
GG955	G600_P	STA 6 SECTION 1, INFLOW PUMP STATION	HENDRY
J5566	G601	STA 6 SECTION 1 CELL 5 INFLOW WEIR 1	HENDRY
J5567	G602	STA 6 SECTION 1 CELL 5 INFLOW WEIR 2	HENDRY
J5568	G603	STA 6 SECTION 1 CELL 3 INFLOW WEIR 3	HENDRY
H3143	G605	STA 6 SECTION 1 BYPASS CANAL	HENDRY
GA116	G606	STA 6 SECTION 1 DISCHARGE CANAL OUTFLOW	HENDRY
HD889	STA6OUT	STA 6 ESTIMATED COMBINED OUTFLOW FROM CELLS 3 AND 5	HENDRY

Table A - 4. Rainfall Monitoring Sites

DBKEY	STATION	STATION_DESC	COUNTY
G6530	G600_R	STA 6 SECTION 1 INFLOW PUMP STATION AT RAINGAGE	HENDRY

Table A - 5. Evapotranspiration Monitoring Sites

DBKEY	STATION	STATION_DESC	COUNTY	DATA
JD470	ENRP	AREAL COMPUTED PARAMETER FOR ENR PROJECT	PALM BEACH	ET
GE352	ROTNWX	ROTENBERGER TRACT WEATHER STATION, LOCATED BY G606 AT STA6	BROWARD	AIRT
GE348	ROTNWX	ROTENBERGER TRACT WEATHER STATION, LOCATED BY G606 AT STA6	BROWARD	RADT

Appendix B – Rainfall Data

Table B-1. 1998 Rainfall at G600_R (inches).

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0	0	0.68	0	0.04	0	0.28	0	0	.08E	0	0
2	0	1.59	0.17	0	0	0	0	0	0	0.15	0	0
3	0	0.1	0	0	0	0	0	2.55	0	0	0	0
4	0	0.03	0	0.01	0.01	0	0	0	0.69	0.41	4.5	0.01
5	0	0	0	0	0	0	0	0.15	0.47	0	3.56	0.01
6	.00E	0.36	0	0	0	0.04	0.09	1.09	0.01	0.19	0	0
7	.00E	0	0	0	0	0	1.98	0	0.32	0	0	0.01
8	0	0	0	0	0	0.51	0.06	0	0	0	0	0
9	0	0	1.41	0	0	0	0	0.31	0.12	0	0.01	0
10	0.01	0	0	0	0	0	0.36	0.04	0.01	0.1	0	0.01
11	0	0	0	0	0.01	0	0.07	0.14	0	0	0	0.25
12	0	0	0	0	0	0.01	0	0	0	0.2	0	0.2
13	0	0	0	0	0	0.03	1.57	0	0	0	0	0.06
14	0	0	0	0	0	0	0.42	0.49	0	0.09	0	0.12
15	0.67	1.04	0	0	0	0	0.97	0.01	0.06	0	0	0
16	0.16	0.09	0	0	0	0	0.17	0.31	0.58	0	0	0
17	0	0.54	0	0	0	0	0	0.28	0.97	0	0	0
18	0	0	0.01	0	0	0	0.1	3.4	0.11	0.02	0	0
19	0	0	2.25	0	0	0	0.87	0.05	0.13	0.01	0.2	0
20	0	0	0.54	0	0	0	0.76	0	0.05	0.01	0	0
21	0	0	0	.30E	0	0.04	0.32	0.82	1.24	2.08	0.01	0
22	0	0	0	0	0	0.07	0.42	0.02	0	0	0	0
23	0	0.88	0	0	0	0.04	0	0.04	0.01	0	0	0.01
24	0	0	0	0	0	0.21	0	0	.12E	0	0.52	0
25	0	0	0	0	0	0.12	0	0.02	1.67E	0	0.01	0
26	0.16	0	0	0	0	0.01	0.09	0	.29E	0	0.02	0.01
27	0.09	0.01	0	0	0	0	0	0	0.04	0	0	0
28	0	0	0	0	0.66	0	0	0	0	0	0	0.21
29	0		0	0.34	0.2	0	0	0	0	0	0	0
30	0		0	0.03	0.11	0.81	0	0	0	0.01	0	0
31	0		0		0.02		0	0		0		0

Table B-2. 1999 Rainfall at G600_R (inches).

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.01	0.21	0	0.1	0	0.01	0.05	0.01	0.01	0	0.04	0
2	0.16	0.01	0	0	0	0.67	0.99	0	0	0	0.68	0
3	0.38	0.01	0.09	0	0	0.91	0.03	2.32	0	0.03	0	0
4	0.05	0	0	0	0	0.01	0.13	0	0	0.86	0	0
5	0.01	0	0	0	0	0.77	0.06	0.68	0	0	0	0
6	0	0.01	0	0	0	0	0	0.62	0.22	0.02	0	0
7	0.02	0	0	0	1.19	2.2	0	0	1.3	0.78	0	0
8	0	0.01	0	0	0	1.58	0.04	0.18	0.84	0.41	0	0
9	0.15	0	0	0	2.08	0.48	0	1.29	.77E	0.21	0	0
10	0.1	0.17	0	0	0.06	0.19	0	0	.49E	0	0	0
11	0	0	0	0	0.44	1.47	1.31	0.13	.00E	0	0	0.02
12	0	0.12	0	0.01	0.66	0	0	0.06	.00E	0.03	0	0
13	0	0	0	0	0.48	0.02	0	0	.02E	0	0	0
14	0.02	0	0.08	0	0.01	0.67	0.18	0.02	.04E	2.52	0	0
15	0.01	0	0.05	0	0.93	0.27	0.18	0	.01E	4.3	0	0
16	0.01	0	0	0	0	0.38	0.19	0	.00E	0.02	0	0
17	0	0	0	0.2	0	0.83	0.8	0.21	.02E	0	0	0.06
18	0.01	0.36	0	0.05	0	0.21	0.01	0.09	.84E	0	0	0.02
19	0	0	0	0	0.3	0	0	0.14	1.30E	0	0	0
20	0	0	0	0	0.01	0	0	0	.31E	1.88	0.18	0
21	0.01	0	0	0	2.02	0.13	0	0.66	.79E	0	0	0.02
22	0.01	0	0	0	0	0	0.09	0.09	.00E	0	0	0
23	0	0	0	0	0	0.14	0	1.36	.01E	0	0	0
24	0.89	0	0	0	0	0	0	0	.15E	0	0.23	0
25	0.01	0	0	0	0	0.46	0	0	.21E	0	0	0
26	0.02	0	0.04	0.2	0	1.62	0.54	0	.64E	0	0	0
27	0.01	0	0	0.11	0	1.56	0	0	2.10E	0	0	0
28	0	0.01	0	0.12	0.27	0	0	0.04	.03E	0	0	0.24
29	0		0	0	1	0.01	0	0.3	.04E	0	0	0
30	0		0	0.01	1.49	0.32	0	1.16	0	0	0	0
31	0		0		0.01		0.19	0.1		0		0

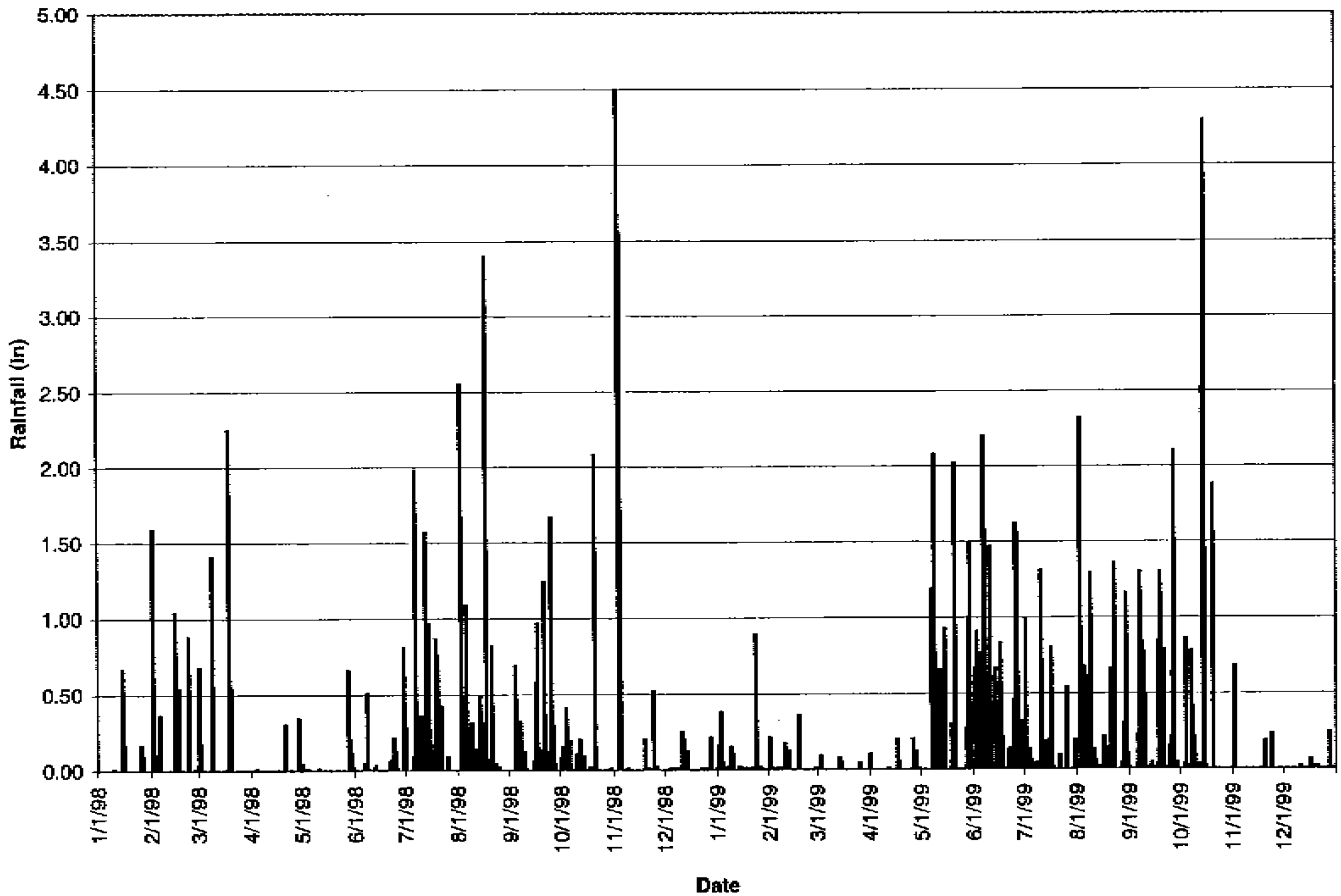

Figure B-1. Rainfall in Inches at G600_R 1998-1999.

Appendix C – Evapotranspiration Data

Table C-1. 1998 Evapotranspiration at STA 6 (mm).

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	2.24	3.66	1.01	3.37	3.87	4.87	6.09	4.88	5.13	4.47	4.10	2.55
2	2.47	0.96	3.88	3.51	5.83	5.53	6.35	4.17	5.00	4.57	2.84	2.95
3	1.67	0.82	3.26	4.02	6.67	5.63	6.29	6.47	5.72	4.68	1.98	2.64
4	3.71	3.21	4.18	3.83	6.05	6.28	5.33	5.96	4.95	3.60	0.30	2.96
5	2.19	3.36	4.02	5.35	5.54	6.59	4.67	6.46	1.47	4.07	0.70	0.59
6	1.68	1.26	3.35	4.99	5.58	6.49	5.90	2.10	5.16	3.15	2.18	2.86
7	1.93	2.56	3.52	3.77	4.99	7.08	4.22	4.01	1.65	4.54	3.00	3.21
8	2.74	2.61	2.84	3.61	5.95	4.49	5.39	4.41	4.62	4.17	3.59	1.79
9	2.84	2.96	2.76	3.41	5.54	5.54	6.39	4.67	4.18	3.91	3.96	2.64
10	3.41	3.42	3.64	5.15	6.21	5.07	4.94	4.65	2.18	3.16	3.69	2.92
11	3.77	2.08	4.23	4.04	7.18	5.28	4.68	6.36	3.32	4.01	4.21	1.12
12	3.52	1.83	4.14	4.27	6.30	6.03	4.74	5.69	3.57	2.96	4.37	0.71
13	2.08	2.18	3.92	4.03	6.39	6.20	5.49	5.54	4.65	3.02	4.52	2.18
14	3.25	3.26	2.70	4.03	5.91	5.95	2.80	6.67	4.97	2.39	2.87	1.83
15	1.52	0.65	2.34	3.87	6.67	6.81	2.64	6.14	1.63	4.28	3.90	2.34
16	2.80	1.42	3.51	4.78	6.73	7.15	5.29	5.76	1.02	4.09	2.40	2.92
17	3.48	1.01	3.25	5.19	6.36	6.58	4.82	5.23	1.83	4.34	2.50	3.07
18	2.53	3.80	1.32	4.68	5.89	5.89	4.98	5.49	1.98	3.93	2.65	2.92
19	1.57	2.91	1.68	5.40	5.08	6.39	3.00	5.33	2.90	2.04	1.89	2.08
20	2.34	2.29	2.95	3.76	5.54	5.68	3.15	2.50	2.55	3.57	2.88	3.06
21	1.42	4.12	3.21	2.34	6.40	6.10	3.66	3.33	4.36	2.90	3.57	2.90
22	2.18	2.69	2.20	6.01	6.71	4.89	5.03	4.69	4.37	2.61	3.05	2.74
23	0.91	3.51	3.97	5.50	6.65	5.49	5.70	5.45	3.73	3.74	2.80	2.45
24	1.78	4.43	4.09	5.70	5.38	4.47	5.89	5.77	3.80	3.32	1.47	2.65
25	1.53	4.18	3.77	4.62	5.19	5.75	6.15	6.06	1.52	3.91	3.64	2.75
26	1.10	3.36	3.83	4.67	3.97	3.51	4.62	5.04	2.87	3.93	3.44	2.13
27	1.48	3.00	2.85	4.78	4.52	6.80	5.89	3.20	4.48	3.74	3.62	2.77
28	3.68	2.74	2.64	3.70	1.73	5.83	6.15	5.04	4.50	3.94	3.53	1.33
29	2.69		3.93	2.59	2.74	4.56	5.99	5.38	4.33	3.63	2.76	3.12
30	3.04		3.27	4.17	4.41	6.50	6.31	5.59	4.33	3.64	2.80	3.28
31	3.08		3.31		4.21		4.17	5.90		3.88		4.38

Table C-2. 1999 Evapotranspiration at STA 6 (mm)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	2.62	1.31	3.92	3.93	4.52	2.44	2.42	5.81	5.04	4.21	2.45	3.40
2	1.87	2.25	3.91	4.31	5.84	2.41	2.44	3.50	4.40	4.13	3.29	3.46
3	1.87	3.19	1.30	4.87	4.52	3.57	2.68	4.17	5.72	2.03	4.16	2.42
4	0.75	3.57	4.47	4.49	5.28	4.87	3.00	3.61	5.34	2.13	3.64	1.55
5	2.24	3.19	4.29	4.67	3.96	4.69	4.88	3.72	4.89	2.60	3.35	1.65
6	2.98	3.19	3.36	3.74	5.47	5.25	5.48	3.98	3.95	1.75	3.00	2.53
7	2.61	2.25	3.92	4.87	5.48	0.75	4.70	4.09	1.69	2.78	3.02	2.55
8	2.05	2.25	3.73	4.68	3.97	1.31	3.95	4.86	3.58	2.35	3.82	2.66
9	2.80	2.25	4.10	4.68	3.95	4.12	4.32	3.15	2.82	2.30	3.77	2.08
10	0.75	2.06	3.36	5.06	5.45	3.75	4.51	4.13	4.08	4.63	3.62	2.01
11	2.80	2.81	4.29	4.69	3.39	3.75	3.38	5.13	4.70	4.07	2.50	2.46
12	2.24	2.25	4.10	3.75	2.26	2.63	5.02	4.04	3.63	3.05	3.72	2.06
13	2.05	1.88	3.17	5.06	5.45	4.88	5.07	2.57	3.80	3.26	3.56	2.78
14	2.05	3.00	2.99	4.69	4.89	4.70	4.38	1.48	3.35	1.16	3.30	0.94
15	2.05	2.06	2.24	4.69	1.88	3.36	4.51	4.58	3.33	0.17	3.74	1.55
16	2.80	1.87	4.29	4.13	3.95	2.42	4.51	4.41	5.20	3.48	3.35	1.85
17	2.62	2.43	4.10	2.06	4.51	3.46	4.94	3.44	2.42	3.84	1.92	1.97
18	2.43	3.18	3.73	3.19	4.32	1.92	5.26	1.52	2.54	4.19	3.44	1.93
19	2.81	3.00	4.66	4.68	4.70	2.05	4.70	2.44	2.40	4.16	1.82	3.24
20	2.62	3.56	3.17	5.25	2.82	3.49	3.95	4.37	1.16	3.18	2.28	2.11
21	2.99	3.18	3.92	5.44	4.32	5.76	4.89	3.04	2.18	3.14	3.26	1.76
22	2.99	3.74	4.85	4.32	4.32	4.64	3.95	3.47	4.45	2.36	3.39	2.95
23	3.00	2.06	3.73	4.33	5.82	4.15	4.86	2.95	3.96	4.27	3.41	1.65
24	1.87	3.74	4.30	5.09	4.32	4.02	5.32	2.08	2.52	4.37	2.74	3.21
25	2.99	3.36	4.31	4.15	5.07	3.32	5.26	5.05	1.13	3.26	2.96	3.38
26	3.37	3.74	3.37	4.71	5.26	3.70	4.13	4.86	1.69	2.25	3.00	3.30
27	3.18	3.74	4.87	2.64	5.64	3.89	4.47	5.22	2.89	3.94	2.90	3.25
28	3.18	3.36	3.93	2.07	5.26	3.31	3.94	4.87	4.36	3.88	3.27	1.42
29	2.62		3.18	3.96	3.38	3.38	5.22	5.28	3.79	3.44	3.26	3.33
30	3.37		3.74	4.72	3.01	2.87	4.89	5.38	4.38	4.00	3.03	3.35
31	1.12		2.81		4.32		5.07	2.84		2.48		3.14

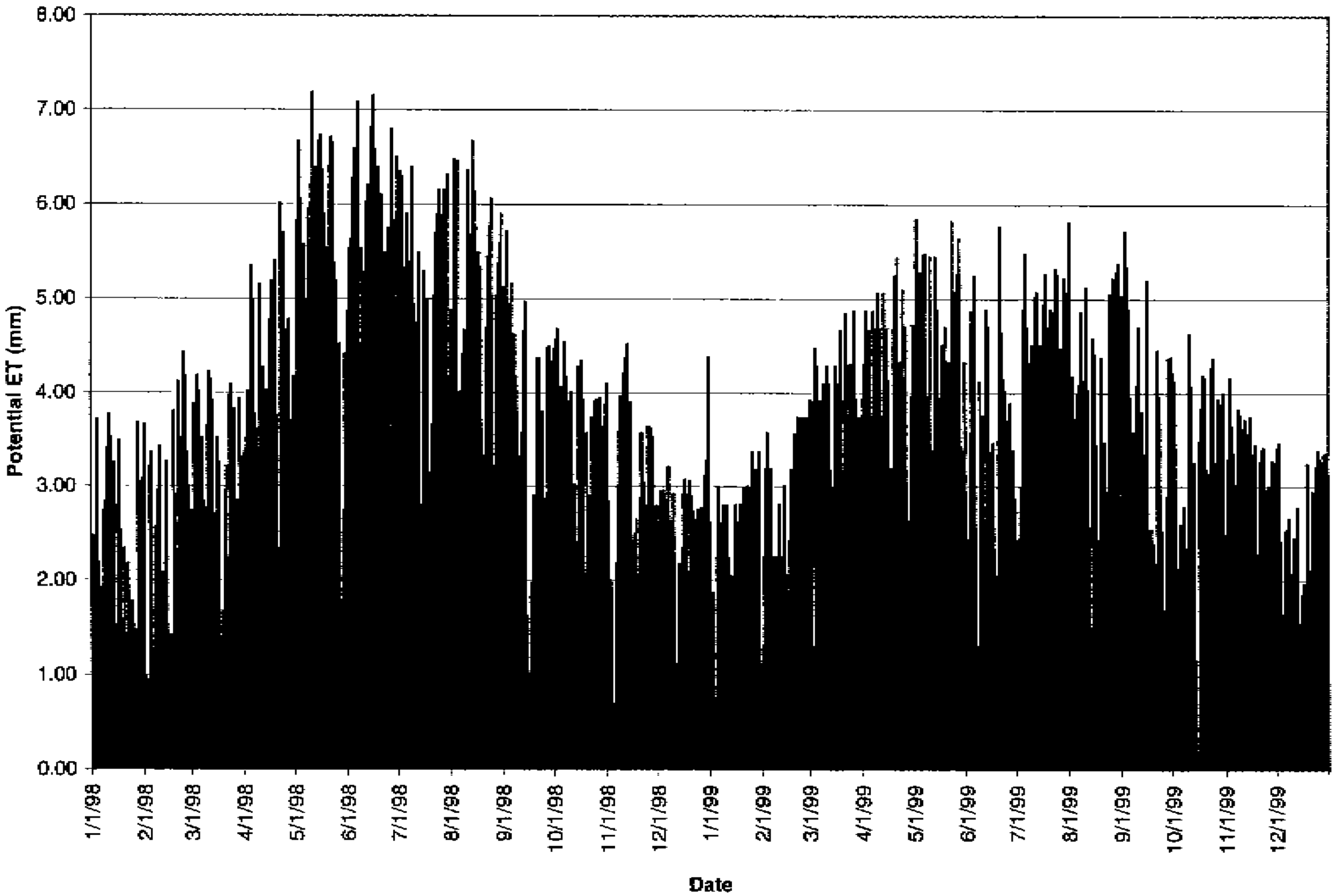

Figure C-1. Evapotranspiration in Millimeters at STA 6 1998-1999

Appendix D - Soil Moisture Equations

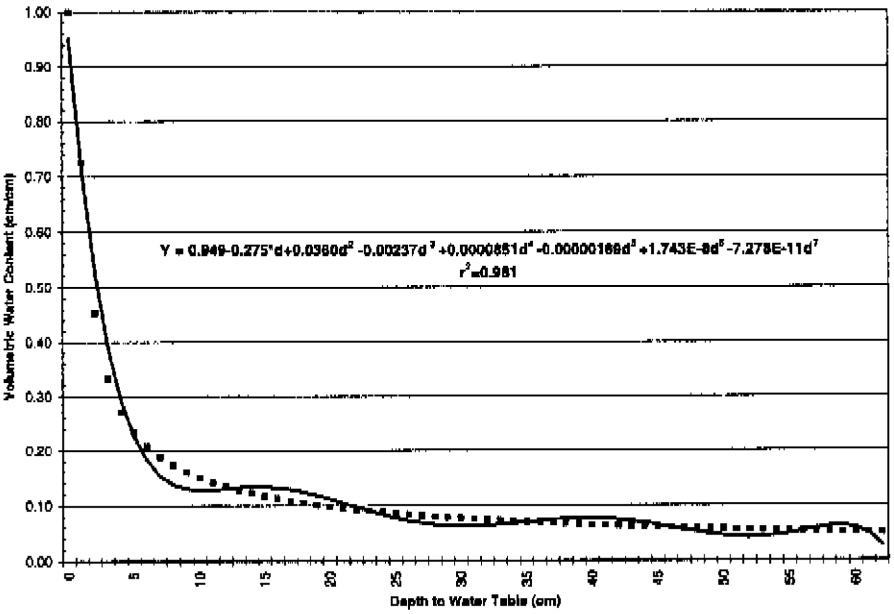

Figure D- 1. Falling Water Table (Drying Front) Equation

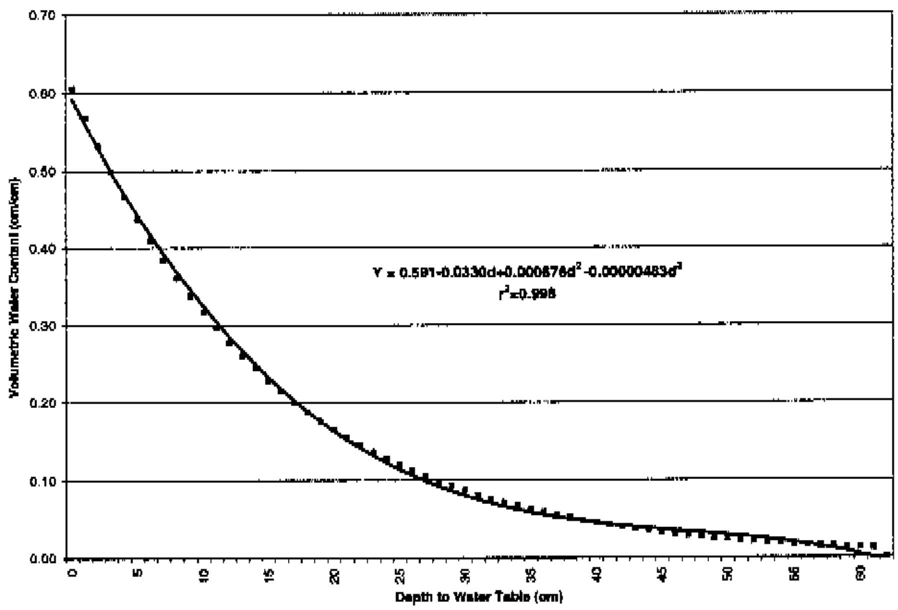

Figure D- 2. Rising Water Table (Wetting Front) Equation