Technical Publication
ERA # 440

Water Budget Analysis for Stormwater Treatment Area 6, Section 1

(Water Year 2005; May 1, 2004 through April 30, 2005)

July 2006

By

R. Scott Huebner

Water Quality Assessment Division
Environmental Resource Assessment Department
South Florida Water Management District
West Palm Beach, Florida 33406

EXECUTIVE SUMMARY

A water budget for Stormwater Treatment Area 6 (STA-6), Section 1 for Water Year 2005 (WY2005, May 1, 2004 through April 30, 2005) is presented in this report. During this period, a fire in the pump station at G600 destroyed pumps and data sensing and logging equipment. Also, this year U.S. Sugar Corporation abandoned sugarcane farming operations in their Unit 2 fields just north of the STA. Because operations ended, the pumps at G600 were not used, and the STA became a rain-driven system. Also four hurricanes, Charley, Frances, Ivan, and Jeanne, impacted the Florida peninsula in August and September 2004.

STA-6, Section 1 was the first of six STAs to be built as part of the Everglades Construction Project (ECP). It became fully operational on December 9, 1997. It is used to reduce the phosphorous concentration in runoff from approximately 10,400 acres of agricultural land north of STA-6. This study covers the seventh water year of STA operation.

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 (ft) with a long-term design operating water depth of 2.0 ft. Water flows from west to east across the cells, then south in the discharge canal through culverts at G607 to the L4 canal.

In WY2005, STA-6 received 34,035 acre-feet (ac-ft) of water from pumping operations at G600_P; 34,714 ac-ft entered treatment Cells 3 and 5 at G601, G602, and G603. An additional 3,600 ac-ft were input to STA-6 from rainfall; 3,674 ac-ft were lost through evapotranspiration (ET). Estimated seepage was 27.0 percent of the water budget during this period with an estimated loss due to seepage of 9,560 ac-ft to surrounding water bodies and the surficial aquifer. Outflow from STA-6 at G354 and G393 was 63.9 percent of the flow entering STA-6 at G601, G602, and G603, or 22,188 ac-ft. The amount of water stored in STA-6 increased by 471 ac-ft. The error in the water budget was 1,906 ac-ft, or 5.2 percent of the budget. Water entering Cell 3 was retained for an average of 2.34 days in WY2005. The average retention time in Cell 5 was 6.03 days.

Estimated seepage constituted a large percentage of the water budget, but was consistent with previous budget analysis. Mean hydraulic residence times continued to be lower than those observed at other STAs.

ACKNOWLEDGMENTS

The author would like to acknowledge the following individuals for technical and editorial contributions to this report: Hedy Marshall, Wendy Wagman, Wossenu Abtew, Pamela Lehr, Michael Chimney and Muluneh Imru.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Hydrologic analysis of Stormwater Treatment Areas (STAs) is vital to ongoing efforts to optimize their performance. It is important to develop an understanding of the physical processes affecting water quality, and identify and quantify water sources and sinks in the system.

A water budget for STA-6, Section 1 covering Water Year 2005 (WY2005) (May 1, 2004 through April 30, 2005) is presented in this report. During this period, a fire in the pump station at G600 destroyed data sensing and data logging equipment. Also, this year U.S. Sugar Corporation (USSC) abandoned sugarcane farming operations in their Unit 2 fields just north of the STA. Because farming operations ended, the pumps at G600 were not used, and the STA became a rain-driven system. The pumps at G600 will be used in the future to dewater the construction site for STA-6, Section 2, and provide flood protection for the remaining area in Compartment C of the Everglades Agricultural Area (EAA). Also, four hurricanes impacted the Florida peninsula in August and September 2004.

If this report is used to compare water budgets from previous years (Huebner, 2001; Huebner, 2003; Liyanage et al., 2005), the following facts should be considered: in the beginning of WY1999, South and Central Florida experienced the end of a La Niña-influenced weather pattern; Hurricane Irene affected the area from October 14 through 17, 1999 (Abtew and Huebner, 2000), resulting in an average of 6.84 inches (in.) of rain over the South Florida Water Management District (SFWMD or District); and one of the most severe long-term droughts ever to impact the area began in November 1999 and ended in September 2001. Rainfall during calendar years 1998, 1999, 2000, 2001, 2002, 2003, and 2004 was 55.94 in., 55.62 in., 39.46 in., 53.25 in., 54.37 in., 53.31 in., and 48.45 in., respectively, compared with a historical average of 52.75 in.

This analysis is based on a daily water budget for hydrologic units in STA-6. Daily results were aggregated in order to develop monthly and annual water budgets. The daily water budget accounted for inflow, outflow, rainfall, evapotranspiration (ET), seepage, storage, 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 actual water budget analysis is presented thereafter, followed by a summary and discussion, 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 Project. Construction of STA-6 was substantially completed by October 31, 1997. It was funded as part of the ECP, an element of the Everglades Program established by the Everglades Forever Act [Section 373.4592, Florida Statutes (F.S.)]. STA-6 received a discharge permit from the Florida Department of Environmental Protection and became fully operational on December 9,

1997. Its principal purpose is to reduce phosphorous concentrations in runoff from U.S. Sugar Corporation's (USSC's) Unit 2 development, approximately 10,400 acres north of STA-6. Prior to construction of STA-6, the area was a runoff detention area that belonged to USSC. The Unit 2 development is now owned by the District. USSC continued to farm this area until the spring 2005 harvest. Design of STA-6, Section 2 is under way and will add a treatment cell north of Cell 5 in STA-6.

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

- Inflow at pumps and weirs
- Outflow at weirs
- Rainfall
- ET
- Seepage
- Change in storage
- Water budget error

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

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

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, volume per unit time. In this report, units of acre-feet (ac-ft) per unit time (day, month, or year) are used. All of the terms can be determined from observation or estimated. The error term is determined by solving Equation 1 for the error term. In order to establish values for rainfall and ET, units (in inches or millimeters) are converted to feet and multiplied by the effective surface area of the treatment cell in acres (e.g., 245 acres for Cell 3) to get a volume of rainfall or ET for a selected time period. Change in storage is calculated by multiplying the effective surface area of each cell by the change in water surface elevation over time.

Site Description

STA-6 is in the southwestern corner of the Everglades Agricultural Area (EAA), adjacent to the Rotenberger Wildlife Management Area (RWMA). STA-6 and its location relative to major canals and roadways are shown in **Figure 1**. It is comprised of two 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. Vegetation is described by Huebner (2001), based on a study by GEONEX (1999). In general, vegetation consists of mixed wetland species for both cells. Cell 3 has 3 percent open water, whereas Cell 5 has nearly 15 percent open water. **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 west of the cells and east of the L-3 borrow canal (**Figure 2**). Under normal operating conditions, water enters the supply canal from the north through pump station G600_P. It can also enter the supply canal through G604 at the southern end of the supply canal, consisting of a set of five culverts with upstream flap gates. Water entering the supply canal through G604 is used to irrigate the Unit 2 development to the north of STA-6. This water rarely enters the treatment cells because the stage in the canal is typically below the crest of the inlet weirs under the conditions prevalent during the dry season when irrigation occurs.

There is one inflow weir (G603) for Cell 3, and two inflow weirs (G601 and G602) for Cell 5. Each treatment cell has a series of three outlet combination weir box, gated culvert structures (Cell 3: G393A, B, and C; Cell 5: G354A, B, and C) through which water exits the cell. Under the current operation plan for STA-6, only one gate (G393B) is open for Cell 3 discharges, but all three gates (G354A, B, and C) are open in Cell 5. Treated water from each cell then enters a discharge canal that connects to the L4 canal (the canal runs east to west along the southern boundary of the EAA). It then flows east during the wet season, either to the District's S8 pump station and the Miami Canal, or through a breech in the L-4 levee to the northwest corner of Water Conservation Area 3A.

A full description of STA-6, its design and operation are provided in the Operation Plan Stormwater Treatment Area 6 (SFWMD, 2002).

Monitoring

Two hydrologic parameters, stage and rainfall, were monitored at STA-6. Pump speed was also monitored. The depth of rainfall in inches was recorded at G600_R, located near pump station G600, and at a weather station (ROTNWX) located in the RWMA. The rainfall data at G600_R were compared to rainfall amounts at nearby rainfall recording locations and any potential data errors were corrected before they were uploaded to a preferred DB key in DBHYDRO, the District's corporate hydrologic and water quality database. The station names, database (DB) keys, and station descriptions are shown in **Tables A-2** through **A-5** in Appendix A.

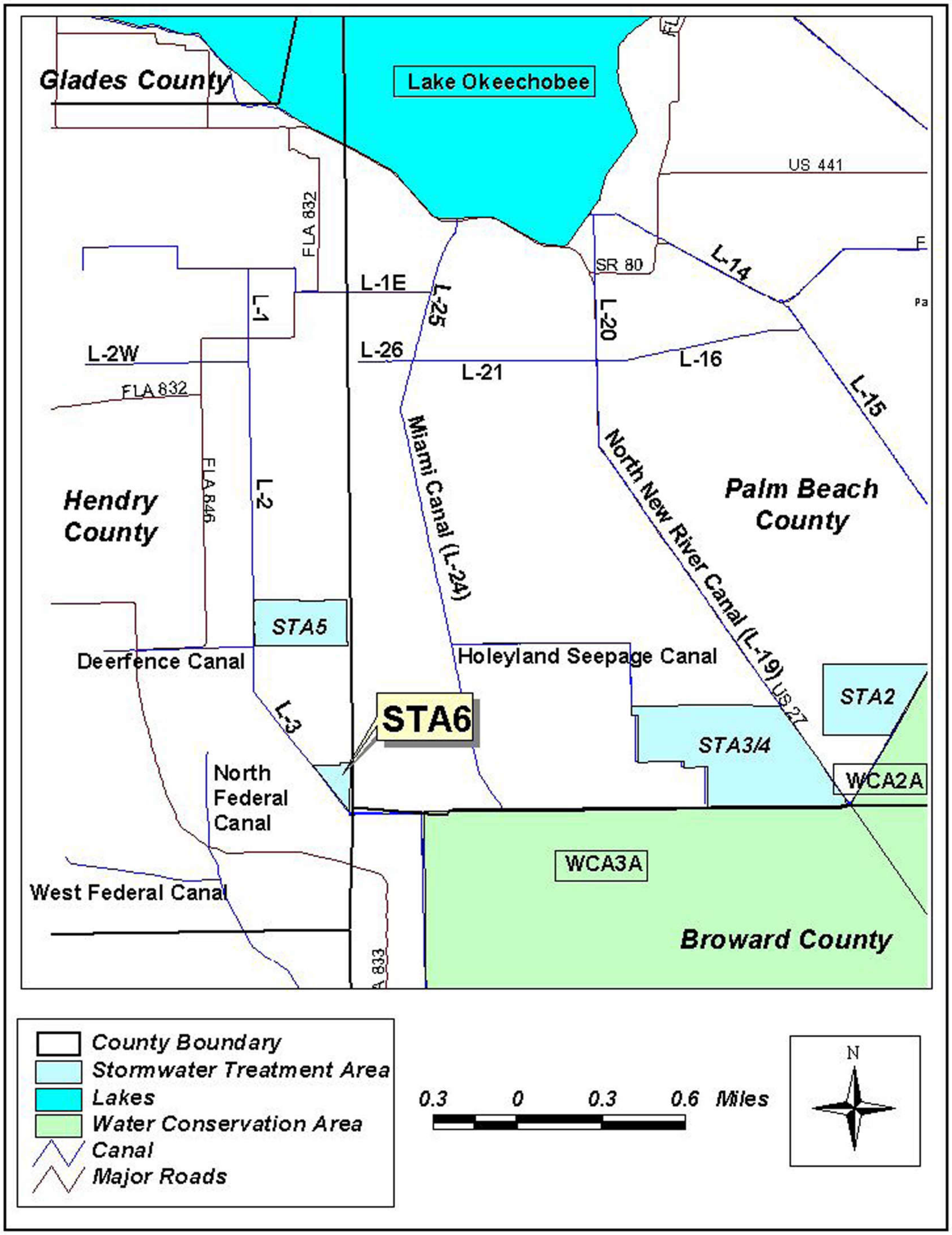

Figure 1. STA-6 Site Map

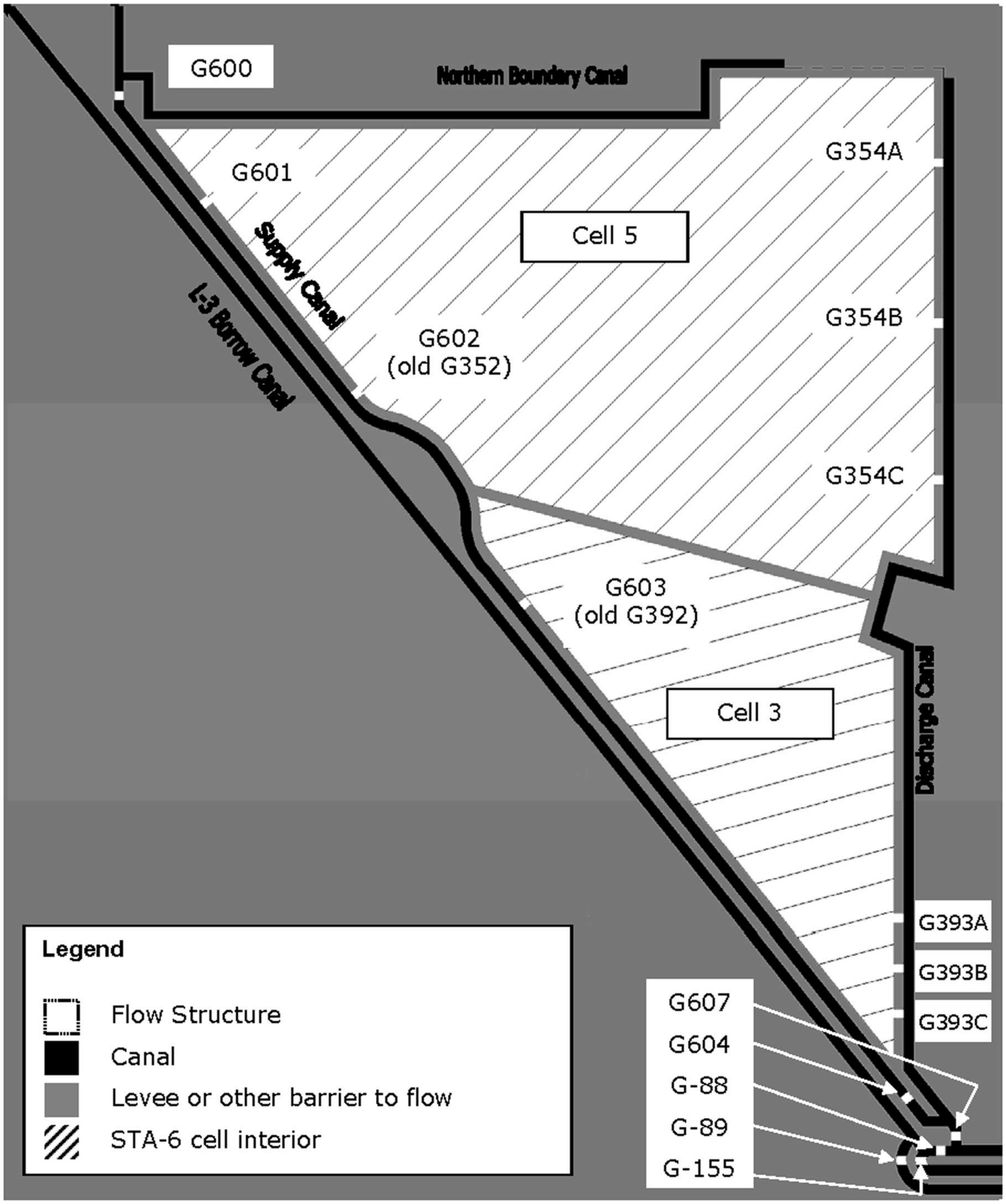

Figure 2. STA-6, Section 1 Structure and Monitoring Locations (not to scale)

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 ET data used in this water budget analysis were derived from ET data for Stormwater Treatment Area 1 West (STA-1W). The station information for the ET data 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 cubic feet per second (cfs). The pumps are cycled on and off, depending upon the amount of water to be withdrawn from the fields. This water discharges into the STA-6 supply canal and creates a hydraulic head on the inlet weirs, G601, G602, and G603, to Cells 3 and 5. The only means of inflow control for the treatment cells is accomplished by controlling the stage in the supply canal. This is done by varying the amount of water pumped at G600_P. Since Cell 3 has a surface area that is 28 percent of the total effective treatment area of STA-6 (245 acres vs. 870 acres), it was designed to treat 28 percent of the total inflow. The design of the inlet weirs was based upon this distribution of flow (SFWMD, 1997). The inlet weir crests for G601 and G602 (Cell 5) are set at 14.1 ft National Geodetic Vertical Datum (NGVD). The crest of the weir at G603 (Cell 3) is set at 14.2 ft NGVD. The maximum total design inflow for the entire STA 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, and attributed to runoff caused by Hurricane Irene.

The cells are designed to have water depths of 0.5 to 4.5 ft under typical operating conditions. 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 originally set at 13.6 ft NGVD. During the first two years of operation, the outlet weir boxes at G354 (Cell 5) and G393 (Cell 3) were not level. In April 2000, weir plates were installed to correct this problem, leveling the weir crest. 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 STA-6 discharge canal. The gates are manually controlled. Normally, all three gates in Cell 5 (G354A through C) are open. In Cell 3, only one gate is usually open, G393B. Because of this, the maximum flow rate under normal operating conditions in Cell 3 is 140 cfs, which is 28 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.

During extreme storm conditions, all the outlet structures for Cells 3 and 5 are opened and are operated at maximum capacity. Under drought conditions, minimum water levels in the cells are, to the greatest extent practicable, 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 used for the water budget computations, and any special considerations for using the data. The source for the data was DBHYDRO (SFWMD, 2000), the District's corporate database. The corresponding DB keys and station names are presented in Appendix A.

Rainfall

Daily rainfall data for STA-6 were collected at G600_R and at the ROTNWX weather station. G600_R is located in the northwest corner of the STA. The weather station, ROTNWX, is located near the southeast corner of the STA in the RWMA. Missing values were filled based upon the best available information, usually from nearby rain gauges. The data were also compared to rainfall values at seven other nearby rain gauges in order to check for data errors. The data for G600_R were loaded into a preferred DB key every month; a final Quality Assurance/Quality Check (QA/QC) check is completed on a quarterly basis. This preferred DB key provides a high-quality continuous record of daily rainfall amounts.

Data from the ROTNWX rain gauge were averaged with values from the G600_R gauge and used for the mean daily rainfall at STA-6 for this report. **Table B-1** and **Figure B-1** in Appendix B show the average daily rainfall amounts recorded at G600_R and ROTNWX for WY2005. **Figure B-2** shows the monthly rainfall quantity for the water year.

Evapotranspiration

Daily ET data were taken from a preferred DB key for STA-1W. The data for ET in this DB key were considered to be of the highest quality available. The DB key was populated with data using Equation 2 (Abtew et al., 2003), daily air temperature, and total solar radiation. **Table C-1** and **Figure C-1** in Appendix C show the daily ET values used in this study. **Figure B-2** shows the monthly ET quantity for the water year.

$$ET = K_1 \frac{R_s}{\lambda} \tag{2}$$

where

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

Stage

Stage data were collected on an instantaneous basis, averaged, and recorded as daily mean stage in DBHYDRO. A headwater stage and a tailwater stage are needed in order to compute flow at each structure. As a result, more than one stage value was available for and used in computing average daily stage within each treatment cell. **Tables D-1** and **D-2** show the mean daily stage values for Cell 3 and Cell 5, respectively.

Stage data were also used to estimate seepage to and from treatment cells and the STA. The equation used for seepage estimation is described below (Equation 3). Seepage was driven by stage differences between each treatment cell and surrounding water bodies. Details are provided in Appendix E.

When the recorded stage in a treatment cell fell below the average ground elevation, a function was used to estimate the volume of water available for release or that was 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 (Abtew et al., 1998), and are discussed in detail by Huebner (2001).

Flow

Daily mean flow rates were obtained from DBHYDRO. In this study, the daily mean inflow at G601, G602, and G603 was used for the cell water budgets. Inflow at G600_P was used for the STA-6 water budget. Since flow at G600_P is not equal to the sum of flows at G601, G602, and G603, there are discrepancies between cell water budgets and the STA water budget. G600_P consists of a set of five pumps. G601, G602, G603, G354A through C, and G393A through C (outlet weir-culverts) are weir structures. Negative flow values at the weirs were retained in the analysis; however, daily mean flows that were negative had relatively small values.

At G600_P, average daily flow was computed instantaneously using pump motor speed and headwater and tailwater elevation data. The daily average flow at G354, G393 and G600_P was recorded in DBHYDRO and reviewed monthly for accuracy and missing data. A complete record of daily average flow is loaded monthly into a preferred DB key in DBHYDRO. A final QA/QC check of the flow data in the preferred DB key was conducted quarterly.

The flows recorded for G601, G602, and G603 were considered to be less accurate than flow calculated at the G600 pumps. The calibration of the weir coefficients used in flow calculations has not been completed for G601, G602, and G603. However, in this study, the flow at G601, G602, and G603 was not adjusted as had been the case in the water budget report for WY2003 and WY 2004 (Liyanage, et al., 2005).

According to the Operations Plan for the STA, Cell 5 inflow should be about twice as Cell 3 inflow values, since it has two inflow weirs, as opposed to one in Cell 3. This was not the case in WY2005, where the inflow to Cell 3 was slightly greater than the inflow to Cell 5.

Outflow in this report was computed at weirs G354A, B, and C, and G393A, B, and C. Flow equation calibration work at these weirs was completed last year. Flow at station G606 was not considered in this analysis, since the water quality monitoring compliance points were moved to G354 and G393 for STA-6 in 2002. The sum of the flow through the G354 and G393 structures was taken as the outflow of the entire STA-6.

Seepage

No direct measurement of seepage was made at the STA. A number of attempts to quantify seepage at wetland treatment sites like STA-6 have been made and are discussed extensively in Huebner (2001). In general, seepage losses have been reported on the order of 2.0 to 10.0 cubic ft per second per mile of levee per foot of head difference (cfs/mi/ft). Huebner (2001) also shows the estimated groundwater table gradient around STA-6 for dry and wet periods, with and without the STA. In general, the regional groundwater table gradient is from north to south. By impounding water within the STA, the local gradients tend to carry water away from the STA to the surrounding shallow aquifer and nearby canals.

In this analysis, seepage was computed as:

$$G = 1.983 * K_{sp} * L * \Delta H \qquad (3)$$

where

G	=	levee (horizontal) and deep (vertical) seepage (ac-ft/d)
K_{sp}	=	coefficient of seepage (cfs/mi/ft)
L	=	length along the seepage boundary (mi)
ΔH	=	elevation difference between the water level in the treatment cell or canal and the water level adjacent to the cell or canal (ft)
1.938	=	constant to convert from cubic ft per second (cfs) to ac-ft/d

The value of K_{sp} was optimized by minimizing the error in the water budget for the six-year period from WY2003 to WY2005. This report used different seepage coefficients than previous reports, and used a different seepage coefficient for each treatment cell.

WATER BUDGET

Methodology

Three sets of water budgets were produced; one for each treatment cell and one for the entire STA. Each set of water budgets were computed on a daily, monthly, and annual basis using Equation 1. Terms in Equation 1 were converted to ac-ft per unit time (day, month, or year, depending on the period being used for the water budget calculations). The water year used in this report extends from May 1 to April 30, and was used for the annual period. Wet season months are June through October, and the dry season extends from November to May.

Results

Cell 3

Table 1 and **Figure 3** show the annual water budget for Cell 3 for WY2005. Error in the annual water budget was 11.0 percent. Seepage was 34.5 percent of the annual water budget. Outflow through weir boxes G393A through C was 56.8 percent of the inflow to Cell 3, measured at G603.

Table 2 contains the monthly water budget for Cell 3. The mean daily error in the monthly water budget analysis shown in **Table 2** is less than 2.0 in. for all 12 months, and less than 1.0 in. for seven of the 12 months in the period. The seepage coefficient used for the water budget for Cell 3 was 9.47 cfs/mi/ft, which is within the values found in the literature.

Figure 4 shows the daily errors or residuals in the Cell 3 water budget for WY2005. Cell 3 displayed the lower amount of variation in the water budget residuals compared to Cell 5. **Figure 5** depicts the estimated seepage into and out of Cell 3. The variation in Cell 3 inflow, outflow, and stage is depicted in **Figure 6**. **Figure 7** shows the stage in Cells 3 and 5 versus that in the supply and discharge canals.

Table 1. Cell 3 Annual Water Budget Summary (ac-ft), WY2005

Cell 3	Inflows				Outflows				ΔS	r	ε
	Is	Ig	P	Σinflow	Os	Og	ET	Σoutflow			
wy 2004-2005	18,614	513	1,014	20,141	10,575	6,126	1,035	17,735	328	2,078	11.0%
TOTAL	18,614	513	1,014	20,141	10,575	6,126	1,035	17,735	328	2,078	11.0%
% inflow	92%	3%	5%	% outflow	60%	35%	6%				

Notes:

1. All values in ac-ft
2. I_s measured at G603
3. P is average of values at G600_R and ROTNWX
4. O_s measured at G393B
5. ET measured at ROTNWX from total radiation and air temperature for WY 01-02 (missing values are from STA1W); ET data from STA1W and ENRP used for WY98-99 through WY 00-01
6. Ig and Og estimated based on head differences between cell water levels and surrounding water levels using a seepage coefficient of: Cell 3=9.47 cfs/mi/ft, Cell 5=1.31 cfs/mi/ft
7. ΔS for water levels below average ground level estimated using equations developed by Huebner (2001) based on data available in Abtew, et al. (1998)

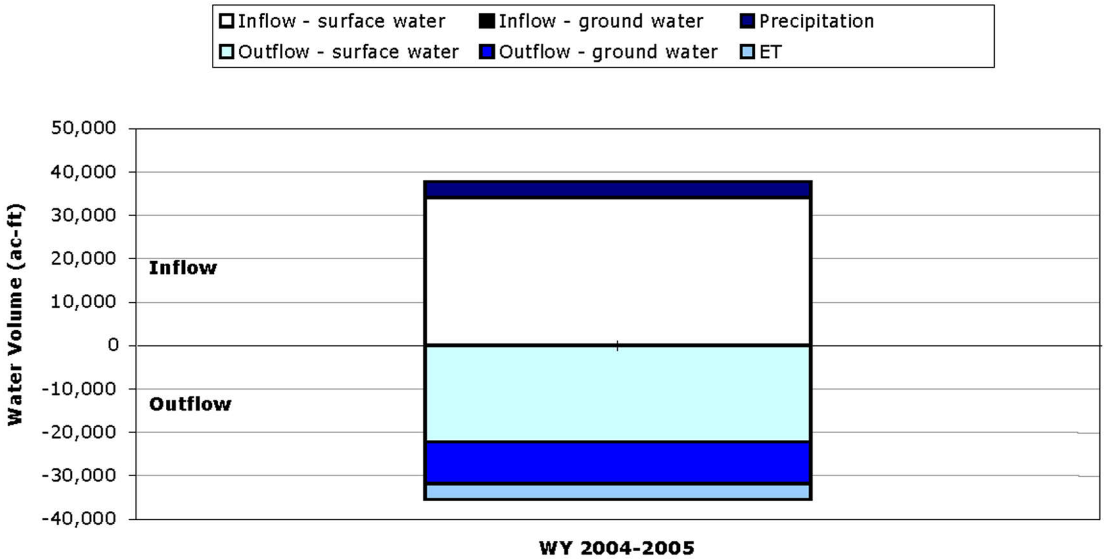

Figure 3. Cell 3 Annual Water Budget Summary, WY2005

Table 2. Cell 3 Monthly Water Budget, WY2005

Month-Year	Inflow surface water	Outflow surface water	Change in storage	Rain	ET	Seepage	Error	Daily Average Error
	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	in
May - 2004	0.000	0.000	-35.224	25.844	127.715	217.578	-284.224	-0.449
Jun - 2004	361.393	0.000	468.095	253.273	105.502	330.101	-289.032	-0.472
Jul - 2004	1781.583	686.524	227.355	200.668	103.435	351.519	613.417	0.969
Aug - 2004	4789.538	3678.152	-16.181	193.834	87.359	90.585	1143.456	1.807
Sep - 2004	3039.912	2293.300	91.623	153.275	81.336	-102.754	829.682	1.355
Oct - 2004	2383.505	1351.987	-152.765	33.813	82.511	9.566	1126.018	1.779
Nov - 2004	923.292	299.943	-55.483	3.680	62.228	749.239	-128.955	-0.211
Dec - 2004	713.131	111.355	29.030	2.456	55.005	925.651	-405.453	-0.641
Jan - 2005	612.988	123.799	14.957	3.162	61.814	968.957	-553.378	-0.874
Feb - 2005	1057.791	263.495	41.037	14.908	66.938	406.694	294.536	0.515
Mar - 2005	2726.001	1583.866	44.223	87.002	89.856	245.336	849.722	1.343
Apr - 2005	225.191	182.484	-329.160	41.864	110.933	1420.174	-1117.376	-1.824

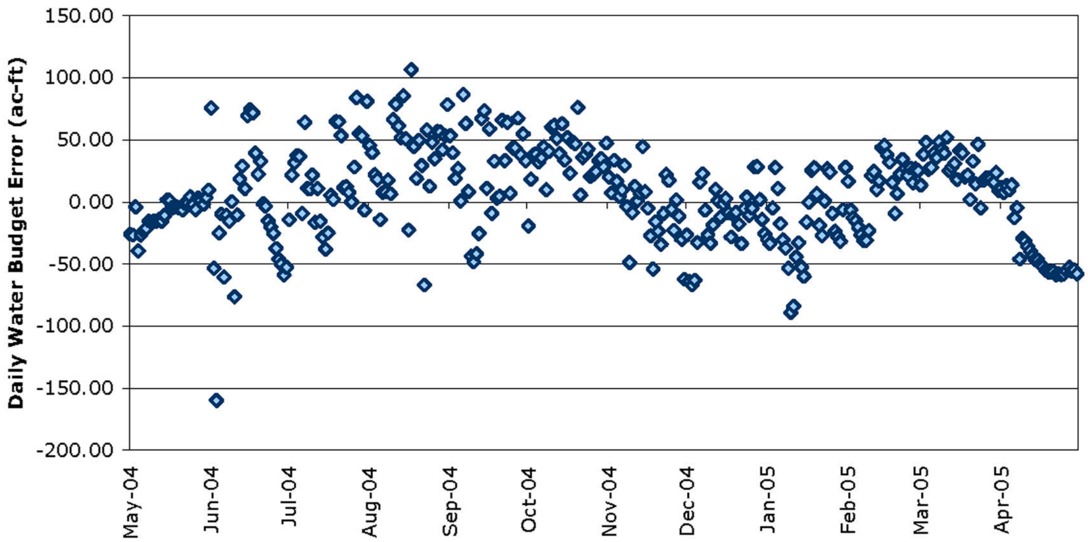

Figure 4. Cell 3 Daily Water Budget Error, WY2005

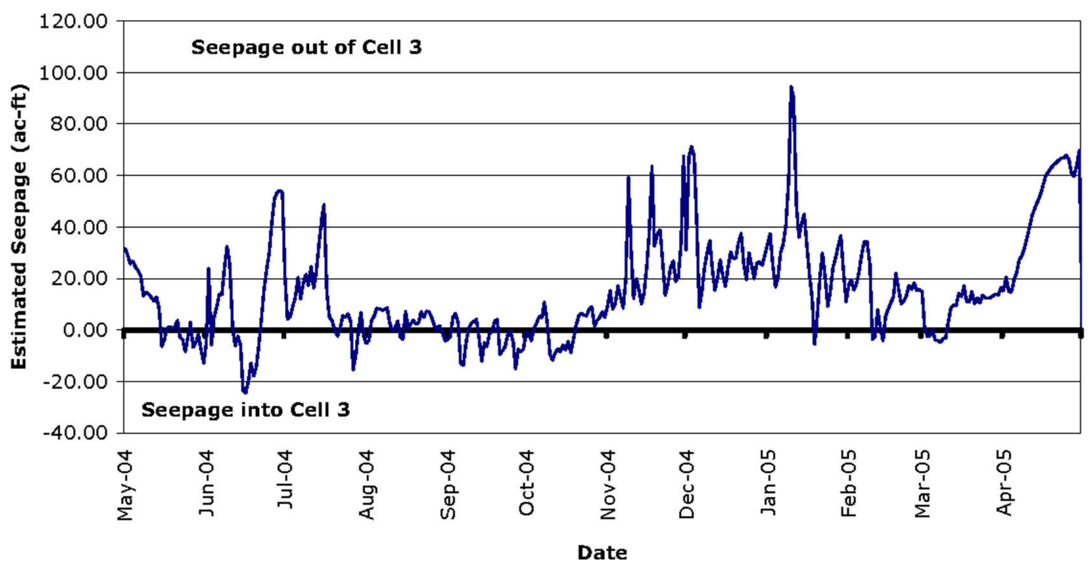

Figure 5. Cell 3 Estimated Daily Seepage, WY2005

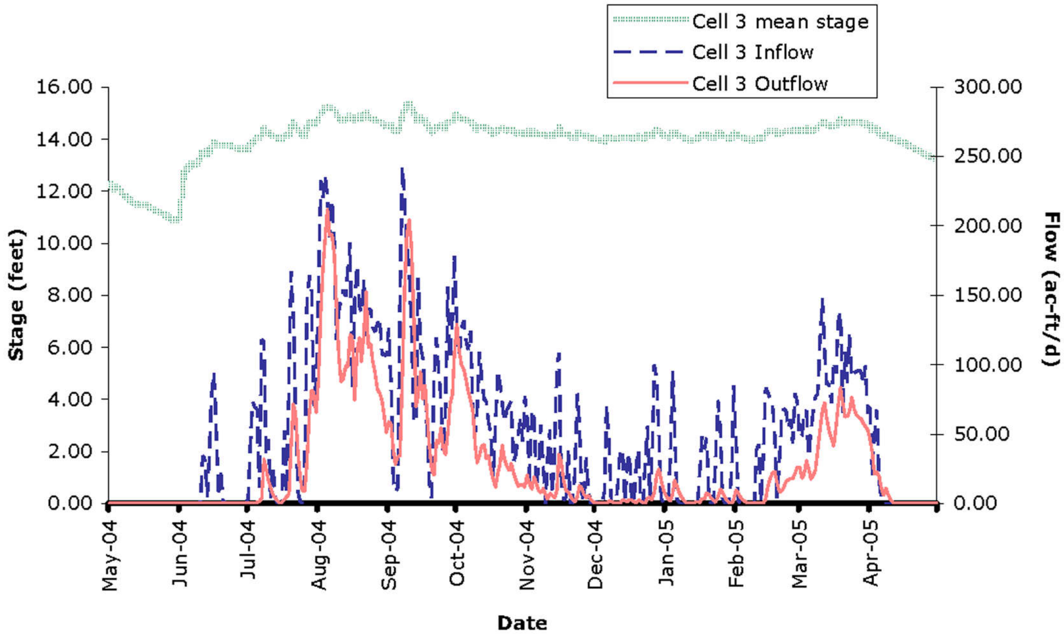

Figure 6. Cell 3 Inflow, Outflow, and Stage, WY2005

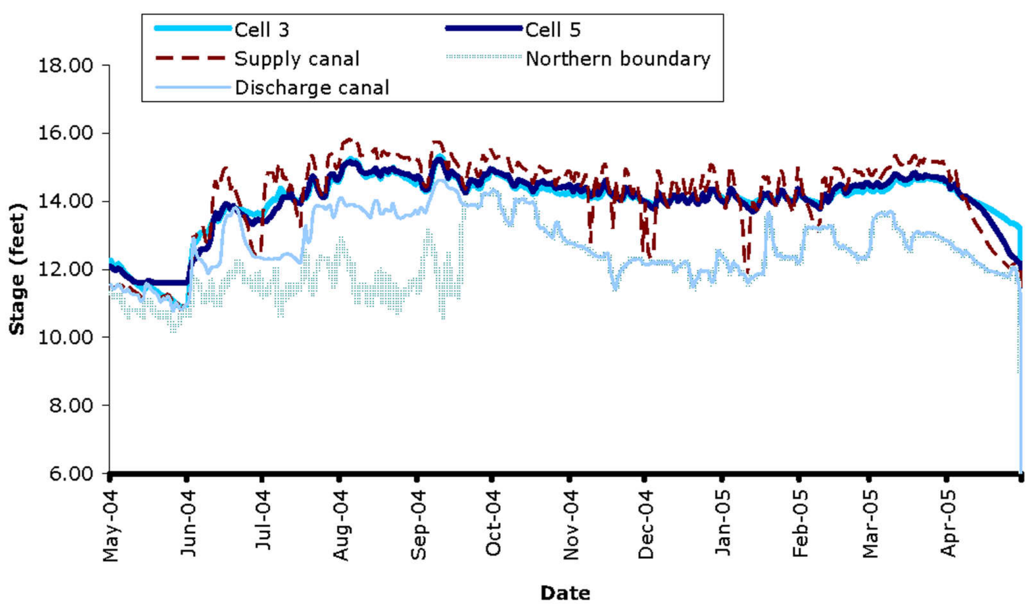

Figure 7. Stage in Cells 3, 5, and Surrounding Water Bodies, WY2005

Cell 5

Table 3 and **Figure 8** show the annual water budget for Cell 5. Cell 5 is the northern cell of the two treatment cells in STA-6. As a percentage of the annual water budget, error for Cell 5 was 2.8 percent. **Figure 9** shows the residual error plot for the Cell 5 water budget. The seepage coefficient used for the Cell 5 water budget was 1.31 cfs/mi/ft, which agrees with values from the literature. Seepage constituted 21.1 percent of the water budget.

Seepage into and out of Cell 5 is depicted in **Figure 10.** Stage in Cells 3 and 5 and in surrounding water bodies was presented in **Figure** 7. In WY2005, 78 percent of the inflow to the cell at G601 and G602 left the cell at G354A, B, and C. **Figure 11** shows the inflow, outflow, and stage in Cell 5 for WY2005.

The monthly water budgets for WY2005 are shown in **Table 4**. The two columns on the right in the table show the monthly error in ac-ft/month, and the daily average error in inches. The average daily error is less than 1.0 in. for all 12 months. The sum of the mean daily error was lower for Cell 5 than Cell 3, partially because the budget is being applied to a unit that has a much larger surface area (625 acres versus 245 acres for Cell 3).

Table 3. Cell 5 Annual Water Budget Summary (ac-ft), WY2005

Cell 5	Inflows				Outflows				ΔS	r	ε
	Is	Ig	P	Σinflow	Os	Og	ET	Σoutflow			
wy 2004-2005	16,101	33	2,586	**18,720**	11,613	3,817	2,639	**18,069**	143	508	2.8%
TOTAL	16,101	33	2,586	**18,720**	11,613	3,817	2,639	**18,069**	143	508	2.8%
% inflow	86%	0%	14%	% outflow	64%	21%	15%				

Notes:

1. All values in ac-ft
2. I_s measured at G601 and G602
3. P is average of values at G600_R and ROTNWX
4. O_s measured at G354C
5. ET measured at ROTNWX from total radiation and air temperature for WY 01-02 (missing values are from STA1W); ET data from STA1W and ENRP used for WY98-99 through WY 00-01
6. Ig and Og estimated based on head differences between cell water levels and surrounding water levels using a seepage coefficient of: Cell 3=9.47 cfs/mi/ft, Cell 5=1.31 cfs/mi/ft
7. ΔS for water levels below average ground level estimated using equations developed by Huebner (2001) based on data available in Abtew, et al. (1998)

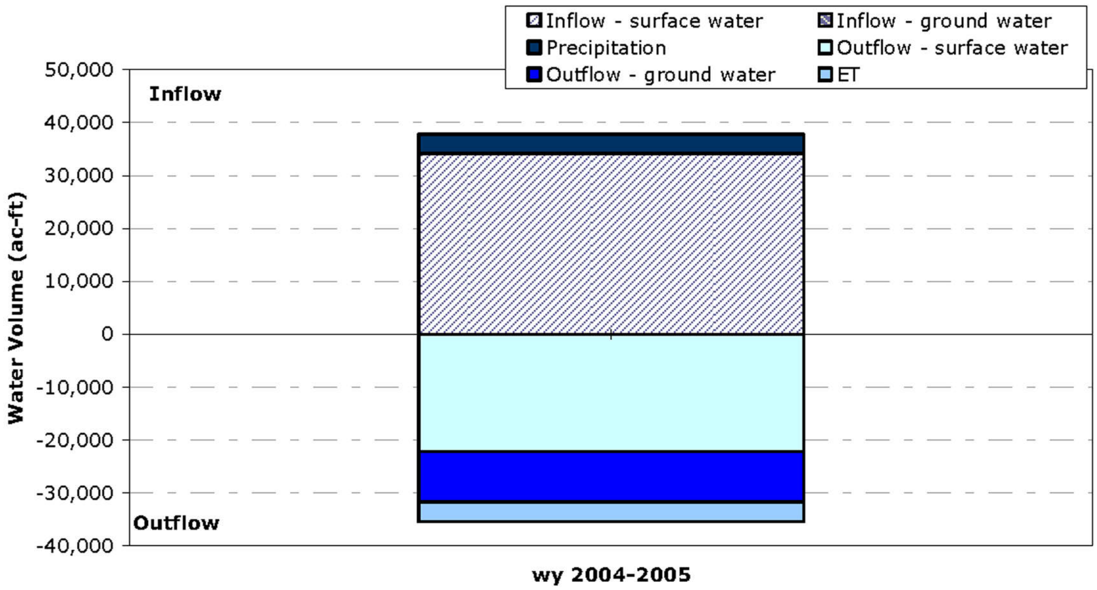

Figure 8. Cell 5 Annual Water Budget Summary, WY2005

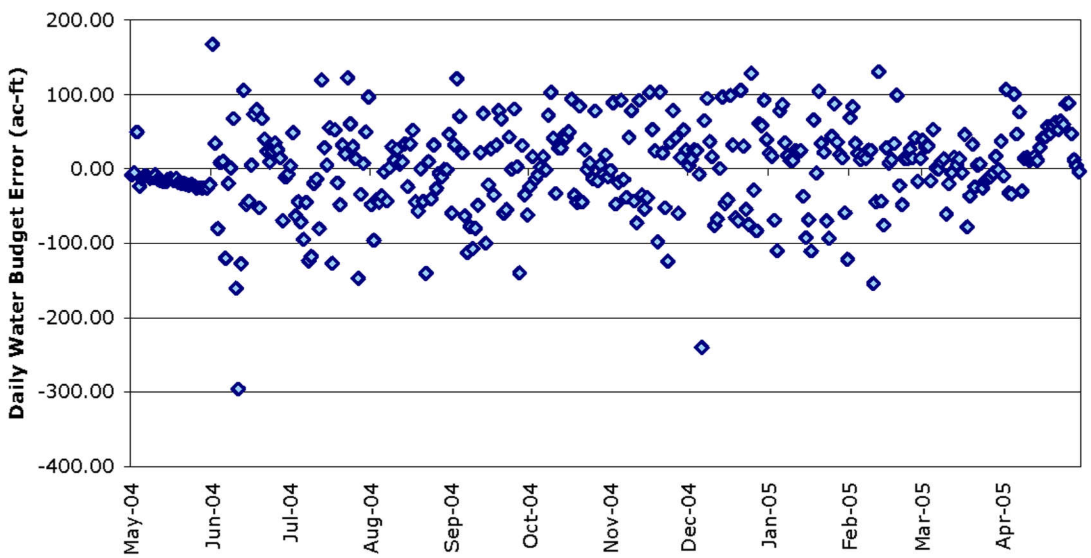

Figure 9. Cell 5 Daily Water Budget Error, WY2005

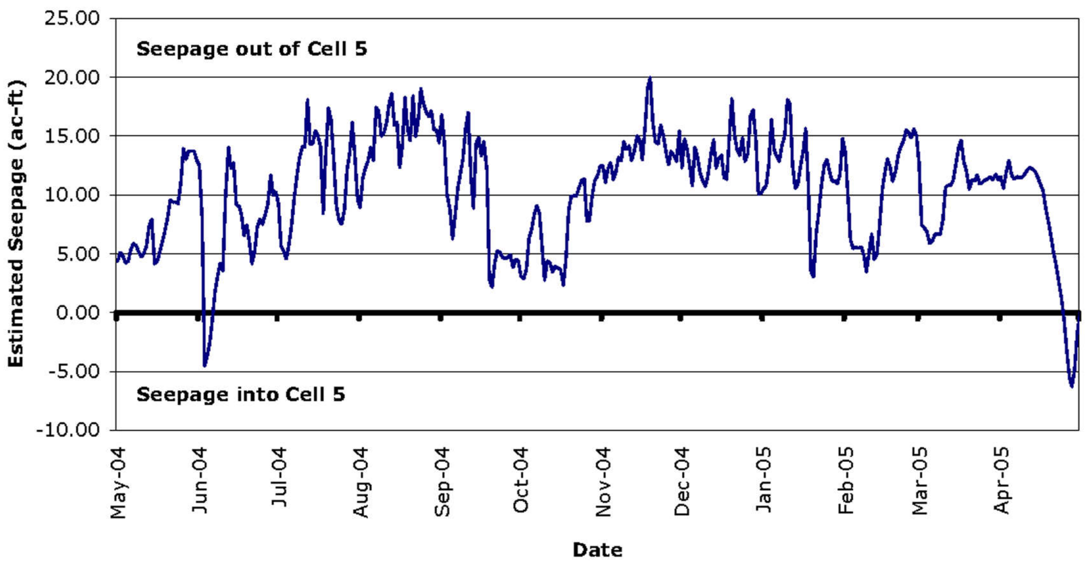

Figure 10. Cell 5 Estimated Daily Seepage, WY2005

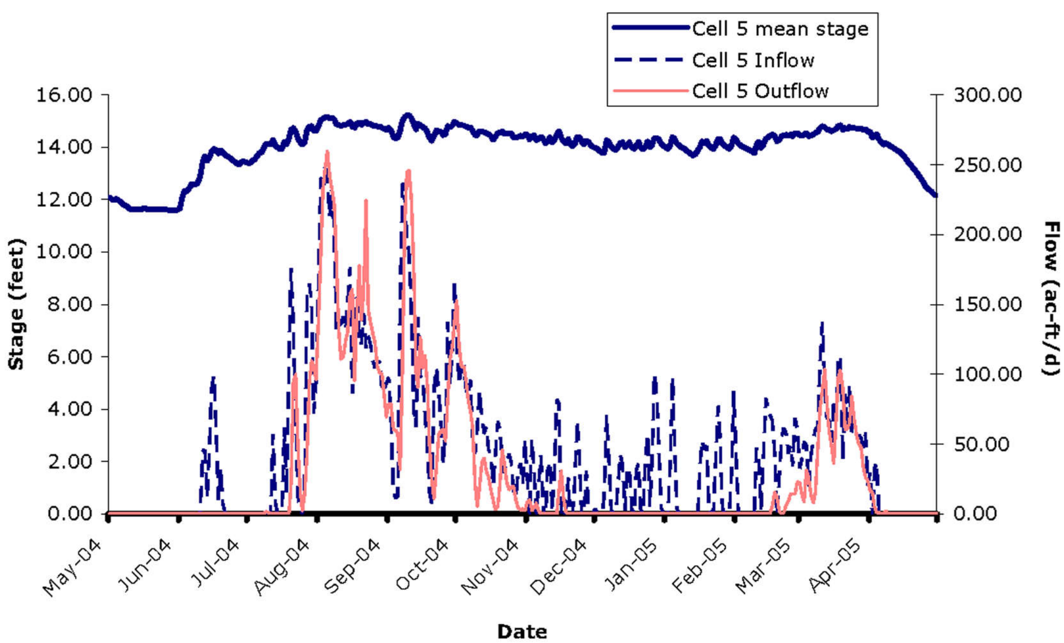

Figure 11. Cell 5 Inflow, Outflow, and Stage, WY2005

Table 4. Cell 5 Monthly Water Budget, WY2005

Month-Year	Inflow surface water	Outflow surface water	Change in storage	Rain	ET	Seepage	Error	Daily Average Error
	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	in
May - 2004	0.000	0.000	-33.967	65.908	325.877	240.237	-466.238	-0.289
Jun - 2004	444.236	0.000	864.542	646.080	269.162	199.071	-242.458	-0.155
Jul - 2004	1299.917	746.101	747.496	511.912	263.828	358.264	-303.859	-0.188
Aug - 2004	4608.740	4799.712	17.186	494.450	222.815	479.396	-415.919	-0.258
Sep - 2004	2914.273	2991.515	186.570	391.040	207.437	273.313	-353.521	-0.226
Oct - 2004	1761.267	1212.502	-300.924	86.216	210.469	219.638	505.799	0.313
Nov - 2004	621.954	94.687	-292.826	9.363	158.691	421.902	248.863	0.159
Dec - 2004	740.621	0.000	26.550	6.250	140.280	411.979	168.062	0.104
Jan - 2005	659.918	0.000	197.498	8.074	157.726	371.899	-59.131	-0.037
Feb - 2005	968.487	115.400	107.804	38.037	170.737	277.917	334.665	0.229
Mar - 2005	2000.442	1611.632	28.122	221.964	229.244	318.881	34.527	0.021
Apr - 2005	80.987	41.037	-1404.730	106.799	283.016	211.004	1057.459	0.677

STA 6

Table 5 and **Figure 12** contain the summary of the WY2005 water budget for the entire STA-6, which includes Cells 3 and 5, as discussed previously. Water budget error constituted 5.2 percent of the budget. Seepage was 27.0 percent of the water budget.

Table 6 shows the monthly water budget summary. The daily average errors are less than 1.0 in. **Figure 13** 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. Work completed for STA-5 indicates that this may be due to transient flow and stage conditions that take place in less than one day (Parrish and Huebner, 2004.). **Figure 14** 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** 7.

Figure 15 shows the daily inflow and outflow volumes for STA-6 for WY2005. Outflow from Cells 3 and 5 was 63.9 percent of the inflow recorded at G601, G602, and G603 during WY2005. **Figure 16** depicts the one-year water budget values for STA-6 for WY2005.

Table 5. STA6 Annual Water Budget Summary (ac-ft), WY2005

STA 6	Inflows				Outflows				ΔS	r	ε
	Is	Ig	P	Σinflow	Os	Og	ET	Σoutflow			
wy 2004-2005	34,035	164	3,600	37,798	22,187	9,560	3,674	35,421	471	1,906	5.2%
TOTAL	34,035	164	3,600	37,798	22,187	9,560	3,674	35,421	471	1,906	5.2%
% inflow	90%	0%	10%	% outflow	63%	27%	10%				

Notes:

1. All values in ha-m
2. I_s measured at G600.
3. P is average of values at G600_R and ROTNWX
4. O_s measured at at G606 through 2/28/01 and at G354 and G393 thereafter
5. ET measured at ROTNWX from total radiation and air temperature for WY 01-02 (missing values are from STA1W); ET data from STA1W and ENRP used for WY98-99 through WY 00-01
6. Ig and Og estimated based on head differences between cell water levels and surrounding water levels using a seepage coefficient of: Cell 3=9.47 cfs/mi/ft, Cell 5=1.31 cfs/mi/ft
7. ΔS for water levels below average ground level estimated using equations developed by Huebner (2001) based on data available in Abtew, et al. (1998)

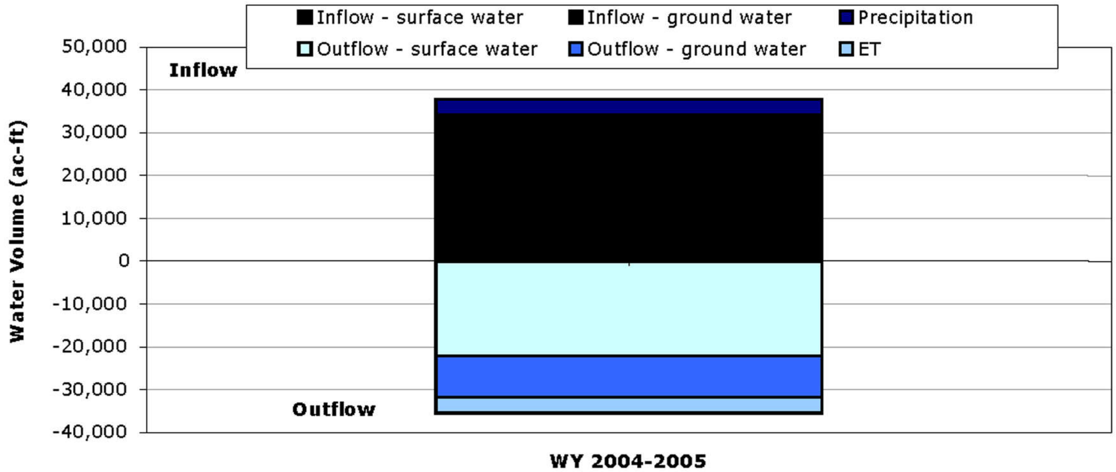

Figure 12. STA-6 Annual Water Budget Summary, WY2005

Table 6. STA-6 Monthly Water Budget, WY2005

Month-Year	Inflow surface water	Outflow surface water	Change in storage	Rain	ET	Seepage	Error	Daily Average Error
	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	in
May - 2004	0.000	0.000	-69.192	91.753	453.592	457.759	-750.406	-0.334
Jun - 2004	727.796	0.000	1332.661	899.344	374.664	529.163	-609.348	-0.280
Jul - 2004	3446.330	1432.626	974.883	712.572	367.214	709.791	674.388	0.300
Aug - 2004	9185.912	8477.864	1.038	688.308	310.158	569.981	515.179	0.229
Sep - 2004	6628.209	5284.807	278.193	544.315	288.756	170.559	1150.209	0.529
Oct - 2004	3369.478	2564.481	-453.729	120.037	292.955	229.195	856.613	0.381
Nov - 2004	2153.434	394.655	-348.325	13.044	220.886	1171.149	728.112	0.335
Dec - 2004	1767.080	111.355	55.580	8.707	195.285	1337.614	75.953	0.034
Jan - 2005	1552.087	123.799	212.447	11.228	219.540	1340.816	-333.287	-0.148
Feb - 2005	1727.324	378.904	148.865	52.937	237.683	684.587	330.222	0.163
Mar - 2005	2952.675	3195.482	72.345	308.958	319.100	564.185	-889.478	-0.396
Apr - 2005	524.210	223.521	-1733.923	148.671	393.958	1631.177	158.147	0.073

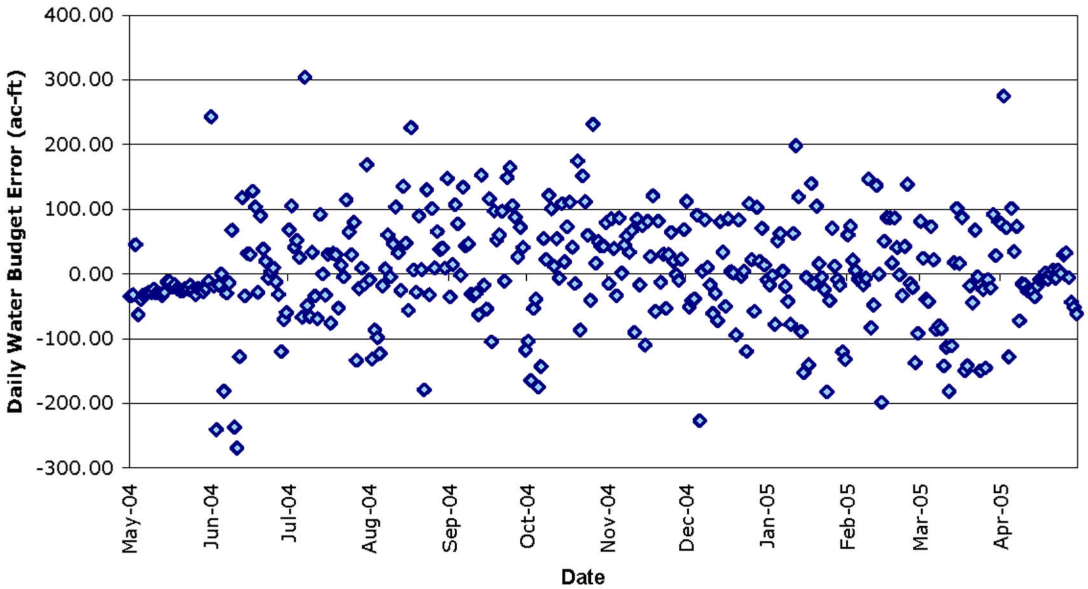

Figure 13. STA-6 Daily Water Budget Error, WY2005

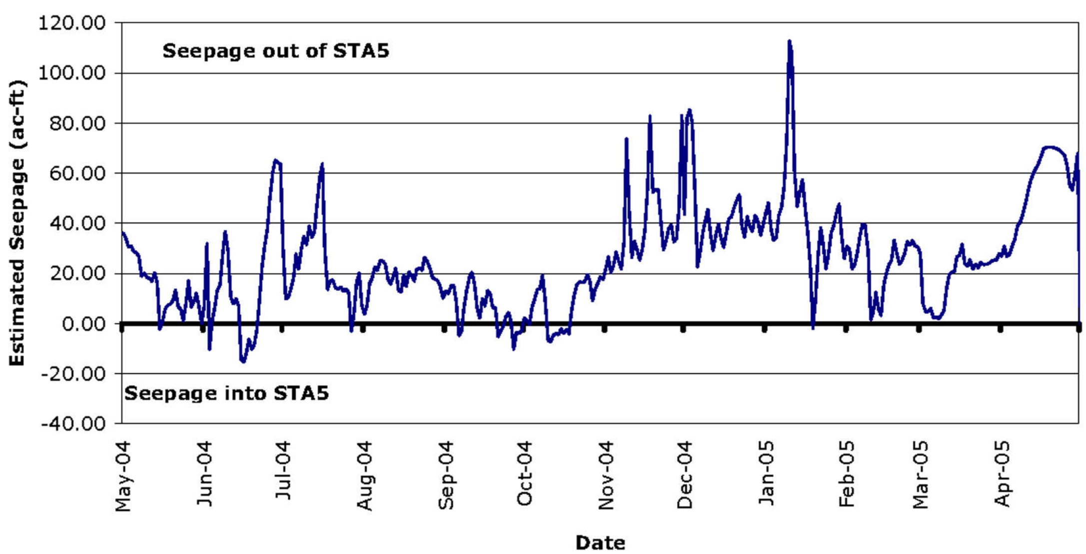

Figure 14. STA-6 Estimated Daily Seepage, WY2005

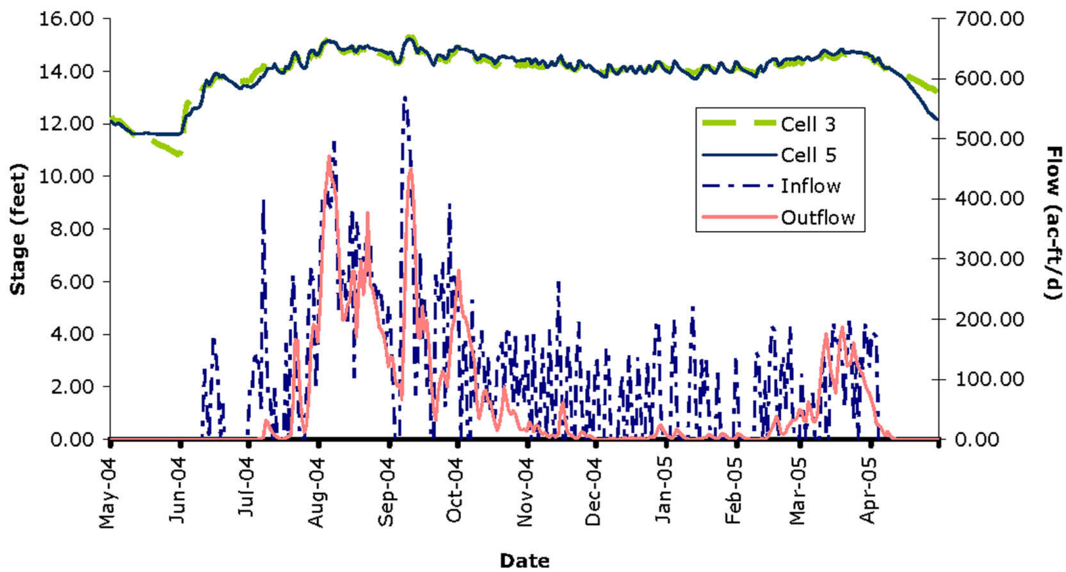

Figure 15. STA-6 Inflow, Outflow, and Stage, WY2005

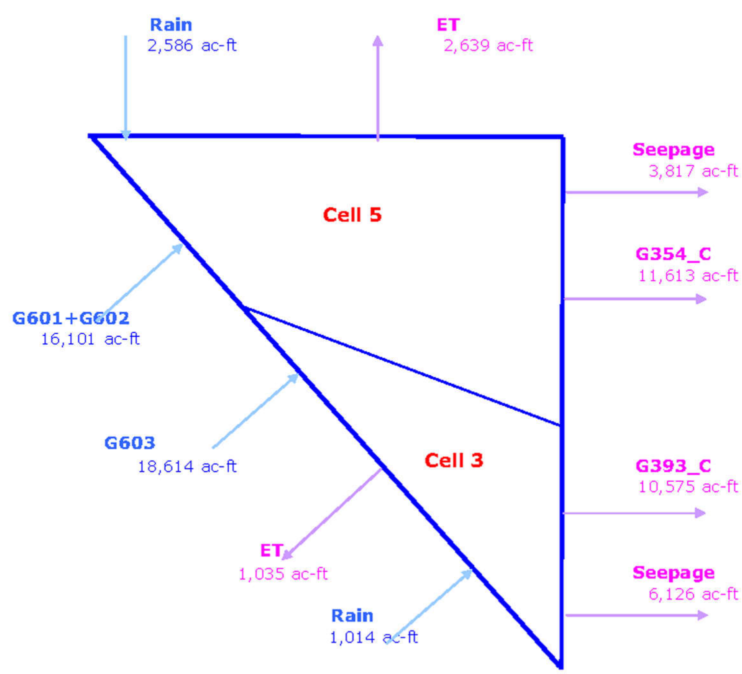

Figure 16. STA-6 Water Budget Volumes, WY2005

Mean Hydraulic Retention Time

Mean hydraulic retention time (MHRT) is an estimate of how long water remains in each cell. During that time, physical, chemical, and biological processes remove particulate and soluble phosphorous and other contaminants. The MHRT, also referred to as mean cell residence time, was determined using Equation 5:

$$t = \frac{V}{Q} \tag{5}$$

where

t	=	mean hydraulic retention time (d)
V	=	cell volume (ac-ft)
Q	=	flow rate (mean of inflow and outflow; ac-ft/d)

Table 7 shows the MHRT in days for Cells 3 and 5. The annual mean was based on the average stage during the water year or season, and the average rate of inflow and outflow including rainfall, ET, and seepage. Wet-season MHRT is based on data spanning June to October, and dry-season MHRT is based on data spanning November to May.

Table 7. Mean Hydraulic Retention Time, WY2005

	Annual		Wet Season		Dry season	
Cell 3	Average depth (ft)	MHRT (days)	Average depth (ft)	MHRT (days)	Average depth (ft)	MHRT (days)
wy 2004-2005	1.58	7.69	1.90	6.38	1.35	9.69
1-yr. Mean	1.58	7.69	1.90	6.38	1.35	9.69
Cell 5						
wy 2004-2005	1.60	19.79	1.91	14.26	1.37	32.74
1-yr. Mean	1.60	19.79	1.91	14.26	1.37	32.74
STA-6						
wy 2004-2005	1.59	13.89	1.91	10.60	1.37	20.21
1-yr. Mean	1.59	13.89	1.91	10.60	1.37	20.21

During the wet season, the MHRT for Cell 3 was 6.38 days, and 14.26 days for Cell 5. Dry-season MHRTs were 9.69 days for Cell 3 and 32.74 days for Cell 5. For the year, MHRT for Cell 3 was 7.69 days for Cell 3 and 19.79 days for Cell 5. At maximum normal flow conditions in the STA, as described in the STA's Operation Plan (SFWMD, 1997), Cell 3 has a MHRT of 4.0 days, based on a flow of 140 cfs and a depth of 4.5 ft. Cell 5 has a MHRT of 3.9 days, based on a flow of 360 cfs and a depth of 4.5 ft.

Hydraulic Loading Rate

Hydraulic loading rate (HLR) is the rate at which water flows into a system. This was calculated by dividing the inflow (ac-ft/day) at the control structures by the treatment area. For this analysis, the entire STA-6 was considered and therefore inflow was divided by 870 acres (the area of STA-6). **Table 8** presents the average HLR for each month for WY2005. The highest HLR occurred in August 2004, which was 0.34 ft/day. The HLR was zero in May 2004, since inflow was zero. **Figure 17** shows the HLR based on the wet and dry seasons of the water year. During the dry season in WY2005, STA-6 had a mean HLR of 0.05 ft/day. The WY2005 wet season hydraulic loading rate of STA-6 was 0.19 ft/day. The mean HLR for all of WY2005 was 0.11 ft/day.

Table 8. Hydraulic Loading Rate, WY2005

WY2005	
Month	Hydraulic loading (ft/day)
May 2004	0.00
Jun 2004	0.03
Jul 2004	0.13
Aug 2004	0.34
Sep 2004	0.25
Oct 2004	0.12
Nov 2004	0.08
Dec 2004	0.07
Jan 2005	0.06
Feb 2005	0.07
Mar 2005	0.11
Apr 2005	0.02

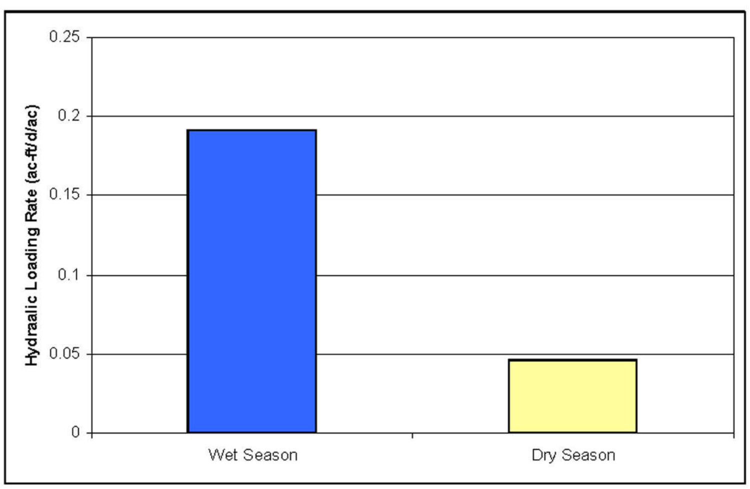

Figure 17. Hydraulic Loading based on Season, WY2005

SUMMARY AND DISCUSSION

Over WY2005, STA-6 received 34,035 ac-ft of water from pumping operations at G600_P. An additional 3,600 ac-ft were input to STA-6 via rainfall; 3,674 ac-ft were lost through ET. Estimated seepage was 27.0 percent of the water budget during this period, losing 9,560 ac-ft to surrounding water bodies and the surficial aquifer. Outflow from STA-6 at G354 and G393 was 63.9 percent of the flow entering STA-6 at G601, G602, and G603 or 22,188 ac-ft. This volume was released into the discharge canal at STA-6 and was eventually discharged at G607 to the L-4 canal. The amount of water stored in STA-6 increased by 471 ac-ft. The error in the water budget was 1,906 ac-ft or 5.2 percent of the budget. Cell 3 retained water an average of 2.34 days in WY2005. The average retention time in Cell 5 was 6.03 days.

Determining the seepage coefficient for each treatment cell was the biggest challenge in this water budget analysis. This was the first time that unique seepage coefficient for each treatment cell was used. The seepage coefficient used for Cell 3 was 9.47 cfs/mi/ft, and 1.31 cfs/mi/ft for Cell 5 based on water budget data from WY2003, WY2004, and WY2005.

Cell 5 contains two inflow weirs (G601 and G602), and Cell 3 only has one inflow weir structure (G603). This is consistent with the design of STA-6, Section 1. Cell 5 was intended to treat approximately twice the volume of water that Cell 3 treated. In WY2005, like WY2004, Cell 5 inflow was lower than Cell 3 inflow. This can be attributed to the fact that the weir at G603 (Cell 3) is larger than either of the weirs at G601 and G602 (Cell 5). However, the elevation of the weir crest at G603 is 14.2 ft. NGVD; the crest elevation of weirs at G601 and G602 is 14.1 ft. NGVD. This higher loading rate was also reflected in MHRT values for both cells.

There are two other structures, an irrigation pump at station G600I_P, and a gated culvert at station G600_C at STA-6, that were instrumented in 2004. The culverts and irrigation pumps typically do not affect the STA water budget, and were not used in this analysis.

The largest factor affecting the water budget for WY2005 was the fire at pump station G600. This affected the data logger located at the site as well as the pumps starting on September 18, 2004. Flows, stages, and rainfall after that date at G600 are based on daily manual log readings or, in the case of rainfall, values interpolated from nearby rain gages. Pump station G600 is now inactive pending dewatering activities associated with construction of STA-6, Section 2.

The water budget residuals for STA-6 shown in **Figures 4**, **9**, and **13** (residuals for Cell 3, Cell 5, and STA-6 as a whole) are not random. In general, the residuals increase when flow increases, as shown in **Figure 18**, which shows daily inflow, seepage, and budget error for the four-year period. Although seepage also increases during these periods (in response to increased stage in STA-6), the volume of outflow from STA-6, plus the increased seepage and the increase in storage, do not equal the daily volume of water entering STA-6. Flow measurement error may account for this. The algorithm for inflow is based on a uniform trapezoidal shape. The construction drawings show that inflow weirs have sloped sides approximating a trapezoid, but the crest elevation (bottom of the trapezoid) is irregular. Likewise, the outflow structures are a combination of gated culvert and weir. Flow equations for these structures are being revised to account for the complex nature of flow through these structures, and flow values used for this study represent best estimates at the time flow values were entered into DBHYDRO. Error in the budget may also indicate a systemic response to flow that is not adequately represented by daily mean values used in water budget calculations.

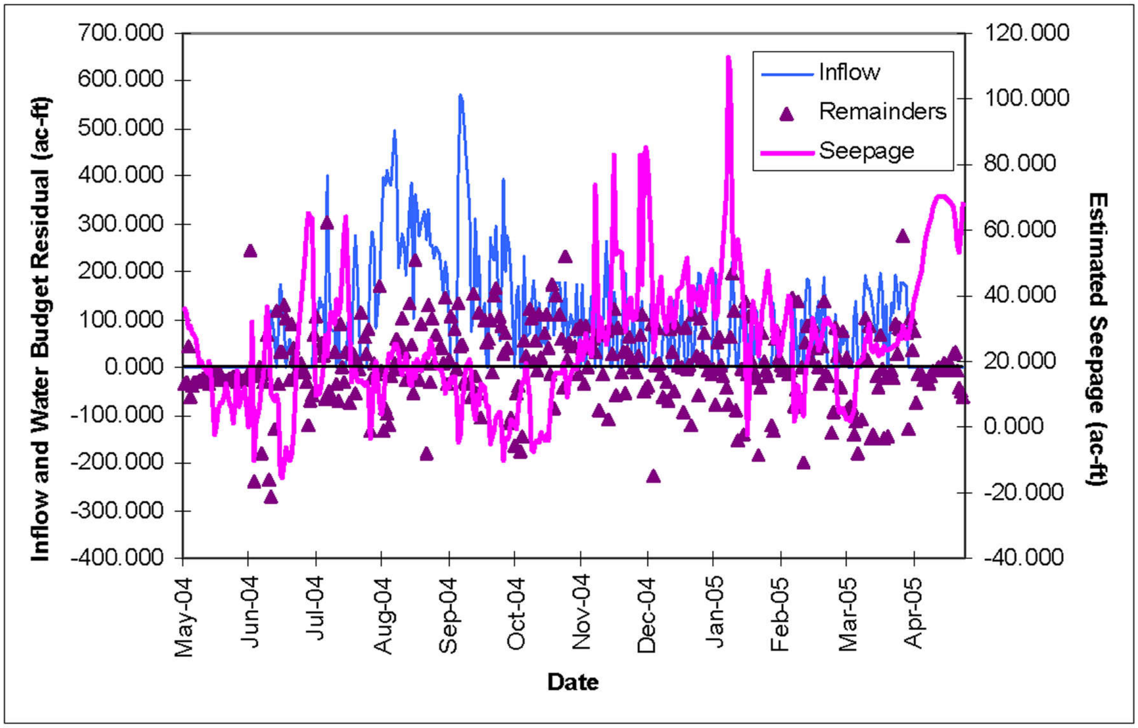

Figure 18. STA-6 Daily Inflow, Estimated Seepage and Water Budget Residuals, WY2005

RECOMMENDATIONS AND CONCLUSIONS

Seepage constituted the largest single quantifiable unknown at the site. The geology and the seepage characteristics of the area have received additional study with the installation and operation of test cells for the EAA Reservoir project. These test cells have shown that the limestone shell rock area lying beneath the peat layer in the EAA can be highly transmissive. The quantity and quality of water lost through seepage has implications for STA design and water quality management in the basin. Further investigation of this aspect of treatment cell dynamics, especially with respect to long-term aquifer and downstream impacts, remains a research need. Data from groundwater observation wells with stage recorders located in and outside the boundary of STA-6 would aid the analysis and quantification of seepage especially along the northern and eastern boundaries. As recommended in previous water budget reports, location and installation of observation wells for this purpose should be a design/construction requirement for all STAs.

Also, since the retention time of Cell 3 was significantly lower than that reported for Cell 5, it is likely that short-circuiting would be an issue and may impact the removal efficiency of the cell. There may be an issue of significant flow measurement error at the inflow weirs to Cells 3 and 5 (G601, G602 and G603). However, these structures are slated to be replaced by gated culverts as part of the work for STA-6, Section 2 in 2006 and 2007.

REFERENCES

Abtew, W., D.L. Anderson, L.J. Lindstrom and A. Cadogan. 1998. Soil Moisture and Shallow Water Table Monitoring for Irrigation and Drainage Decision-making. Drainage in the 21st Century: Food Production and the Environment, Proceedings of the 7th Annual Drainage Symposium. Orlando, FL, March 9-10, 1998. ASAE. St. Joseph, MI.

Abtew W. and R. S. Huebner. 2000. Hydrologic Impact of Hurricane Irene on South Florida. Technical Publication EMA #386. South Florida Water Management District, West Palm Beach, FL. May 2000.

Abtew W., J. Obeysekera, M. Irizarry-Ortiz, D. Lyons and A. Reardon. 2003. Evapotranspiration Estimation for South Florida, Technical Publication EMA #407. South Florida Water Management District, West Palm Beach, FL. January 2003.

GEONEX. 1999. Stormwater Treatment Area 6 Aerial Photointerpretation Summary Report, August 24, 1998. Prepared for the South Florida Water Management District, West Palm Beach, FL. January 19, 1999.

Huebner, R.S. 2001. Water Budget Analysis for Stormwater Treatment Area 6, Section 1 (January 1, 1998 to December 31, 1999). Technical Publication EMA #391. South Florida Water Management District,West Palm Beach, FL. February 2001.

Huebner, R.S. 2003. Water Budget Analysis for Stormwater Treatment Area 6, Section 1 (May 1, 1998 to April 30, 2002). Technical Publication EMA #408. South Florida Water Management District,West Palm Beach, FL. January 2003.

Liyanage, T.R., D.M. Parrish and R.S. Huebner. 2005. Water Budget Analysis for Stormwater Treatment Area 6, Section 1 (May 1, 2002 to April 30, 2004). Technical Publication ERA #426. South Florida Water Management District, West Palm Beach, FL. July 2005.

Parrish, D.M. and R.S. Huebner. 2004. Water Budget Analysis for Stormwater Treatment Area 5, Technical Publication EMA #418. South Florida Water Management District, West Palm Beach, FL. May 2004.

SFWMD. 1997. Operation Plan Stormwater Treatment Area No. 6, Section 1. South Florida Water Management District, West Palm Beach, FL. July 1997.

SFWMD. 2000. User's Guide to Accessing the South Florida Water Management District Hydrometeorologic and Water Quality Database "DBHYDRO." South Florida Water Management District, West Palm Beach, FL. July 2000.

SFWMD. 2002. Operation Plan Stormwater Treatment Area 6. South Florida Water Management District, West Palm Beach, FL. May 2002.

APPENDICES

Appendix A – Site Properties and Monitoring Stations

Table A-1. STA-6 Site Properties

Surface Area		
Cell 5	625	ac
Cell 3	245	ac
Cell 5 Ground Elevation (NGVD)	~ 12.4	ft
Cell 3 Ground Elevation (NGVD)	~ 12.4	ft
Levee Length		
Along Northern Boundary	7,785	ft
Supply Canal		
Along Cell 5	4,412	ft
Along Cell 3	7,136	ft
Discharge Canal		
Along Cell 5	6,012	ft
Along Cell 3	4,584	ft
Between Cells 3 and 5	4,195	ft

Table A-2. Stage Monitoring Stations

DBKEY	Structure	STA	COUNTY
G6559	G352S_H	STA-6 Section 1 (in 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 (in supply canal across from Cell 3)	HENDRY
G6562	G392S_T	STA-6 Section 1 (in Cell 3 across from supply canal)	HENDRY
G6565	G393B_H	STA-6 Section 1 (in Cell 3 at Weir-culvert B)	HENDRY
G6566	G393B_T	STA-6 Section 1 (in discharge canal at Weir-culvert 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

Table A-3. Flow Monitoring Stations

DBKEY	Structure	STA	COUNTY
MC958	G354_C	STA-6 Section 1 discharge canal, combined flow for G354A, B, C	HENDRY
MC959	G393_C	STA-6 Section 1 Cell 3 combined Outflow for G393A, B, C	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

Table A-4. Rainfall Monitoring Stations

DBKEY	Structure	STA	COUNTY
JJ025	G600_R	STA-6 Section 1 Inflow pump station at rain gauge	HENDRY
GE354	ROTNWX	STA-6 Rotenberger tract weather station, located by G606 at STA-6	BROWARD

Table A-5. Evapotranspiration Monitoring Stations

DBKEY	Structure	STA	COUNTY
KN810	STA-1W	Areal computed parameter for STA-1W project	PALM BEACH

Appendix B – Rainfall Data

Table B-1. Daily average rainfall at G600_R and ROTNWX (inches), WY2005

Day	2004-05	2004-06	2004-07	2004-08	2004-09	2004-10	2004-11	2004-12	2005-01	2005-02	2005-03	2005-04
1	0.01	3.73	0.00	0.93	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.01	2.54	1.15	0.26	0.08	0.00	0.00	0.00	0.02	0.00	0.00	0.16
3	1.09	0.01	0.00	0.39	0.48	0.00	0.00	0.00	0.01	0.00	0.65	0.00
4	0.00	0.18	0.01	0.04	1.77	0.00	0.00	0.00	0.00	0.01	0.21	0.00
5	0.00	1.48	0.22	0.22	1.76	0.00	0.05	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.01	0.04	0.07	0.04	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.01	0.01	0.01	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.90
8	0.00	0.10	0.00	0.16	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.49
9	0.00	2.28	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.86	0.00
10	0.00	0.05	0.00	0.08	0.03	0.00	0.00	0.02	0.00	0.00	0.02	0.00
11	0.00	0.00	0.03	0.10	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00
12	0.00	0.00	0.01	0.29	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.25	0.08	0.80	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.26	0.00	1.00	0.00	0.00	0.03	0.00	0.07	0.00	0.00	0.00
15	0.00	0.10	0.00	0.48	0.00	0.22	0.05	0.00	0.00	0.00	0.00	0.01
16	0.10	0.00	1.36	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.01	0.00	0.05	0.01	0.07	0.00	0.01	0.01	0.00	0.00	1.59	0.00
18	0.00	0.12	0.12	1.49	0.01	0.00	0.00	0.01	0.01	0.00	0.02	0.00
19	0.00	0.01	0.50	0.45	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.46	0.42	0.00	0.18	1.26	0.01	0.00	0.00	0.00	0.00	0.00
21	0.00	0.01	1.32	0.93	0.11	0.01	0.00	0.00	0.00	0.00	0.01	0.07
22	0.00	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.05	0.01	0.00	0.00	0.00	0.03	0.00	0.89	0.00
24	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
25	0.00	0.00	0.00	0.85	0.77	0.00	0.01	0.07	0.00	0.32	0.00	0.00
26	0.00	0.00	1.31	0.05	0.62	0.00	0.00	0.00	0.00	0.01	0.01	0.00
27	0.00	0.00	1.03	0.12	0.07	0.00	0.01	0.00	0.00	0.39	0.00	0.41
28	0.00	0.42	0.02	0.18	0.70	0.00	0.00	0.00	0.01	0.00	0.00	0.00
29	0.00	0.31	0.01	0.03	0.24	0.00	0.00	0.00	0.00		0.00	0.00
30	0.01	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00		0.00	0.00
31	0.05		2.13	0.22		0.00		0.01	0.00		0.00	
MAX	*1.09*	*3.73*	*2.13*	*1.49*	*1.77*	*1.26*	*0.05*	*0.07*	*0.07*	*0.39*	*1.59*	*0.90*
MEAN	*0.04*	*0.41*	*0.32*	*0.31*	*0.25*	*0.05*	*0.01*	*0.00*	*0.00*	*0.03*	*0.14*	*0.07*
MIN	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
SUM	*1.27*	*12.40*	*9.82*	*9.49*	*7.50*	*1.66*	*0.18*	*0.12*	*0.15*	*0.73*	*4.26*	*2.05*

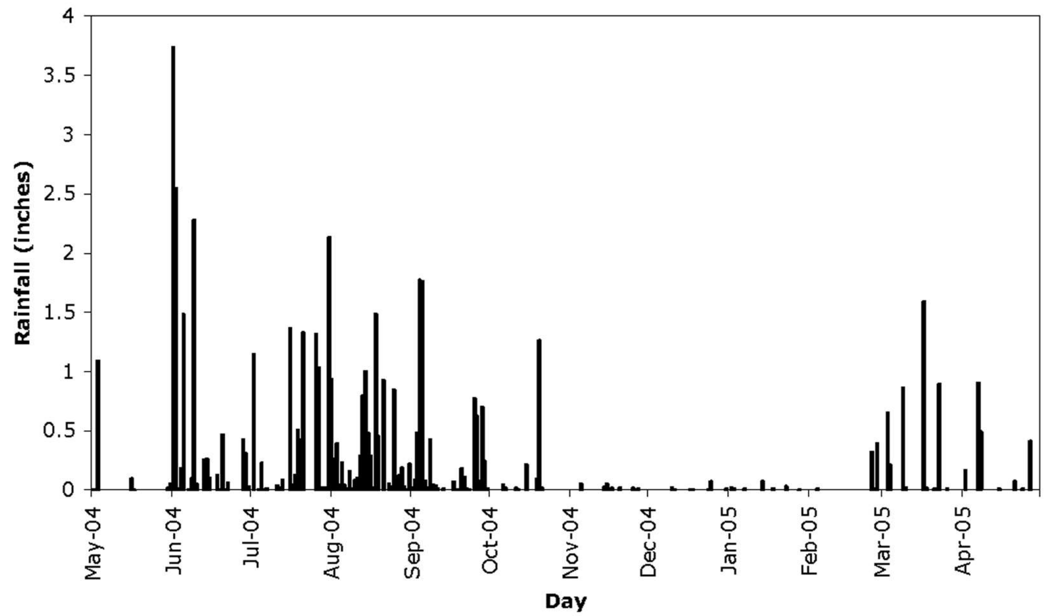

Figure B-1. Daily rainfall at G600_R and ROTNWX, WY2005

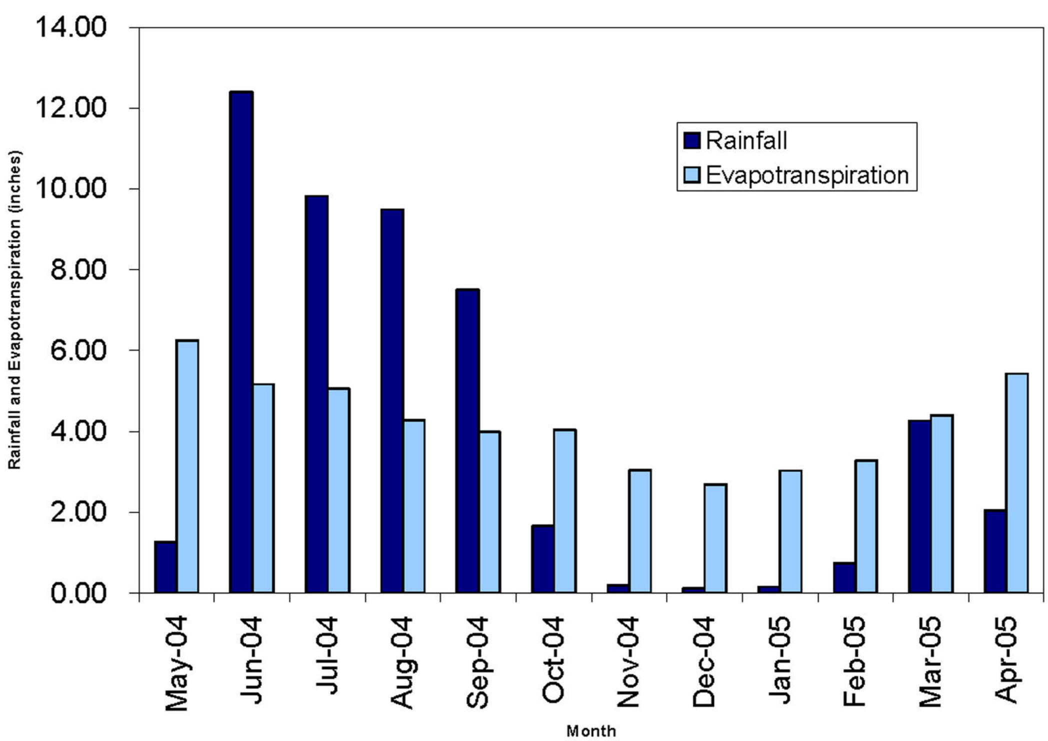

Figure B-2. Monthly rainfall and ET, WY2005

Appendix C – Evapotranspiration Data

Table C-1. STA-1W ET (inches), WY2005

Day	2004-05	2004-06	2004-07	2004-08	2004-09	2004-10	2004-11	2004-12	2005-01	2005-02	2005-03	2005-04
1	0.18	0.18	0.12	0.13	0.17	0.18	0.13	0.10	0.08	0.12	0.15	0.19
2	0.14	0.18	0.15	0.12	0.17	0.16	0.10	0.10	0.11	0.11	0.18	0.08
3	0.10	0.18	0.11	0.15	0.14	0.17	0.12	0.11	0.12	0.10	0.04	0.22
4	0.19	0.07	0.13	0.15	0.03	0.14	0.11	0.10	0.09	0.06	0.08	0.21
5	0.24	0.19	0.11	0.08	0.04	0.17	0.05	0.09	0.09	0.13	0.18	0.20
6	0.21	0.22	0.21	0.16	0.15	0.07	0.07	0.08	0.10	0.10	0.15	0.18
7	0.19	0.10	0.24	0.15	0.13	0.13	0.13	0.06	0.09	0.09	0.15	0.16
8	0.21	0.10	0.21	0.13	0.12	0.17	0.15	0.07	0.10	0.10	0.05	0.09
9	0.19	0.19	0.22	0.19	0.20	0.17	0.12	0.10	0.10	0.10	0.01	0.19
10	0.15	0.13	0.17	0.15	0.18	0.09	0.14	0.09	0.10	0.11	0.18	0.18
11	0.20	0.14	0.12	0.09	0.17	0.07	0.10	0.09	0.09	0.15	0.14	0.21
12	0.19	0.21	0.15	0.15	0.16	0.09	0.10	0.11	0.10	0.16	0.19	0.17
13	0.19	0.17	0.22	0.10	0.13	0.16	0.12	0.11	0.06	0.15	0.18	0.13
14	0.19	0.21	0.20	0.12	0.08	0.16	0.04	0.09	0.04	0.13	0.14	0.19
15	0.18	0.15	0.21	0.08	0.12	0.11	0.10	0.11	0.03	0.14	0.15	0.19
16	0.18	0.19	0.15	0.15	0.16	0.15	0.11	0.09	0.04	0.14	0.15	0.20
17	0.22	0.16	0.18	0.12	0.17	0.16	0.06	0.03	0.13	0.16	0.04	0.15
18	0.17	0.10	0.15	0.13	0.17	0.12	0.09	0.11	0.12	0.14	0.16	0.17
19	0.22	0.23	0.15	0.15	0.13	0.09	0.11	0.10	0.11	0.15	0.20	0.19
20	0.23	0.24	0.15	0.15	0.10	0.10	0.12	0.12	0.09	0.13	0.19	0.15
21	0.20	0.21	0.18	0.15	0.10	0.13	0.11	0.11	0.12	0.16	0.13	0.18
22	0.23	0.16	0.23	0.09	0.15	0.14	0.10	0.10	0.09	0.13	0.13	0.20
23	0.24	0.20	0.12	0.20	0.17	0.09	0.11	0.04	0.11	0.14	0.14	0.21
24	0.23	0.20	0.14	0.15	0.17	0.16	0.09	0.04	0.13	0.11	0.13	0.23
25	0.23	0.13	0.18	0.08	0.04	0.15	0.07	0.06	0.13	0.05	0.15	0.23
26	0.23	0.15	0.13	0.11	0.11	0.11	0.12	0.10	0.13	0.07	0.15	0.18
27	0.24	0.24	0.15	0.21	0.19	0.12	0.09	0.10	0.11	0.08	0.17	0.09
28	0.24	0.18	0.15	0.18	0.14	0.11	0.12	0.06	0.10	0.09	0.11	0.23
29	0.22	0.11	0.14	0.18	0.11	0.11	0.11	0.07	0.11		0.21	0.23
30	0.24	0.22	0.18	0.15	0.09	0.14	0.07	0.10	0.07		0.19	0.20
31	0.21		0.12	0.11		0.10		0.06	0.13		0.17	
MAX	*0.24*	*0.24*	*0.24*	*0.21*	*0.20*	*0.18*	*0.15*	*0.12*	*0.13*	*0.16*	*0.21*	*0.23*
MEAN	*0.20*	*0.17*	*0.16*	*0.14*	*0.13*	*0.13*	*0.10*	*0.09*	*0.10*	*0.12*	*0.14*	*0.18*
MIN	*0.10*	*0.07*	*0.11*	*0.08*	*0.03*	*0.07*	*0.04*	*0.03*	*0.03*	*0.05*	*0.01*	*0.08*
SUM	*6.25*	*5.17*	*5.06*	*4.28*	*3.98*	*4.04*	*3.05*	*2.69*	*3.03*	*3.28*	*4.40*	*5.43*

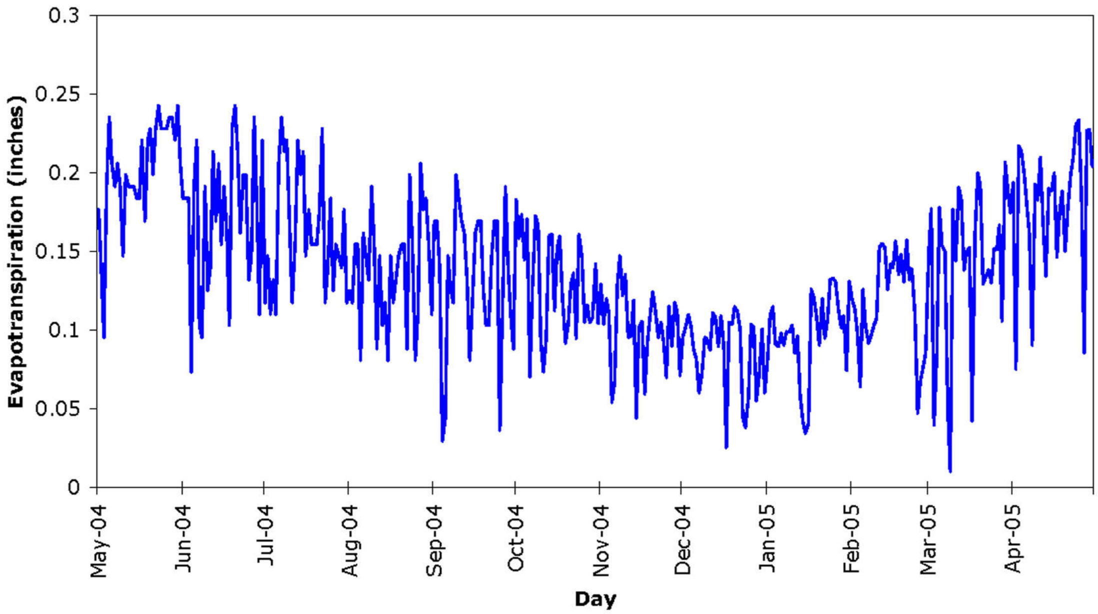

Figure C-1. Daily ET, WY2005

Appendix D – Stage Data

Table D-1. Cell 3 daily average stage (feet), WY2005

Day	2004-05	2004-06	2004-07	2004-08	2004-09	2004-10	2004-11	2004-12	2005-01	2005-02	2005-03	2005-04
1	12.26	11.02	13.60	14.71	14.55	14.93	14.29	13.99	14.09	14.19	14.32	14.53
2	12.11	12.05	13.75	14.97	14.51	14.84	14.18	13.97	14.05	14.11	14.28	14.36
3	12.07	12.71	13.89	15.09	14.35	14.79	14.23	13.95	14.08	14.07	14.33	14.33
4	12.16	12.80	13.97	15.17	14.28	14.76	14.28	13.92	14.25	14.04	14.38	14.39
5	12.08	12.91	14.06	15.25	14.32	14.72	14.18	13.91	14.25	14.02	14.29	14.23
6	11.97	13.08	14.04	15.17	14.47	14.67	14.15	14.09	14.16	13.99	14.28	14.14
7	11.87	13.06	14.17	15.19	14.87	14.67	14.18	14.10	14.11	13.97	14.33	14.09
8	11.79	13.03	14.38	15.12	15.14	14.57	14.17	14.03	14.07	13.95	14.36	14.15
9	11.73	13.07	14.27	14.94	15.28	14.41	14.09	14.00	14.03	13.93	14.44	14.10
10	11.66	13.27	14.22	14.78	15.32	14.36	14.10	13.99	14.00	14.01	14.55	14.05
11	11.60	13.44	14.15	14.71	15.22	14.45	14.18	14.02	13.97	14.08	14.65	14.01
12	11.54	13.50	14.11	14.72	14.98	14.46	14.09	14.06	13.95	14.00	14.64	13.98
13	11.48	13.42	14.07	14.76	14.66	14.46	14.12	14.11	13.93	14.05	14.57	13.95
14	11.41	13.54	14.03	14.77	14.75	14.39	14.25	14.04	13.97	14.20	14.53	13.92
15	11.45	13.67	13.99	14.89	14.79	14.38	14.45	14.06	14.02	14.26	14.49	13.88
16	11.48	13.84	13.99	14.82	14.69	14.29	14.31	14.11	14.04	14.30	14.50	13.84
17	11.47	13.82	14.10	14.66	14.69	14.20	14.20	14.04	14.13	14.32	14.56	13.80
18	11.42	13.74	14.08	14.83	14.51	14.22	14.13	14.02	14.11	14.30	14.66	13.76
19	11.36	13.80	14.19	14.86	14.36	14.34	14.17	14.05	14.17	14.19	14.74	13.72
20	11.32	13.75	14.46	14.78	14.25	14.36	14.09	14.11	14.10	14.16	14.62	13.68
21	11.25	13.77	14.60	14.88	14.31	14.43	14.05	14.03	14.06	14.22	14.63	13.63
22	11.21	13.75	14.53	14.99	14.50	14.36	14.06	14.00	14.04	14.26	14.61	13.59
23	11.17	13.74	14.34	14.83	14.45	14.34	14.21	14.04	14.07	14.29	14.66	13.53
24	11.14	13.71	14.20	14.84	14.50	14.32	14.24	14.15	14.20	14.28	14.67	13.48
25	11.13	13.68	14.13	14.77	14.37	14.37	14.15	14.07	14.21	14.30	14.65	13.42
26	11.06	13.65	14.13	14.73	14.38	14.26	14.09	14.09	14.12	14.26	14.63	13.36
27	11.00	13.61	14.40	14.67	14.58	14.22	14.12	14.26	14.07	14.35	14.63	13.36
28	10.95	13.61	14.60	14.66	14.64	14.21	14.09	14.32	14.04	14.36	14.63	13.32
29	10.90	13.65	14.67	14.61	14.69	14.23	14.05	14.30	14.01		14.60	13.27
30	10.85	13.63	14.62	14.56	14.87	14.20	14.02	14.19	14.03		14.61	13.20
31	10.83		14.56	14.49		14.24		14.14	14.20		14.54	
MAX	*12.26*	*13.84*	*14.67*	*15.25*	*15.32*	*14.93*	*14.45*	*14.32*	*14.25*	*14.36*	*14.74*	*14.53*
MEAN	*11.47*	*13.34*	*14.20*	*14.85*	*14.64*	*14.43*	*14.16*	*14.07*	*14.08*	*14.16*	*14.53*	*13.84*
MIN	*10.83*	*11.02*	*13.60*	*14.49*	*14.25*	*14.20*	*14.02*	*13.91*	*13.93*	*13.93*	*14.28*	*13.20*

Table D-2. Cell 5 daily average stage (feet), WY2005

Day	2004-05	2004-06	2004-07	2004-08	2004-09	2004-10	2004-11	2004-12	2005-01	2005-02	2005-03	2005-04
1	12.09	11.66	13.40	14.79	14.74	14.92	14.47	13.97	13.99	14.29	14.46	14.58
2	12.01	12.06	13.40	15.03	14.64	14.83	14.29	13.92	13.94	14.13	14.42	14.37
3	11.97	12.30	13.48	15.09	14.39	14.83	14.41	13.85	14.08	14.06	14.48	14.42
4	12.02	12.31	13.53	15.14	14.33	14.83	14.45	13.78	14.38	14.01	14.54	14.50
5	11.98	12.40	13.65	15.16	14.36	14.79	14.28	13.79	14.30	13.97	14.42	14.29
6	11.89	12.58	13.77	15.09	14.62	14.75	14.30	14.26	14.14	13.93	14.44	14.18
7	11.81	12.60	13.81	15.12	14.99	14.76	14.40	14.19	14.05	13.89	14.49	14.10
8	11.76	12.59	13.97	15.06	15.15	14.60	14.30	14.02	13.99	13.83	14.53	14.15
9	11.72	12.65	14.12	14.89	15.22	14.45	14.14	13.93	13.94	13.78	14.60	14.09
10	11.64	12.89	14.11	14.84	15.21	14.46	14.22	13.88	13.89	14.08	14.72	14.04
11	11.62	13.41	14.10	14.81	15.12	14.61	14.37	14.01	13.81	14.20	14.80	13.98
12	11.62	13.65	14.28	14.83	14.89	14.61	14.20	14.16	13.75	13.97	14.76	13.93
13	11.61	13.49	14.07	14.86	14.68	14.57	14.27	14.18	13.69	14.08	14.68	13.87
14	11.61	13.62	13.98	14.88	14.89	14.53	14.46	14.00	13.73	14.32	14.66	13.82
15	11.61	13.81	13.93	14.96	14.85	14.49	14.60	14.09	13.86	14.37	14.61	13.74
16	11.66	13.93	13.92	14.78	14.76	14.43	14.36	14.19	13.99	14.43	14.65	13.64
17	11.65	13.88	14.19	14.75	14.71	14.28	14.22	14.01	14.21	14.48	14.69	13.54
18	11.61	13.76	14.11	14.92	14.56	14.39	14.15	13.93	14.16	14.44	14.80	13.42
19	11.61	13.87	14.32	14.92	14.37	14.54	14.30	14.06	14.23	14.23	14.84	13.31
20	11.61	13.78	14.64	14.86	14.24	14.55	14.10	14.19	14.05	14.28	14.67	13.20
21	11.61	13.69	14.73	14.94	14.45	14.59	14.03	13.99	13.98	14.40	14.72	13.08
22	11.61	13.64	14.60	14.96	14.63	14.51	14.13	13.91	13.92	14.45	14.69	12.98
23	11.61	13.59	14.32	14.88	14.59	14.51	14.40	14.03	14.07	14.47	14.76	12.85
24	11.60	13.53	14.18	14.88	14.58	14.51	14.37	14.22	14.31	14.45	14.74	12.74
25	11.60	13.45	14.10	14.83	14.46	14.53	14.22	14.00	14.30	14.48	14.72	12.58
26	11.60	13.38	14.18	14.81	14.51	14.38	14.12	14.07	14.13	14.42	14.71	12.42
27	11.60	13.32	14.64	14.79	14.80	14.39	14.24	14.33	14.05	14.53	14.71	12.37
28	11.60	13.43	14.78	14.79	14.76	14.39	14.19	14.34	13.99	14.53	14.70	12.30
29	11.60	13.45	14.80	14.74	14.82	14.43	14.07	14.29	13.94		14.66	12.22
30	11.60	13.43	14.63	14.71	14.95	14.40	14.00	14.13	14.06		14.68	12.17
31	11.60		14.63	14.65		14.47		14.05	14.36		14.58	
MAX	*12.09*	*13.93*	*14.80*	*15.16*	*15.22*	*14.92*	*14.60*	*14.34*	*14.38*	*14.53*	*14.84*	*14.58*
MEAN	*11.70*	*13.20*	*14.14*	*14.89*	*14.71*	*14.56*	*14.27*	*14.06*	*14.04*	*14.23*	*14.64*	*13.50*
MIN	*11.60*	*11.66*	*13.40*	*14.65*	*14.24*	*14.28*	*14.00*	*13.78*	*13.69*	*13.78*	*14.42*	*12.17*

Appendix E – Seepage Calculation

There are three boundaries around STA-6; the northern boundary, the western boundary, and the eastern boundary. To calculate the seepage of Cell 5, there are four boundaries that should be taken into account: the northern boundary, the western boundary of Cell 5, the eastern boundary of Cell 5, and the boundary between Cell 3 and Cell 5. Cell 3 has three boundaries: the western boundary of Cell 3, the eastern boundary of Cell 3, and the boundary between Cell 3 and Cell 5. Lengths along these seepage boundaries (L) are included in the **Figure E-1**.

In this analysis, seepage was computed as:

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

where

G	=	levee (horizontal) and deep (vertical) seepage (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

To calculate hydraulic head difference between the unit and the boundary (ΔH), it is necessary to know the average stage values at each location. Units are Cell 3, Cell 5, or the entire STA-6.

Average stage east of STA-6 (stage discharge canal)
= Avg. (G354C_T, G393B_T, G607_H)
Average stage west of STA-6 (stage supply canal)
= Avg. (G352S_H, G392S_H, G600_T, G604_H)
Average stage north boundary = Avg. (G393B_T, G600_H)
Average stage Cell 3 = Avg. (G392S_T, G393B_H)
Average stage Cell 5 = Avg. (G352S_T, G354C_H)

Example of a seepage calculation equation:

STA-6 Seepage (ha-m) = [(24 * (3600/43560) / 5280) / 8.1068) * (K_{C5} * L_{N_C5} * (S_{C5} - S_N) + K_{C5} * L_{E_C5} * (S_{C5} - S_E) + K_{C3} * L_{E_C3} * (S_{C3} - S_E) + K_{C3} * L_{W_C3} * (S_{C3} -S_E) + K_{C5} * L_{W_C5} * (S_{C5} - S_W)]

KC5 = seepage coefficient of Cell 5
KC3 = seepage coefficient of Cell 3
S_N = average stage north of STA6
S_E = average stage east of STA-6
S_W = average stage west of STA-6
S_{C5} = average stage of Cell 5
S_{C3} = average stage of Cell 3

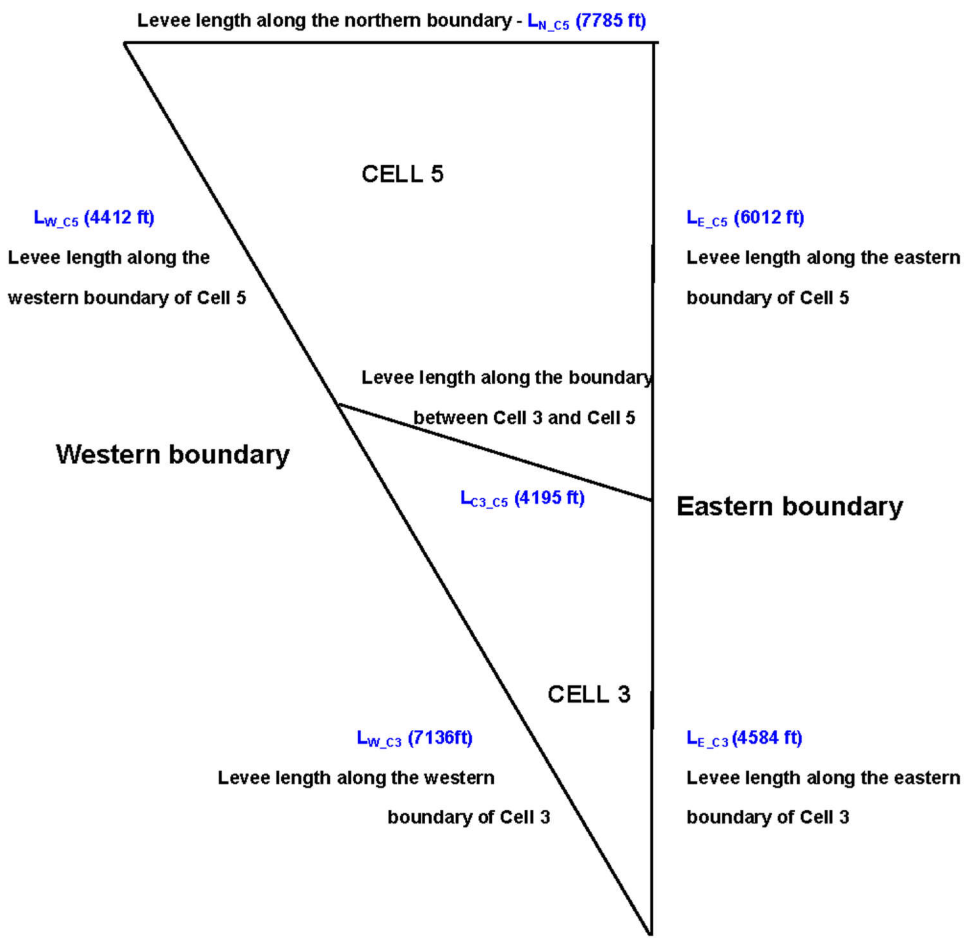

Figure E-1. Length of STA-6 Seepage Boundaries