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Water Budget Analysis for Stormwater Treatment Area 5

(Water Year 2007; May 1, 2006–April 30, 2007)

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EXECUTIVE SUMMARY

This report presents the water budget for Stormwater Treatment Area 5 (STA-5) from May 1, 2006–April 30, 2007 (Water Year 2007, or WY2007), augmenting previous water budget reports for STA-5. The information presented in this report coincides with the WY2007 period used in the *2008 South Florida Environmental Report – Volume I* (SFWMD, 2008), which includes all previous consolidated reports from 1999–2007. The report is based upon daily water budgets for Flow-ways (or Treatment Cells) 1 and 2 in STA-5.

STA-5 is located along the western boundary of the Everglades Agricultural Area (EAA) adjacent to the L-2 Canal, west of the northwestern corner of the Rotenberger Wildlife Management Area. Flow-ways 1 and 2 have a total effective treatment area of 4,118 acres. After initial flooding in 1999, culminating in October flood flows caused by Hurricane Irene, the Florida Department of Environmental Protection issued an emergency order to the South Florida Water Management District authorizing discharges from STA-5 for a 14-day period in October 1999. STA-5 began routine flow-through operations in June 2000.

WY2007 was the beginning of an extended drought in South Florida that started in spring 2006. The drought impacted STA-5 by reducing flows through the STA and water levels in each of the two flow-ways. Newly-constructed, Flow-way 3 was flow capable in December 2006 but was not used in WY2007 and does not appear in this report.

In WY2007, a total of 58,690 acre-feet (ac-ft) of water entered STA-5 from the gated culverts at structures G-342A through D. This flow constituted about 67 percent of the total inflow to the STA. Rainfall accounted for 14,399 ac-ft or 16 percent of the total inflow. Flow from seepage canal pumps at G-349A and G-350A contributed 4,208 ac-ft of water, which was 5 percent of the total inflow to the treatment area during the water year; 10,110 ac-ft of water came from the Miami Canal via pumping at G-507 (12 percent of total inflow). The pumps at G-349B and G-350B were not operational. The area around STA-5 received 41.96 inches of rainfall, about 78 percent of annual average rainfall. The STA-5 Pollution Prevention Plan (SFWMD, 2000b) cites expected flows into the STA through the G-342A through D culverts of 78,340 ac-ft per year or 215 ac-ft per day. During the study period, STA-5 received 161 ac-ft per day or 75 percent of the expected annual volume of flow through these structures.

During the same period, 54,163 ac-ft of water were discharged from the STA at G-344A through D (62 percent of the total outflow). Evapotranspiration accounted for an additional 17,795 ac-ft of water leaving the STA (20 percent of the total outflow). Estimated seepage out of STA-5 accounted for 18 percent of the total outflow from the STA or 15,305 ac-ft. Estimated seepage into STA-5 accounted for less than 1 percent (482 ac-ft) of the total inflow to the STA.

Water budget error was also less than 1 percent (13 ac-ft) for WY2007. Significant errors in the water budgets for the Flow-ways 1 and 2 during WY2007 were mainly due to the volume of water pumped from Cell 2B to Cell 1B during reconstruction of the G-343 structures between Cells 2A and 2B. The volume of water pumped between cells during construction was not recorded. Errors in the cell-by-cell water budgets ranged from 23 to 91 percent but effectively negate each other in the overall water budget for the entire STA.

ACKNOWLEDGMENTS

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INTRODUCTION

This report presents the water budget for Stormwater Treatment Area 5 (STA-5) during Water Year 2007 (WY2007) (May 1, 2006–April 30, 2007). The information presented in this report coincides with the WY2007 period used in the *2008 South Florida Environmental Report – Volume I* (SFWMD, 2008). The report is based upon daily water budgets for Treatment Cells (or Flow-ways) 1 and 2 in STA-5. Daily results were aggregated to develop monthly and annual water budgets for WY2007. The daily water budget accounted for inflow, outflow, rainfall, evapotranspiration, seepage, and error.

WY2007 was the beginning of an extended drought in South Florida that started in spring 2006. The drought impacted STA-5 by reducing flows through the STA and water levels in each of the two flow-ways. Newly-constructed, Flow-way 3 was flow capable in December 2006 but was not used in WY2007 and does not appear in this report.

This section of the report presents background and describes hydrometeorological monitoring at STA-5. Subsequent sections describe the operation of STA-5 and the sources of data used for the report. The actual water budget analyses for each treatment cell (flow-way) and the entire STA are presented, followed by a summary and recommendations. Supporting information on STA-5 site properties and monitoring stations, rainfall data, evapotranspiration data, and soil storage is also appended to the report.

Background

STA-5 is located along the western boundary of the Everglades Agricultural Area (EAA), adjacent to the L-2 Canal, west of the northwestern corner of the Rotenberger Wildlife Management Area. STA-5 and its location relative to major canals and roadways are shown in **Figure 1**. STA-5's principal purpose is to reduce the phosphorous load in runoff from the C-139 Basin to the north and west of STA-5. The land now occupied by the STA was used for agricultural purposes prior to construction.

STA-5 was completed in December 1998. Initial flooding occurred in January 1999 through October 1999. On October 15, 1999, due to conditions caused by Hurricane Irene, the Florida Department of Environmental Protection (FDEP) issued an emergency order to the South Florida Water Management District (SFWMD or District) authorizing discharges from STA-5 for a 14-day period until October 29, 1999.

The FDEP issued an Everglades Forever Act permit for STA-5 on February 29, 2000. The issuance of the National Pollution Discharge Elimination System (NPDES) permit was delayed due to objections by the Friends of the Everglades, an environmental interest group. However, authorization for interim operations of STA-5 under the terms and conditions of the NPDES permit was recommended by the Division of Administrative Hearings and granted by the FDEP on March 20, 2000. The project received an NPDES permit on May 24, 2001.

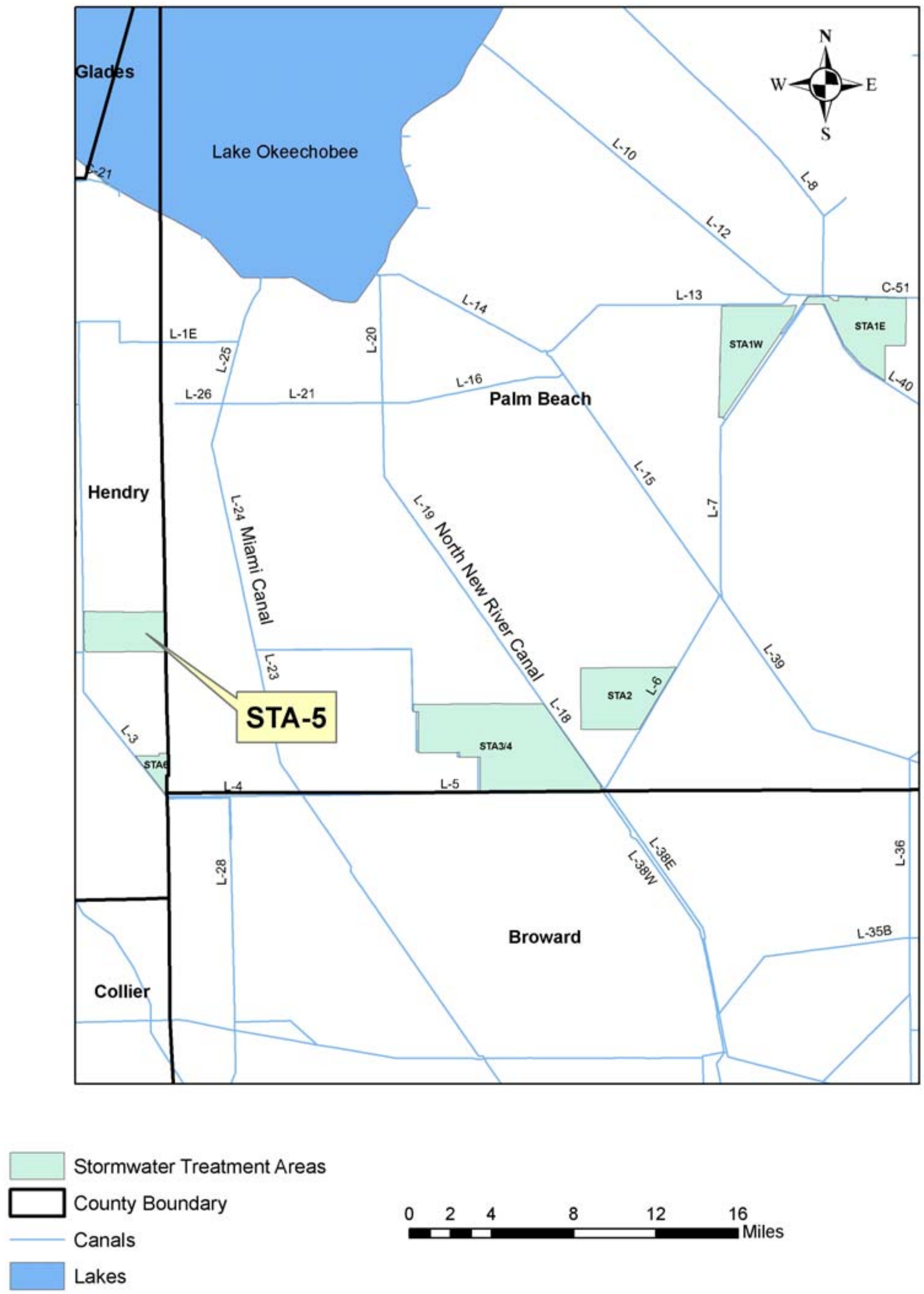

Figure 1. STA-5 location map.

At STA-5, Flow-way 2 (Cells 2A and 2B) began routine flow-through operations in June 2000; water entered the flow-way at G-342C and D and was discharged from the STA at G-344C and D (see **Figure 2**). Flow-way 1 (Cells 1A and 1B) began routine flow-through operations in August 2000.

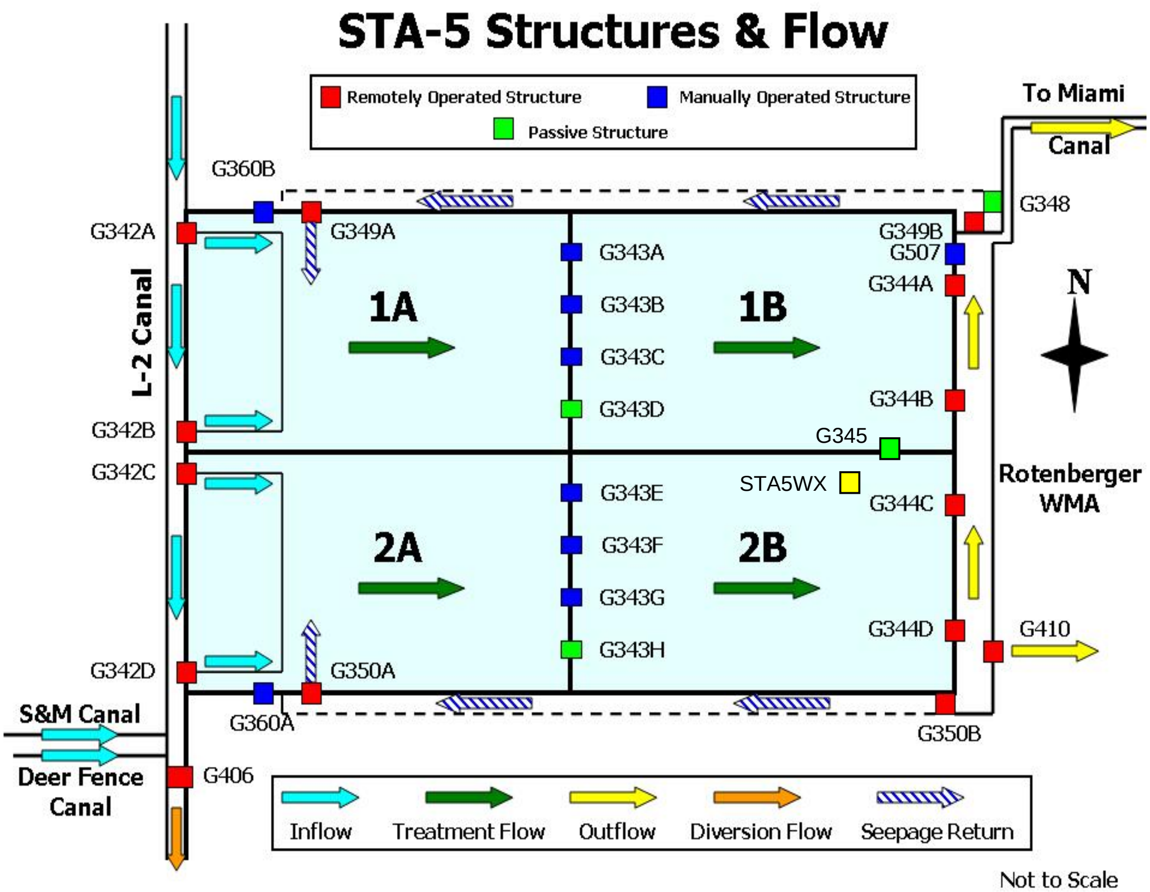

Figure 2. Schematic diagram of STA-5.

The water budget at STA-5 was comprised of the following hydrologic/hydraulic components:

- Inflow through pumps and gated structures
- Outflow through gated structures
- Rainfall
- Evapotranspiration
- Estimated Seepage
- Change in storage
- Water budget error

Each component made up an important part of the water budget for STA-5. The budget was developed for periods ranging from one day to one year using the following equation:

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

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 (ac-ft) per day, month or year]. Rainfall and evapotranspiration values (in inches or millimeters) have been converted to feet and multiplied by the effective surface area in acres (e.g., 839 acres for Cell 1A) to determine a volume of rainfall or evapotranspiration for a selected period.

A full year of daily average stage (water surface elevation), flow, rainfall, and evapotranspiration data was used in this report. The daily data were analyzed using Equation 1 and aggregated monthly and annually.

Site Description

Flow-ways 1 and 2 consist of four treatment cells with a total effective treatment area of 4,118 acres. **Figure 2** shows a schematic of the cells and control structures. The cells are divided into two flow-ways running from west to east. Flow-way 1 consists of Cells 1A and 1B, and Flow-way 2 consists of Cells 2A and 2B. The cells are bermed wetlands with gated culverts and weir structures that control inflow, outflow, and stage within the cells.

Vegetation in the STA-5 cells varies. It includes primrose willow, cattail, smartweed, mixed grasses, and submerged aquatic vegetation (Environmental Research Institute, 2001). The results of a recent vegetation study are shown in **Figure 3** and **Table 1** (Scheda Ecological Associates, 2006). **Appendix A**, **Table A-1**, contains a summary of site properties used in the water budget calculations for STA-5.

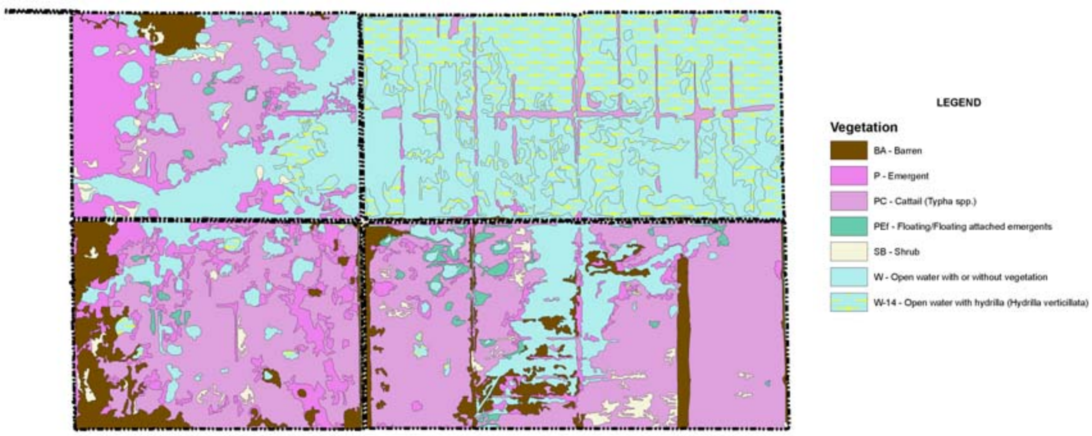

Figure 3. STA-5 2006 vegetation map.

Table 1. Summary of STA-5 2006 vegetation coverage.

Habitat	Percent Area
Emergent	11%
Cattail (Typha spp.)	36%
Floating/Floating attached emergents	1%
Shrub	2%
Open water with or without vegetation	26%
Open water with hydrilla (Hydrilla verticillata)	17%
Barren/Other	7%

STA Operation

The STA treatment cells receive runoff from the C-139 Basin via the L-2 Canal north of the Deer Fence Canal (see **Figure 2**). Under normal operating conditions, the bypass structure in the L-2 Canal south of the STA, G-406, is closed. The gates at G-406 are opened when the water level in the L-2 Canal exceeds 16.0 feet National Geodetic Vertical Datum of 1929 (ft NGVD29).

In the STA, water flows west to east by gravity, into distribution ditches located east of the gated culverts at G-342A through D in Cells 1A and 2A (see **Figure 2**). Two pump units at G-349A and two at G-350A recirculate water from the seepage canals located along the northern and southern borders of the STA into Cells 1A and 2A, respectively. The pump at G-349A was removed in August 2006 as work began on STA-5 expansion (construction of Flow-way 3). Eight intermediate combination weir/box culvert structures, G-343A through H, pass flow from Cells 1A and 2A to Cells 1B and 2B. The G-343A through D structures were reconstructed starting in WY2005. Upon completion of work on the G-343 structures in Flow-way 1 between Cells 1A and 1B in WY2006, the G-343 E through H structures in Flow-way 2 were reconstructed. Culverts at G-345 located near G-344B and G-344C between Cells 1B and 2B, provide the ability to transfer water between Flow-ways 1 and 2 in the eastern treatment cells.

Water is discharged to the east through structures G-344A through D. Water from the STA flows in a canal leading to the Miami Canal, five miles to the east. Water discharged from STA-5 is also used for hydropattern restoration in the Rotenberger Wildlife Management Area using pumps located at structure G-410 on the discharge canal near the southeastern corner of STA-5.

STA-5 operates under a revised operation plan (SFWMD, 2000a). This interim plan accommodates additional flow to STA-5, which will be directed to STA-6 after Section 2 of STA-6 is constructed. STA-6, Section 2 became flow capable in December 2006 but because of the drought, no additional flow was routed to it from STA-5. A full description of STA-5, including its design and operation, are provided in the plan.

Cell 1B was taken out of service in February 2005 (WY2005) for installation of new gated structures at G-343A through D. Starting in January 2006, the water levels in Cells 2A and 2B were drawn down to allow reconstruction of the G-343 structures in Flow-way 2. This work was completed in WY2007 but installation of the instruments needed to record headwater and tailwater stage at each of the structures was not completed. This also prevented the computation of flow at these structures.

Monitoring

During WY2007, rainfall, stage, gate openings, and pump operations were monitored at STA-5. Flow was computed for pumps and gated culverts using calibrated rating equations. The calibration was based on in-channel flow measurements using acoustic Doppler devices. Evapotranspiration was estimated for STA-5 based on data from a monitoring station located approximately 30 miles to the east at Stormwater Treatment Area 1 West (STA-1W). Seepage in each cell was estimated using an equation that relates differences in water surface elevations along a length of levee to the amount of water gained or lost due to seepage. This is discussed in detail below, however, estimated seepage is not recorded in DBHYDRO, the District's hydrometeorological database.

Appendix A, **Table A-2** through **Table A-5**, lists the stations where daily average stage, flow, rainfall, and evapotranspiration data were recorded together with database (DB) key numbers and station descriptions. Station locations are shown in **Figure 2**.

Rainfall

Daily rainfall data for STA-5 were collected at weather stations, STA5WX and G343B_R. Missing values were filled based upon the best available information, usually from nearby rain gauges. The data were loaded into a preferred DB key every month. The preferred DB key provided a high quality, continuous record of daily rainfall amounts. **Appendix B**, **Table B-1**, lists the daily rainfall amounts recorded at STA-5 and used in this analysis. **Figure B-1** displays this information graphically. Monthly rainfall and evapotranspiration are shown in **Figure B-2**.

Stage and Gate Openings

Stage and gate opening data were monitored on an instantaneous basis. Both parameters were recorded using two methods. The first method sampled the state of the stage and gate openings, stored data on-site in solid-state, CR10 data loggers, and transmitted the data periodically to a District database. The second method transmitted stage and gate opening data to a District database via telemetry. Daily mean stage values and gate openings used in this study were based on telemetered data.

Flow

The instantaneous stage data and gate openings were used to compute instantaneous flows at the inlet and outlet structures at STA-5. Instantaneous stage data were also averaged and recorded as daily average stage in DBHYDRO. Each treatment cell has several structures associated with it. As a result, more than one stage value was available to compute average daily stage within each of the treatment cells. The daily stage at each of the recording gauges within a cell was arithmetically averaged to generate a daily mean stage for the entire cell.

Daily average flow rates were determined using two methods, culvert equations and pump performance equations. At pump stations G-349A, G-350A, G-349B, G-350B, and G-507, average daily flow was computed instantaneously using motor speed and headwater and tailwater elevation data. The daily average flow at these stations was recorded in DBHYDRO and reviewed on a monthly basis for accuracy and missing data.

Daily average flow at the gated culverts in STA-5 (G-342A through D, G-344A through D, and G-406) were based on flow values that were calculated using instantaneous headwater stage, tailwater stage, and gate openings. A complete record of daily average flow was loaded monthly to a preferred DB key in DBHYDRO. A final quality assurance/quality control check of the flow data in the preferred DB keys was performed on a quarterly basis.

Evapotranspiration

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 potential evapotranspiration data used in this report were derived from ET data for STA-1W that is based on a predictive equation (Abtew, 1996). These data for ET were considered to be of the highest quality available. **Appendix C**, **Table C-1**, lists the daily ET values used, and **Figure C-1** displays this information graphically.

Estimated Seepage

No direct measurement of seepage was made at STA-5 during the period of this study. In this analysis, seepage was computed as (Bouwer, 1978):

$$G = 1.983\, K_{sp}\, L \Delta H \qquad \text{(Equation 2)}$$

where

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 cell stage and the water level along the cell's boundary (ft)
	1.983	=	constant to convert from cfs to ac-ft/d

The value of K_{sp} was adjusted to minimize the sum of the squared daily water budget error for the entire STA for the period of record starting in WY2001 through WY2007. Unique seepage coefficient values were used for each treatment cell in this report (Huebner, 2001) and are shown in **Appendix A**, **Table A-6**.

In general, there is a net loss of water from the STA due to higher water surface elevations maintained in the treatment cells as compared to the discharge canal and the seepage canals located along the northern and southern boundaries of the STA.

WATER BUDGET

Methodology

In this analysis, STA-5 was divided into two hydrologic units: Flow-way 1, consisting of Cells 1A and 1B, and Flow-way 2, consisting of Cells 2A and 2B. A water budget analysis was performed on each of the units on a daily, monthly, and annual basis using Equation 1. A daily, monthly, and annual water budget was also completed for the entire STA using data from both flow-ways. 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 annual water budgets.

Results

Rainfall and Evapotranspiration

Rainfall data for STA-5 are presented in **Appendix B**. Evapotranspiration (ET) data is presented in **Appendix C**. **Table 2** presents the annual rainfall summary for WY2007. The amount of rainfall for WY2007 was 41.96 inches (78 percent of expected rainfall based on the historic record for the Everglades Agricultural Area). **Figure 4** shows the monthly rainfall surplus or deficit based on the sum of rainfall less estimated ET at STA-5. In 11 of 12 months, ET exceeded rainfall. During WY2007, ET exceeded rainfall by a total of 9.9 inches.

Table 2. Rainfall amounts for WY2007.

Water Year	Rainfall Amount (inches)	Percent of Expected Rainfall
WY2007	41.96	78

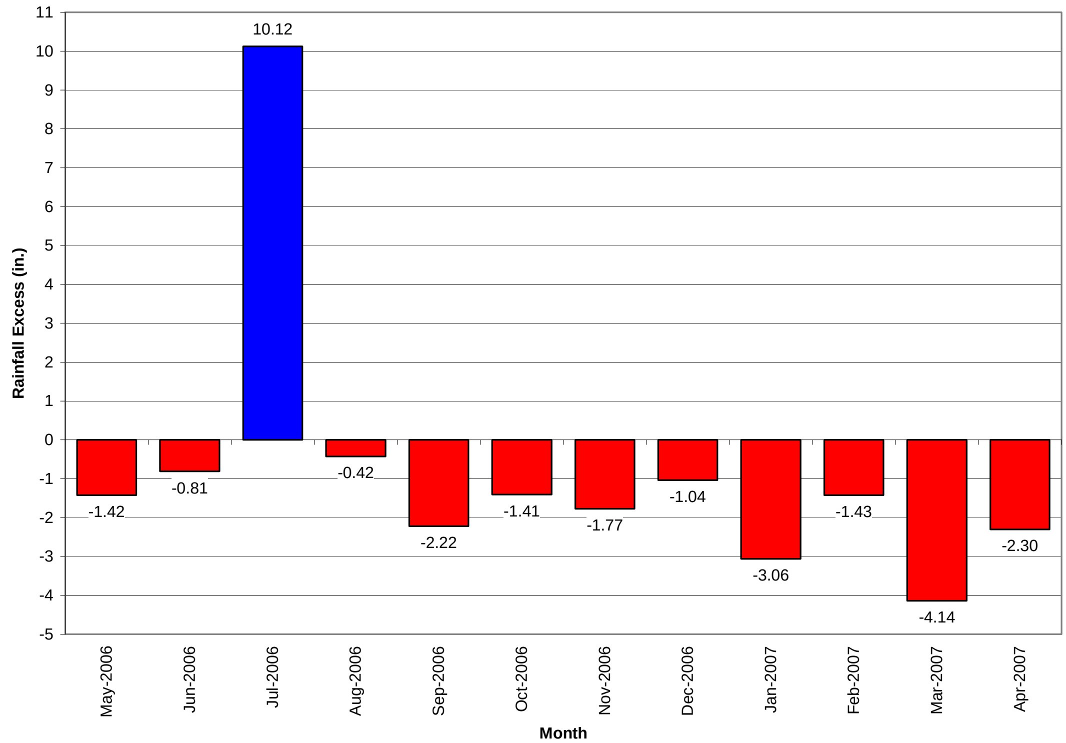

Figure 4. Monthly rainfall less estimated evapotranspiration at STA-5.

Flow-way 1 – Cells 1A and 1B

Table 3 presents the annual water budget summary for Flow-way 1 at STA-5. The properties (width, length, and surface area) of the elements that make up Flow-way 1 are listed in **Appendix A**, **Table A-1**. **Table 3** also summarizes errors for the analysis based on WY2007 daily water budgets. This document includes similar summaries in discussion of other hydrologic units at STA-5 (see **Table 6** and **Table 10**). Inflow was measured at G-342A and B, G-349A, and G-507_P; outflow was measured at G-344A and B.

Error in the water budget was less than 23 percent. However, the water budget results for WY2007 for each flow-way are misleading because, from February 2005 through the remainder of the water year, Cells 1B, 2A and 2B were drawn down at some time for reconstruction of the intermediate culverts at G-343. The water from Cell 1B was pumped to Cell 2B and, later in WY2007, water from Cell 2B was subsequently pumped into Cell 1B.

A coefficient of seepage that was unique for each flow-way was used for this report. The seepage coefficient used for Cells 1A and 1B was 0.9 cfs/mi/ft. The previous report (Huebner, 2007) used a seepage coefficient of 0.5 cfs/mi/ft for these cells. Daily water budget residuals are shown in **Figure 5**. Estimated net seepage in Flow-way 1 constituted 7.5 percent of the water budget for WY2007.

Table 3. Annual water budget summary for Cells 1A and 1B.

Cells 1A & 1B	WY 2007	% Inflow
INFLOW	56,942	88.8
SEEPAGE IN	0	0
RAIN	7,200	11.2
TOTAL INFLOW	64,142	% Outflow
OUTFLOW	64,661	80.1
SEEPAGE OUT	7,141	8.9
ET	8,898	11.0
TOTAL OUTFLOW	80,699[1]	
CHANGE IN STORAGE	42	% ERROR
REMAINDER	16,599	23

Notes:
1. Includes 13,638 ac-ft of flow from Cell 1B to Cell 2B.
2. All values in ac-ft.
3. INFLOW measured at G-342A , G-342B, G-349A, and G-507.
4. RAIN measured at G343B_R and STA5WX.
5. OUTFLOW measured at G-344A and G-344B.
6. ET measured at STA-1W.
7. SEEPAGE IN and SEEPAGE OUT estimated based on head differences between cell water levels and surrounding water levels using a seepage coefficient of: Cell 1A=0.9 cfs/mi/ft, Cell 1B=0.9 cfs/mi/ft, Cell 2A=4.0 cfs/mi/ft, Cell 2B=4.0 cfs/mi/ft.
8. ΔS for water levels below average ground level estimated using an equation (**Appendix D**) based on data available in Abtew et al. (1998).

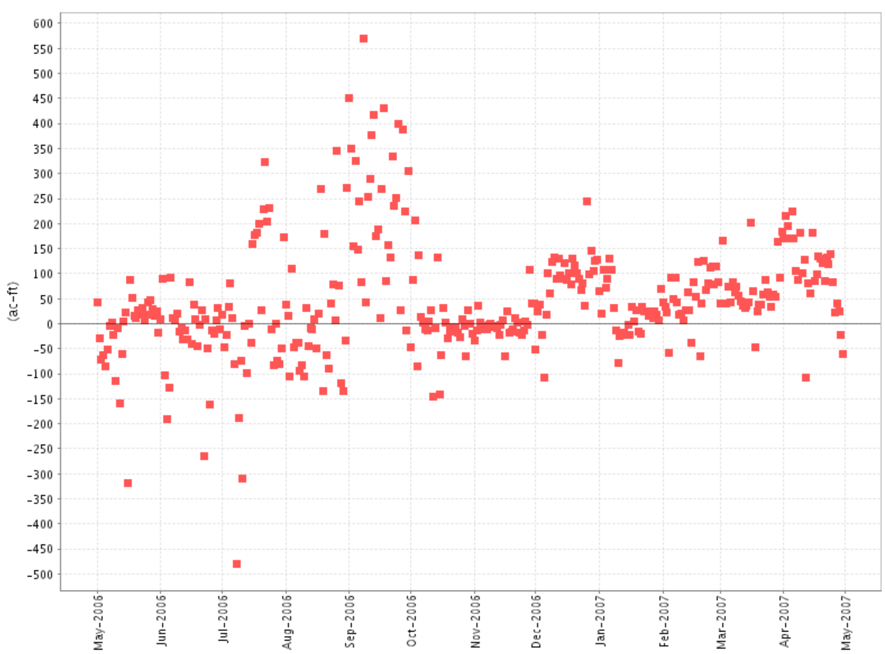

Figure 5. Daily water budget residuals for Cells 1A and 1B.

Figure 6 shows the estimated seepage for Cells 1A and 1B for WY2007. Table 4 summarizes inflow and outflow at culverts and pumps in Flow-way 1 for WY2007. **Figure 7** displays the water levels in the treatment cells versus surrounding canals and cells. For the year examined, seepage out of Flow-way 1 was greater than seepage in. In general, seepage flowed into the treatment cells from the L-2 Canal and Cells 2A and 2B and out of the treatment cells toward the seepage canal along the STA's northern boundary and the discharge canal along the eastern boundary. Inflow, outflow, and stage for Cells 1A and 1B are shown in Figure 8. Approximately 88 percent of the flow leaving Flow-way 1 at G-344A and B entered the STA at G-342A and B for WY2007. Table 5 presents the results of the monthly water budget analysis for Cells 1A and 1B. Average daily error is less than 1.0 inch, except in September 2006.

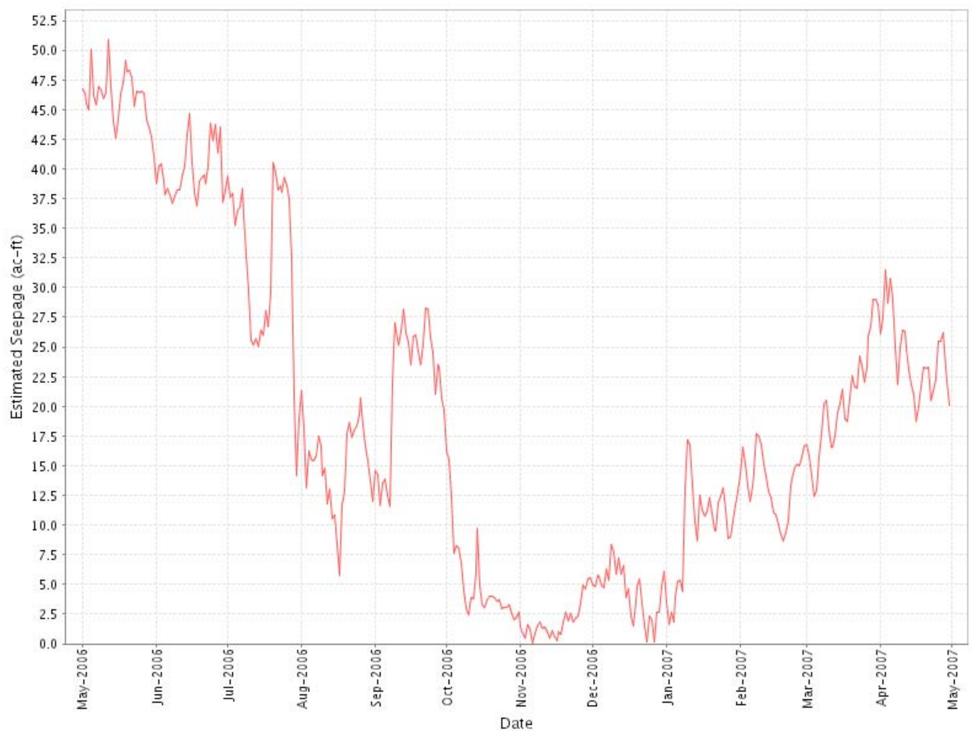

Figure 6. Estimated daily seepage into Cells 1A and 1B.

Table 4. Inflow and outflow at structures – Flow-way 1.

Water Year	Inflow (ac-ft)	Outflow (ac-ft)	Outflow as Percentage of Inflow
WY2007	56,942*	64,661	114

Notes: **Inflow calculated at G-342A, G-342B, G-349A, and G-507_P.**

Outflow calculated at G-344A, G-344B, and G-345.

*does not include water pumped from Cell 2B to Cell 1B for G-343 reconstruction

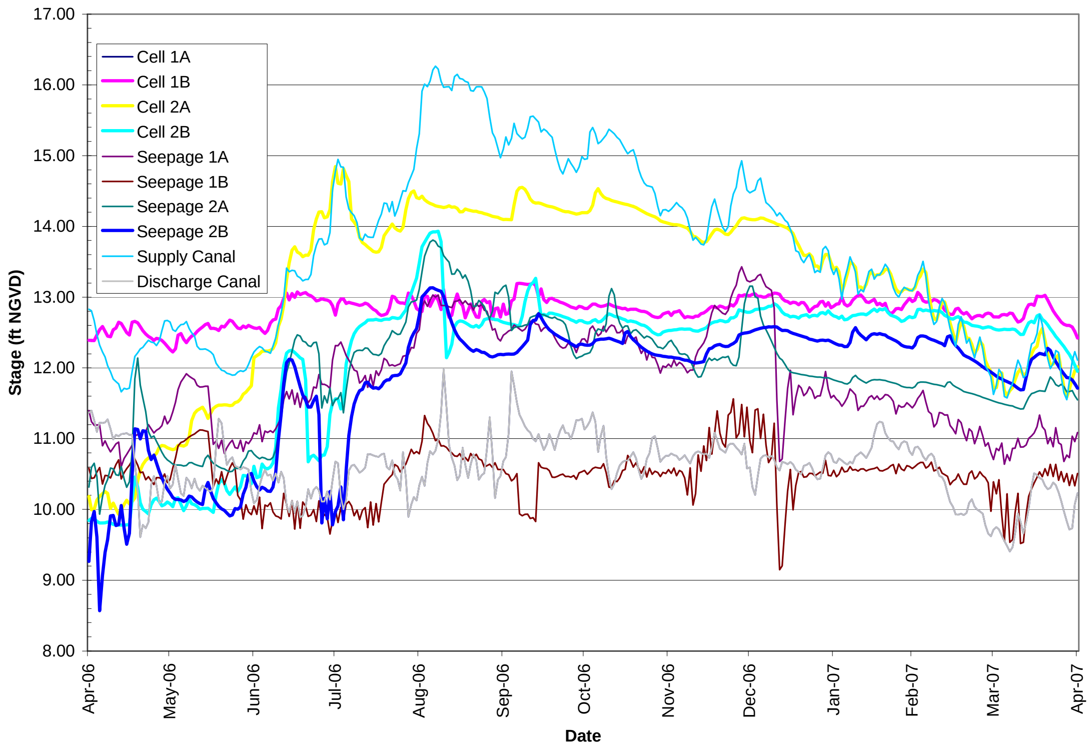

Figure 7. Cells 1A, 1B, 2A, and 2B stage versus surrounding areas.

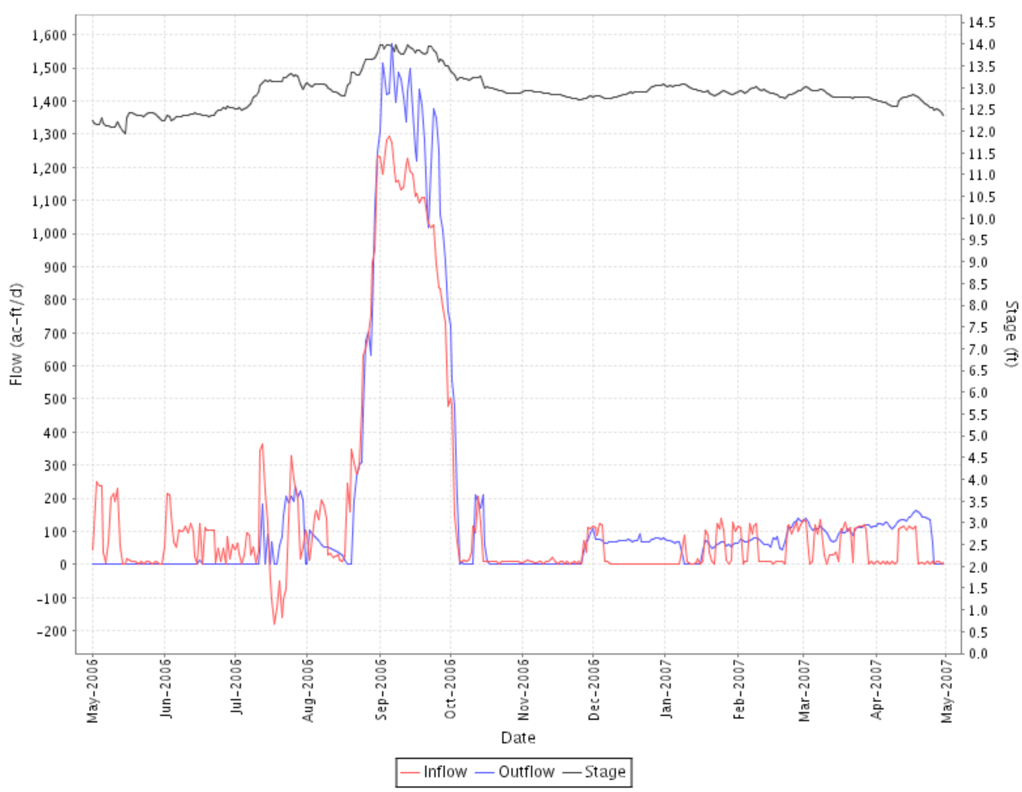

Figure 8. Inflow, outflow, and stage for Cells 1A and 1B.

Table 5. Monthly water budget for Cells 1A and 1B.

Month-Year	INFLOW	OUTFLOW	CHANGE IN STORAGE	ET	RAIN	SEEPAGE	REMAINDER
May-06	1,986	0	-200	1,013	769	1,429	-512
Jun-06	2,445	16	401	848	709	1,193	-697
Jul-06	2,012	2,317	840	873	2,610	996	404
Aug-06	9,247	7,505	1,490	869	796	470	291
Sep-06	32,286	39,173	-625	753	372	662	7,304
Oct-06	1,972	2,818	-1,290	737	496	164	-39
Nov-06	529	283	-123	530	226	57	-9
Dec-06	579	2,287	552	442	264	136	2,573
Jan-07	1,133	1,421	-400	534	9	297	710
Feb-07	1,593	2,301	114	542	297	379	1,446
Mar-07	2,162	3,262	-406	827	117	632	2,037
Apr-07	997	3,278	-311	930	535	726	3,090

Note: Negative change in storage values indicate decreasing stage over the month. No signs are shown for other values, except error. To compute the water budget error, flow into the cell was considered positive and flow out of the cell was considered negative.

Flow-way 2 – Cells 2A and 2B

Table 6 shows the WY2007 water budget for Flow-way 2, comprised of Cells 2A and 2B. Inflow was measured at G-342C and D and G-350A; outflow at G-344C and D. The seepage coefficient for the Cells 2A and 2B was 4.0 cfs/mi/ft. As a percentage of the budget, error was 91 percent for WY2007. The apparently large error is attributed to the unmeasured, inter-flow-way pumping that occurred during the reconstruction of the G343 structures.

Table 6. Annual water budget summary for Cells 2A and 2B.

Cells 2A & 2B	WY 2007	% Inflow
INFLOW	29,703[1]	71.4
SEEPAGE IN	4,718	11.4
RAIN	7,200	17.2
TOTAL INFLOW	41,621	% Outflow
OUTFLOW	3,140	20.6
SEEPAGE OUT	3,207	21.1
ET	8,898	58.3
TOTAL OUTFLOW	15,245	
CHANGE IN STORAGE	570	% ERROR
REMAINDER	-25,805	-91

Notes:

1. Includes 13,637 ac-ft of flow from Cell 1B to Cell 2B.
2. All values in ac-ft.
3. INFLOW measured at G-342C, G-342D, G-350A, and G-345.
4. RAIN measured at G343B_R and STA5WX.
5. OUTFLOW measured at G-344C and G-344D.
6. ET measured at STA1W.
7. SEEPAGE IN and SEEPAGE OUT estimated based on head differences between cell water levels and surrounding water levels using a seepage coefficient of: Cell 1A=0.9 cfs/mi/ft, Cell 1B=0.9 cfs/mi/ft, Cell 2A=4.0 cfs/mi/ft, Cell 2B=4.0 cfs/mi/ft.
8. ΔS for water levels below average ground level estimated using an equation (**Appendix D**) based on data available in Abtew et al. (1998).

Figure 9 shows the daily residual error plot for the WY2007 water budget. **Table 7** shows the annual inflow and outflow at culverts and pumps for Flow-way 2 during WY2007.

Net estimated seepage was into the flow-way in WY2007 (1,511 ac-ft). Seepage into and out of Flow-way 2 is depicted in **Figure 10**. In general, seepage into Flow-way 2 occurred during the latter part of the water year when Cells 2A and 2B were drawn down for G-343 reconstruction. Stage in the cells and in surrounding areas is shown in **Figure 7**. **Figure 11** shows the inflow, outflow, and stage in Cells 2A and 2B for the study period. Approximately 88,343 ac-ft of water were discharged at G-344C and D. This was 102 percent of the inflow to the southern flow at G-342C and D for WY2007.

In the monthly water budget shown in **Table 8**, the right column shows the monthly error in ac-ft/month. All average daily errors based on the monthly water budget are less than 1.0 inch, except for July and August 2006.

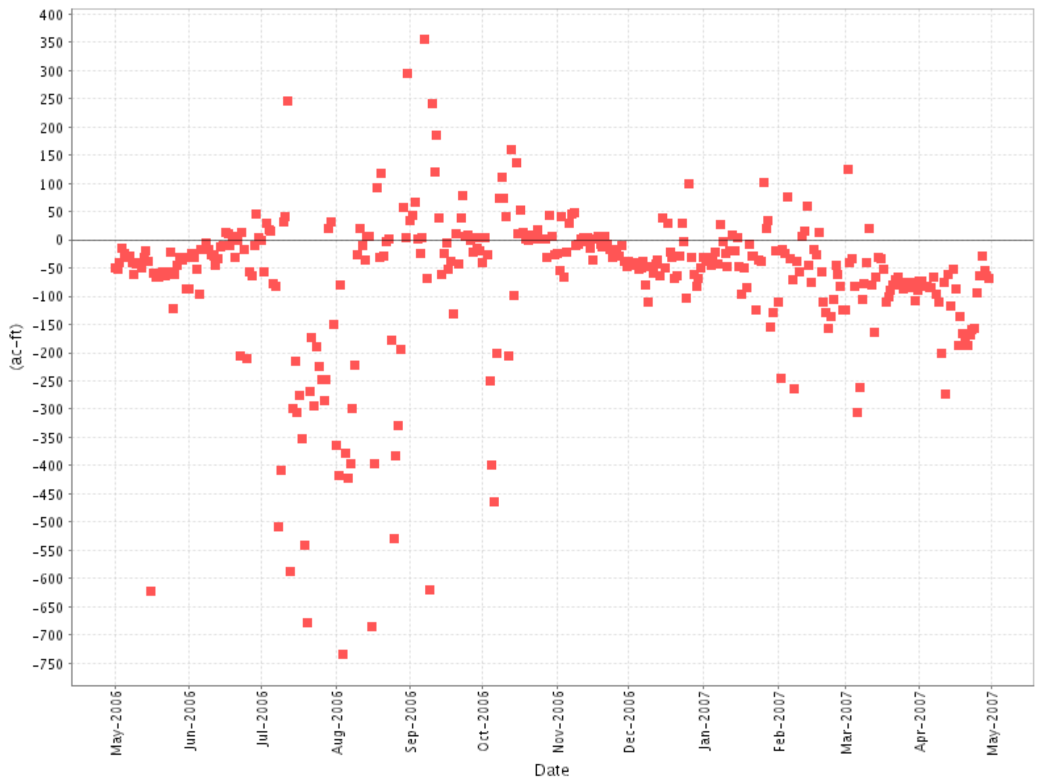

Figure 9. Water budget residuals for Cells 2A and 2B.

Table 7. Inflow and outflow at structures – Flow-way 2.

Water Year	Inflow (ac-ft)	Outflow (ac-ft)	Outflow As Percentage of Inflow
WY2007	29,703	3,140*	10

Note: Inflow calculated at G-342C, G-342D, G-350A, and G-345.
Outflow calculated at G-344C and G-344D.
*does not include water pumped from Cell 2B to Cell 1B for G-343 reconstruction

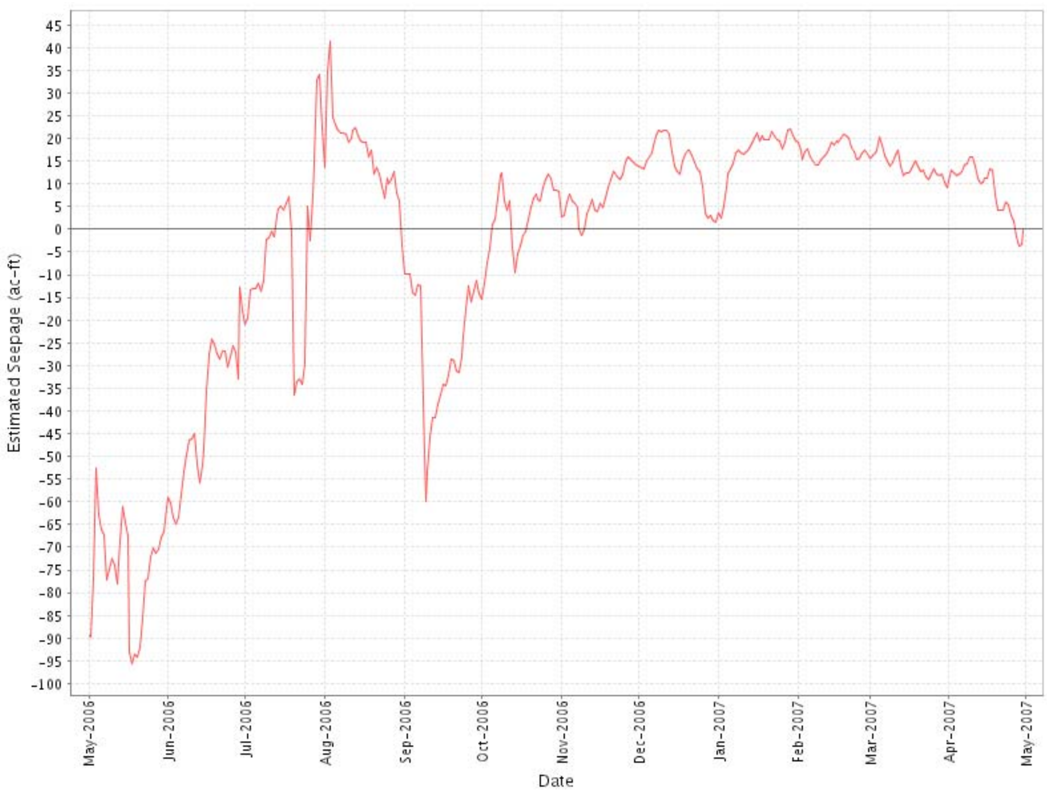

Figure 10. Estimated daily seepage at Cells 2A and 2B.

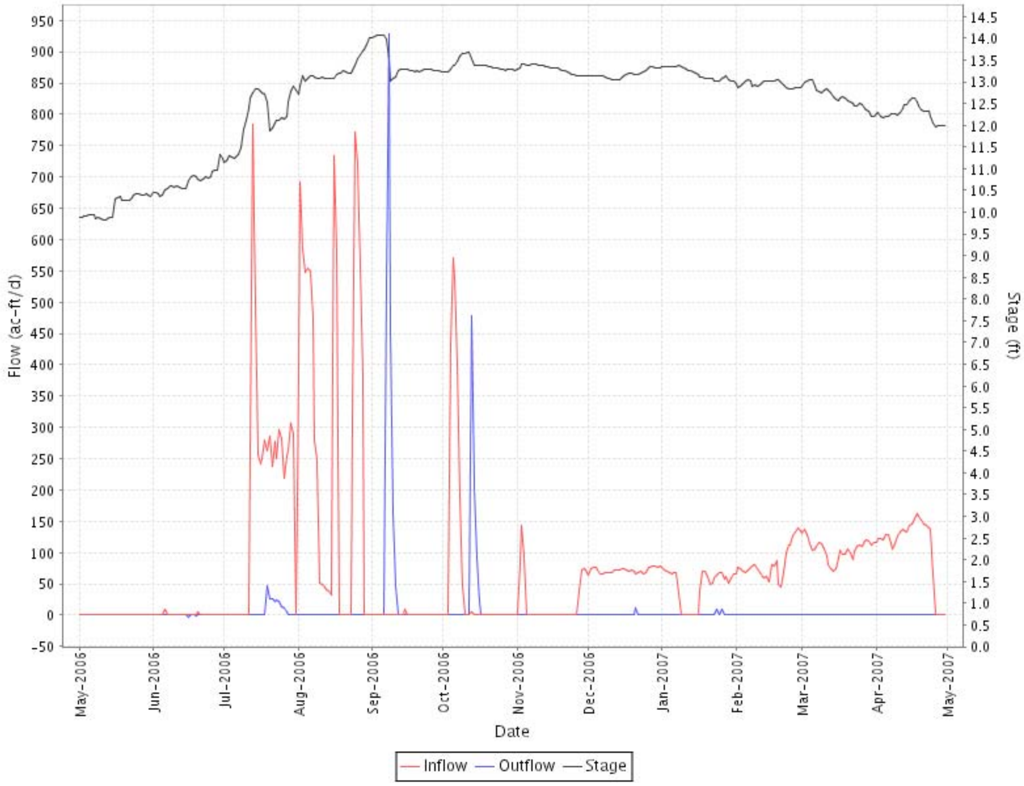

Figure 11. Inflow, outflow, and stage at Cells 2A and 2B.

Table 8. Monthly water budget for Cells 2A and 2B.

Month-Year	INFLOW	OUTFLOW	CHANGE IN STORAGE	ET	RAIN	SEEPAGE	REMAINDER
May-06	0	0	41	1,013	769	-2,335	-2,050
Jun-06	14	-3	78	848	709	-1,216	-1,016
Jul-06	5,805	197	1,457	873	2,610	-148	-6,037
Aug-06	8,623	1	2,475	869	796	528	-5,547
Sep-06	10	2,115	-1,580	753	372	-795	111
Oct-06	2,190	801	70	737	496	91	-987
Nov-06	579	0	-257	530	226	230	-303
Dec-06	2,218	12	377	442	264	437	-1,214
Jan-07	1,420	18	-659	534	9	524	-1,012
Feb-07	2,303	0	-288	542	297	486	-1,861
Mar-07	3,262	0	-435	827	117	434	-2,553
Apr-07	3,278	0	-707	930	535	255	-3,336

Note: Negative storage values indicate decreasing stage over the month. No signs are shown for other values, except error. To compute the water budget error, flow into the cell was considered positive and flow out of the cell was considered negative.

STA-5

Table 9 summarizes the annual inflow and outflow volumes at culverts and pumps at STA-5 for WY2007. **Table 10** shows the summary of the water budget for the entire STA, which includes both flow-ways, discussed above. Using a seepage coefficient of 0.9 cfs/mi/ft for Cells 1A and 1B and 4.0 cfs/mi/ft for Cells 2A and 2B, error for the WY2007 budget negligible. Net estimated seepage was about 18 percent of the water budget for WY2007. **Figure 12** shows the residual in the daily water budgets. The peaks in the residual plot occur during periods of high inflow from July through October 2006.

Table 9. Annual inflow and outflow at culverts and pumps - STA-5.

Water Year	Inflow (ac-ft)	Outflow (ac-ft)	Outflow as Percentage of Inflow
WY2007	73,007	54,163	74

Note: Inflow calculated at G-342A through D, G-349A, G-350A, and G-507_P. Outflow calculated at G-344A through D.

Table 10. Annual water budget summary for STA-5.

STA-5	WY 2007	% Inflow
INFLOW	73,007	83.1
SEEPAGE IN	482	0.6
RAIN	14,399	16.4
TOTAL INFLOW	87,889	% Outflow
OUTFLOW	54,163	62.1
SEEPAGE OUT	15,305	17.6
ET	17,795	20.4
TOTAL OUTFLOW	87,264	
CHANGE IN STORAGE	612	% ERROR
REMAINDER	-13	0

Notes:

1. All values in ac-ft.
2. INFLOW measured at G-342C, G-342D, and G-350A.
3. RAIN measured at STA5WX.
4. OUTFLOW measured at G-344C and G-344D.
5. ET measured at STA-1W.
6. SEEPAGE IN and SEEPAGE OUT estimated based on head differences between cell water levels and surrounding water levels using a seepage coefficient of: Cell 1A=0.9 cfs/mi/ft, Cell 1B=0.9 cfs/mi/ft, Cell 2A=4.0 cfs/mi/ft, Cell 2B=4.0 cfs/mi/ft.
7. ΔS for water levels below average ground level estimated using an equation (**Appendix D**) based on data available in Abtew et al. (1998).

Figure 13 presents the estimated seepage out of STA-5. Inflow, outflow, and stage are shown in **Figure 14**. **Table 11** shows the monthly water budget summary. The daily average errors were less than 1.0 in.

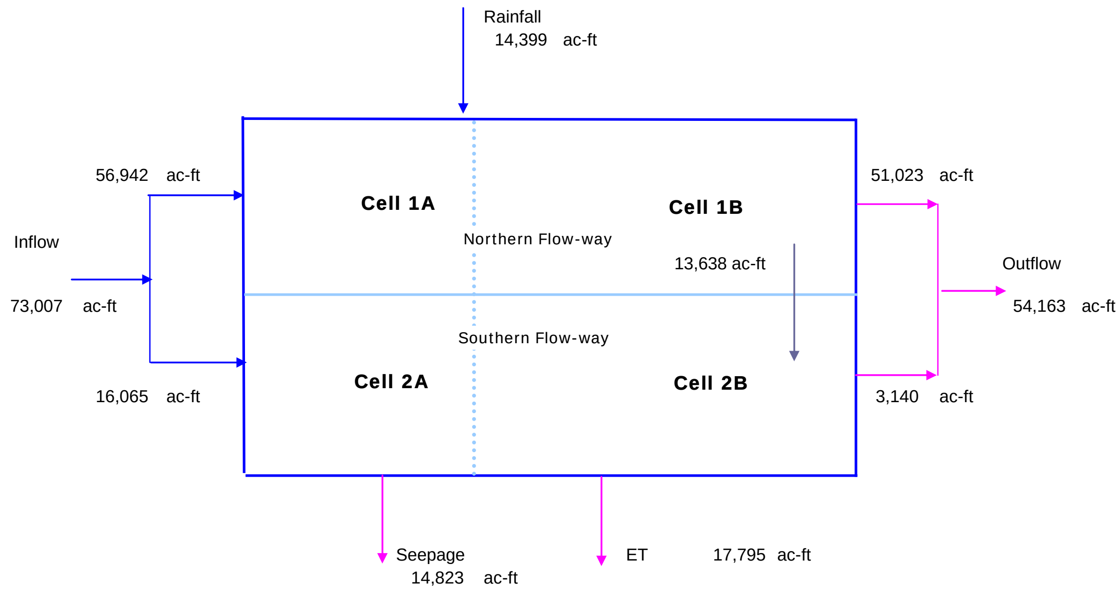

Figure 15 summarizes the inflows and outflows to STA-5. The inflow volume includes seepage water return at the G349A and G350A pumps. The outflow volume during this one-year period at G-344A through D was 94 percent of the inflow volume at G-342A through D.

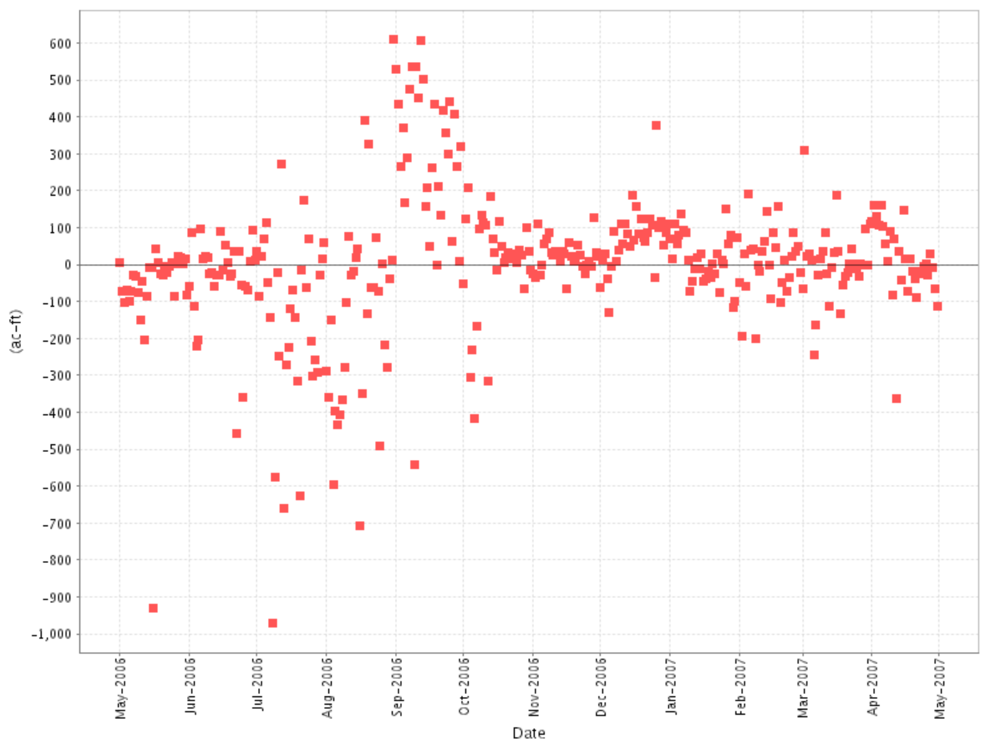

Figure 12. Water budget residuals for STA-5.

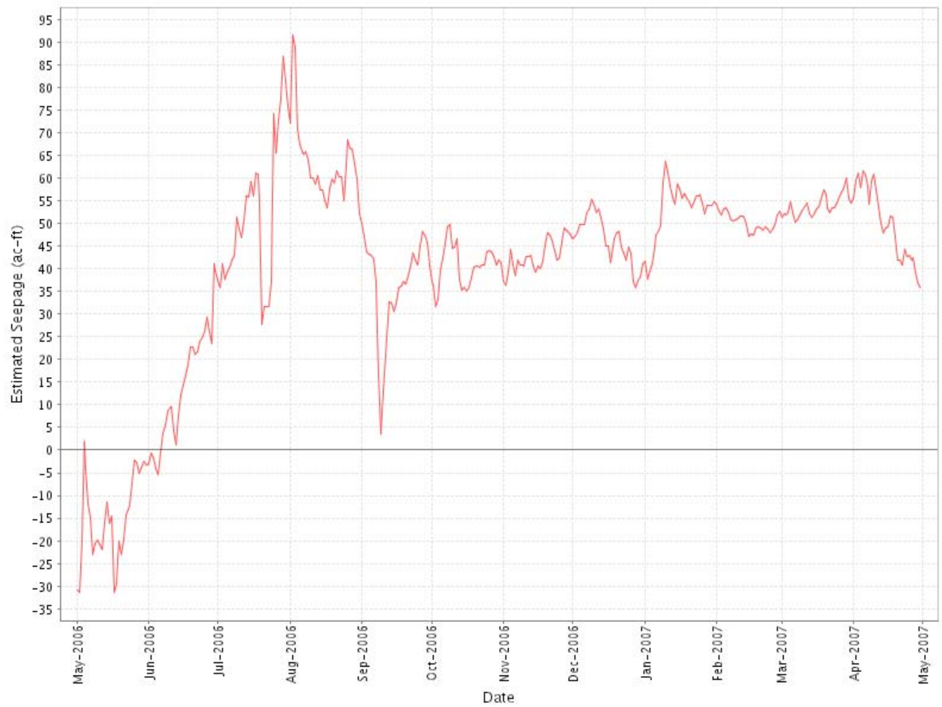

Figure 13. Estimated daily seepage at STA-5.

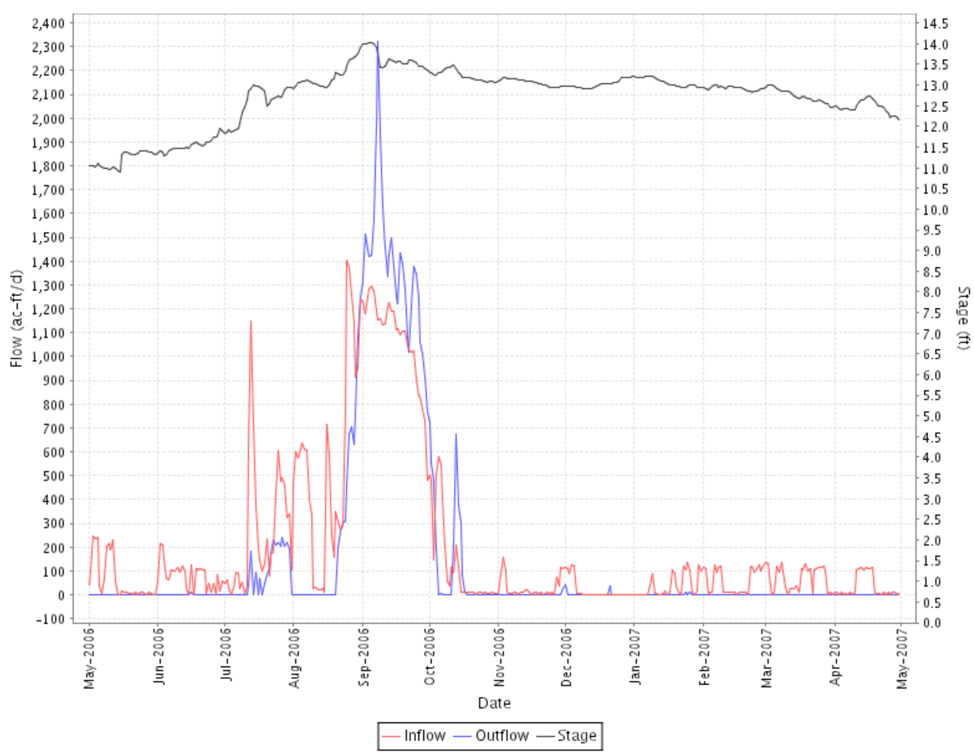

Figure 14. Inflow, outflow and stage at STA-5.

Table 11. Monthly water budget for STA-5.

Month-Year	INFLOW	OUTFLOW	CHANGE IN STORAGE	ET	RAIN	SEEPAGE	REMAINDER
May-06	1,986	0	-159	2,026	1,537	-465	-2,121
Jun-06	2,460	12	478	1,696	1,417	419	-1,271
Jul-06	7,817	2,514	2,297	1,745	5,220	1,611	-4,870
Aug-06	16,970	6,606	3,965	1,737	1,592	1,966	-4,287
Sep-06	32,296	41,288	-2,206	1,507	745	1,095	8,643
Oct-06	4,162	3,619	-1,220	1,474	992	1,259	-22
Nov-06	850	25	-381	1,060	453	1,284	686
Dec-06	579	81	929	884	528	1,437	2,223
Jan-07	1,133	18	-1,059	1,068	17	1,641	518
Feb-07	1,596	0	-175	1,084	594	1,412	132
Mar-07	2,162	0	-841	1,654	233	1,668	87
Apr-07	997	0	-1,019	1,860	1,071	1,496	270

Note: Negative storage values indicate decreasing stage over the month. No signs are shown for other values, except error. To compute the water budget error, flow into the cell was considered positive and flow out of a cell was considered negative.

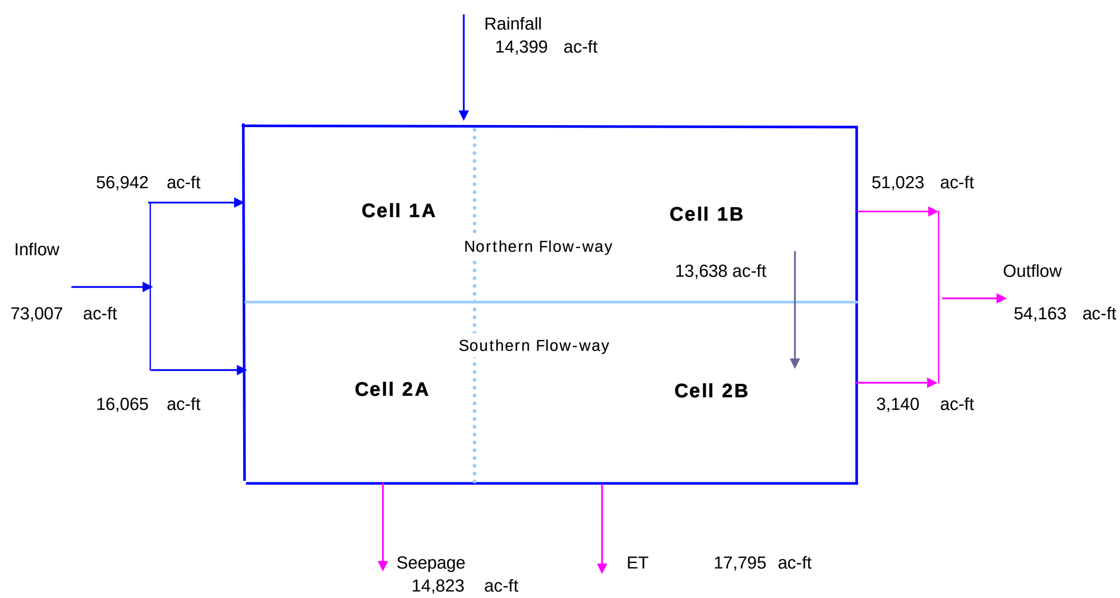

Figure 15. Water budget volumes for STA-5.

Mean Hydraulic Retention Time

Mean hydraulic retention time (MHRT) is a nominal estimate of how long water remains in each cell and estimates the average treatment time. Over this period, physical, chemical, and biological processes remove particulate and soluble phosphorous, other nutrients and contaminants. The mean hydraulic retention time (also referred to as *mean cell residence time*) was determined using Equation 3:

$$t = \frac{V}{Q} \qquad \text{(Equation 3)}$$

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

The MHRT was based upon the average stage during the study period and the average volume of total inflow and total outflow including rainfall, evapotranspiration, and estimated seepage, which are large percentages of the water budget.

Table 12 shows the MHRT in days for Flow-way 1 (Cells 1A and 1B) and Flow-way 2 (Cells 2A and 2B) and the entire STA for wet and dry seasons. MHRT was 6 days for Flow-way 1 and 12 days for Flow-way 2 during the wet season in WY2007 (June to October). During the dry season (May and November to April), the MHRT was 20 days for Flow-ways 1 and 2. The annual average MHRT for the entire STA was 12 days (7 days during the wet season and 34 days during the dry season).

Table 12. Mean hydraulic retention time at STA-5.

WY2007	ANNUAL AVG DEPTH	ANNUAL MHRT	WET AVG DEPTH	WET MHRT	DRY AVG DEPTH	DRY MHRT
Flow-way 1	0.89	9	1.08	6	0.75	20
Flow-way 2	0.54	15	0.58	12	0.51	20
STA-5	0.71	12	0.83	7	0.63	34

Notes:
1. All depths in ft.
2. MHRT in days.

SUMMARY AND DISCUSSION

A total of 58,690 ac-ft of water entered STA-5 from the gated culverts at G-342A through D in WY2007. This flow constituted about 67 percent of the total inflow to the STA. Rainfall accounted for 14,399 ac-ft or 16 percent of the total inflow. Flow from seepage canal pumps at G-349A and G-350A contributed 4,208 ac-ft of water, which was 5 percent of the total inflow to the treatment area during the water year.

During WY2007, 10,110 ac-ft of water came from the Miami Canal via pumping at G507; the pumps at G-349B and G-350B did not operate. The area around STA-5 received 41.96 inches of rainfall, about 78 percent of what is expected annually. The STA-5 Pollution Prevention Plan (SFWMD, 2000b) cites expected flows into the STA through the G-342A through D culverts of 78,340 ac-ft per year or 215 ac-ft per day. During the study period, STA-5 received 161 ac-ft per day or 75 percent of the expected annual volume of flow through these structures.

During the same period, 54,163 ac-ft of water was discharged from the STA at G-344A through D (62 percent of the total outflow). Evapotranspiration accounted for an additional 17,795 ac-ft of water leaving the STA (20 percent of the total outflow). Estimated seepage out of STA-5 accounted for 18 percent of the total outflow from the STA or 15,305 ac-ft. Estimated seepage into STA-5 accounted for <1 percent (482 ac-ft) of the total inflow to the STA. The volume of seepage was based upon head differences between the treatment cells and the water levels in the areas surrounding the STA and an estimated seepage coefficient of 0.9 cfs/ft/mi for Cell 1 and 4.0 cfs/ft/mi for Cell 2. These coefficients were well within the values found in literature concerning the design of STAs and other analyses of seepage potential. Water budget error was negligible for WY2007. The daily average error in the monthly water budgets for STA-5 represented an equivalent depth of less than 1.0 inch per day throughout the period of study. Also, since the inter-flow-way pumping that caused high water budget errors in each of the individual flow-ways were internal to the STA, they did not affect the water budget error for the entire STA.

Cells 1A and 1B, constituting Flow-way 1, received 42,815 ac-ft of water during WY2007 through structures G-342A and B. The pumps at G-349A provided an additional 4,017 ac-ft of water during the same period. At G-507, 10,110 ac-ft of water was pumped into Cell 1B. Rain into these cells accounted for 7,200 ac-ft of inflow. The volume of water stored in the cells increased by 42 ac-ft over this period. G-344A and B discharged 51,023 ac-ft of water. ET accounted for another 8,898 ac-ft. Net seepage out of Cells 1A and 1B was estimated at 7,141 ac-ft using seepage coefficients of 0.9 cfs/ft/mi for Flow-way 1 and 4.0 cfs/ft/mi for Flow-way 2. At G-345, 13,638 ac-ft of water was discharged from Cell 1B to Cell 2B. Water budget error was

23 percent. This value was due largely to unmeasured inter-cell pumping from Cell 2B to Cell 1B for G-343 structure reconstruction in Flow-way 2.

Flow-way 2, Cells 2A and 2B, received 15,875 ac-ft of water during the study period through culverts G-342C and D. The pumps at G-350A discharged 191 ac-ft of water into Cell 2A before it was removed for Flow-way 3 construction. Inflow from Cell 1B into Cell 2B at G-345 of 13,638 ac-ft of water was reported. Rainfall contributed 7,200 ac-ft of water to these cells. Storage in Cells 2A and 2B increased by 570 ac-ft. G-344C and D released 3,140 ac-ft of water during the study period. ET accounted for a loss of 8,898 ac-ft. There was an estimated net seepage gain of 1,511 ac-ft. Water budget error was 91 percent. Again, this value was due to unmeasured inter-cell pumping from Cell 2B to Cell 1B for G-343 structure reconstruction in Flow-way 2.

For Flow-way 1, Cells 1A and 1B, mean hydraulic retention time was 6 days for the wet season and 20 days during the dry season. Wet season MHRT for Flow-way 2, Cells 2A and 2B, was 12 days and 20 days for the dry season. Overall, the MHRT for the STA was 12 days in WY2007.

There were a number of problems associated with calculating the WY2007 water budget for STA-5. The lack of measured and recorded data for the water volume pumped from Cell 1B to Cell 2B during the G-343 reconstruction was a major source of errors in water budget calculations for Flow-ways 1 and 2. However, when the new structures at G-343 are instrumented, cell-by-cell water budgets can be developed for each STA-5 treatment cell, (1A, 1B, 2A, and 2B). This should reduce error in water budget for WY2008 and beyond.

The daily water budget residuals or error for STA-5 were shown in **Figure 5**, **Figure 9**, and **Figure 12** (residuals for Cells 1A and 1B, for Cells 2A and 2B, and for STA-5 as a whole). **Figure 16** shows the residuals for STA-5 plotted with flow data and estimated seepage data. All follow the same pattern; the residuals tend to increase when flow increases.

Other possible sources of error in the budget include use of ET values from STA-1W located approximately 33 miles to the northeast of STA-5, using average ground elevations for the bottom of the treatment cells and assuming a constant surface area independent of water depth in the cells. However, these weaknesses are expected to have had a minor impact on the water budget.

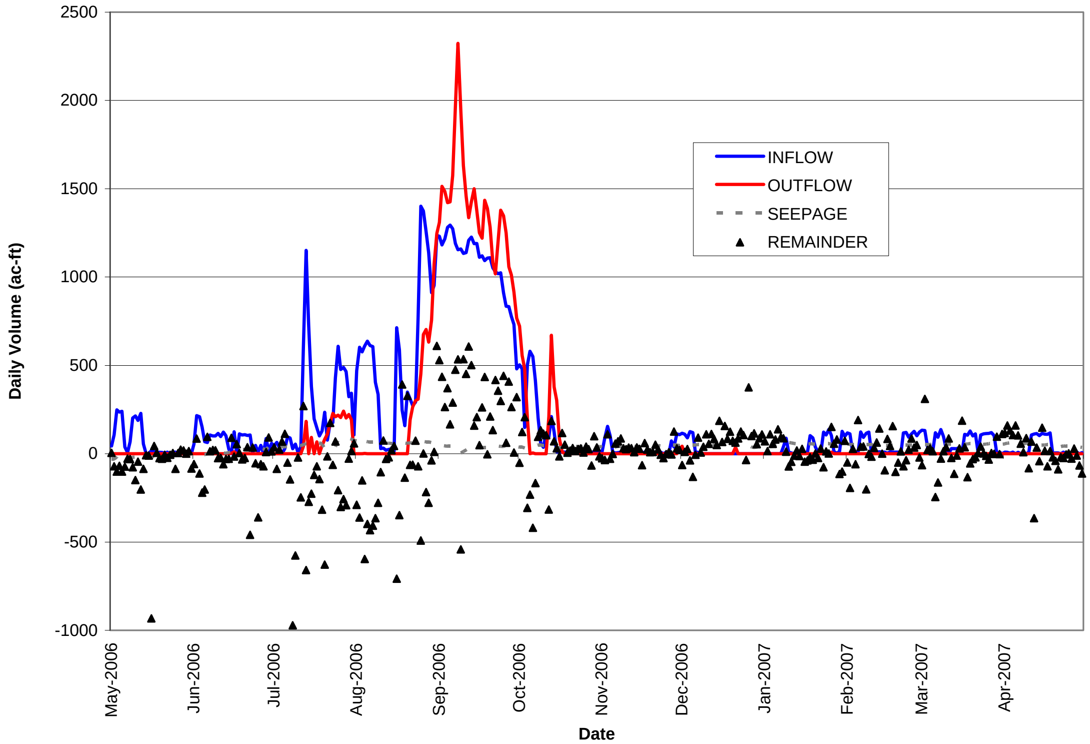

Figure 16. STA-5 Inflow, outflow, seepage and water budget residuals.

RECOMMENDATIONS

The design of the gated culverts at STA-5 is susceptible to backflow, or reverse flow, under certain conditions. Although the magnitude of these flows is small relative to flow during major runoff events, backflow into or out of the STA is contrary to the design principles of STAs in general. Efforts have been undertaken by the District to eliminate or minimize these events to the extent possible.

Seepage was the largest single quantifiable unknown at the site. Additional study of the groundwater flow regime and the impact of seepage on treatment performance continues to be warranted. Locating piezometers with water level recorders located outside the boundary of STA-5 could support a more accurate analysis of seepage, especially at the canals along the STA's northern and southern boundaries.

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APPENDICES

Appendix A

Site Properties and Monitoring Stations[1]

Table A-1. STA-5 site properties.

Surface Area	
Cell 1A	839 ac
Cell 1B	1220 ac
Cell 2A	839 ac
Cell 2B	1220 ac
Ground Elevation	
Cell 1A	~ 12.75 ft
Cell 1B	~ 11.50 ft
Cell 2A	~ 12.75 ft
Cell 2B	~ 11.50 ft
Levee Length	
Along Northern Boundary	
Along Cell 1A	7140 ft
Along Cell 1B	10380 ft
Along Southern Boundary	
Along Cell 2A	7140 ft
Along Cell 2B	10380 ft
Along Eastern Boundary	
Along Cell 1A	5120 ft
Along Cell 2A	5120 ft
Along Western Boundary	
Along Cell 1B	5120 ft
Along Cell 2B	5120 ft

[1] Information in Appendix A includes stations in Flow-ways 1 and 2 only as of April 30, 2007.

Table A-2. Stage monitoring stations.

DBKEY	Structure
JJ109	G342A_H
JJ110	G342A_T
JJ114	G342B_H
JJ115	G342B_T
JJ121	G342C_H
JJ123	G342C_T
JJ127	G342D_H
JJ128	G342D_T
JJ812	G343B_H
JJ813	G343B_T
JJ815	G343F
JJ816	G343F_T
JJ133	G344A_H
JJ135	G344A_T
JJ138	G344B_H
JJ140	G344B_T
JJ143	G344C_H
JJ145	G344C_T
JJ148	G344D_H
JJ150	G344D_T
JJ156	G349A_H
JJ157	G349A_T
JJ802	G349B_H
JJ803	G349B_T
JJ160	G350A_H
JJ161	G350A_T
JJ810	G350B_H
JJ811	G350B_T

Table A-3. Flow monitoring stations.

Inflow Stations

DBKEY	Station	STA
J6406	G342A	STA5
J6398	G342B	STA5
J6407	G342C	STA5
J6405	G342D	STA5
JJ838	G349A	STA5
JJ839	G350A	STA5
SJ382	G507_P	STA5
J6406	G342A	STA5C1
J6398	G342B	STA5C1
JJ838	G349A	STA5C1
SJ382	G507_P	STA5C1
J6407	G342C	STA5C2
J6405	G342D	STA5C2
JJ839	G350A	STA5C2

Outflow stations

DBKEY	Station	STA
J0719	G344A	STA5C
J0720	G344B	STA5
J0721	G344C	STA5
J0722	G344D	STA5
J0719	G344A	STA5C1
J0720	G344B	STA5C1
J0721	G344C	STA5C2
J0722	G344D	STA5C2

Table A-4. Rainfall monitoring stations.

DBKEY	Structure
JJ837	G343B_R
UK533	STA5WX

Table A-5. Evapotranspiration stations**.**

DBKEY	Structure	STA
KN810	STA1W	STA5

Table A-6. Seepage coefficients.

Cell	Seepage Coefficient
1A	0.9
1B	0.9
2A	4.0
2B	4.0

Appendix B

Rainfall Data

Table B-1. Rainfall at STA5WX (in.) for WY2007.

Day	May-2006	Jun-2006	Jul-2006	Aug-2006	Sep-2006	Oct-2006	Nov-2006	Dec-2006	Jan-2007	Feb-2007	Mar-2007	Apr-2007
1	0	0.34	0	0	0.07	0.25	0.45	0	0	0	0.41	0
2	0	0.01	0.33	0	0.1	0.01	0.46	0	0	0	0	0
3	0	0	0	0.49	0.04	0.15	0.01	0	0	0	0	0
4	0	0.05	0	0	0.05	0	0	0	0	0.62	0	0
5	0	0.38	0	0.07	0.03	0	0	0	0	0.3	0	0
6	0	0	0.49	0.04	0.07	0	0	0	0	0.02	0	0.04
7	0	0	0.59	0	0	0	0	0	0	0	0	0
8	0	0	3.02	0	0.09	0	0	0	0.01	0	0	0
9	0.08	0	2.05	0	0.07	0.04	0	0	0	0	0	0
10	0	0	1.04	0.21	0.01	0	0	0	0	0	0	0.62
11	0	0	2.82	0	0.15	0	0	0	0	0.05	0	0.61
12	0.06	0.02	0.12	0	0.58	1.7	0	0	0	0.5	0	1.48
13	0	0	0.34	0.16	0.03	0	0	0	0	0	0	0
14	0	0.01	0	0.01	0.15	0	0	0.26	0	0	0	0
15	0.03	0	0	0	0.01	0	0	0.02	0	0.13	0	0.27
16	3.51	0	0	0.22	0	0	0.27	0.39	0.01	0.04	0.14	0
17	0.01	0	0	0.12	0	0	0	0.01	0	0	0	0
18	0	0	0.29	0.01	0	0	0	0	0	0.07	0	0
19	0	0	0.04	0.59	0.61	0	0	0.01	0	0	0	0
20	0	0.09	0.64	0	0.08	0	0	0	0	0	0.13	0
21	0	0	0.63	0.04	0	0	0	0	0	0	0	0
22	0.04	1.27	0.86	0.02	0	0	0	0	0	0	0	0
23	0	0	1.09	0.22	0	0.04	0	0.07	0	0	0	0
24	0	0	0	0.12	0	0	0	0	0	0	0	0
25	0.42	1.18	0	0.4	0	0	0	0.77	0	0	0	0
26	0.05	0.38	0	0.04	0	0	0.08	0.01	0	0	0	0.1
27	0	0.36	0.42	0	0.03	0	0	0	0.01	0	0	0
28	0	0.04	0.44	0.02	0	0.51	0.02	0	0.02	0	0	0
29	0	0	0	0.14	0	0	0.03	0	0		0	0
30	0	0	0	1.52	0	0	0	0	0		0	0
31	0.28		0	0.2		0.19		0	0		0	
MAX	3.51	1.27	3.02	1.52	0.61	1.7	0.46	0.77	0.02	0.62	0.41	1.48
MEAN	0.145	0.138	0.491	0.15	0.072	0.093	0.044	0.05	0.002	0.062	0.022	0.104
MIN	0	0	0	0	0	0	0	0	0	0	0	0
SUM	4.48	4.13	15.21	4.64	2.17	2.89	1.32	1.54	0.05	1.73	0.68	3.12

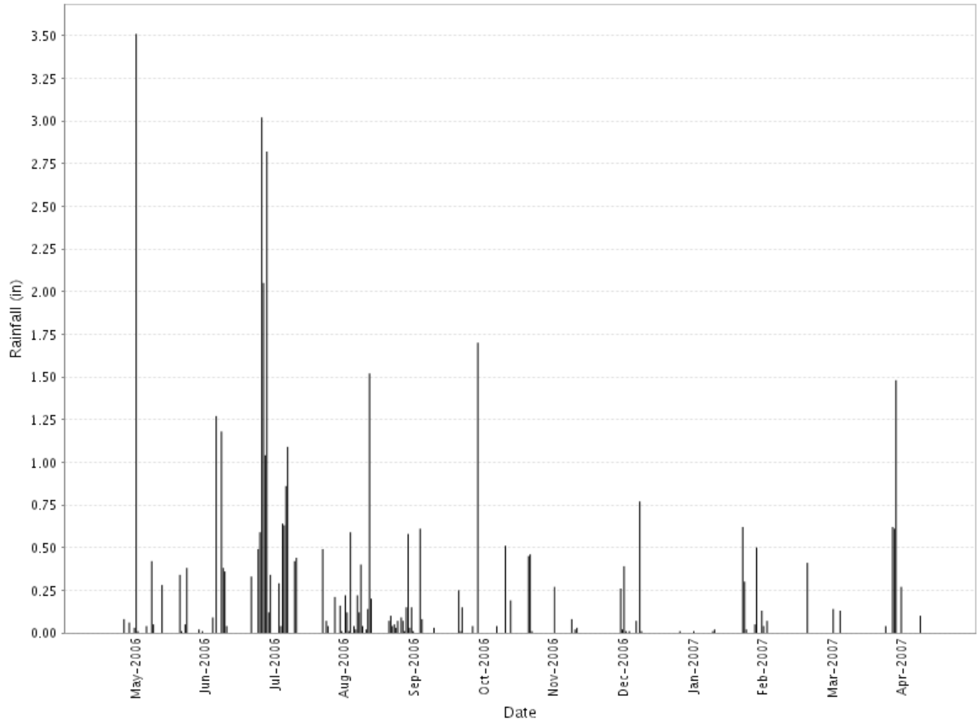

Figure B-1. Daily rainfall at STA5WX for WY2007.

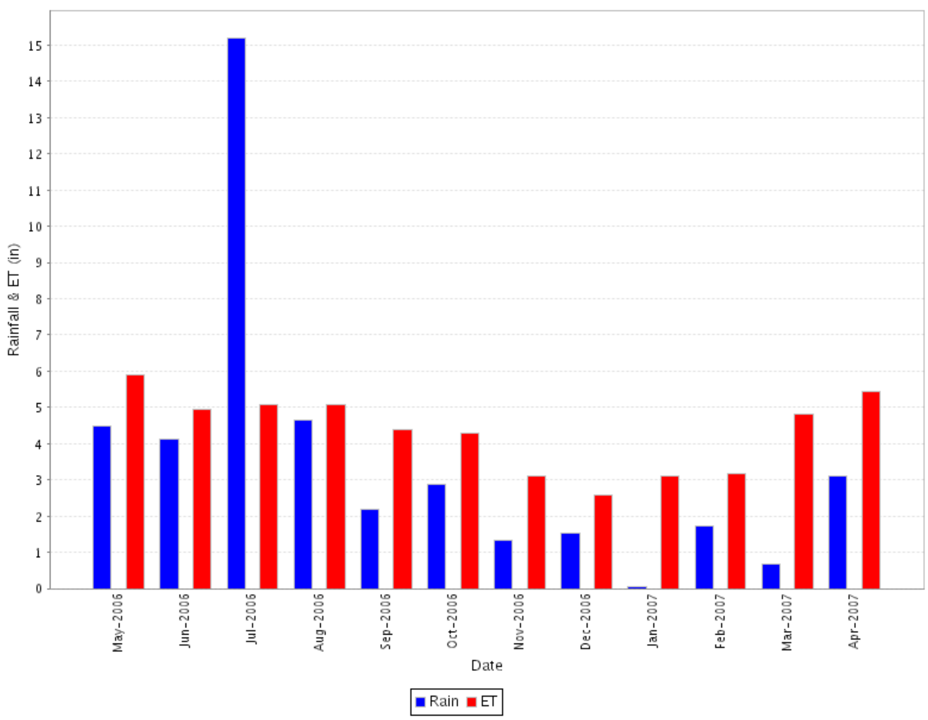

Figure B-2. Monthly rainfall and ET for WY2007.

Appendix C

Evapotranspiration Data

Table C-1. Evapotranspiration at STA-5 (in.) for WY2007.

Day	May-2006	Jun-2006	Jul-2006	Aug-2006	Sep-2006	Oct-2006	Nov-2006	Dec-2006	Jan-2007	Feb-2007	Mar-2007	Apr-2007
1	0.224	0.141	0.171	0.212	0.119	0.152	0.105	0.092	0.097	0.092	0.124	0.185
2	0.213	0.206	0.114	0.202	0.083	0.16	0.023	0.104	0.077	0.098	0.131	0.154
3	0.228	0.223	0.202	0.15	0.138	0.127	0.083	0.106	0.092	0.052	0.113	0.186
4	0.232	0.16	0.201	0.172	0.109	0.12	0.081	0.089	0.091	0.035	0.063	0.196
5	0.221	0.158	0.169	0.176	0.063	0.146	0.13	0.048	0.082	0.03	0.173	0.164
6	0.205	0.243	0.104	0.194	0.155	0.169	0.124	0.107	0.125	0.093	0.192	0.172
7	0.219	0.191	0.179	0.203	0.184	0.177	0.037	0.11	0.105	0.149	0.153	0.216
8	0.214	0.242	0.112	0.206	0.155	0.15	0.111	0.023	0.092	0.15	0.176	0.219
9	0.168	0.166	0.192	0.188	0.147	0.125	0.145	0.091	0.124	0.126	0.159	0.162
10	0.178	0.117	0.171	0.204	0.143	0.163	0.139	0.1	0.112	0.155	0.176	0.091
11	0.194	0.079	0.17	0.196	0.138	0.154	0.106	0.081	0.085	0.126	0.171	0.19
12	0.23	0.078	0.076	0.217	0.123	0.135	0.127	0.087	0.111	0.028	0.156	0.108
13	0.221	0.158	0.109	0.202	0.16	0.166	0.113	0.07	0.108	0.121	0.189	0.198
14	0.243	0.224	0.224	0.136	0.125	0.137	0.113	0.028	0.101	0.138	0.144	0.18
15	0.181	0.21	0.207	0.169	0.16	0.155	0.112	0.042	0.056	0.02	0.146	0.055
16	0.055	0.215	0.207	0.114	0.116	0.157	0.052	0.017	0.123	0.053	0.159	0.237
17	0.202	0.161	0.217	0.154	0.15	0.113	0.092	0.118	0.065	0.173	0.207	0.232
18	0.228	0.059	0.176	0.172	0.176	0.132	0.139	0.113	0.113	0.143	0.204	0.219
19	0.244	0.202	0.117	0.1	0.142	0.117	0.144	0.101	0.107	0.174	0.147	0.183
20	0.22	0.126	0.164	0.128	0.156	0.118	0.085	0.103	0.132	0.135	0.074	0.223
21	0.218	0.187	0.117	0.118	0.174	0.159	0.136	0.08	0.124	0.145	0.172	0.121
22	0.178	0.215	0.129	0.139	0.173	0.133	0.118	0.09	0.081	0.174	0.166	0.195
23	0.077	0.209	0.153	0.172	0.183	0.143	0.135	0.07	0.082	0.175	0.168	0.193
24	0.14	0.097	0.196	0.15	0.142	0.164	0.104	0.085	0.053	0.159	0.156	0.183
25	0.11	0.085	0.18	0.132	0.187	0.15	0.07	0.081	0.019	0.105	0.16	0.221
26	0.106	0.123	0.192	0.17	0.174	0.141	0.085	0.033	0.138	0.087	0.17	0.172
27	0.169	0.147	0.112	0.151	0.115	0.13	0.111	0.13	0.125	0.121	0.116	0.171
28	0.224	0.165	0.185	0.188	0.155	0.048	0.109	0.119	0.109	0.098	0.122	0.191
29	0.179	0.19	0.152	0.144	0.185	0.146	0.086	0.093	0.149		0.179	0.202
30	0.218	0.166	0.195	0.057	0.158	0.14	0.075	0.087	0.096		0.151	0.205
31	0.165		0.193	0.148		0.069		0.077	0.136		0.203	
MAX	0.244	0.243	0.224	0.217	0.187	0.177	0.145	0.13	0.149	0.175	0.207	0.237
MEAN	0.19	0.165	0.164	0.163	0.146	0.139	0.103	0.083	0.1	0.113	0.155	0.181
MIN	0.055	0.059	0.076	0.057	0.063	0.048	0.023	0.017	0.019	0.02	0.063	0.055
SUM	5.904	4.943	5.086	5.064	4.388	4.296	3.09	2.575	3.11	3.155	4.82	5.424

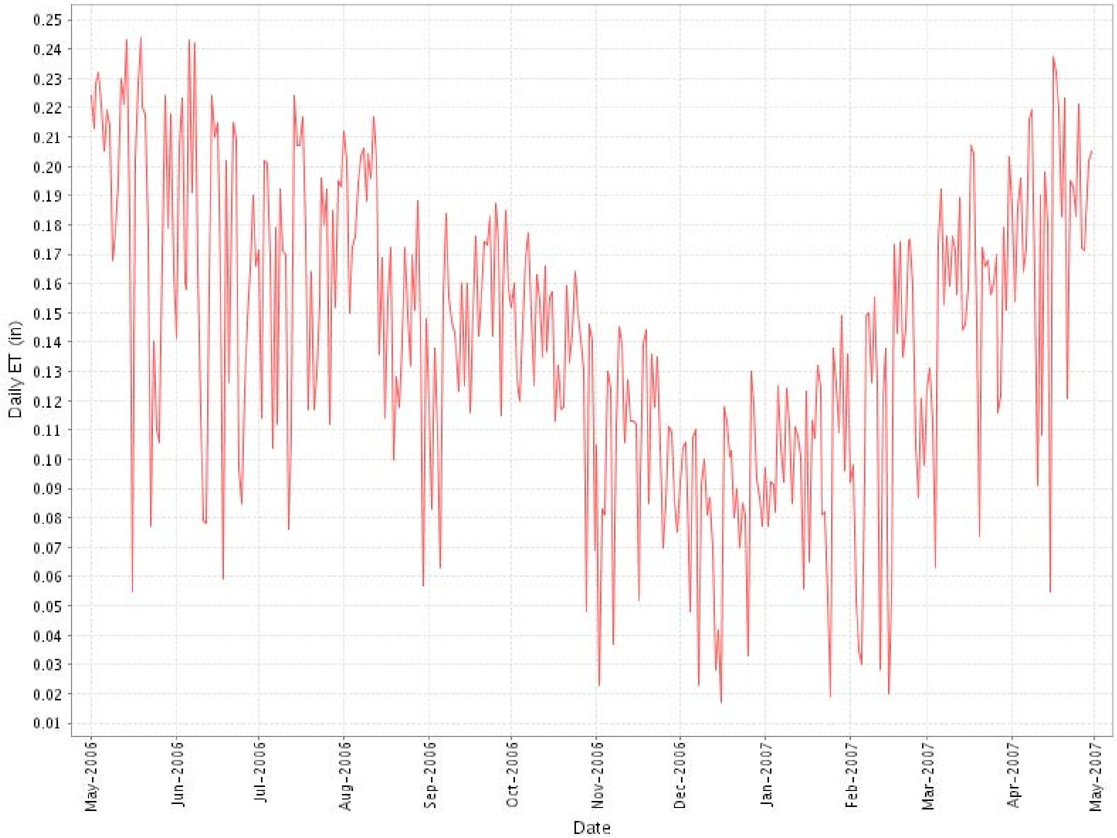

Figure C-1. STA-5 daily evapotranspiration for WY2007.

Appendix D
Soil Storage

When the water level in an STA treatment cell falls below the average ground elevation, the change in volume of storage becomes a function of the soil porosity as well as the water surface elevation and geometry of the cell. Previous water budget reports for STA-5 and STA-6 relied on a 7th order wetting curve equation and a 3rd order drying curve equation (Huebner, 2001) to account for change of storage when the water level was below ground elevation. Unfortunately, due to a hysteresis effect, following these curves through wetting and drying cycles occasionally lead to the problem that summing the daily change in storage over a period did not result in a change of storage equal to calculating the change in storage from the beginning of the period to the end of the period. In order to correct this anomaly, the curves were collapsed into the following equation, which is shown in **Figure D-1**:

f=a*exp(-b*x)+c*exp(-d*x)		
	a	0.605
r^2 = 0.9990	b	16.8264
	c	0.3786
	d	1.5843

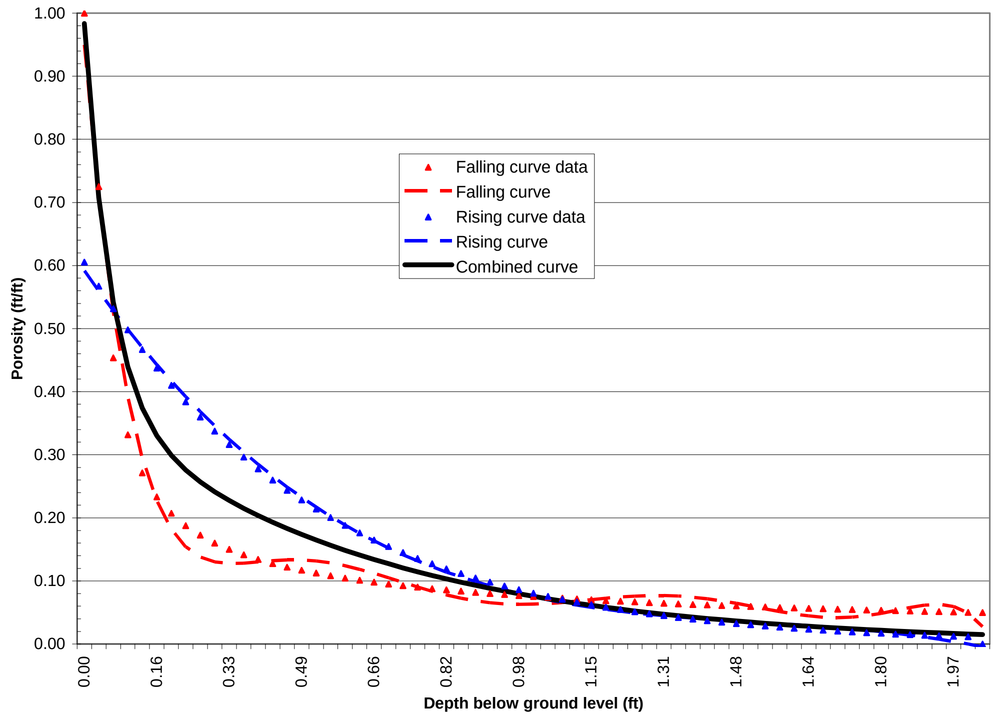

Figure D-1. Wetting and drying curves.

By allowing the wetting and drying curves to follow the same line, daily change in storage can be summed and the sum will equal that calculated based on the beginning water surface elevation and the ending water surface elevation over a period of interest. This introduces minimal error into the change in storage calculations over a day and only affects that calculation when the water level is below the ground surface, i.e. when the cell is dry.