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A-1 Flow Equalization Basin Seepage Study



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EXECUTIVE SUMMARY

As part of the implementation of the *Restoration Strategies Regional Water Quality Plan* (SFWMD 2012), the South Florida Water Management District constructed the A-1 Flow Equalization Basin (FEB), a 15,000-acre shallow aboveground impoundment. The primary purpose of the A-1 FEB is to attenuate peak stormwater flows, temporarily store stormwater runoff, and improve inflow delivery rates to stormwater treatment areas (STAs), thereby providing enhanced operation and phosphorus treatment performance. Construction of the A-1 FEB was substantially completed in July 2015 and initial operation commenced in August 2015.

Water budget analyses for the A-1 FEB for the first two years of operation contained high residuals that limited the usefulness of the analyses. The high residuals are most likely the result of uncertainties and errors associated with structure flow data estimates and seepage estimates. To improve the A-1 FEB seepage estimates, a seepage study was conducted in the 2018 dry season. A 7.5-week period was designated during which the operators were instructed to suspend inflow and outflow structure flows, thereby reducing water budget errors/uncertainties associated with flow data estimates. From January 5, 2018, through February 26, 2018, all inflow and outflow structures were closed and stage decline in the FEB was observed. Rainfall was minimal during the period; therefore, stage decline was mainly due to evapotranspiration and net seepage out of the FEB.

The A-1 FEB estimated seepage was divided into four zones: East, North/Northwest, Southwest, and South. The estimated seepage coefficient for the 7.5-week observation period and the stage conditions studied is $52 \text{ ft}^3 \text{ d}^{-1} \text{ ft-levee}^{-1} \text{ ft-head}^{-1}$ (cubic feet per day per foot levee per foot head) or $3.18 \text{ cfs mile-levee}^{-1} \text{ ft-head}^{-1}$ (cubic feet per second per mile of levee per foot of head), which is comparable to the seepage rates used during the design of STA-3/4 and the A-1 FEB. This seepage rate is appropriate for use in future water budget analyses for the A-1 FEB. Most of the estimated seepage outflows for the period studied occurred on the North/Northwest Zone followed by the East Zone, while seepage inflows into A-1 FEB were estimated along the Southwest and South zones from the STA-3/4 Supply/Inflow Canal. Different stage conditions (i.e., head differences across the levees) for each of the zones from what was observed during the seepage test could impact the direction (i.e., into or out of the FEB) and magnitude of the estimated seepage volumes.

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ACRONYMS, ABBREVIATIONS, AND UNITS OF MEASUREMENT

Δh	stage difference
ac-ft	acre-foot
cfs	cubic foot per second
DBHYDRO	SFWMD's corporate environmental database
ET	evapotranspiration
FEB	flow equalization basin
ft	foot
$\text{ft}^3 \text{d}^{-1}$	cubic foot per day
$\text{ft}^3 \text{d}^{-1} \text{ft-levee}^{-1} \text{ft-head}^{-1}$	cubic foot per day per foot levee per foot head
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
SEEP2D	two-dimensional seepage analysis program written by Dr. Fred Tracy of the United States Army Corps of Engineers used to analyze water seepage
SFWMD	South Florida Water Management District
STA	stormwater treatment area

INTRODUCTION

BACKGROUND

As part of the implementation of the *Restoration Strategies Regional Water Quality Plan* (SFWMD 2012), the South Florida Water Management District (SFWMD) constructed the A-1 Flow Equalization Basin (FEB), a 15,000-acre shallow aboveground impoundment. The primary purpose of the A-1 FEB is to attenuate peak stormwater flows, temporarily store stormwater runoff from the central Everglades Agricultural Area and improve inflow delivery rates to two of the Everglades Stormwater Treatment Areas (STAs), STA-2 and STA-3/4, thereby providing enhanced operation and phosphorus treatment performance. The A-1 FEB can also be used to assist in maintaining minimum water levels and reducing the frequency of dryout conditions within STA-2 and STA-3/4, which will also sustain phosphorus treatment performance.

Construction of the A-1 FEB was substantially completed in July 2015 and initial operation commenced in August 2015. Water budget analyses for the A-1 FEB for the first two years of operation contained high residuals that limited the usefulness of the analyses. The high residuals are most likely the result of uncertainties and errors associated with structure flow data estimates and seepage estimates. To improve the A-1 FEB seepage estimates, a seepage study was conducted in the 2018 dry season.

A-1 FLOW EQUALIZATION BASIN

The A-1 FEB is located adjacent to and directly north of STA-3/4 (**Figure 1**) and has a capacity of approximately 60,000 acre-feet at an approximate maximum operating depth of 4 feet. The bottom elevation of the A-1 FEB is approximately 9.9 feet (ft) National Geodetic Vertical Datum of 1929 (NGVD29). Water levels in the A-1 FEB are designed to fluctuate between 9.9 and 13.9 ft NGVD29 (WRScompass 2013). Inflows from the Miami Canal are conveyed to the A-1 FEB via the G-720 water control structure in conjunction with pump station G-372. Inflows from the North New River Canal are conveyed to the A-1 FEB via the G-721 water control structure in conjunction with pump station G-370 (**Figure 3**). After inflows are conveyed to the north end of the FEB, water moves from north to south. Outflows from the A-1 FEB can be directed to STA-3/4 or to STA-2. A-1 FEB outflows to STA-3/4 occur in one of two ways. The first way is by gravity flows through the G-724A through J structures into the STA-3/4 Inflow Canal. The second way, which is used more often, is through the G-722 discharge structure (which discharges into the canal reach between the North New River Canal and the G-370 pump station), then through the G-370 pump station, and then into the STA-3/4 Inflow Canal. A-1 FEB outflows through the G-722 discharge structure can also be delivered to STA-2 via the North New River Canal and then through the G-434 and G-435 STA-2 inflow pump stations (SFWMD 2015).

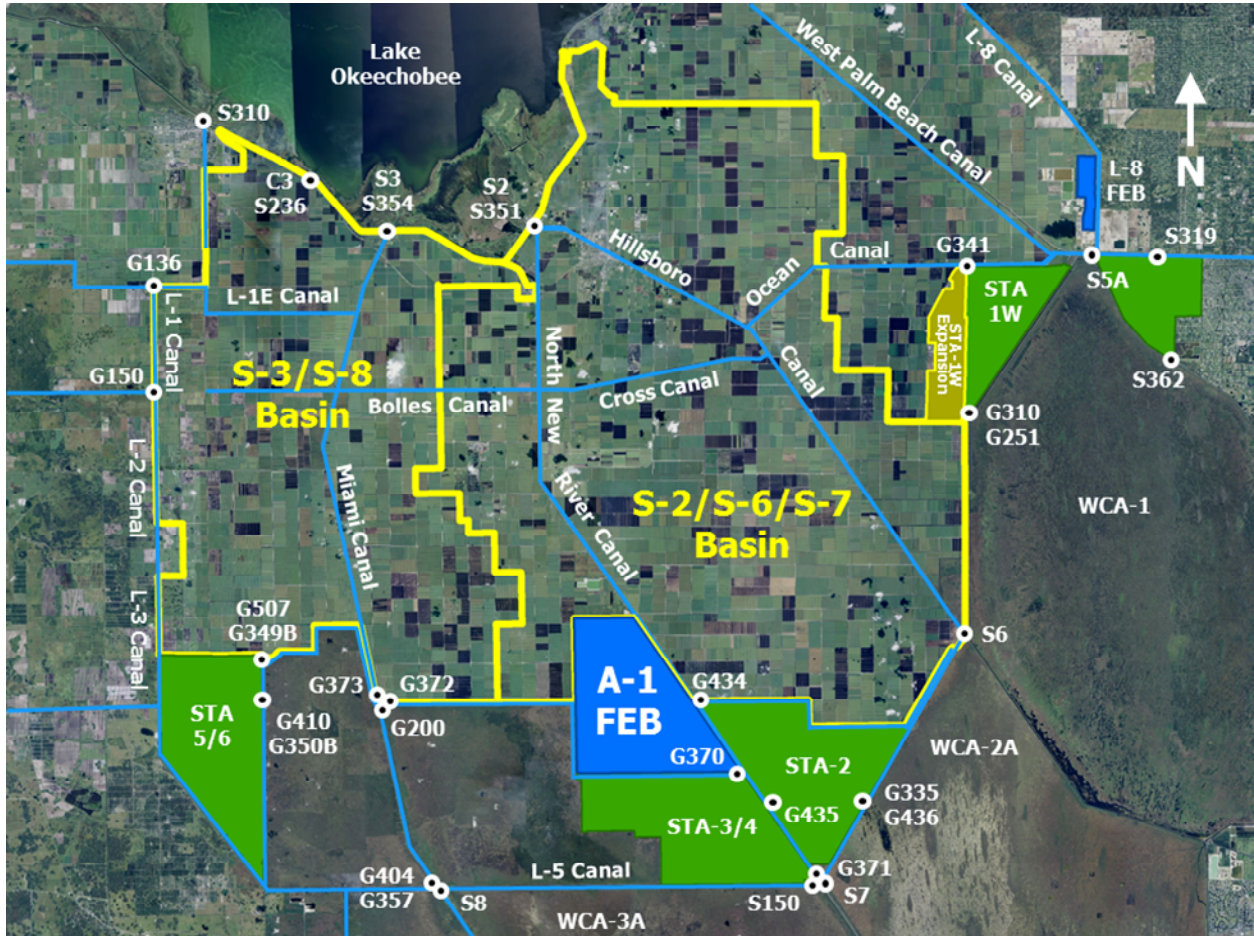


Figure 1. A-1 FEB location map.

The A-1 FEB has been in operation since August 14, 2015. Water level fluctuations in the FEB are the result of structure inflows and outflows, rainfall over the FEB, evapotranspiration (ET), and seepage in and out of the FEB. After the initial period of operation, the FEB was drained from January 12 to March 29, 2017, for completion of some outstanding construction items. Once those items were complete, the A-1 FEB was returned to operation. **Figure 2** depicts daily average stage fluctuations at the A1FEBCE stage gauge, which is representative of the FEB water level fluctuations; G-723N_H stage gauge, which is representative of stage in the East Seepage Canal; G-372S_H stage gauge, which is representative of stage in the North/Northwest Seepage Canal, and G377D_H, which represents stage in STA-3/4 Inflow Canal (see **Figure 3** later in the report for locations of seepage canals and structures).

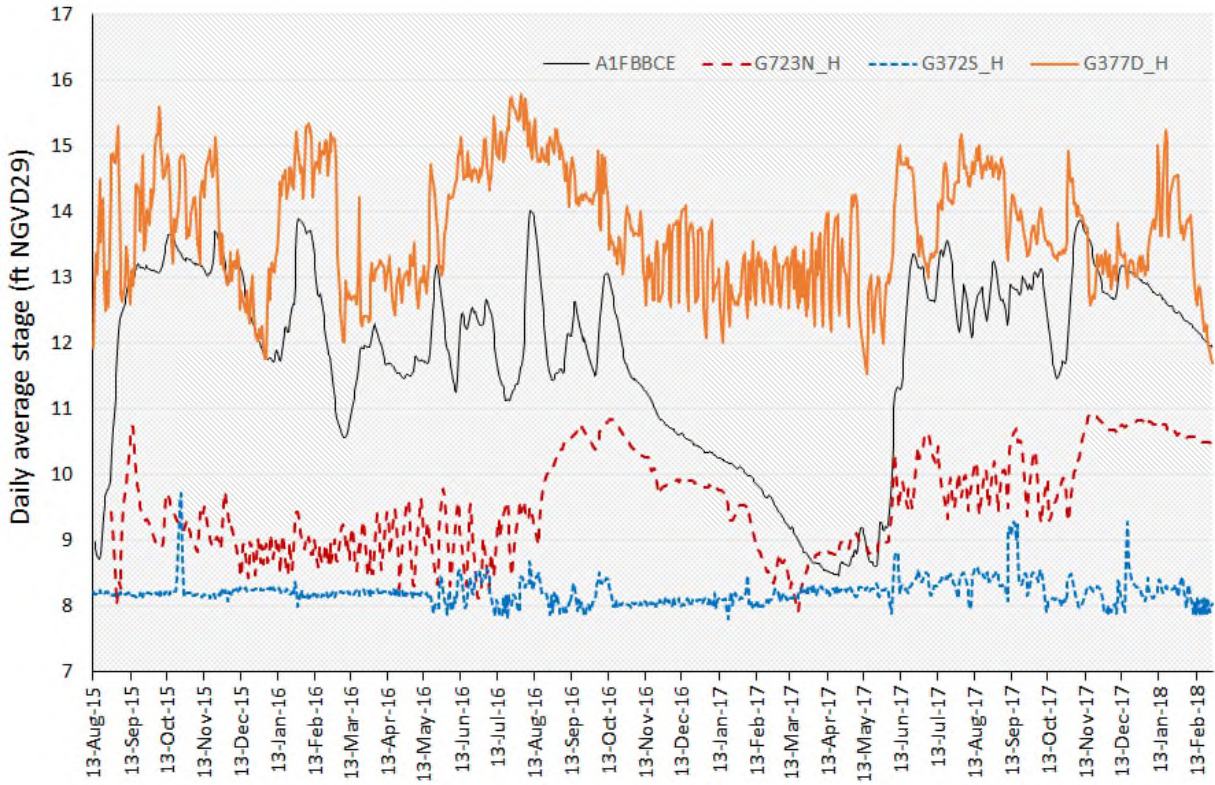


Figure 2. Daily average stage fluctuations in the A-1 FEB (A-1FEBCE), East Seepage Canal (G723N_H), North/Northwest Seepage Canal (G372S_H), and STA-3/4 Inflow Canal (G377D_H).

METHODS

An approximate 7.5-week period during the dry season was designated during which the operators were instructed to suspend inflow or outflow structure flows, thereby reducing water budget errors/uncertainties associated with flow data estimates. From January 5, 2018, through February 26, 2018 (Period 1), all inflow and outflow structures were closed, and stage decline in the FEB was observed. Rainfall was minimal during the period and the stage decline was mainly due to ET and seepage out of the FEB.

A second period from December 13, 2017, through February 26, 2018 (Period 2), was also evaluated. During this longer period, the starting average stage in A-1 FEB was higher than the Period 1 starting stage; however, there were some structure inflows and minimal structure outflows during this longer period. Seepage analysis was conducted for Period 1 (January 5, 2018–February 26, 2018) and compared to the results for Period 2 (December 13, 2017–February 26, 2018). While Period 2 provided a longer period of stage fluctuation data and a higher starting stage, structure flows, albeit relatively small, introduce some uncertainties to the seepage analysis for this period. No direct seepage measurements were made in this study. Seepage can occur both laterally and vertically. In this study, net daily seepage through each zone was estimated with no distinction as to vertical or lateral components.

DATA

The source for data was DBHYDRO, the SFWMD's corporate environmental database. Three rainfall stations were used to develop average rainfall estimates for the A-1 FEB. Daily ET data is available at site ROTNWX, which is nearby the A-1 FEB. Inflows to the A-1 FEB are delivered through structures G-720 and G-721. Outflows are delivered through structures G-722 and G-724A through J. A summary of the flow, rainfall, and ET sites used in the A-1 FEB seepage analysis are shown in **Table 1**. Twenty stage monitoring sites were used to estimate the average stage in the A-1 FEB and the stage difference across the four seepage zones (**Table 2**).

Table 1. A-1 FEB flow, rainfall, and ET monitoring sites.

Flow Station	DBKEY	Rainfall Station	DBKEY	ET Station	DBKEY
G720 (inflow)	P8674	EAA5	15184	ROTNWX	UP568
G721 (inflow)	64172	S7_R	K8688		
G722 (outflow)	64174	3A_NE_R	LX283		
G724A (outflow)	92164				
G724B (outflow)	92162				
G724C (outflow)	92166				
G724D (outflow)	92169				
G724E (outflow)	92170				
G724F (outflow)	92172				
G724G (outflow)	92174				
G724H (outflow)	92175				
G724I (outflow)	92178				
G724J (outflow)	92180				

Table 2. A-1 FEB seepage stage monitoring sites.

Stage Station Inside FEB	DBKEY	Stage Station Outside FEB	DBKEY
A1FEBCE	64066	G723N_H	64117
A1FEBNE	64068	G372S_H	T0989
A1FEBNW	64070	G720_H	64093
A1FEBCW (G720_SW)	64111	G380B_H	T9931
G720_T	64091	G380E_H	T9997
G721_T	64101	G374B_H	T9921
G722_H	64120	G374E_H	T9923
G724B_H	92128	G377B_H	T9925
G724D_H	92138	G377D_H	T9927
G724I_H	92113		
G724G_H	92099		

SEEPAGE STUDY

The A-1 FEB was divided into four seepage zones: East, North/Northwest, Southwest, and South (**Figure 3**). The East Seepage Zone is between the FEB and the A-1 FEB East Seepage Canal. The North/Northwest Seepage Zone is between the FEB and the North/Northwest Seepage Canal. The Southwest Seepage Zone is between the FEB and the STA-3/4 Supply/Inflow Canal along the southwest portion of the FEB. The South Seepage Zone is between the FEB and the STA-3/4 Inflow Canal along the southern portion of the FEB. **Table 3** shows the approximate levee length of each seepage zone.

Table 3. A-1 FEB seepage zone levee lengths.

Seepage Zone	Levee Length (miles)
East	7
North/Northwest	5
Southwest	3
South	6
Total	21

A-1 Flow Equalization Basin Seepage Study

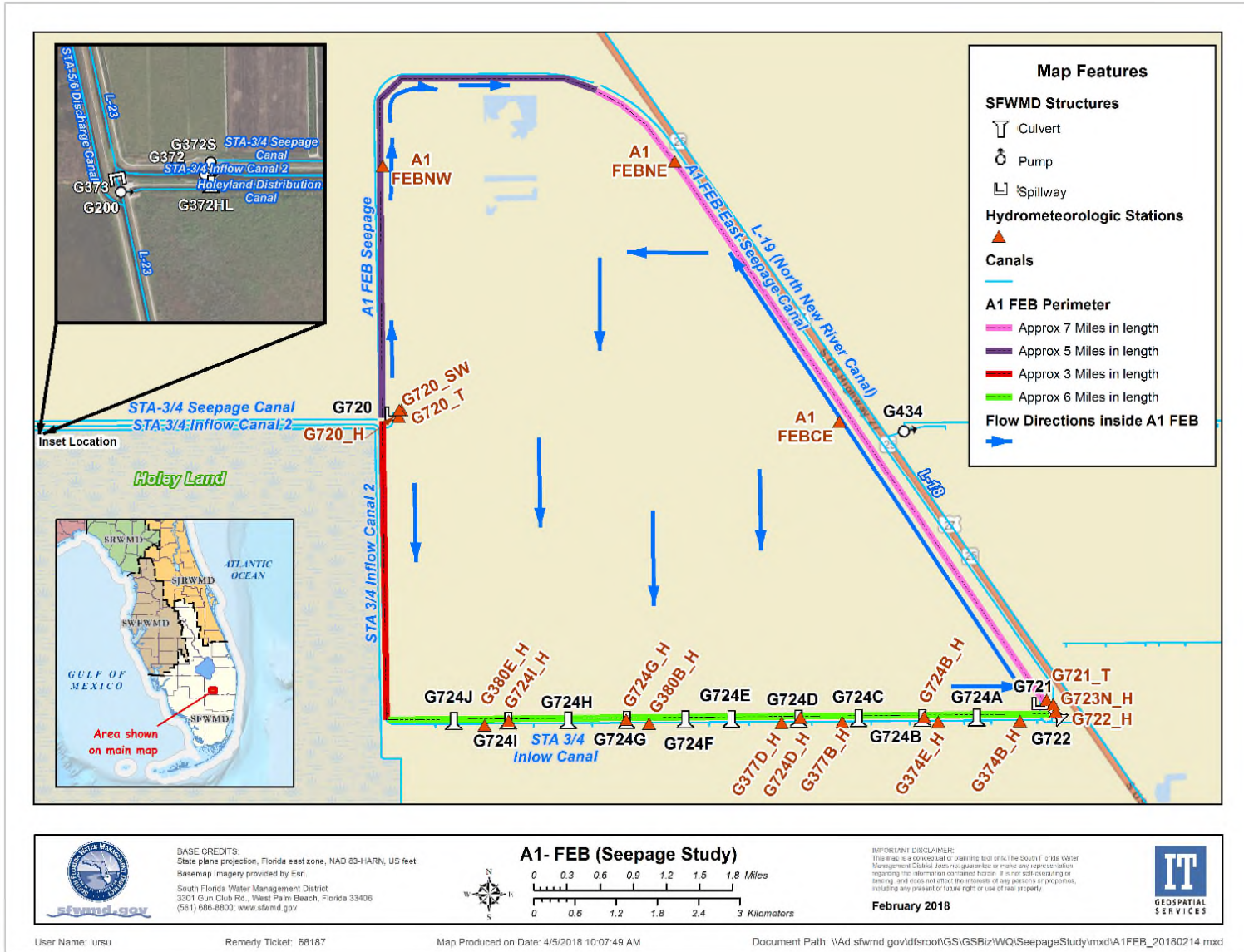


Figure 3. A-1 FEB seepage zones and stage monitoring sites.

WEATHER CONDITION

During the December 2017 through February 2018 period, the weather condition was dry with well below average rainfall in the East Everglades Agricultural Area rainfall area. Rainfall measurements for the months of December 2017, and January and February 2018 were 1.32 inches (84%), 1.01 inches (57%), and 0.39 inches (21%), respectively, with percentage of normal rainfall shown.

AVERAGE STAGE ESTIMATION

Various stage averaging approaches for the A-1 FEB were evaluated and differences in the results were minor. The areal average daily stage for the FEB was estimated from 11 stations where nearby stations were averaged as depicted by **Equation 1**. **Figure 4** depicts the A-1 FEB daily average stage during the seepage study (Periods 1 and 2).

$$S_{avg} = (A1FBCW (G720_SW) + G720_T)/2 + (G724B_H + G724D_H + G724I_H + G724G_H)/4 + A1FEBCE + A1FEBNE + A1FEBNW + G721_T+G722_H)/7 \quad 1$$

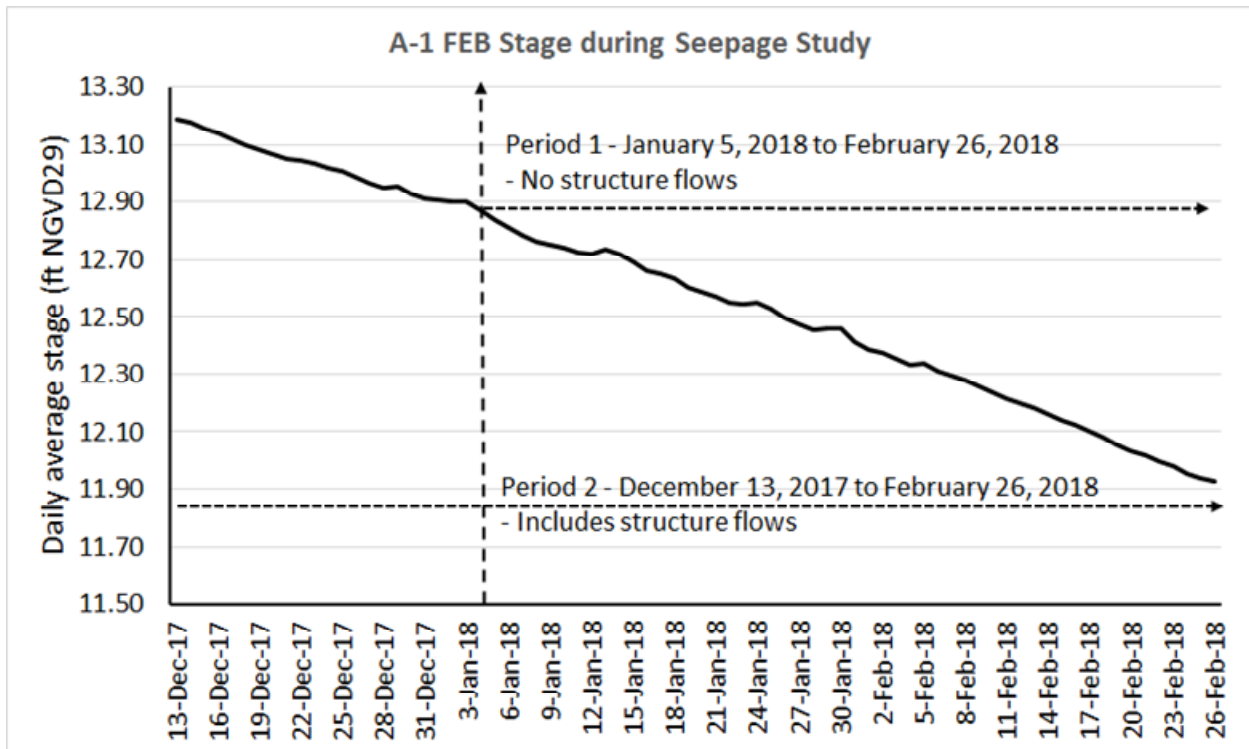


Figure 4. A-1 FEB daily average stage (average of 11 stage monitoring sites).

AVERAGE STAGE DIFFERENCE ESTIMATION

Stage differences (Δh) along each levee seepage zone were estimated using available stage monitoring sites inside and outside the FEB that are representatives of the stage on both sides. **Equations 2 to 10** show how inside and outside average stages were calculated across each levee seepage zone and difference in stage was computed as follows:

$$\text{East Zone (Inside)} = (A1FEBNE + A1FEBCE + G721_T) / 3 \quad \mathbf{2}$$

$$\text{East Zone (Outside)} = G723N_H \quad \mathbf{3}$$

$$\text{North/Northwest (Inside)} = (A1FEBCW (G720_SW) + A1FEBNW) / 2 \quad \mathbf{4}$$

$$\text{North/Northwest (Outside)} = G372S_H \quad \mathbf{5}$$

$$\text{Southwest Zone (Inside)} = (A1FEBCW (G720_SW) + G724I_H) / 2 \quad \mathbf{6}$$

$$\text{Southwest Zone (Outside)} = (G720_H + G380E_H) / 2 \quad \mathbf{7}$$

$$\text{South Zone (Inside)} = (G724B_H + G724D_H + G724G_H + G724I_H) / 4 \quad \mathbf{8}$$

$$\text{South Zone (Outside)} = (G374B_H + G374E_H + G377B_H + G377D_H + G380B_H + G380E_H) / 6 \quad \mathbf{9}$$

$$\Delta h = \text{Inside} - \text{Outside} \quad \mathbf{10}$$

Figure 5 shows daily average stages across the seepage zones for Period 1 and **Figure 6** shows daily average stages for Period 2. The gradient for the East and North/Northwest seepage zones (out of the FEB) is opposite the gradient for the Southwest and South seepage zones (into the FEB).

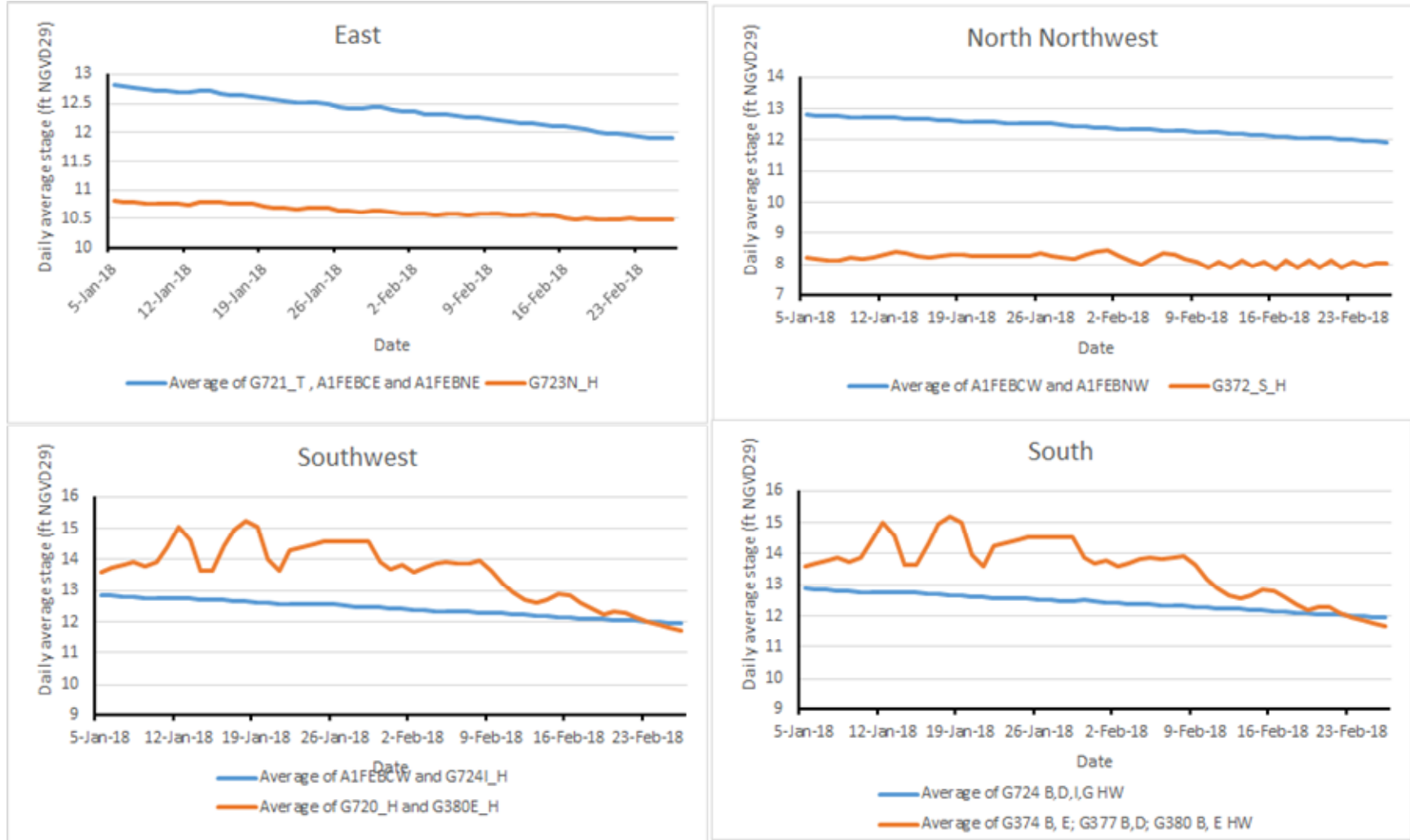


Figure 5. Daily average stages across the levee seepage zones for Period 1. The blue line is the stage inside the FEB and orange line is stage outside the FEB.

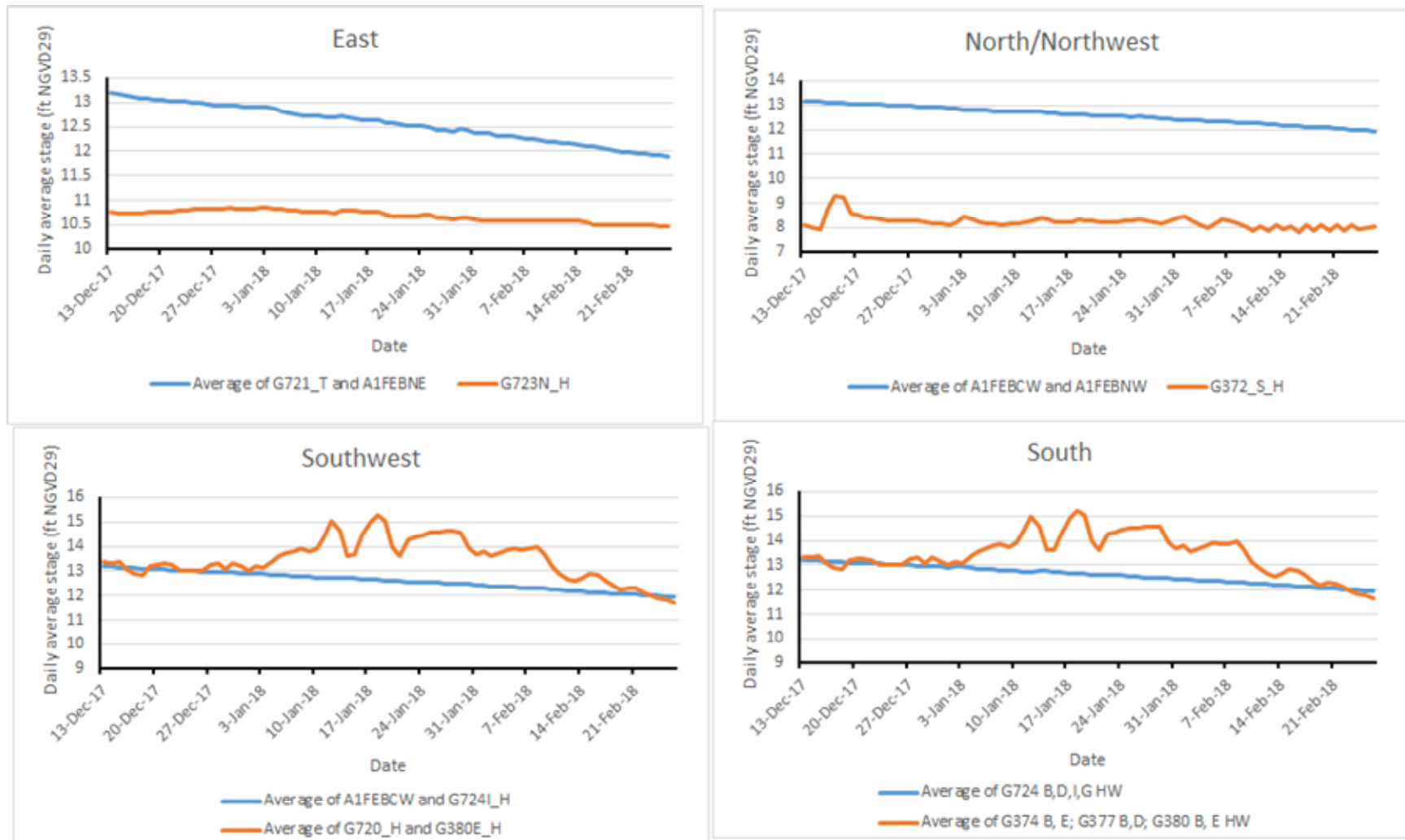


Figure 6. Daily average stages across the levee seepage zones for Period 2. The blue line is stage inside the FEB and the orange line is stage outside the FEB.

SEEPAGE ESTIMATION WITH WATER BUDGET

Water budgets are comprised of structure flows (inflows and outflows), seepage, rainfall, ET, and change in storage. Water budget analysis can be utilized to estimate seepage when reliable data are available for the other water budget components. Seepage was estimated from mass balance of hydrometeorology observations as shown by **Equations 11** and **12** for the two periods. The parameters are rainfall, ET, inflow, outflow, and change in storage, which are shown in **Table 4** for Period 1 and **Table 5** for Period 2 in the *Results* section.

$$\Delta\text{storage} = \text{Stage (beginning)} - \text{Stage (final)} \quad \mathbf{11}$$

$$\text{Seepage} = \text{Inflow} + \text{Rain} - \text{Outflow} - \text{ET} + \Delta\text{storage} \quad \mathbf{12}$$

Where all parameters are in the unit of depth (ft).

RESULTS

SEEPAGE STUDY RESULTS

The estimated seepage using water budget analysis for Period 1 (January 5 through February 26, 2018) was 6.16 inches in 53 days for all seepage zones combined (**Table 4**). The estimated seepage using water budget analysis for Period 2 (December 13, 2017, through February 26, 2018) was 10.74 inches in 76 days for all seepage zones combined (**Figure 5**). **Figure 7** shows rainfall and ET for the two observation periods and **Figure 8** shows inflows and outflows for the two observation periods.

Table 4. Hydrometeorology parameters and water budget estimated seepage for Period 1 in depth and volume units.

Water Budget Parameter	January 5, 2018–February 26, 2018			
	Depth (inches)	Volume (ac-ft)	Initial Stage (ft NGVD29)	Final Stage (ft NGVD29)
Structure Inflow	0	0		
Rain	1.207	1,509		
Structure Outflow	0	0		
ET	6.09	7,613		
Change in Storage	11.04	13,800	12.84	11.92
Seepage	6.16	7,700		

Table 5. Hydrometeorology parameters and water budget estimated seepage for Period 2 in depth and volume units.

Water Budget Parameter	December 13, 2017–February 26, 2018			
	Depth (inches)	Volume (ac-ft)	Initial Stage (ft NGVD29)	Final Stage (ft NGVD29)
Structure Inflow	2.43	3,038		
Rain	1.423	1,779		
Structure Outflow	0.017	21		
ET	8.34	10,425		
Change in Storage	15.24	19,050	13.19	11.92
Seepage	10.736	13,420		

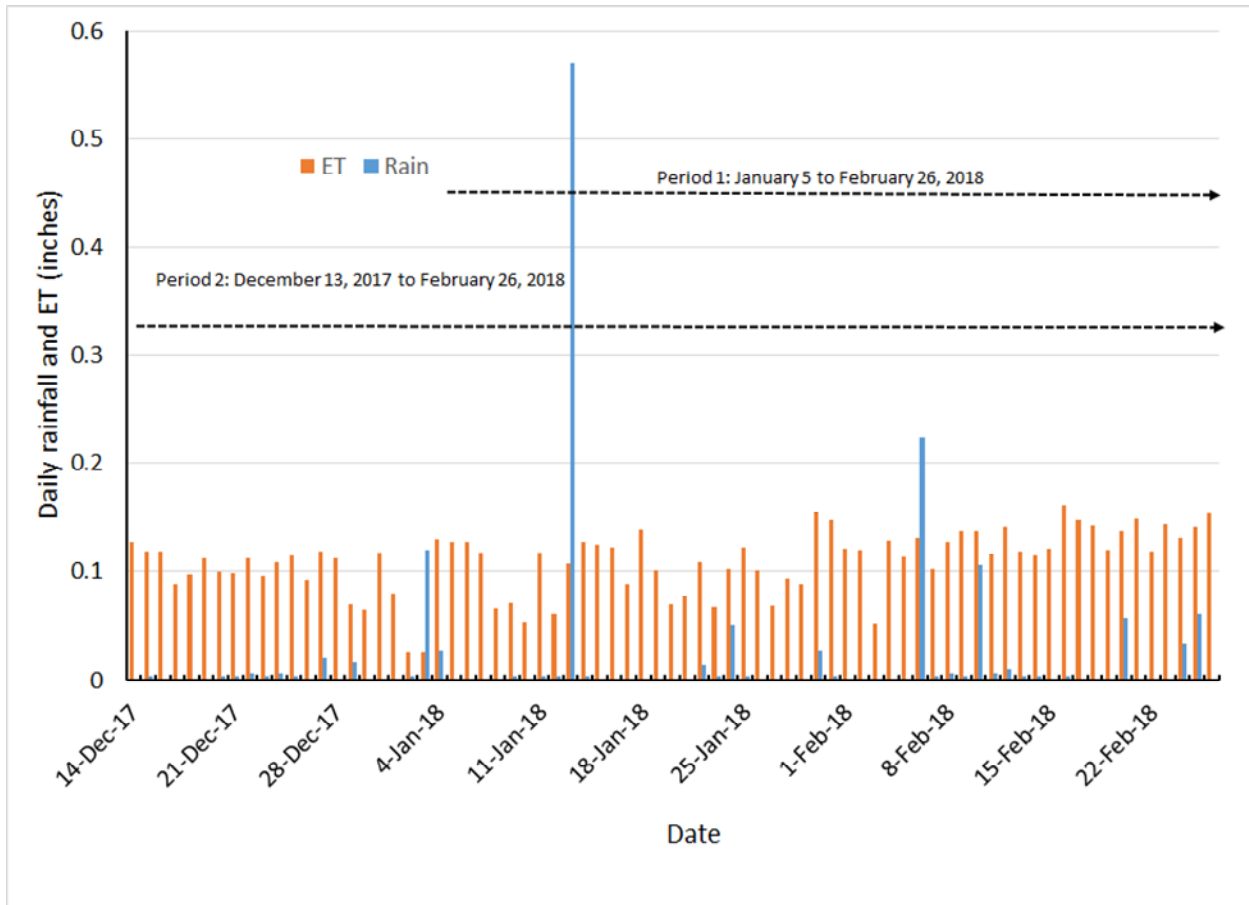


Figure 7. Daily rainfall and ET during the two seepage observation periods.

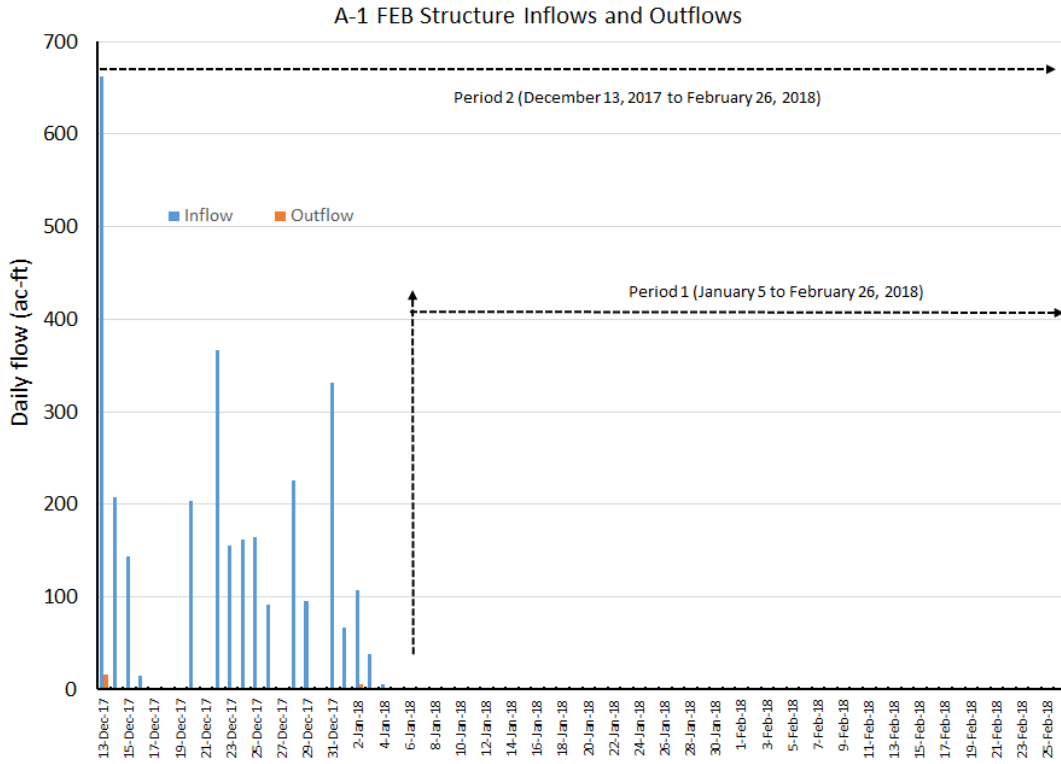


Figure 8. Daily inflow and outflow during the two seepage observation periods.

SEEPAGE RATE ESTIMATION

Head difference across the four seepage zones shows that during the two observation periods, the seepage gradient for the East and North/Northwest seepage zones was from the A-1 FEB to the seepage canals, while for the Southwest and South seepage zones, the seepage gradient was into the A-1 FEB from the STA-3/4 Supply/Inflow Canal (Table 6). The areas outside the A-1 FEB in the North/Northwest and East seepage zones were wet (Figures 9 and 10) during the observation periods.

Table 6. Average head difference across each seepage zone for the two observation periods.

Seepage Zone	Period 1 (ft)	Period 2 (ft)
East	1.74	1.88
North/Northwest	4.24	4.36
Southwest	-1.18	-0.87
South	-1.13	-0.82
4-Zone Weighted Average	1.11	1.31



Figure 9. Wet area outside North/Northwest Seepage Zone on February 22, 2018.



Figure 10. East Seepage Zone Canal on September 13, 2017.

Assuming the same seepage rate along the four seepage zones, seepage was estimated for each zone weighted by the levee lengths and zone-specific average head differences from this study. **Table 7** divides 7,700 acre-feet (ac-ft) of seepage in Period 1 and 13,420ac-ft of seepage in Period 2 across each of the four seepage zones. The weight of each zone in seepage contribution is a function of zone length and zone head. Each zone’s seepage is estimated by multiplying the total seepage by the respective zone weight.

$$Wt_i = \frac{L_i \times h_i}{\sum_1^4 (L_i \times h_i)} \quad 13$$

Where Wt_i is weight for Zone i, L_i is Zone i length, and h_i is head difference for Zone i.

Table 7. Seepage estimate assuming the same seepage rate for all four seepage zones.

Seepage Zone	Period 1 Seepage (ac-ft)	Period 2 Seepage (ac-ft)
East	4,067	6,438
North/Northwest	7,079	10,666
Southwest	-1,182	-1,277
South	-2,264	-2,407
4-Zone Total	7,700	13,420

The seepage rate is computed from the water budget-derived seepage, levee length, and average head across the four seepage zones for each period using **Equations 14** and **15**.

$$Q_{sp} = K_{sp} L_{levee} \Delta h \tag{14}$$

$$K_{sp} = \frac{Q_{sp}}{L_{levee} \Delta h} \tag{15}$$

Where Q_{sp} is the seepage rate in cubic feet per day ($\text{ft}^3 \text{d}^{-1}$), K_{sp} is the estimated seepage coefficient in cubic feet per day per foot levee per foot head ($\text{ft}^3 \text{d}^{-1} \text{ft-levee}^{-1} \text{ft-head}^{-1}$), L_{levee} is levee length in ft, and Δh is the average difference in stage across the levee.

For Period 1, K_{sp} is estimated to be $51 \text{ ft}^3 \text{d}^{-1} \text{ft-levee}^{-1} \text{ft-head}^{-1}$ or 3.12 cfs mile-levee⁻¹ ft-head⁻¹, using levee zone-weighted head difference for the whole FEB (**Table 8**).

$$K_{sp} = \frac{7700 \times 43560}{21 \times 5280 \times 1.11 \times 53} \tag{16}$$

For Period 2, K_{sp} is estimated to be $52 \text{ ft}^3 \text{d}^{-1} \text{ft-levee}^{-1} \text{ft-head}^{-1}$ or 3.18 cfs mile-levee⁻¹ ft-head⁻¹, using levee zone-weighted head difference for the whole FEB (**Table 8**).

$$K_{sp} = \frac{13420 \times 43560}{21 \times 5280 \times 1.31 \times 76} \tag{17}$$

The average seepage rate for the A-1 FEB from the two observation periods was $52 \text{ ft}^3 \text{d}^{-1} \text{ft-levee}^{-1} \text{ft-head}^{-1}$ or 3.18 cfs mile-levee⁻¹ ft-head⁻¹ (**Table 8**).

Table 8. Seepage coefficient calibration from the two observation periods.

Period	Seepage Rate Calibration			
	K_{sp} ($\text{ft}^3 \text{d}^{-1} \text{ft-levee}^{-1} \text{ft-head}^{-1}$)	Q_{sp} ($\text{ft}^3 \text{d}^{-1}$)	Levee Length (ft)	Average Head (ft)
1 (53 days)	51.42	6,328,609	110,880	1.11
2 (76 days)	52.55	7,633,035	110,880	1.31
Average	51.99			

SEEPAGE ESTIMATION USING SEEPAGE RATE FROM THE A-1 FEB FINAL DESIGN REPORT

The *Everglades Agricultural Area A-1 Flow Equalization Basin Corrected Final Design Documentation Report* (WRSScompass 2013) included a seepage estimation equation for the East and North/Northwest seepage zones combined as follows:

$$\text{Total Seepage} = 1.3 \text{ cfs} / (\text{mile} \times \text{ft of head}) \times (S_{88}-6) \text{ ft of head} \times 11.95 \text{ miles} \quad \mathbf{18}$$

Where Total Seepage is the total seepage from the A-1 FEB East and North/Northwest seepage zones combined in cfs; S_{88} is the A-1 FEB stage in ft North American Vertical Datum of 1988 (NAVD88); and 11.95 miles is the combined levee length for the East and North/Northwest seepage zones.

Since the correction from ft NAVD88 to ft NGVD29 is 1.4 ft for the A-1 FEB location, and total seepage in this study is presented in ac-ft, **Equation 18** is modified as follows with 12 miles of combined levee length from this study:

$$\text{Total Seepage} = 1.3 \text{ cfs} / (\text{mile} \times \text{ft of head}) \times (S_{29}-7.4) \text{ ft of head} \times 12 \text{ miles} \quad \mathbf{19}$$

Where S_{29} is A-1 FEB stage in ft NGVD29.

Table 9 compares the daily average seepage estimates for the East and North/Northwest seepage zones for the two seepage observation periods using the WRSScompass (2013) equation and the daily average seepage estimates developed in this study. The seepage estimates developed in this study are about 25% higher than the seepage estimates developed using the WRSScompass (2013) seepage equation. The difference may likely be due to assumptions and methods of seepage estimation.

Table 9. Daily average seepage in acre per feet per day ($\text{ac ft}^{-1} \text{d}^{-1}$) for the East and North/Northwest seepage zones for the two seepage observation periods estimated from the WRSScompass (2013) seepage equation compared to the seepage estimates developed in this study.

Period	Average Stage (ft NGVD29)	Daily Average Seepage for East and North/Northwest Seepage Zones using WRSScompass (2013) Seepage Equation (ac ft d^{-1})	Daily Average Seepage for East and North/Northwest Zones for This Study (ac ft d^{-1})
Period 1	12.4	155	203
Period 2	12.59	161	225

SEEPAGE ESTIMATION USING SEEPAGE COEFFICIENT FOR STA-3/4 LEVEES

The A-1 FEB seepage rate estimate of $52 \text{ ft}^3 \text{d}^{-1} \text{ft-levee}^{-1} \text{ft-head}^{-1}$ or $3.18 \text{ cfs mile-levee}^{-1} \text{ft-head}^{-1}$, developed in this study is comparable to the estimate for the STA-3/4 levees of $47.68 \text{ ft}^3 \text{d}^{-1} \text{ft-levee}^{-1} \text{ft-head}^{-1}$ or $2.91 \text{ cfs mile-levee}^{-1} \text{ft-head}^{-1}$, which is the average of the North Perimeter, East Perimeter North, East Perimeter South, and West Perimeter STA-3/4 levees for Scenario A (Montgomery Watson Americas, Inc. 1999). The Montgomery Watson Americas, Inc. (1999) seepage study provided a range of seepage estimates for STA-3/4 design to be used for maximum seepage collection and pumping capacity. Scenario A was based on geotechnical investigation, an aquifer performance test, and a SEEP2D model

application. SEEP2D is a seepage analysis program developed by the United States Army Corps of Engineers to measure water seepage through dams and levees.

Table 10 depicts seepage rates through the four A-1 FEB seepage zones for the two seepage observation periods using the Montgomery Watson Americas, Inc. (1999) K_{sp} estimate ($47.68 \text{ ft}^3 \text{ d}^{-1} \text{ ft-levee}^{-1} \text{ ft-head}^{-1}$ or $2.91 \text{ cfs mile-levee}^{-1} \text{ ft-head}^{-1}$). The seepage estimates from the four seepage zones are close to the water budget total seepage estimate. **Figure 11** compares zone seepage for each period estimated by this study and using the seepage coefficient from Montgomery Watson Americas, Inc. 1999.

Table 10. Total and daily average seepage for each seepage zone for the two seepage observation periods estimated from the Montgomery Watson Americas, Inc. (1999) K_{sp} estimate, which is $47.68 \text{ ft}^3 \text{ d}^{-1} \text{ ft-levee}^{-1} \text{ ft-head}^{-1}$ or $2.91 \text{ cfs mile-levee}^{-1} \text{ ft-head}^{-1}$.

Seepage Zone	Period 1 (ac-ft)	Period 2 (ac-ft)	Period 1 Average (ac-ft d ⁻¹)	Period 2 Average (ac-ft d ⁻¹)
East	3,731	5,780	70.39	76.06
North/Northwest	6,494	9,575	122.52	125.99
Southwest	-1,084	-1,146	-20.46	-15.08
South	-2,077	-2,161	-39.18	-28.43
Total	7,064	12,048		

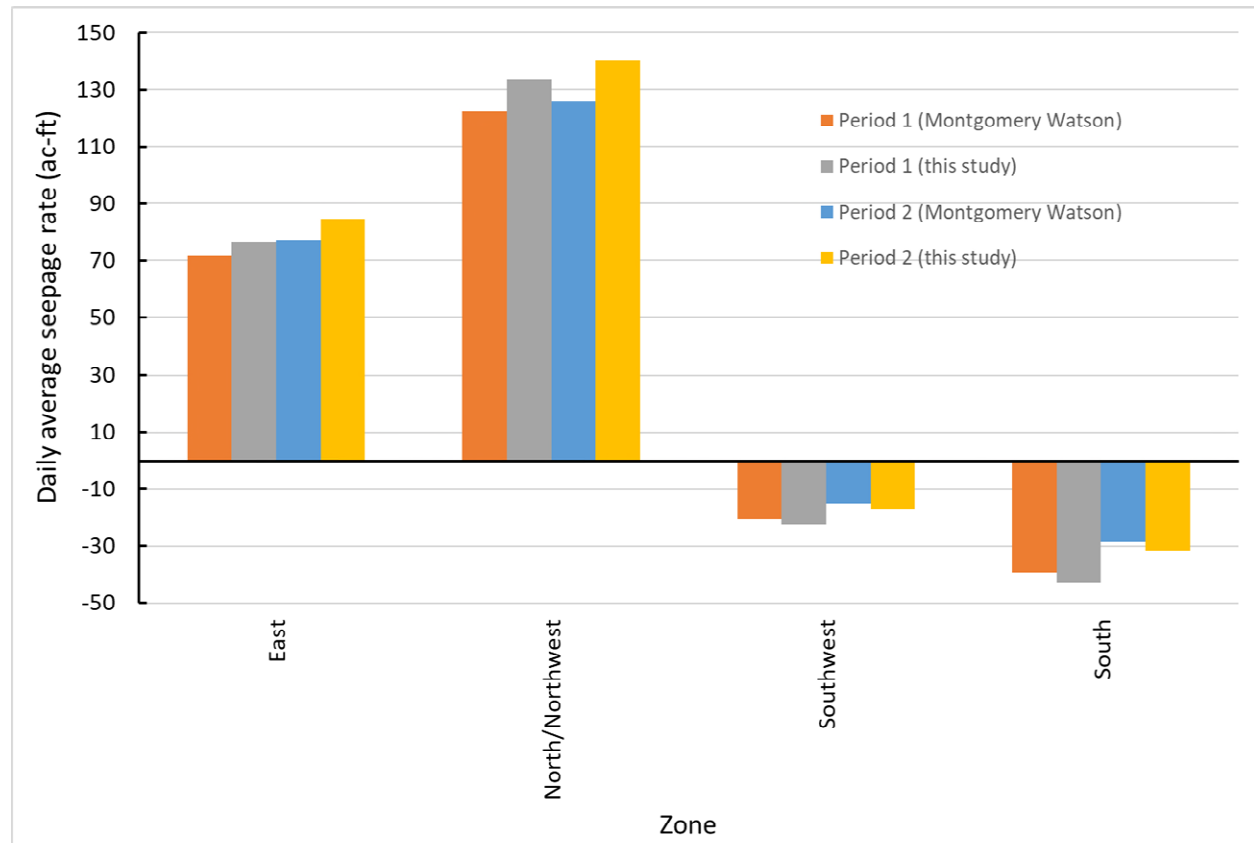


Figure 11. Comparison of daily average seepage rates for the four seepage zones for the two seepage observation periods estimated from the Montgomery Watson Americas, Inc. (1999) K_{sp} estimate and the estimate from this study.

Table 11 compares daily average seepage estimates for East and North/Northwest seepage zones combined from this study, the WRScompass (2013) equation, and Montgomery Watson Americas, Inc. (1999) modeling.

Table 11. Seepage estimates from the three studies.

Period	Seepage for East and North/Northwest Zones (ac-ft d ⁻¹)		
	This Study	WRScompass (2013)	Montgomery Watson Americas, Inc. (1999)
Period 1	203	155	194
Period 2	225	161	203

SEEPAGE PUMPING DURING OBSERVATION PERIODS

Seepage return pumping for the A-1 FEB occurs via the G-370S and G-372S pump stations (SFWMD 2015). G-372S serves as the seepage return for the A-1 FEB North/Northwest Seepage Canal as well as the STA-3/4 Supply/Inflow Canal reach from the G-372 pump station to the G-720 spillway. G-370S seepage pumping is mainly from the A-1 FEB East Seepage Canal. Seepage return pumping occurred at both seepage return pump stations for the two observation periods included in this seepage study.

Seepage pumping at G-372S was 8,195 ac-ft during Period 1 and 11,675 ac-ft during Period 2 (**Figure 12**). **Table 12** depicts the average stage in the G-372S Seepage Canal and inside the A-1 FEB along the North/Northwest Seepage Zone. G-372S seepage return pumping was on average 125% of the seepage estimates for the two periods from this study. The difference is because the G-372S pump station receives seepage from sources that are in addition to the A-1 FEB.

Seepage pumping at G-370S was 64 ac-ft during Period 1 and 91 ac-ft during Period 2 (**Figure 12**). **Table 13** depicts the average stage in the G-370S Seepage Canal and inside A-1 FEB on the east side. G-370S seepage return pumping was a very small fraction of the seepage estimates for the two periods. The difference is because G-723N (which allows delivery of seepage water from the east seepage canal to the G-370S seepage pumps) was closed during the observations periods except for an approximate 20-minute period when the G-723N gate was opened. In addition, stages in the A-1 FEB East Seepage Canal are maintained 2.5 ft higher than the G-372S Seepage Canal resulting in less expected seepage from the A-1 FEB along the East Seepage Zone in comparison to the North/Northwest Seepage Zone.

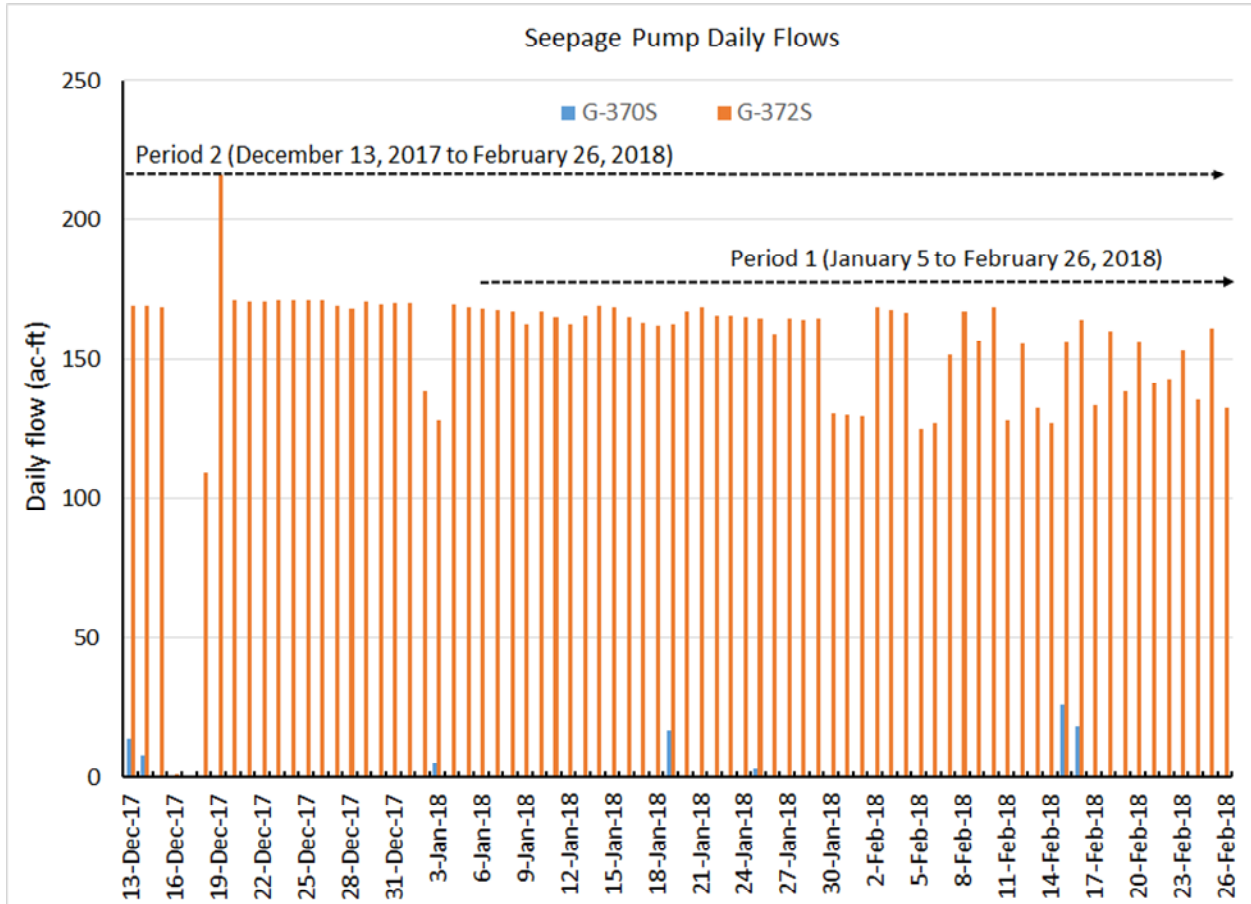


Figure 12. Seepage pumping at G-370S and G-372S during the two seepage observation periods.

Table 12. North/Northwest Seepage Canal average stage, A-1 FEB average stage, A-1 FEB average stage, G-372S flow, and North/Northwest Seepage Zone seepage estimates from this study for the two seepage observation periods.

Period	North/Northwest Seepage Canal Average Stage (ft NGVD29)	A-1 FEB (North/Northwest) Average Stage (ft NGVD)	G-372S Flow (ac-ft)	North/Northwest Zone Seepage Estimate (ac-ft)
Period 1	8.16	12.41	8,242	7,079
Period 2	8.23	12.59	11,722	10,666

Table 13. East Seepage Canal average stage, A-1 FEB average stage, G-370S flow, and East Seepage Zone seepage estimates from this study for the two observation periods.

Period	East Seepage Canal Average Stage (ft NGVD29)	A-1 FEB (East) Average Stage (ft NGVD29)	G-370S Flow (ac-ft)	East Zone Seepage Estimate (ac-ft)
Period 1	10.63	12.40	64	4,067
Period 2	10.68	12.59	91	6,438

SUMMARY

The estimated seepage coefficient for the 7.5-week observation period and the stage conditions studied is $52 \text{ ft}^3 \text{ d}^{-1} \text{ ft-levee}^{-1} \text{ ft-head}^{-1}$ or $3.18 \text{ cfs mile-levee}^{-1} \text{ ft-head}^{-1}$, which is comparable to the seepage rates used during the design of STA-3/4 and the A-1 FEB. This seepage rate is appropriate for use in future water budget analyses for the A-1 FEB. Most of the estimated seepage outflows for the period studied occurred on the North/Northwest Seepage Zone followed by the East Seepage Zone, while seepage inflows were estimated along the Southwest and South seepage zones from the STA-3/4 Supply/Inflow Canal. Different stage conditions (i.e., head differences across the levees) for each of the zones from what was observed during the seepage test could impact the direction (i.e., into or out of the FEB) and magnitude of the estimated seepage volumes.

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