TECHNICAL NOTES

Hydrologic Mass Balance Analysis for Storm Water Treatment Area 1 West Inflow Basin and Flow Data Estimation for G301 Spillway (November 2, 1999 to September 30, 2004)

January 2005

By

Wossenu Abtew

Water Quality Assessment Division
Environmental Resource Assessment Department
South Florida Water Management District
3301 Gun Club Road
West Palm Beach, FL 33409

Background

The Stormwater Treatment Area 1 West (STA-1W) Inflow and Distribution Basin is a 272-acre portion of northern Water Conservation Area 1 (WCA-1) near the S5A pump station that was levied to form a basin that serves as storage and distribution for STA - 1W and STA-1E. The STA-1W Inflow Basin has five structures (Figure 1). The major inflow structure is the S5A pump station. The G301, G300 and S5AS spillways contribute a relatively smaller amount of inflow to the basin. The G300 and G301 structures are designed for by-pass flow from the Inflow Basin to Water Conservation Area 1 through the L-40 and L-7 canals, respectively. The major outflow structure is the G302 spillway that discharges into STA-1W. Other discharges from the Inflow Basin are through G301 and G300 into WCA-1 and through S5AS into the S5A complex. The S5A complex is the junction of the L-8 and the C-51 canals. Water in S5A complex can flow north to the L-8 canal, to the C-51 canal east through the S5AE structure or to the C-51 canal west through the S5AW structure.

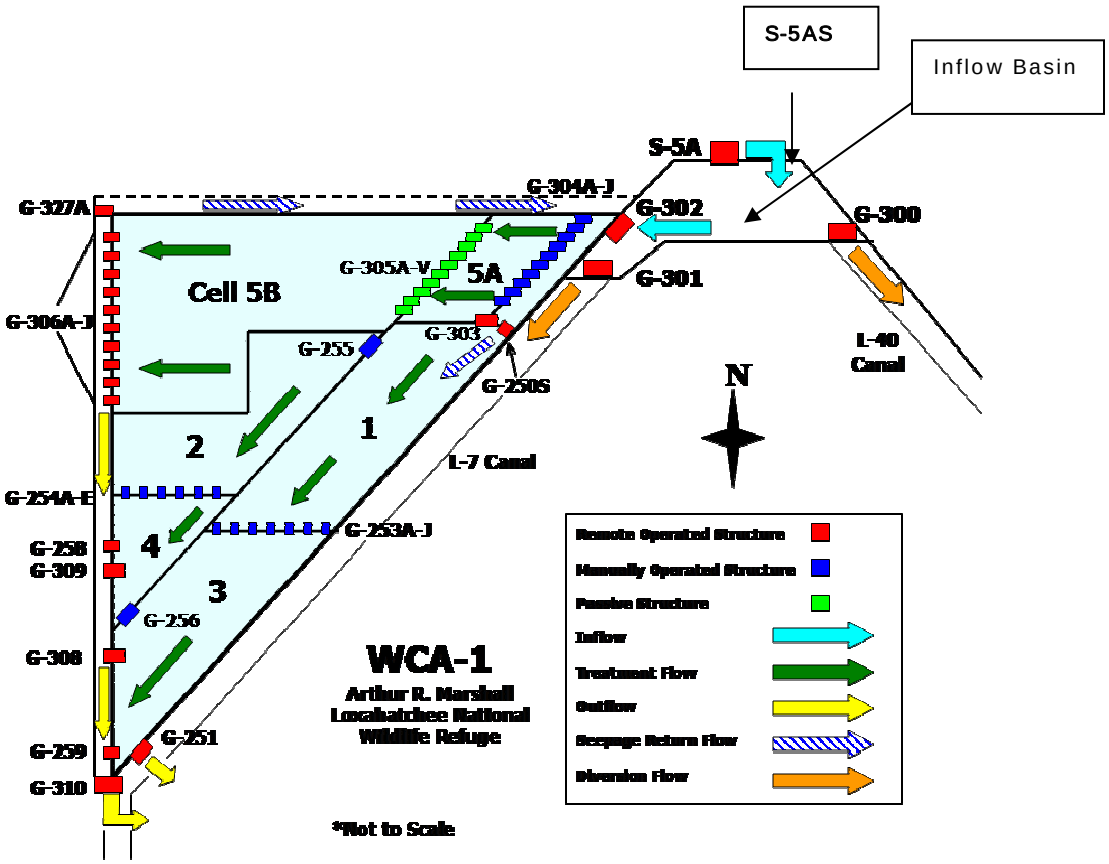

Figure 1. STA-1W and the Inflow and Distribution Basin.

Flow Data

Questions were raised by Dr. W. Walker on the validity of by-pass flow data (G300+G301) in the DBHydro database and he suggested re-examination of the entire

period of record. The G300 and G301 structures are designed for by-pass flow from the Inflow Basin to Water Conservation Area 1 through the L-40 and L-7 canals, respectively. Back flow conditions have been recorded when tailwater water levels started exceeding headwater water levels. A team from Operations and Hydro Data Management; Operations Control, Engineering and Vegetation Management; Water Resources staff (Gary Goforth), and Environmental Resources Assessment evaluated an initial hydrologic mass balance of the Inflow Basin and G301 flow data in DBHydro. A general consensus was reached that there was a need for improvement of the G301 flow data quality. On December 6, 2004, Operations and Hydro Data Management staff revised flow equations for G301 and G300 structures, recomputed flows and reloaded new flow data into DBHydro for the period of record (August, 1999 to November, 2004). After evaluating the hydrologic mass balance results from the new flow data, the team requested a complete hydrologic mass balance analysis of the Inflow Basin and daily flow estimation for the G301 structure for days when the absolute value of head ($\left|$ Headwater-Tailwater $\right|$) was less than or equal to 0.2 ft and one or more gates were open. This report summarizes the process of hydrologic mass balance analysis and the resulting flow data estimation for the G301 structure and includes comparison of the estimated, current, and original DBHydro flow data.

Hydrologic Mass Balance Analysis

Flow and stage data from DBHydro for the period November 2, 1999 to September 30, 2004 were used for the hydrologic mass balance evaluation of the Inflow Basin. A schematic hydrologic model for the Inflow Basin and flow monitoring structures is shown in Figure 2.

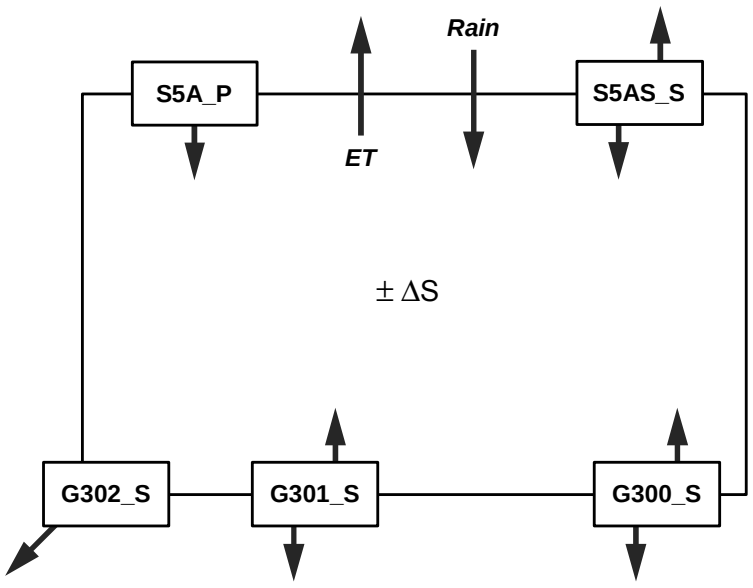

Figure 2. Schematic hydrologic model for STA-1W Inflow Basin with arrows showing flux direction.

Flow and stage Dbkeys that were used in this analysis are shown in Table 1. The hydrologic mass balance analysis for the 272-acre Inflow Basin was performed based on the following equation:

$$\textbf{Balance} = \textbf{S5A-G300-G301-G302+S5AS+RAIN-ET-}\Delta\textbf{S} \quad (1)$$

Where:

- Balance is daily mass balance error in ac-ft;
- S5A is daily flow in ac-ft through the S5A pump station;
- G300 is daily flow in ac-ft through the G300 structure;
- G301 is daily flow in ac-ft through the G301 structure;
- G302 is daily flow in ac-ft through the G302 structure;
- S5AS is daily flow in ac-ft through the S5AS structure;
- Rain is daily rain in ac-ft from the S5A rain gauge (Dbkey 15202);
- ET is wetland or open water evapotranspiration in ac-ft from STA-1W (Dbkey KN810);
- ΔS is change in storage in ac-ft computed from daily change in water level in the Inflow Basin. Daily average water level for the Inflow Basin was computed as the average of five gages shown in Table 1 (S5A_T, S5AS_T, G300_H, G301_H and G302_H).

Table 1. Flow and stage database Dbkeys associated with hydrologic mass balance analysis for the Inflow Basin.

	Flows	**Head Stage**	**Tail Stage**
Structure	**Dbkey**	**Dbkey**	**Dbkey**
S5A_P	JW226		
S5A_T			06677
S5AS	L7444		
S5AS_T			06693
G300	KD315		
G300_H		KN627	KN628
G300_T			
G301	JJ809		
G301_H		KS685	
G301_T			KS686
G302	JW221		
G302_H		KS683	
G251_T			16219

Discussion

Initially, a simple mass balance of surface water inflows and outflows was performed and the results are depicted in Table 2. Since the Inflow Basin area is small (272 acres) and the hydrology is dominated by surface water flows, the effect of rainfall, ET and change in storage on long term hydrologic mass balance is minimal. It is clear from the mass balance analysis (Table 2) that the balance for September 2004 revealed a large error (51,736 ac-ft), that is 29 percent of the total surface water inflows. This error indicates there is either too high inflow or too low outflows in the Inflow Basin. Based on Operations Control, Engineering and Vegetation Management Department staff field observations during the September 2004 hurricane events, and flow mass balance results for September 2004, G301 was isolated as the potential source of flow monitoring problems.

Table 2. Flow mass balance for two periods (Inflow-Outflow) with original DBHydro flow data for G301 and G300 (before December 6, 2004).

Structure	**1999 to August 2004**		**September 2004**	
	Inflow	Outflow	Inflow	Outflow
	ac-ft	ac-ft	ac-ft	ac-ft
S5A	1,686,181		152,987	
S5AS	61,901	278,635	2,266	587
G300	105,502	94,196	-------	16,601
G301	**61,721**	**82,940**	**24,206**	**622**
G302		1,465,972		109,913
Balance		**6,438**	**51,736**	

Operations and Hydro Data Management staff revised the flow computation equations for G301 and G300 and new sets of flow data, for the period of record (August, 1999 to November, 2004), were reloaded into DBHydro on December 6, 2004. Table 3 depicts the complete hydrologic mass balance for the period from November 2, 1999 to August 31, 2004 and separately for the month of September 2004, based on flow data in DBHydro that was reloaded on December 6, 2004. An improvement in hydrologic mass balance error was achieved as a result of the new flow data set for the G301 and G300 structures. Nevertheless, the balance for September 2004 still had large error (41,567 ac-ft), 24 percent of total inflow. The error indicates too low outflow from the Inflow Basin or too high inflow into the Inflow Basin. Figure 3 depicts daily mass balance errors for the whole period and Table 4 is summary of monthly errors. In Figure 3, daily balance (error) close to zero indicates a good balance between inflows and outflows. Spikes of positive numbers indicate excess inflows or smaller outflows recorded in error and spikes of negative numbers indicate excess outflows or smaller inflows recorded. In Figure 4, large monthly errors are shown in bold and indicate the months with relatively poor mass balance.

Table 3. Hydrologic mass balance for two periods With DBHydro Flow data for G301 and G300 reloaded on December 6, 2004.

Structure/ Parameter	**Nov. 1999 to Aug. 2004**		**September 2004**	
	Inflow	Outflow	Inflow	Outflow
	ac-ft	ac-ft	ac-ft	ac-ft
S5A	1,686,181		152,987	
S5AS	61,901	278,635	2,266	587
G300	117,524	104.433	-------	18,474
G301	**68,767**	**82,253**	**17,135**	**706**
G302		1,465,972		109,913
Rainfall	5,055		396	
ET		5,796		90
ΔS	1,401			1,447
Balance	**3,740**		**41,567**	

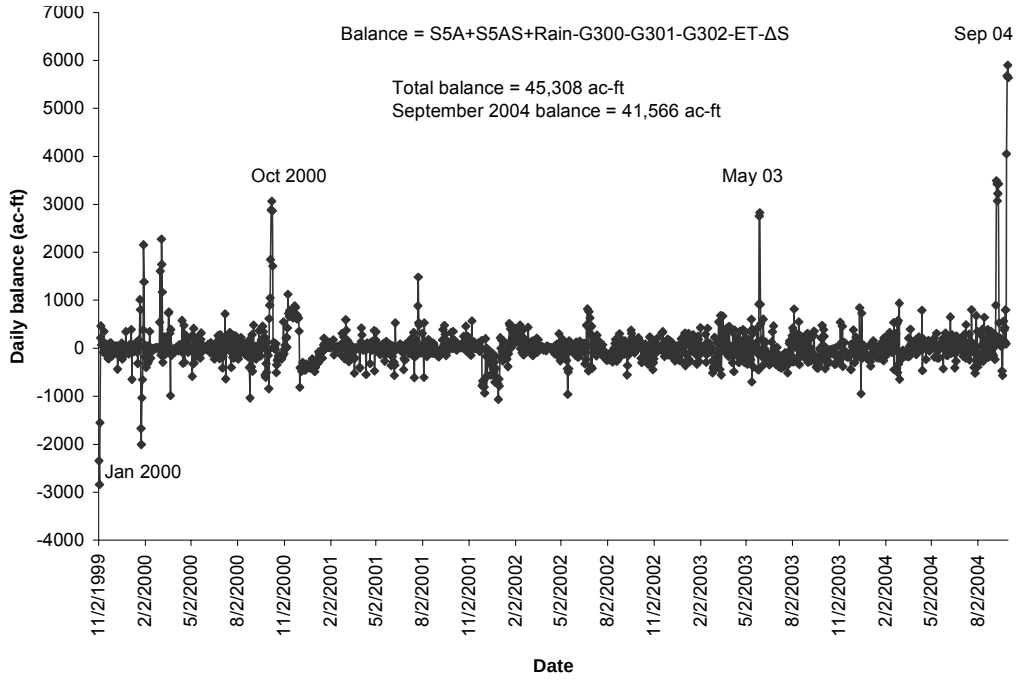

Figure 3. Daily mass balance errors with G301 and G300 flow data reloaded in DBHydro on December 6, 2004.

Table 4. Monthly hydrologic mass balance errors with G301 and G300 flow data reloaded in DBHydro on December 6, 2004.

Sum of ac-ft	Month												
Year	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
1999											-6292	-1652	-7944
2000	-249	-1153	**7791**	821	-150	952	717	-2431	-80	**11712**	**17111**	**-11433**	23608
2001	-2452	1140	-2006	720	638	-2196	3417	25	1626	2741	-1815	**-12873**	-11033
2002	1971	3902	769	29	-2266	2845	-542	-2087	373	-1812	584	-1412	2353
2003	617	-1471	1167	459	**8197**	-2474	**-6362**	2696	-3775	-3970	-1878	-1339	-8132
2004	-1872	1782	-1460	1640	747	1529	1442	1082	**41566**				46457
Grand Total	-1985	4200	6260	3668	7166	657	-1327	-714	39711	8671	7710	-28710	**45308**

The daily average water level in the Inflow Basin as computed from five gages (S5A_T, S5AS_T, G300_H, G301_H, G302_H) is shown in Figure 4. Tail water from G300_T, G301_T and G251_T are also shown for comparison and indicate WCA-1 water level outside the Inflow Basin. Based on Figures 4 and 5, it can be concluded that it is a great challenge to send water south through G300 and G301 while G302 is operating, STA-1W is discharging into WCA-1, and WCA-1 water level is high. Because the Inflow Basin is small, the gradient could reverse and backflow would occur. Most of the time, water level in the Inflow Basin is lower than in WCA-1. As shown in Figure 4, the water level fluctuation in the Inflow Basin is high compared to changes in water level in WCA-1. Figure 5 shows the same head and tail water level comparison with high resolution for the period July 26 to September 30, 2004.

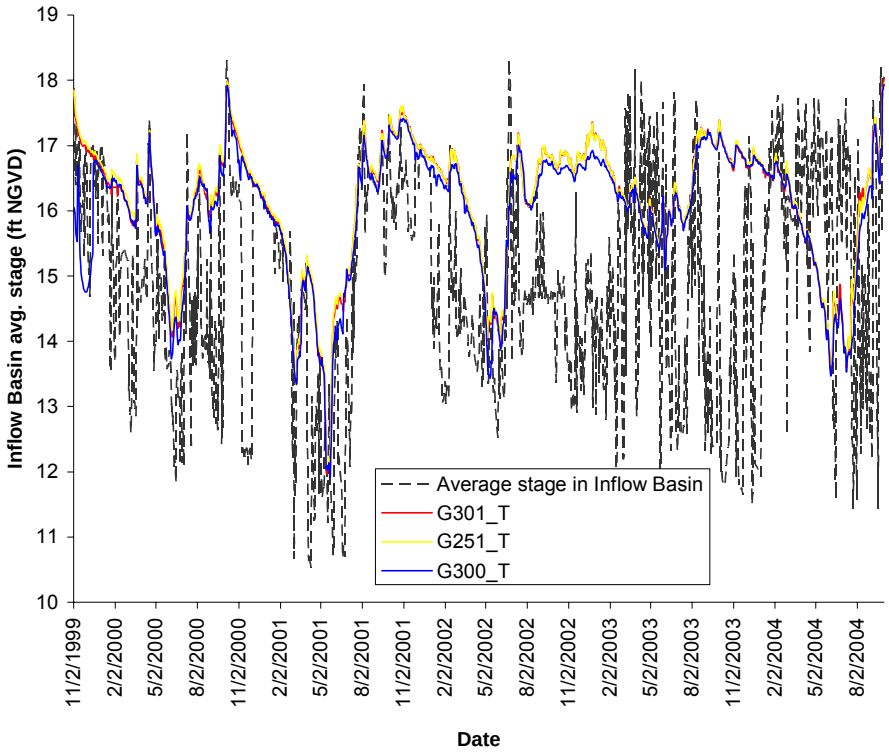

Figure 4. Daily water levels in the Inflow Basin and related structures (November, 1999 to September, 2004).

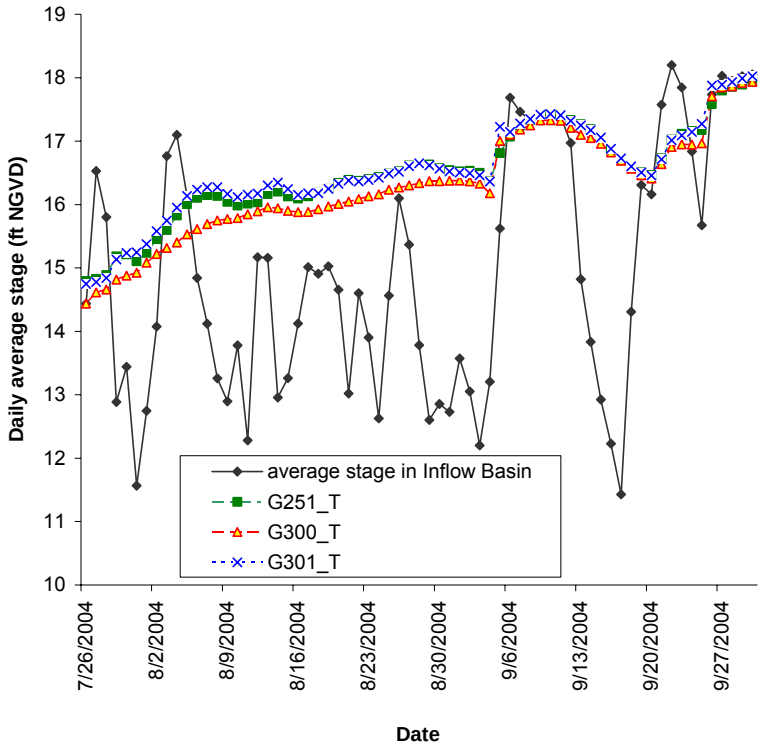

Figure 5. Daily water levels in the Inflow Basin and related structures (July 26 through September 30, 2004)

Collectively, the team decided to estimate daily flows through the G301 structure for the period of record, for days when the gates were open and the absolute head ($|$Headwater-Tailwater$|$) was less than or equal to 0.2 ft. Hydrologic mass balance analysis is deemed to provide a reasonable estimate of flow. The following equation was used to estimate flow through the G301 structure where G301(est) is estimated daily flow for the G301 structure.

$$\mathbf{G301(est) = S5A-G300-G302+S5AS+RAIN-ET-\Delta S}$$
$$\mathbf{(for\ |\Delta h| <= 0.2\ ft\ and\ Gates\ open)} \qquad (2)$$

Where $|\Delta h|$ is absolute value of the difference between headwater and tailwater and other terms are as defined in equation 1. Figure 6 depicts daily balance (errors) from a complete hydrologic mass balance for the Inflow Basin where G301 flow data is the combination of estimates by equation 2 and current values for days when the estimation conditions are not fulfilled. Figure 6 shows decrease in daily error, especially for the month of September, 2004. Figure 7 depicts daily average head (Headwater-Tailwater) and gate opening events and depicts that on most days the head or gradient is reverse (negative).

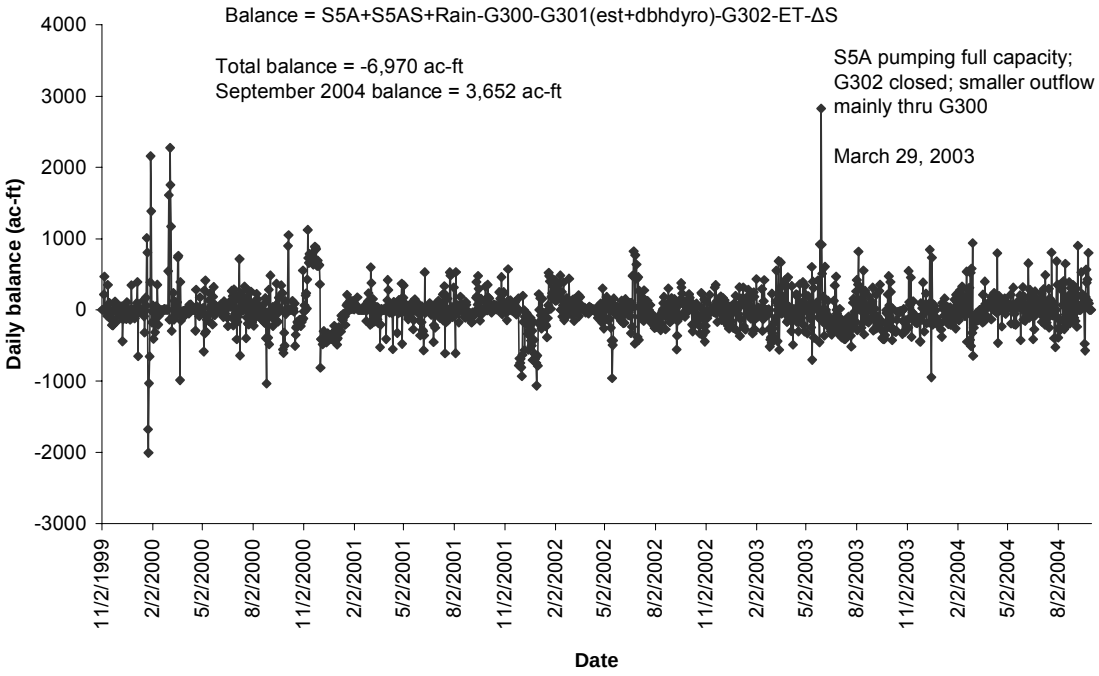

Figure 6. Daily mass balance errors computed with G301 flow data (estimate+DBHydro)

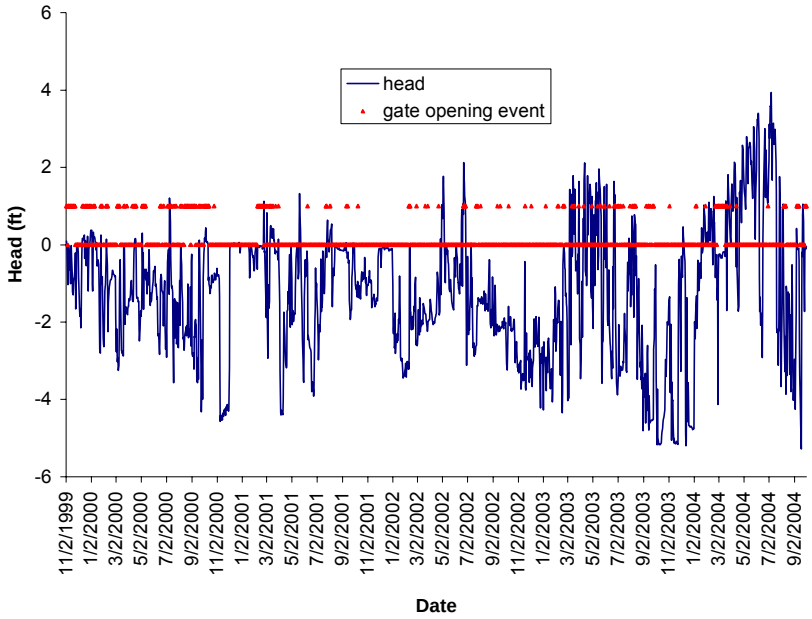

Figure 7. Daily average head and gate opening events for G301.

Table 5 depicts complete hydrologic mass balance with G301 flows (estimated+DBHydro) and for periods November 2, 1999 to August 31, 2004 and separately for the month of September, 2004. The total error for the period of record is -3,319 ac-ft which equates to 0.2 percent overall error. The error for September 2004 is reduced to 3,651 ac-ft (2.4 percent). Table 6 shows monthly summary of G301 flows (estimated+DBHydro) and current G301 flow data in DBHydro database. Figure 8 depicts graphical comparison of daily G301 estimated flows and current flows in DBHydro database. The difference between the two data sets is more significant in September 2004, when DBHydro data shows negative flows for G301 and the mass balance estimates are positive.

Table 5. Hydrologic mass balance for two periods with estimated and current DBHydro flow data for G301 and G300.

Structure/ Parameter	**Nov. 2, 1999 to Aug. 31, 2004**		**September 2004**	
	Inflow	Outflow	Inflow	Outflow
	ac-ft	Ac-ft	ac-ft	ac-ft
S5A	1,686,181		152,987	
S5AS	61,901	278,635	2,266	587
G300	117,524	104,433	--------	18,474
G301	***72,982***	***97,178***	***879***	**22,366**
G302		1,465,972		109,913
Rainfall	5,055		396	
ET		5,796		90
ΔS	1,401			1,447
Balance		***6,970 (0.4 %)***	***3,651 (2.3 %)***	

Table 6. Comparison of monthly G301 flow data with estimates and current flow data in DBHydro.

		month												
year	Data	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
1999	Sum of estimate											-15602	2043	-13559
	Sum of DBHYDRO											-8992	2906	-6086
2000	Sum of estimate	2709	604	1351	12380	4423	-1549	10309	-8518	3172	29110	0	0	53990
	Sum of DBHYDRO	2777	878	1011	11725	4423	-1549	10309	-8456	2561	17106	0	0	40785
2001	Sum of estimate	0	-1136	-478	0	0	36	1225	143	-270	0	0	0	-479
	Sum of DBHYDRO	0	-1560	452	0	0	36	-1144	125	-270	0	0	0	-2360
2002	Sum of estimate	0	53	-2	-2	0	4478	-1306	-1	-4	-1	-2	-11	3201
	Sum of DBHYDRO	0	-211	-2	-2	0	4478	-1306	-1	-4	-1	-2	-11	2937
2003	Sum of estimate	0	-2318	1198	1697	4101	925	-2023	9499	-2437	0	0	0	10642
	Sum of DBHYDRO	0	-2417	1198	1314	1349	925	-2023	9241	-2437	0	0	0	7150
2004	Sum of estimate	-39	-3175	-26275	-2	0	0	0	-107	21486				-8112
	Sum of DBHYDRO	-39	-3175	-25616	-2	0	0	0	-107	-16429				-45369
Total Sum of estimate		2670	-5973	-24206	14072	8523	3890	8205	1017	21948	29110	-15604	2032	45683
Total Sum of DBHYDRO		2737	-6486	-22957	13035	5771	3890	5836	803	-16578	17106	-8994	2895	-2944

*Sum of estimate (mass balance estimates when absolute value of head <= 0.2 ft and gates were open) otherwise current values from DBHydro.

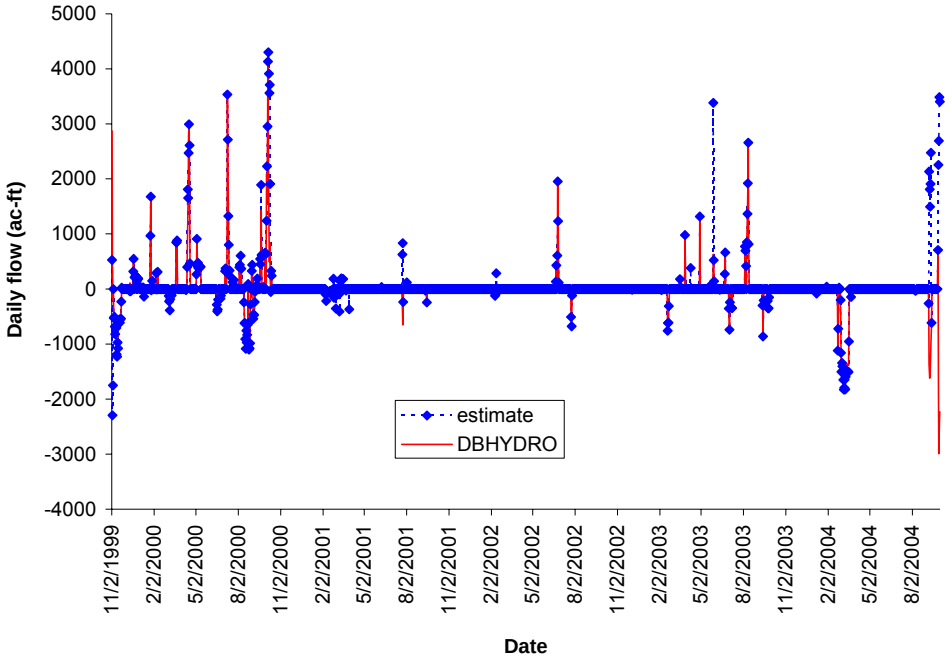

Figure 8. Comparison of daily G301 flow data with estimates and current flow data in DBHydro.

Conclusion

In conclusion, field investigations of flow monitoring in the Inflow Basin under various hydrologic, hydraulic and operational conditions are required to determine the hydrologic mass balance discrepancy for the Inflow Basin and improve flow monitoring at G301 and G300. This report and the mass balance based estimates of flows for the G301 fulfills the request from the team.

Based on mass balance analysis, the mass balance estimated flow data for G301 is a better quality set of flow data. The remaining major daily error spikes should be removed by expanding the criteria for estimating flow and reassigning flow values for affected structures. The resulting data set could be stored in a Preferred Dbkey in DBHydro database and be available for use.