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QUANTIFYING AND COMMUNICATING PUMPED STORM WATER FLOWS FOR REAL-TIME FLOOD MANAGEMENT

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Muluneh Imru
Youchao Wang

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South Florida Water Management District
3301 Gun Club Road
West Palm Beach, FL 33406

EXECUTIVE SUMMARY

This paper presents the process and method used by the South Florida Water Management District (the District) to quantify and communicate pumped storm water flows for real-time flood management. The process employs the linkages between the supervisory control and data acquisition (SCADA) system, the hydrodynamic model used to estimate discharge (FLOW), and the corporate database for archiving hydrologic data (DBHYDRO). The District operates about 500 major water control structures including over 60 pump stations. The flow calculation algorithm development and equation calibration process is demonstrated using a major pump station of the District, S5A, which has a design capacity of 136 m^3/s (4800 cfs). As a result of the calibration process, the percentage of calculated flows within 10% of field measurement values improved from 80% to 100%. The improvement in flow data accuracy leads to more reliable performance measures and better scientific basis for decision making. Instantaneous hydrologic data are useful for real-time flood management decisions. The efficient real-time flood management scheme used by the District has successfully protected large urban and agricultural areas of South Florida against flood impacts from four major hurricanes of 2004 (Charley, Frances, Ivan, and Jeanne).

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LIST OF ABBREVIATIONS AND ACRONYMS

DBHYDRO	Hydrometeorologic and Water Quality Database
DCVP	Data collection/validation process
DWR	Daily water readings
IMS	Information management system
SCADA	Supervisory control and data acquisition

ACKNOWLEDGEMENT

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QUANTIFYING AND COMMUNICATING PUMPED STORM WATER FLOWS FOR REAL-TIME FLOOD MANAGEMENT

1. Introduction

This paper describes the process and method used by the South Florida Water Management District (the District) to quantify and communicate pumped storm water flows for real-time flood management. The linkages between the supervisory control and data acquisition (SCADA) system, the hydrodynamic model used to estimate surface water discharge (FLOW) and the corporate database for archiving hydraulic, hydro-meteorological, and water quality data (DBHYDRO) are presented.

FLOW determines discharge magnitudes and directions in channels, using hydrodynamic information from remote sites and linking to DBHYDRO for static and dynamic parameters. Flow values in one to fifteen-minute time steps are generated and used for real-time operation of major water control structures. Instantaneous data are also used for real-time automatic flow proportional water quality sampling. Real-time flow monitoring in South Florida, coupled with telemetry data acquisition, allows timely access to information for decision making. The efficient real-time flood management scheme used by the District has successfully protected large urban and agricultural areas of South Florida against flood impacts from four major hurricanes of 2004 (Charley, Frances, Ivan, and Jeanne).

For flow data, there is a continuous quality improvement process involving discharge rating evaluation, sample data collection, and rating calibration. The cycle of this process depends on the importance and priority of the control structure in terms of legal mandate, hydraulic capacity, and permit application and compliance requirements.

2. The South Florida Water Management System

As an agency responsible for flood protection, water supply planning, water quality enhancement, and ecosystem restoration, the South Florida Water Management District (the District) recognizes flow as an important performance measure of its water management undertakings. Thus, it monitors flow at over 500 major water control structures spread over an area of about 46,620 sq. km. (18,000 sq. mi.) in 16 counties extending from south of Orlando to the Florida Keys.

As stated in Imru and Damisse (2004), the regional storage system consists primarily of Lake Okeechobee (1,761 sq. km. or 680 sq. mi.), Upper Kissimmee Chain of Lakes (4133 sq. km or 1596 sq. mi.), the Lower Kissimee basin (1883 sq. km. or 727 sq. mi.), Lake Istokpoga (111 sq. km. or 43 sq. mi.), and water conservation areas (WCA-1, WCA-2, WCA-3 totaling 3108 sq. km. or 1200 sq. mi.). Operation planning for the regional storage system depends on flow data. Daily flows are archived to provide historical records for planning and decision making on flood control, water quality enhancement, water supply, and ecosystem restoration. There are over 60 major pump stations spread over the District's water management area moving large quantities of storm water to meet flood control and water supply needs. Figure 1 shows pump stations operated by the District.

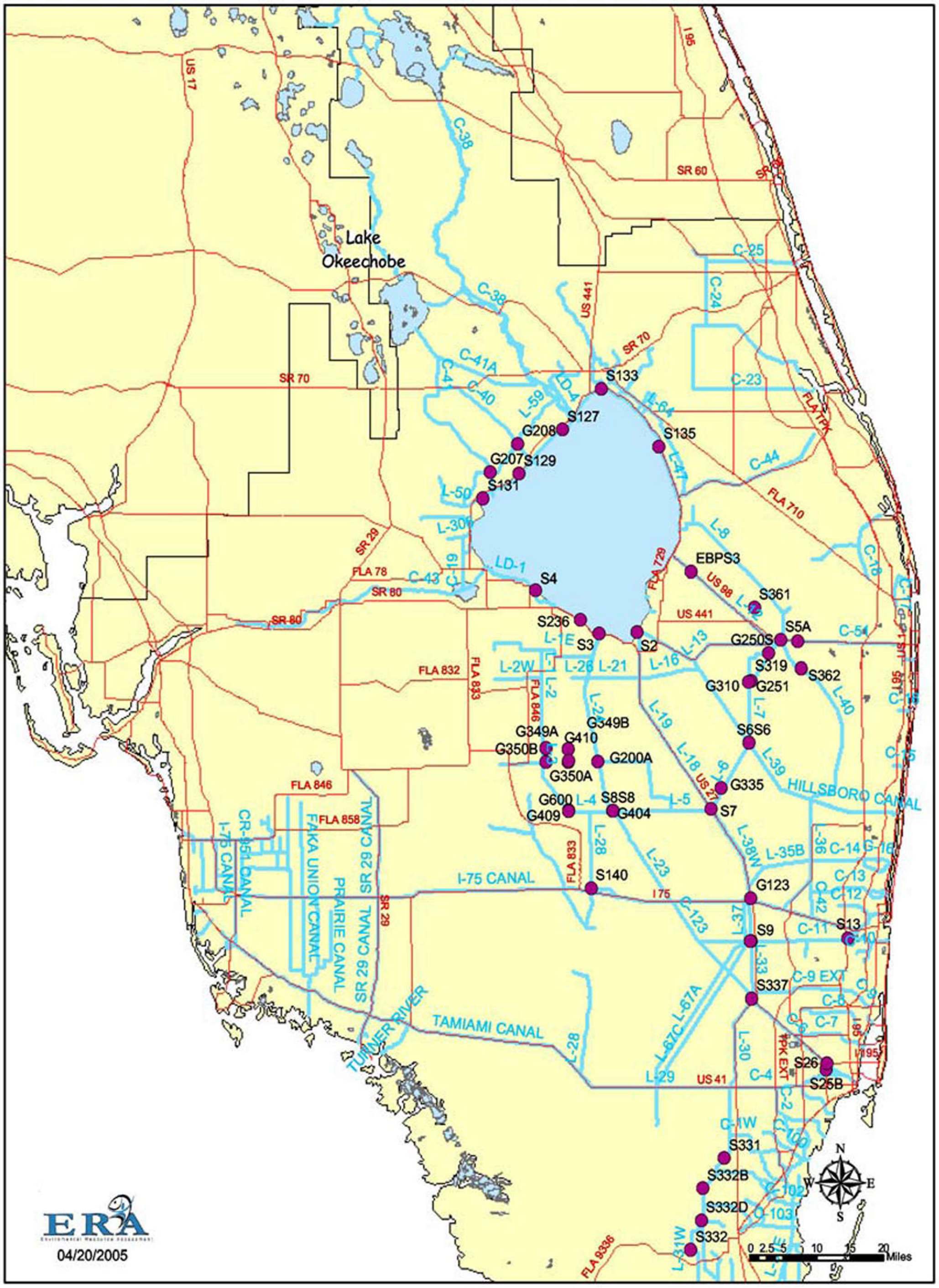

Figure 1. South Florida Water Management District Pump Stations

3. Data Acquisition System and Process

There is a large data collection network in the system for monitoring water levels (stages), weather parameters and structure operation status. The devices and methods used for acquiring hydrologic data have evolved following advances in technology. Hydrologic data based on daily water readings (DWR) and graphic stage data are available dating back to 1968 (Imru and Damisse, 2004). Such data are acquired from remote sites and transported manually.

With advances in technology, data acquisition and transmission has been handled electronically through a telemetry system since 1980. Currently, the District uses microwave telemetry, radio frequency telemetry and manual data collection, and transmission procedures. The field data collection network provides hydrodynamic parameters such as headwater stage, tailwater stage, and control operation status (gate opening, pump speed, etc) used for flow estimation. The hydrodynamic information is loaded to the Data Collection/Validation Preprocessing (DCVP) database where provisional (unprocessed) and processed data are stored.

The SCADA system is a mechanism operated electronically, which facilitates remote operation of control structures and acquiring, processing and displaying stage and structure operation data. Operator-initiated commands carry out remote operation of the structures and scan the sites to acquire hydrodynamic data based on preset rules. The rules include changes in hydrodynamic value (e.g. headwater stage) and/or time interval. Through telemetry, it is possible to acquire data at time intervals of one minute to two hours. The acquisition, transmission and display of data can be done in seconds. This facilitates flow computation at a station within seconds of occurrence (real time option). Primary data including stages, gate opening, and pump speed are checked, processed, and archived in DCVP and summarized in DBHYDRO. The existing hydrologic data acquisition, transmission, processing and dissemination system is shown in Appendix A. KEMA Consulting (2002) provides details of components and notations shown in Appendix A including water quality data collection, processing, and archiving. Appendix A shows parallel routes (LIMS and Contract Labs) for water quality data processing. Water quality data summaries are also archived in DBHYDRO.

4. Flow Estimation

Pump characteristic curves are used in conjunction with the affinity laws to develop equations for quantifying discharge through the major pump stations of the District. Initially equations are developed based on pump characteristic curves; subsequently the equations are evaluated for performance in terms of calculated flow data accuracy in relation to field measurements. The equations are then calibrated using field flow measurements to improve flow data accuracy.

Physical properties which have bearing on fluid discharge need to be considered when developing a flow equation. The flow of a liquid through a pump may be described by a dimensionless relation containing relevant physical quantities including discharge Q, engine speed N, impeller diameter D, length L, head H, acceleration of gravity g, density ρ, and viscosity μ.

$$F\,(Q,\,N,\,D,\,L,\,gH\,,\rho,\,\mu) = 0 \tag{1}$$

Using the Buckingham π Theorem (Featherstone and Nalluri 1982), based on the above relation, the following dimensionless relation can be developed.

$$Q = ND^3\phi\left[\frac{D}{L},\frac{N^2D^2}{gH},\frac{\rho ND^2}{\mu}\right] \tag{2}$$

Considering that the performance of a specific prototype water pump is being investigated, all physical quantities other than Q, N, and H are assumed constant and are lumped into one coefficient A. On the basis of this assumption, the relation further reduces to the following.

$$Q = A\phi[H,N] \tag{3}$$

At the design engine speed the discharge is a function of the required head as can be observed from the performance curve provided by the manufacturer. For the design engine speed, i.e. where N is kept constant at design value, the above function can be written in the following form.

$$Q_0 = f(H) \;= A + BH_0^{\;C} \tag{4}$$

where Q_0 is the discharge for a design engine speed (cfs); H_0 is head differential that corresponds to Q_0 (ft); and A and B are constant coefficients and C is a constant power.

The flow rate changes proportionally according to the pump affinity laws when the engine speed varies. The pump affinity laws assume no change in efficiency when engine speed changes and the relation between the change in discharge and the change in engine speed is given by

$$\frac{Q}{Q_0} = \frac{N}{N_0} \tag{5}$$

Substituting Equation (4) into Equation (5) and rearranging, we obtain Equation (6).

$$Q \;=\; \frac{N}{N_0}(A + BH_0^{\;C}\;) \tag{6}$$

H_0 can be written in terms of H using the following relation of the pump affinity laws.

$$H_0 = \left[\frac{N_0}{N}\right]^2 H \tag{7}$$

Substituting Equation (7) in Equation (6) and rearranging, we obtain Equation (8).

$$Q = A\left[\frac{N}{N_0}\right] + BH^C\left[\frac{N_0}{N}\right]^{2C-1} \tag{8}$$

where Q is the computed discharge (cfs); N is the field measured engine speed (rpm); N_0 is the design engine speed (rpm); H is the field measured head differential (ft); and A, B, and C are the calibration rating coefficients and exponent.

Equation (8) presents a model based on physical laws that can be used to estimate flow through variable speed pumps. This equation describes the relationship between discharge, head differential, and engine speed.

The available measurements and pump performance curves are used for flow rating calibration. The discharges at the rated engine speed were obtained from the field data using the pump affinity laws. The regression coefficients of Equation (4) are determined based on the least-squares method (Davis, 1986). According to the least-squares method, the deviation of the estimate from the measurement is $((A + BH_0^{\;C}) - Q_0)$, and the goal becomes one of finding a method such that

$$F = \sum_{i=1}^{n}\left(\left(A + BH_0^{\;C}\right) - Q_0\right)^2 = \text{ minimum} \tag{9}$$

The expanded form of the above equation is given by

$$F = \sum_{i=1}^{n}\left(Q_0^{\;2} - 2AQ_0 - 2BH_0^{\;C}Q_0 + A^2 + 2ABH_0^{\;C} + B^2H_0^{\;2C}\right) \tag{10}$$

Mathematically F is minimized by setting its partial derivatives with respect to coefficients A, B, and C equal to zero. The partial derivatives were estimated individually; however, the results show that the three partial derivatives are similar as given below

$$\frac{\partial F}{\partial A} = \frac{\partial F}{\partial B} = \frac{\partial F}{\partial C} = \sum_{i=1}^{n}\left(2A + 2BH_0^{\;C} - 2Q_0\right) = 0 \tag{11}$$

$$B = \frac{\sum_{i=1}^{n} Q_0 - nA}{\sum_{i=1}^{n} H_0^{\;C}} \tag{12}$$

where n is the total number of measurements.

A starting estimate for coefficient A would be: $A = \sum Q_0/n$. For a parabolic equation, the coefficient A is between the design discharge and the discharge at zero lift. According to Damisse (2000) the coefficient C is more than one. Equation (12) can help to iteratively solve B for the given values of A and C. An iterative simulation helps to determine the optimum values of coefficients A, B, and C for the new rating equation.

Equation (8) was calibrated for S5A, a major pump station of the District. The structure S5A is located on the south side of U.S. Highway 441 and Canal 51 (West Palm Beach Canal), about 20 miles west of West Palm Beach, Florida. S5A is equipped with six horizontal propeller pumps each having a rated capacity of 800 cfs at 11.1 ft static head. The available stream flow measurements are tabulated in Appendix B and used to calibrate the new rating equation. A more detailed discussion of this calibration is presented in Rating Analysis for Pump Station S5A (Imru and Wang 2004). Equation (13) presents the new rating developed for estimating flow through each diesel pump at S5A. The values of the coefficient B are negative as long as the tailwater is higher than the headwater. This is consistent with the concept that pump discharge is lower when working against a positive static head (Imru and Wang, 2003).

$$Q = 895\left[\frac{N}{N_0}\right] - 1.46H^2\left[\frac{N_0}{N}\right]^3 \tag{13}$$

Equation (13) is valid when the headwater stage is lower than the tailwater, which is expected to be the most prevalent operating condition.

Table 1 shows the measured discharges and discharges computed using the new rating equation. As shown in Table 1, the relative error ranged from –6.02% to 9.61% with the average relative error of 0.71%. The plot of total computed discharges verse measured discharges is shown in Appendix C for the new rating equation. A trend line has been added to the plot forcing the y-intercept to be zero. The slope of the line was determined along with a R^2 value based on the linear regression. For the new rating equation, the slope of the linear regression is 1.0102 with a R^2 of 0.9783. This indicated the water flow data quality improvement for the new model.

Table 1. Measured Discharges and Discharges Computed Using the New Rating Equation

Date	Time	HW (ft)	TW (ft)	Q measured (cfs)	N (rpm)	H (ft)	Q computed new (cfs)	relative error
28-Jun-90	13:34	9.57	15.17	882.0	700	5.6	828.9	-6.02%
3-Jul-90	11:39	9.11	15.33	765.0	700	6.22	817.5	6.86%
24-Oct-90	13:02	9.62	16.26	827.0	700	6.64	809.1	-2.16%
24-Oct-90	13:30	9.1	16.28	727.7	700	7.18	797.6	9.61%
24-Jun-91	11:56	10.15	16.09	753.3	700	5.94	822.8	9.23%
23-Jul-91	11:52	9.36	15.8	815.0	700	6.44	813.2	-0.22%
29-Jul-91	12:11	9.68	16.27	806.8	700	6.59	810.2	0.42%
29-Jul-91	14:37	9.38	16.4	806.3	700	7.02	801.1	-0.64%
5-Aug-91	12:30	9.2	15.86	848.0	720	6.66	839.4	-1.02%
23-Sep-91	12:24	9.34	16.74	776.0	700	7.4	792.6	2.14%
20-Jun-94	12:55	9.02	15.45	826.7	700	6.43	813.4	-1.61%
23-Jun-94	12:28	9.49	15.48	807.0	733	5.99	870.4	7.86%
3-Aug-94	12:45	8.89	16.12	658.5	600	7.23	623.5	-5.32%
6-Aug-94	12:12	10	16.15	843.0	700	6.15	818.9	-2.86%
30-Jan-03	12:42	10.43	15.59	885.7	700	5.16	836.2	-5.59%
Average relative error								0.71%
Standard deviation								5.32%

Figure 2 shows head-discharge relationships for S5A resulting from field measurements, the existing and the new rating equations. The continuous curve (at the right end) represents the pump performance curve at design engine speed 714 rpm; the squares represent field measurements; the triangles represent flows computed using the existing rating equation, and the circles represent flows computed using the new calibrated equation. As shown in Figure 2, the slope of the new rating curve is similar to the original pump curve. Field discharge values indicate that the actual field performance of the pump is lower than what the manufacturer's curves suggest. This is an expected scenario if the manufacturer's curves are based on model test results under laboratory settings. The decrease is attributed to a decrease in pump efficiency, system friction losses, and aging of the pumps or other site conditions not accounted for in laboratory settings.

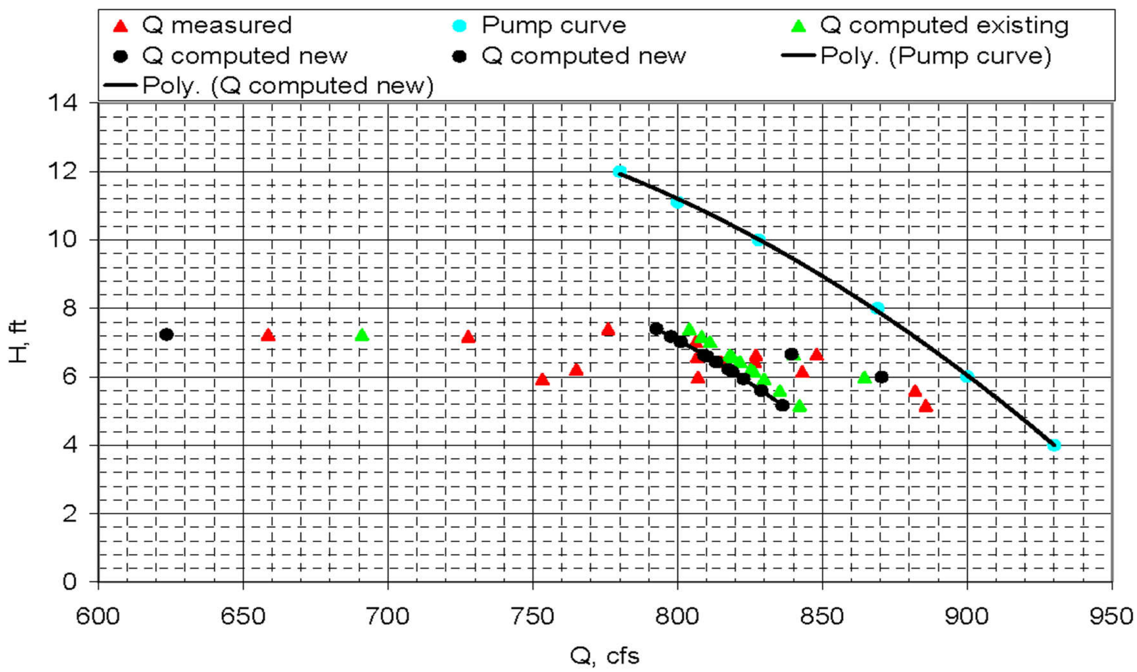

Figure 2. Head and Discharge Relationship for S5A Resulting from Field Measurements, the Existing and the New Rating Equations

The comparison of existing and new ratings shows that the new rating has 53% of calculated flows within 5% of the measured discharges and 100% within 10% while the existing rating equation has 67% of calculated flows within 5% of the measured discharges, 87% of calculated within 10% of measured values.

5. Information Dissemination

Flow computation involves using hydrodynamic data, i.e. stage, gate opening, pump speed as appropriate, in conjunction with static parameters of the control structures available in the District's hydrologic, meteorological and water quality database (DBHYDRO). Either archive or provisional hydrodynamic data can be used in the flow estimation process by FLOW. FLOW computes instantaneous (break-point) discharge through each major control structure in the

District's boundary for any specified period (date and time) on the basis of stage and structure operation data. Input hydrodynamic data can come either from archives for delayed discharge estimation or in real time for use with the real-time option of FLOW. For historical records, the instantaneous flows are summarized into daily flows and stored in DBHYDRO. DBHYDRO allows users to access over 30,000 station-years of data, collected at over 6000 stations in and around the District. Not only does DBHYDRO contain hydrologic and water quality data, but it also stores additional information about sites, structure characteristics, and stations where data are collected.

6. Real-time Communication

Real-time flow computation is made possible by coupling FLOW with telemetry data through the SCADA system. The real-time option of FLOW uses structure parameters extracted from the database, real-time scanned stage and control operation status data from the SCADA system, and gives discharge estimates in seconds. The processing and archival of quality-checked stage and control operation data triggers an automatic chain of activities to compute break-point and daily average discharges that are archived into DBHYDRO.

Flow is monitored in real time through the information management system (IMS) shown in Appendix A. Real-time flow through IMS is used for decision making on the operation of control structures at remote sites, i.e. to open or close gates, to start or stop pumping, and to stop or release flow. Such real-time access to information and timely decisions on control operation are very important during hurricanes, heavy storm events and other emergency conditions. The telemetry SCADA system coupled with the real-time flow monitoring for remote sites provides the opportunity to control flood and mitigate its effects. The benefits of real-time flow monitoring can be extended to stream gauging activities. Getting flow magnitude in real time can help to determine priorities between competing sites for allocating stream gauging resources.

7. Flood Control Operation

Abtew et al. (2001) state that the average rainfall in South Florida is 1340 mm (52.8 inches) per year. The annual rainfall can total over 2032 mm (80 inches) during wet years with heavy tropical storms and hurricanes. Figure 3 shows the daily rainfall at pump station S5A in 2004. The District's average daily rainfall is shown in Figure 4 for the period from August through September in 2004. Large amounts of rainfall caused by tropical storms/hurricanes result in high flood magnitudes in the low lying flat areas of South Florida, which requires continuous flow monitoring.

The continuous 24 hour real-time flow monitoring and SCADA system provide for adequate flood management. The ability to monitor and control flow in the District's canal network on a real-time basis significantly reduces the potential to incur serious damages to property and minimizes the threat to public safety from heavy flood events.

The efficient real-time flood management scheme used by the District has successfully protected large urban and agricultural areas of South Florida against flood impacts from the major hurricanes of 2004 (Charley, Frances, Ivan, and Jeanne), which landed in Florida within a period

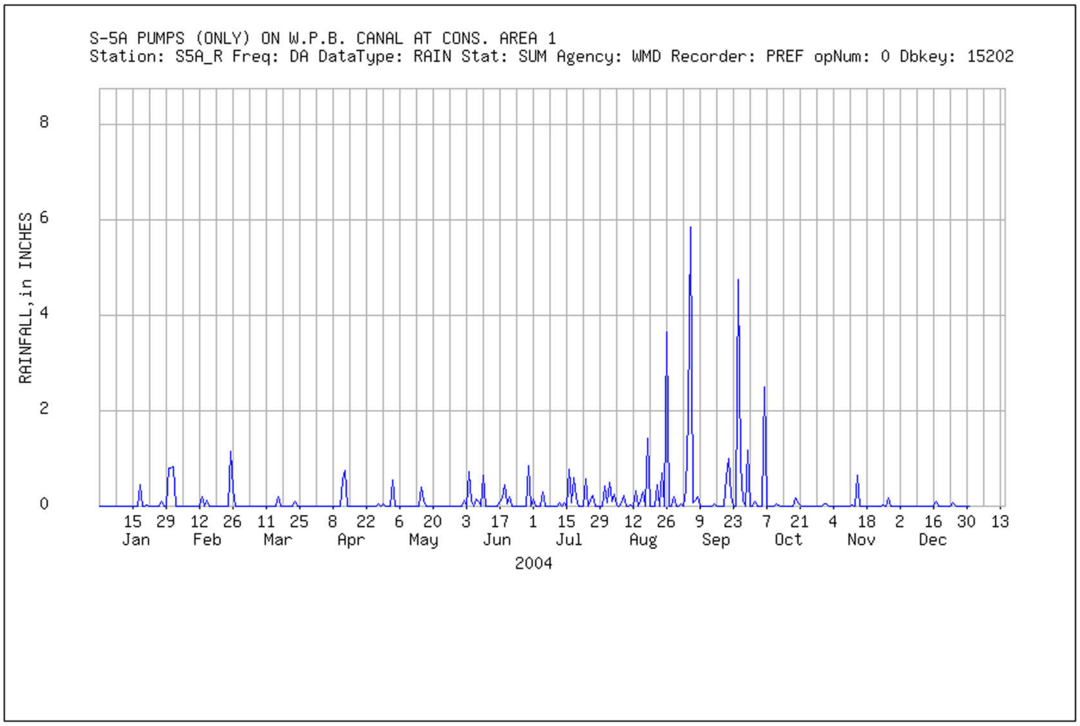

Figure 3. Daily Rainfall at Pump Station S5A in 2004

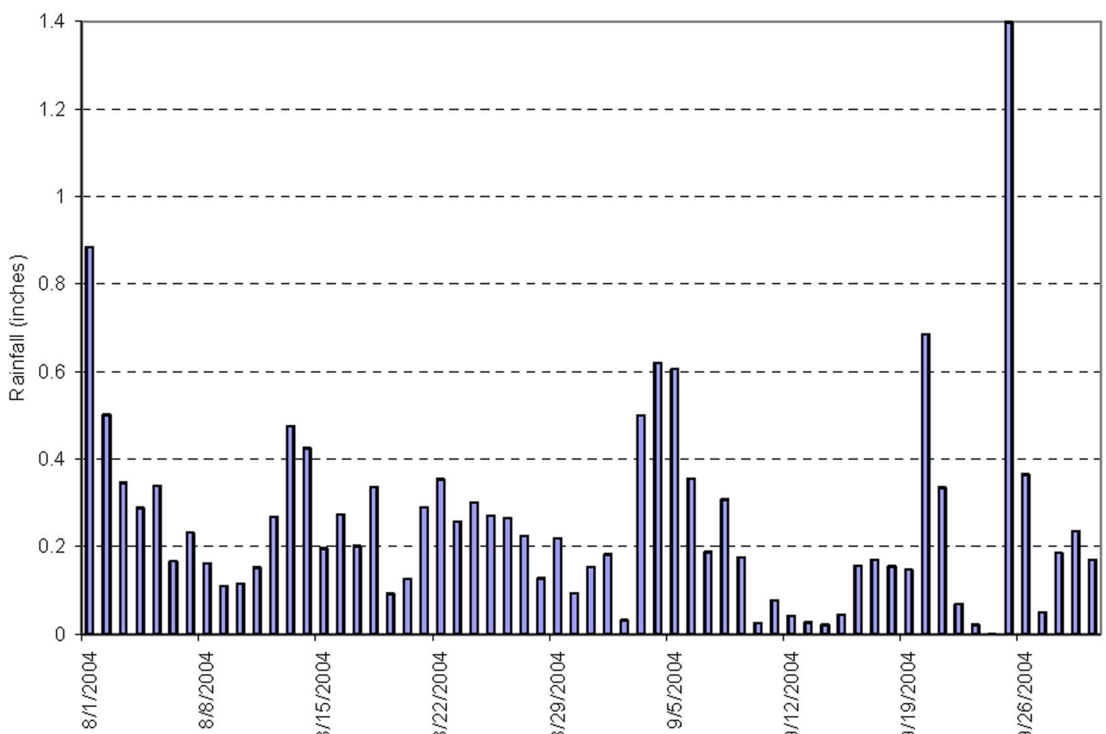

Figure 4. The District's Average Daily Rainfall from August through September in 2004

of six weeks. Table 2 summarizes the landing date, category, peak daily rainfall averaged over the District, and peak daily rainfall at S5A for the major hurricanes in Florida in 2004. It was described in Water Matters (2004) that from August through September 2004, the total rainfall in the 16 counties of the District ranged from 356 mm to 483 mm (14 inches to 19 inches) accounting to about one third of the total annual rainfall. During this period, Lake Okeechobee received a peak rate of almost 850 m^3/s (30,000 cfs). With an area of about 1870 sq. km. (730 sq. mi.), the lake surface elevation rose by over 1.7 m (5.5 feet) from a level of 3.7 m (12.3 feet) in early August to 5.5 m (18 feet) by mid-October. The District water management system moved 325 billion gallons of water in two months. The District operated twenty eight pump stations with a total of 43,600 pumping hours during the period from August through September 2004. Figure 5 shows the average daily flow for pump station S5A in 2004. Figure 6 shows the total flow volume moved for selected pump stations (S6, S5A, G310, and G335) during the hurricane season in August and September in 2004.

Table 2. Four Major Hurricanes Landing in Florida in 2004

	Charley	Frances	Ivan	Jeanne
Landing date	August 13, 2004	September 2,2004	September 16, 2004	September 26,2004
Category	4	2	3	3
Peak daily rainfall, District average	12.1 mm (0.476 inches)	15.7 mm (0.619 inches)	4.3 mm (0.170 inches)	35.5 mm (1.398 inches)
Peak daily rainfall at S5A	36.3 mm (1.43 inches)	148.6 mm (5.85 inches)	25.4 mm (1.00 inches)	121.2 mm (4.77 inches)

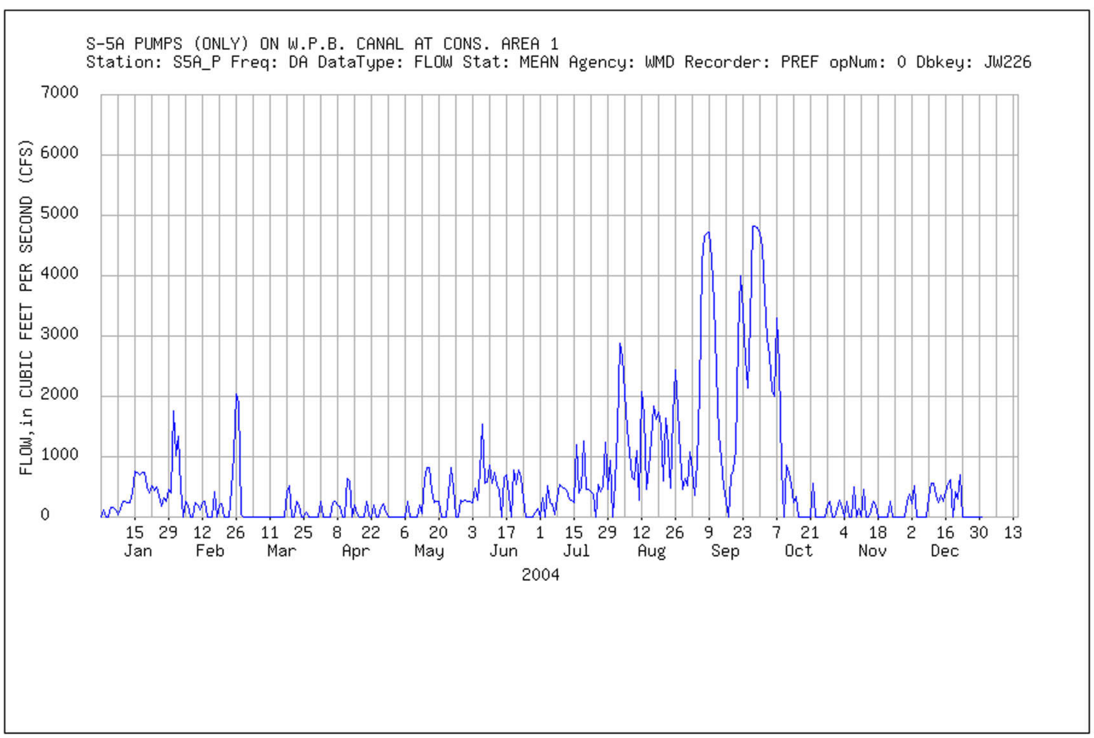

Figure 5. Average Daily Flow through Pump Station S5A in 2004

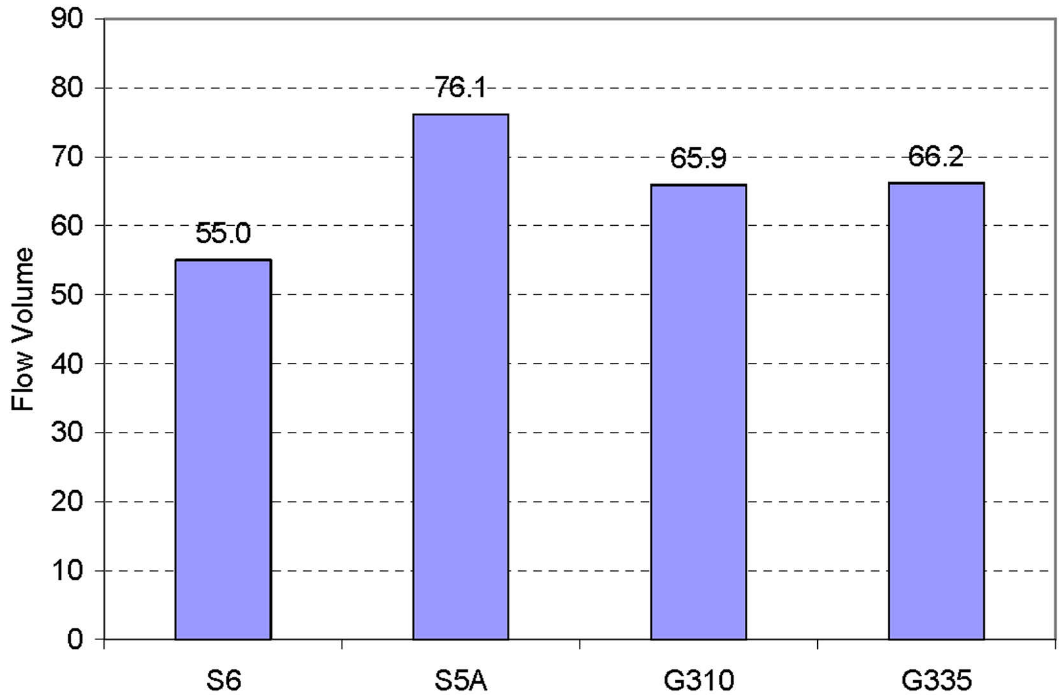

Figure 6. Total Flow Volum from August through September 2004 for Selected Pump Stations (volume in billion gallons)

8. Summary

This paper describes the process and method used by the District to quantify and communicate pumped storm water flows for real-time flood management. The linkages between the major elements of the hydrologic data management infrastructure including the field data acquisition components, the data transmission network and the corporate database facilitate real-time flow monitoring. This capability helps real-time flow estimation as well as timely decision making on structure operations for flood control and water supply.

The data collection, processing, and dissemination techniques have evolved over the years following advances in related technology. All the flows through pumps in the District are calculated by the flow rating equations and methods illustrated in this paper. Summaries of hydrologic data including stage and flow data are archived in DBHYDRO to serve the District's mission elements, i.e. flood control, water supply, water quality enhancement, and ecosystem restoration.

Real-time flow monitoring can be used to prioritize sites competing for allocation of stream gauging resources. Stream gauging activities must thus make good use of real-time flow monitoring through the information management system. The improvement of flow data accuracy leads to more reliable performance measures and better scientific basis for decision making. The real-time flood management system minimizes widespread flooding in South Florida as observed during heavy tropical storms and hurricanes of 2004.

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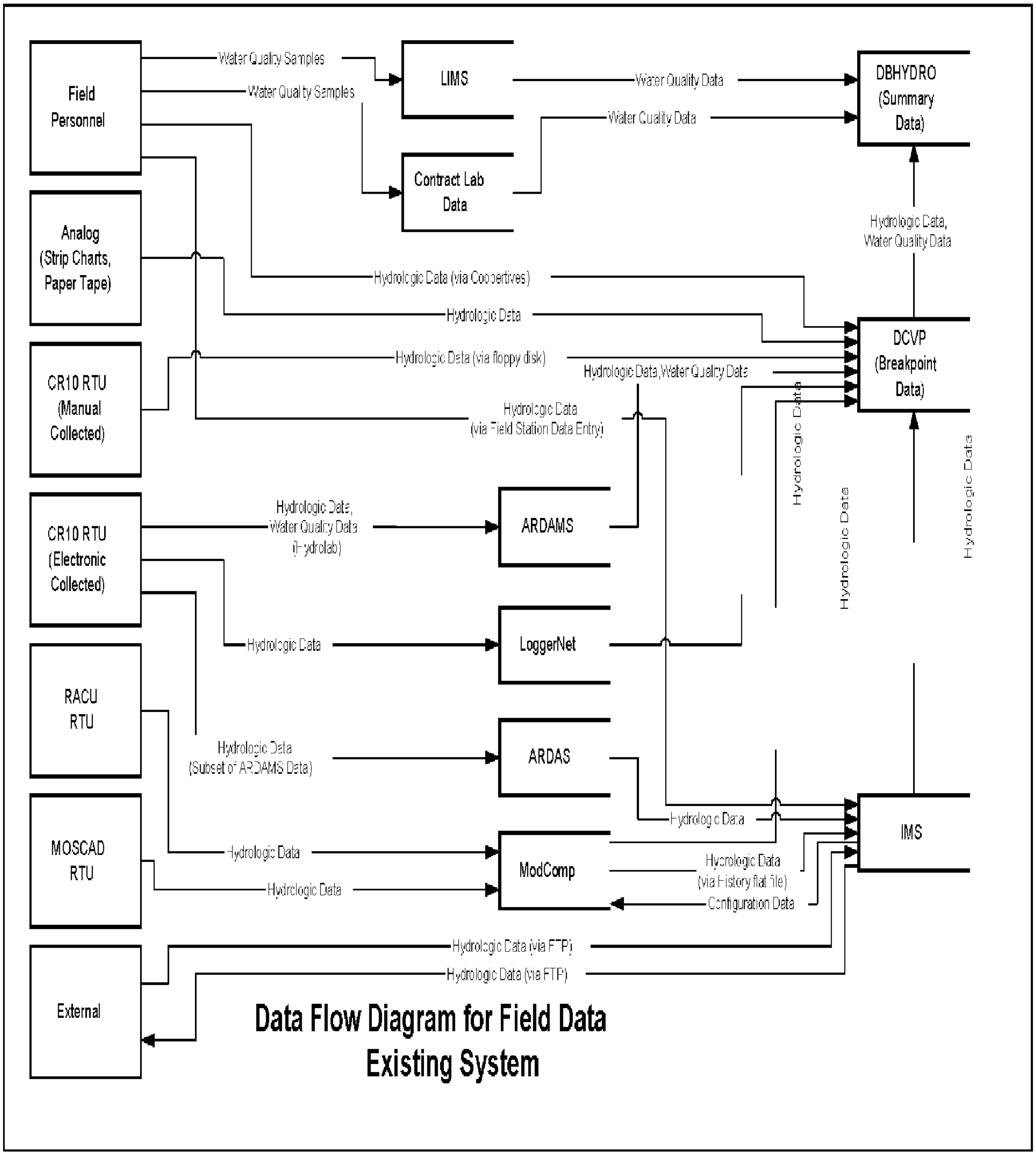
APPENDIX

APPENDIX A

Hydrologic Data Acquisition, Transmission, Processing and Dissemination in the existing South Florida Water Management System (KEMA Consulting, 2002).



Data Flow Diagram for Field Data Existing System

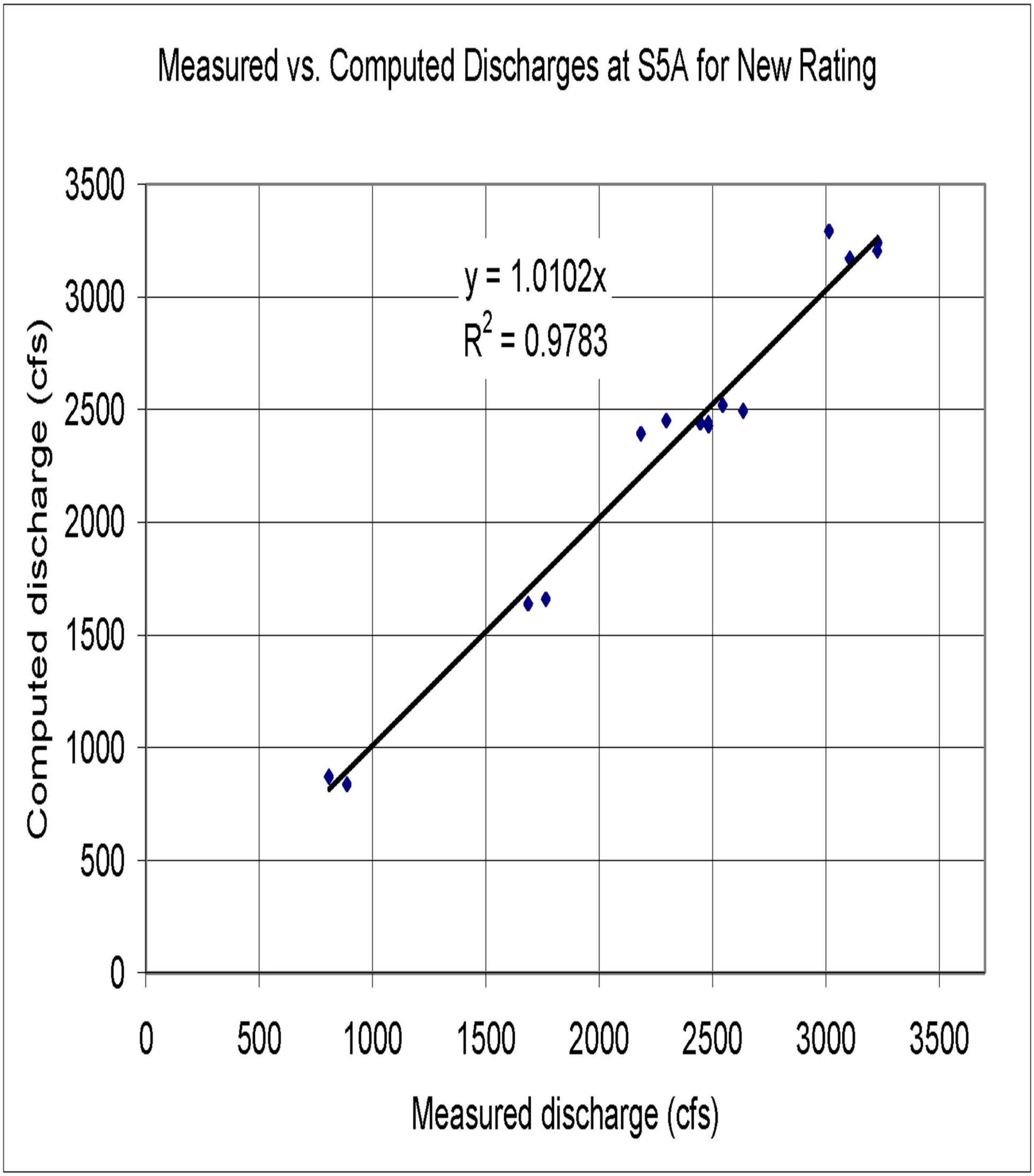
APPENDIX B

Available measurements for pumps at pump station S5A

STATION	DATE	TIME	HW	TW	UNITS	Q	DIST	PUMP#	CASE	PUMPDIA	N	NNOFLOW	T	UNIT
S5A_P	28-Jun-90	13:34	9.57	15.17	6	1764	PUMP	5	3	9.67	700	350	V	5
S5A_P	28-Jun-90	13:34	9.57	15.17	6	1764	PUMP	6	3	9.67	700	350	V	6
S5A_P	3-Jul-90	11:39	9.11	15.33	6	2295	PUMP	1	3	9.67	700	350	V	1
S5A_P	3-Jul-90	11:39	9.11	15.33	6	2295	PUMP	2	3	9.67	700	445	V	2
S5A_P	3-Jul-90	11:39	9.11	15.33	6	2295	PUMP	3	3	9.67	700	443	V	3
S5A_P	24-Oct-90	13:02	9.62	16.26	6	2481	PUMP	2	3	9.67	700	445	V	2
S5A_P	24-Oct-90	13:02	9.62	16.26	6	2481	PUMP	3	3	9.67	700	443	V	3
S5A_P	24-Oct-90	13:02	9.62	16.26	6	2481	PUMP	4	3	9.67	700	450	V	4
S5A_P	24-Oct-90	13:30	9.1	16.28	6	2183	PUMP	2	3	9.67	700	445	V	2
S5A_P	24-Oct-90	13:30	9.1	16.28	6	2183	PUMP	3	3	9.67	700	443	V	3
S5A_P	24-Oct-90	13:30	9.1	16.28	6	2183	PUMP	4	3	9.67	700	450	V	4
S5A_P	24-Jun-91	11:56	10.15	16.09	6	3013	PUMP	1	3	9.67	700	350	V	1
S5A_P	24-Jun-91	11:56	10.15	16.09	6	3013	PUMP	2	3	9.67	700	445	V	2
S5A_P	24-Jun-91	11:56	10.15	16.09	6	3013	PUMP	3	3	9.67	700	443	V	3
S5A_P	24-Jun-91	11:56	10.15	16.09	6	3013	PUMP	4	3	9.67	700	450	V	4
S5A_P	23-Jul-91	11:52	9.36	15.8	6	2445	PUMP	1	3	9.67	700	350	V	1
S5A_P	23-Jul-91	11:52	9.36	15.8	6	2445	PUMP	2	3	9.67	700	445	V	2
S5A_P	23-Jul-91	11:52	9.36	15.8	6	2445	PUMP	3	3	9.67	700	443	V	3
S5A_P	29-Jul-91	12:11	9.68	16.27	6	3227	PUMP	1	3	9.67	700	350	V	1
S5A_P	29-Jul-91	12:11	9.68	16.27	6	3227	PUMP	2	3	9.67	700	445	V	2
S5A_P	29-Jul-91	12:11	9.68	16.27	6	3227	PUMP	3	3	9.67	700	443	V	3
S5A_P	29-Jul-91	12:11	9.68	16.27	6	3227	PUMP	4	3	9.67	700	450	V	4

STATION	DATE	TIME	HW	TW	UNITS	Q	DIST	PUMP#	CASE	PUMPDIA	N	NNOFLOW	T	UNIT
S5A_P	29-Jul-91	14:37	9.38	16.4	6	3225	PUMP	1	3	9.67	700	350	V	1
S5A_P	29-Jul-91	14:37	9.38	16.4	6	3225	PUMP	2	3	9.67	700	445	V	2
S5A_P	29-Jul-91	14:37	9.38	16.4	6	3225	PUMP	3	3	9.67	700	443	V	3
S5A_P	29-Jul-91	14:37	9.38	16.4	6	3225	PUMP	4	3	9.67	700	450	V	4
S5A_P	5-Aug-91	12:30	9.2	15.86	6	2544	PUMP	1	3	9.67	720	350	V	1
S5A_P	5-Aug-91	12:30	9.2	15.86	6	2544	PUMP	2	3	9.67	720	445	V	2
S5A_P	5-Aug-91	12:30	9.2	15.86	6	2544	PUMP	3	3	9.67	720	443	V	3
S5A_P	23-Sep-91	12:24	9.34	16.74	6	3104	PUMP	3	3	9.67	700	443	V	3
S5A_P	23-Sep-91	12:24	9.34	16.74	6	3104	PUMP	4	3	9.67	700	450	V	4
S5A_P	23-Sep-91	12:24	9.34	16.74	6	3104	PUMP	5	3	9.67	700	350	V	5
S5A_P	23-Sep-91	12:24	9.34	16.74	6	3104	PUMP	6	3	9.67	700	350	V	6
S5A_P	20-Jun-94	12:55	9.02	15.45	6	2480	PUMP	1	3	9.67	700	350	V	1
S5A_P	20-Jun-94	12:55	9.02	15.45	6	2480	PUMP	2	3	9.67	700	445	V	2
S5A_P	20-Jun-94	12:55	9.02	15.45	6	2480	PUMP	3	3	9.67	700	443	V	3
S5A_P	23-Jun-94	12:28	9.49	15.48	6	807	PUMP	4	3	9.67	733	450	V	4
S5A_P	3-Aug-94	12:45	8.89	16.12	6	2634	PUMP	1	3	9.67	600	350	V	1
S5A_P	3-Aug-94	12:45	8.89	16.12	6	2634	PUMP	2	3	9.67	600	445	V	2
S5A_P	3-Aug-94	12:45	8.89	16.12	6	2634	PUMP	3	3	9.67	600	443	V	3
S5A_P	3-Aug-94	12:45	8.89	16.12	6	2634	PUMP	4	3	9.67	600	450	V	4
S5A_P	6-Aug-94	12:12	10	16.15	6	1686	PUMP	3	3	9.67	700	443	V	3
S5A_P	6-Aug-94	12:12	10	16.15	6	1686	PUMP	4	3	9.67	700	450	V	4
S5A_P	2-Jan-03	8:30	8	10	6	10	PUMP	1	3	9.67	10	350	V	1
S5A_P	2-Jan-03	8:30	8	10	6	10	PUMP	2	3	9.67	10	445	V	2
S5A_P	30-Jan-03	12:42	10.43	15.59	6	885.67	PUMP	6	3	9.67	700	350	V	6

APPENDIX C


Measured vs. Computed Discharges at S5A for New Rating
y = 1.0102x
R2 = 0.9783
Computed discharge (cfs)
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500
Measured discharge (cfs)