Final Detail Design of the Total Flow Auto-Sampler for Structure S-5A

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Contributors

Nidhi Bhandari, Ph. D.

Eric Shea

Trey Buttelmann

Amer Awwad, P. E.

Rajiv Srivastava, Ph. D.

HEMISPHERIC CENTER FOR ENVIRONMENTAL TECHNOLOGY (HCET)

Florida International University, Center for Engineering & Applied Sciences
10555 West Flagler Street, EAS-2100, Miami, Florida 33174
305-348-4238 • FAX: 348-1852 • World Wide Web Site: http://www. hcet. fiu. edu

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1. Introduction

Structure S-5A is a large pumping station located at the northern tip of the Water Conservation Area 1 (WCA1) on the south side of the US Highway 441 and canal C-51 (West Palm Beach Canal) in South Florida. The pump station consists of 6 horizontal, 116-inch, axial flow pumps each driven by a single Fairbanks Morse 1600 hp diesel engine [1]. Each pump has a rated flow of 800 cubic feet per second (cfs), and the station has a maximum rated flow of 4600 cfs.

The South Florida Water Management District (SFWMD) has been collecting water samples at structure S-5A since the early 1970s. These samples have been collected using an auto-sampler (located at the inlet bay of pump 4 almost at the center of S-5A) and using grab method 15 ft upstream of the pump bay 4 inlet. These samples have provided invaluable information regarding the quality of the water entering WCA1. Over the years this information has become more important as several mandates, including the Everglades Agricultural Area (EAA) rule and the Everglades Forever Act (EFA), have been put in place. As a result of these mandates, the quality of the sample data, including the sample collection process, has come under increasing scrutiny and evaluation.

FIU-HCET conducted a detailed review of the Everglades Agricultural Area (EAA) and Everglades Forever Act (EFA) mandates and statutes that govern the design of the auto-sampler. The ability to satisfy the EAA and the EFA mandates and statutes formed the basis of the conceptual design of the proposed total flow auto-sampler. Modifications to the conceptual design evolved during discussions with the District team to better meet the needs of Structure S-5A. This document presents the final design of the auto-sampler with the list of parts, equipment, and instruments including data acquisition, prices and vendor information.

The proposed auto-sampler will be installed in addition to the current auto-sampler already in place. This will provide an opportunity for comparison of the results of the samples collected by the current auto-sampler and by the proposed auto-sampler.

2. Background

The SFWMD had undertaken an exhaustive analysis of all aspects of the monitoring program at S-5A and after careful review, decided that additional work is required to upgrade the sampling systems at S-5A, employing the latest technology to further improve the quality of monitoring data obtained from this important sampling site. Based on the studies of the existing data and the complexities associated with monitoring a large pumping station with many operational considerations, the SFWMD was of the opinion that outside engineering services were required to design a system for sampling that incorporates these considerations and is consistent with the current state of the art. Florida International University's Hemispheric Center for Environmental Technology (FIU-HCET) undertook to provide these engineering services through this project.

The initial project activity was a study of the current auto-sampler and a report on its limitations [1]. The major limitation of the current auto-sampler is the location of the sampler intake, which is from the inlet bay for Pump 4. When pumps, other than Pump 4 are running, the sampling takes place from a stagnant zone and the samples collected are not representative of the discharge. The proposed auto-sampler is designed to collect samples from each pump (that is running) so that the representative samples can be collected. A thorough performance evaluation of the proposed total flow auto-sampler was also presented covering a range of pump discharge configurations and included error analysis. The sampling technique has been shown to be very accurate [2]. The operation and maintenance of the auto-sampler has been automated to minimize personnel supervision.

3. Conceptual basis of the proposed auto-sampler at S-5A

The proposed total flow auto-sampler system for the structure S-5A is designed to collect samples on a flow-proportional basis, in conjunction with the operation of the pumping station. The sampling system consists of metering pumps, mixing tanks and sample collection tank. A schematic of conceptual design is shown in Figure 1. The conceptual basis of the design is that by **continuous sampling** of the discharge from the station, a true **representative sample** can be collected in a mixing tank and the aliquot sample then taken from the mixing tank would be indicative of the total discharge.

Continuous sampling is accomplished by taking a sampling stream from the inlet bay of each of the pumps (that is running at that time) and collecting the streams in a mixing tank. The composition of the water collected in the mixing tank is representative of the discharge from each pump. The flow rate of the sampling stream is kept proportional to the discharge from that particular pump and is controlled by sending an appropriate signal to a metering pump. Thus the combined flow of the sampling streams is proportional to the total discharge from the station.

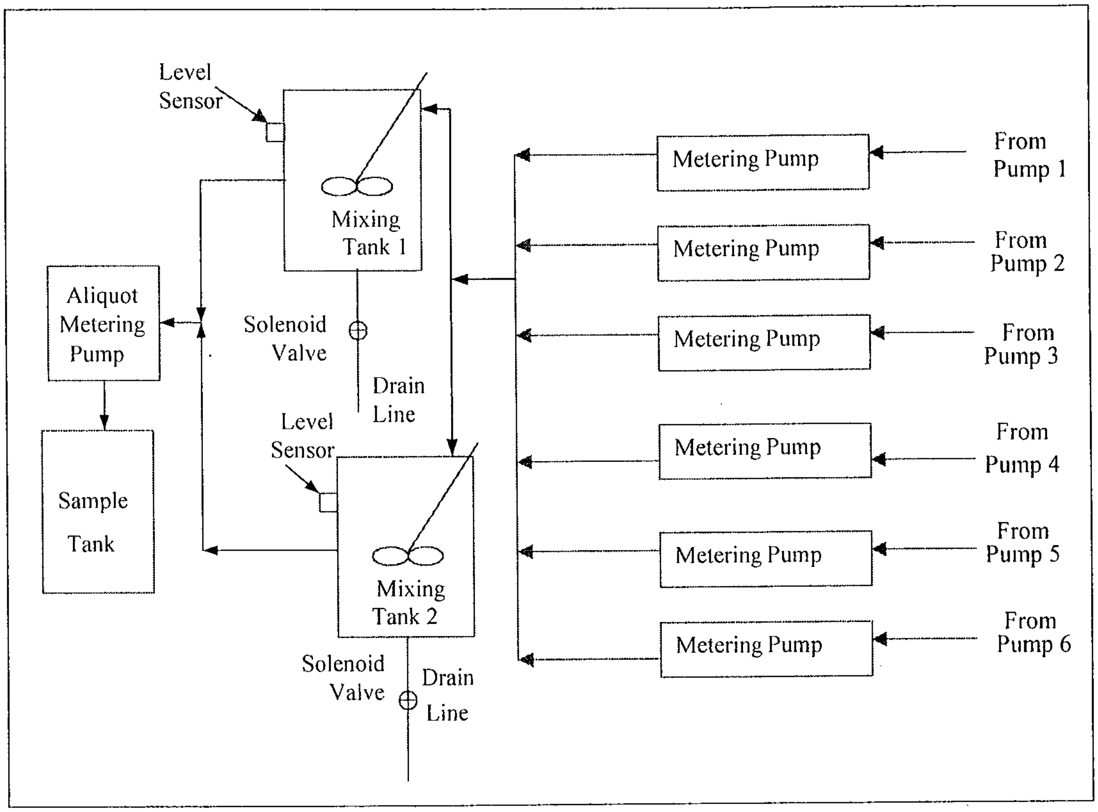

Figure 1. Schematic of the proposed sampling system at S-5A

Two identical mixing tanks (1 and 2) have been used so that the sampling streams can be collected continuously. When the streams are collecting in the first tank, the contents of the second tank are undergoing mixing and aliquot sampling. Each mixing tank has a level sensor, which determines when the mixing tank is full. After the first tank is full, a signal from the level sensor diverts the flow of the sampling streams to the other tank, Mixing Tank 2. The signal from the level sensor also activates the agitator to switch on and mix the contents of Tank 1. After mixing is over, an aliquot metering pump takes a fixed amount of aliquot or sample (50 or 100 ml) from Mixing Tank 1 and deposits it into the Sample Tank. The Mixing Tank 1 is then drained and flushed.

In the mean while, the sampling streams are collecting in Mixing Tank 2. After it is completely filled, the level sensor diverts the sampling streams back to Mixing Tank 1. The contents of Mixing Tank 2 are then mixed and the next aliquot is taken from Mixing Tank 2. After aliquot sampling, Mixing Tank 2 is drained and flushed. Thus two mixing tanks are utilized cyclically and the sample aliquots are taken alternately from Mixing Tank 1 and 2. The advantage of this system lies in the fact that the discharge is sampled at all times, and that the contents of the mixing tanks (1 or 2) are representative of the discharge in real time. Therefore, the sample aliquot is representative of the discharge.

The proposed total flow auto-sampler can be better visualized with the help of layout drawings shown in Figures 2 and 3. Figure 2 presents a layout of the proposed sampling system. Figure 3 presents a layout of the contents of the sampling cabinet containing the mixing tanks and the sampling tank.

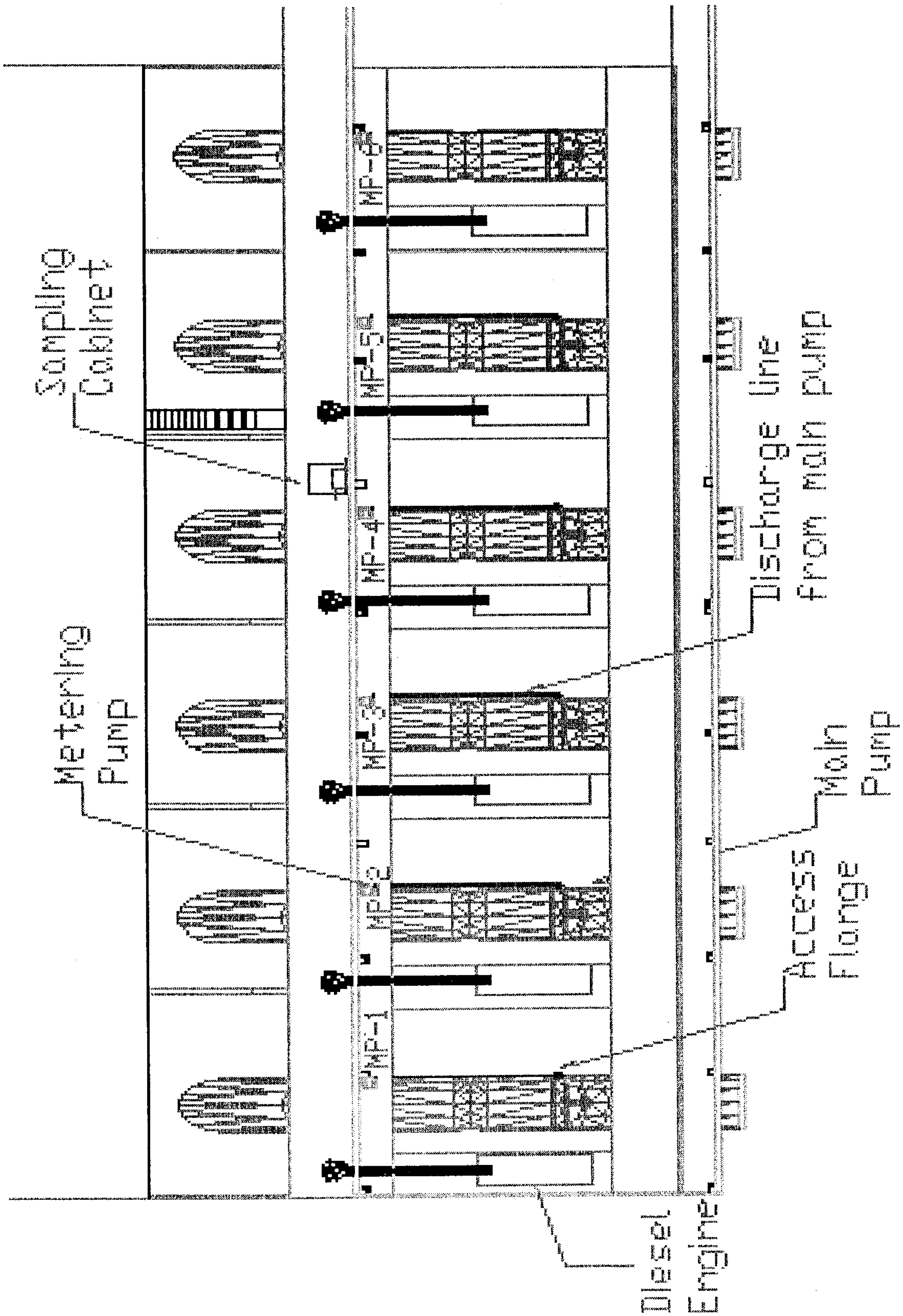

Figure 2. A Top-view of the layout of the sampling system

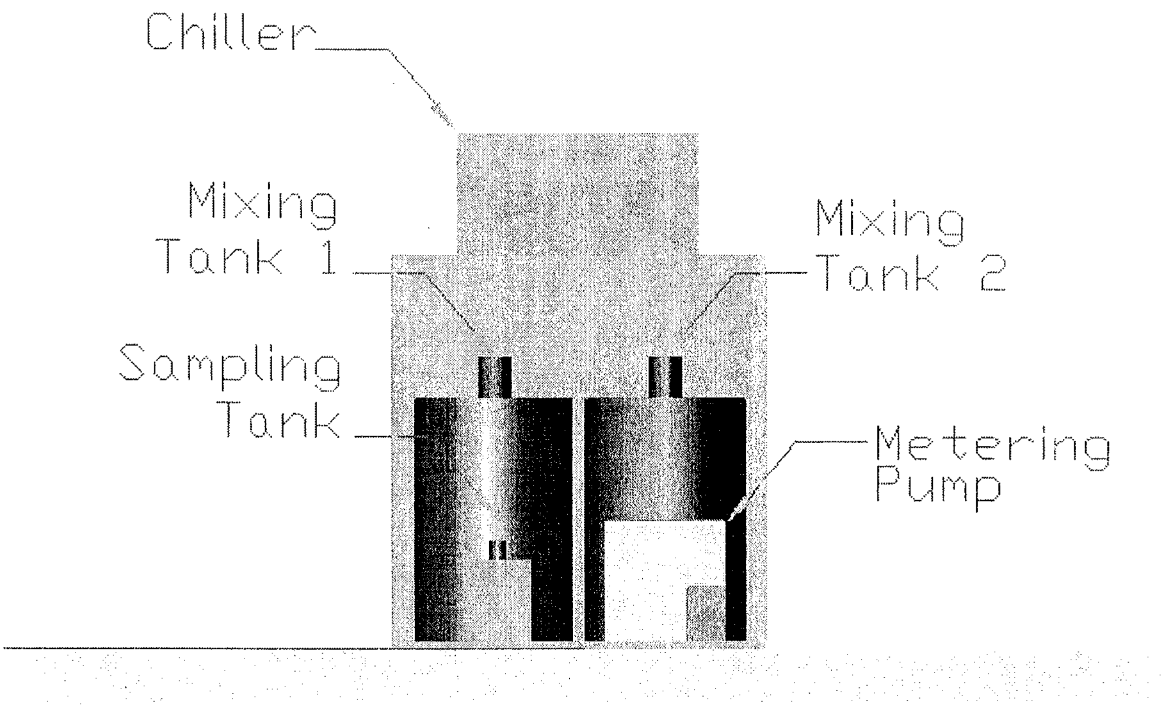

Figure 3. Front view of the layout of the sampling cabinet

4. Detailed Design of the Proposed Total flow Auto-sampler

In this section, quantitative details of the design of the proposed total flow auto-sampler are presented. The important design variables are the size of the piping (tubing) for sampling stream, maximum flow rate of the sampling streams, size of the mixing tanks and the sample tank, and volume and frequency of aliquot sampling.
The values of the design parameters chosen are as follows:

- Flowrate in sampling tube - 6 ft/s (max)
- Diameter of sampling tube - 3/8 in.
- Length of sampling tube - 120 ft (max)
- Volume of Mixing tank(s) - 55 gal (208 L)
- Volume of Sample Tank - 10 gal (38 L)
- Volume of each aliquot sample - 50 mL
- Frequency of Aliquot Sampling - Once every 5 minutes (at maximum discharge).

The flow-proportionality of the proposed total flow auto-sampler lies in the fact that the flow rates of sampling streams are always proportional to the discharge rate through the corresponding main pumps. The metering pumps are chosen, as their flow output does not depend on the length of the tubing; rather, it remains at the set value. They also ensure that bubbles and other particles do not interfere with their operation. In real situations, the main pumps will not have constant discharge.

The discharge will calculated as a function of the pump speed (rpm) using flow computation routine available in [3]. The real time pump rpm will be available to the data acquisition and control system and it will send a continuous signal to the metering pump and the voltage of the signal will be proportional to the flow rate. A flow rate of 2 gpm for the metering pump corresponds to a discharge rate of 800 cfs through the main pump.

5. Operation and maintenance

A piping and instrumentation drawing (P&ID) of the proposed sampling system is shown in Figure 4. In addition to the main equipment, the P&ID shows the valves, and signals communicated to and from the data acquisition and control station. The procedures for sampling, sample collection and flushing are described below.

5.1 Data Acquisition and Control

A programmable logic controller (PLC) will be used for the operation and control of the auto-sampler. The PLC will receive signals from each main pump and control the flow of the corresponding metering pump. The specification of the PLC are based on the number of input/output signals the auto-sampler sends or receives. The PLC will also communicate with a PC, which will provide a means for storing and sending the data to the main station.

5.2 The Sequence of steps for sampling

All valves are normally closed until a signal is sent, or opened manually.

1. When a main pump (1-6) turns on for normal operation, a signal is sent to the computer control station.
2. The control station will send a signal to the corresponding metering pump (13-18) and solenoid valve (7-12) to turn on or open. The set values for the metering pump flow rate is calculated based on pump rpm.
3. Valve 20 will open to allow flow into Mixing Tank 1.
4. When Level Sensor 28 is activated, valve 21 will open and valve 20 will close. This will allow flow into Mixing Tank 2.
5. Mixer 23 will turn on for a given time, after the contents have been agitated, aliquot metering pump 30 will turn on. Simultaneously, the three-way valve 31 will open to the purging setting for a given amount of time. It will then switch to allow flow into the sampling tank.

6. After the aliquot is pumped into the Sample Tank, metering pump 30 and valve 31 will turn off or close.

7. Valve 29 will open to allow for draining of the mixing tank, and valve 26 will open to rinse the mixing tank.

8. The same procedure will repeat with Mixing Tank 2 once level sensor 24 is activated.

5.3 Procedure for sampling of weekly composite from Sample Tank by a technician

1. Open cabinet

2. Turn on mixer 33 for 2 minutes and then turn off.

3. Open valve 36 and allow ten seconds to get a clean flow.

4. Fill sampling container(s).

5. Allow entire contents of tank to drain.

6. Close valve 36 and open valve 32 to wash down tank.

7. Once filled, close valve 32 and open valve 36 until tank is drained.

8. Close valve 36 and close cabinet.

5.4 Overflow safety system

If Level Sensor 35 is activated, the system will send a signal/alarm to the station personnel to take the weekly composite sample and drain the sample tank. If the sample tank is not drained then the sampling system will shut down.

5.5 Procedure for flushing

The system has been designed to take into account the possible fouling of the sampling tubing and hence the need for regular flushing. Flushing will be performed weekly by the computer control station, or when prescribed by station personnel. The steps followed will be:

- Valve 19 will open to allow fresh water (from tap) into the manifold.

- Metering pumps 13-18 will turn on in the reverse setting and valves 7-12 will open.

- After given amount of time, the system will shutdown and return to normal operation.

For further ease of operation, additional metering pumps and valves will be stocked as stand-bys.

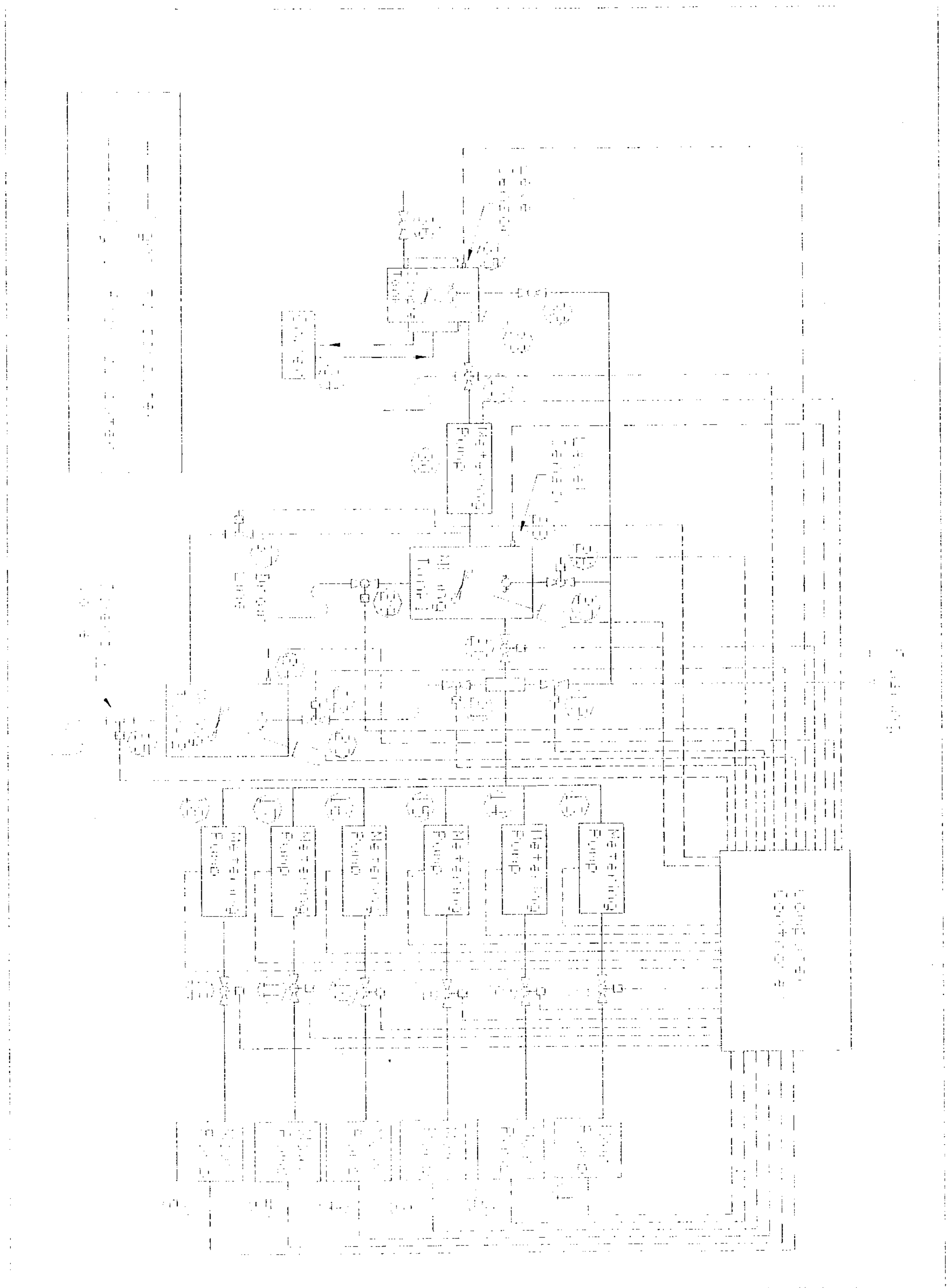

Figure 4. PID of the proposed total flow auto-sample

6. Equipment list and pricing information

The detail list of the various components to be used in the auto-sampler is presented in Table 1 and includes the vendor and catalog number. The list includes the equipment like mixing tanks, metering pumps, as well as the system required for operation, control, and data acquisition.

Table 1. List of components for the auto-sampler

	List of parts	Vendor and Catalog #	Qty.	Unit Price	Ext. Total
1	**EQUIPMENT**	**McMaster Carr**			
1	10 gallon Stainless steel batch can	8241T35	1	$208.31	$208.31
2	58 gallon Stainless steel drum	4562T25	2	$398.29	$796.58
3	¼ HP mixer	3473K13	1	$346.08	$346.08
4	½ HP mixer	3473K25	2	$499.53	$999.06
5	¼ HP air cooled chiller	3521K32	1	$565.44	$565.44
6	3/8" Drum washing nozzle	32225K31	2	$86.91	$173.82
7	3/8" , Brass, manual ball valve	47865K23	2	$4.40	$8.80
8	3/8" SS tubing and fittings				$2,000.00
2	**INSTRUMENTS**	**Cole Parmer**			
1	L/S Metering Pump (4.3-430ml/min)	P-77250-62	7	$230.00	$1,610.00
2	Computer controlled pump drive	P-07550-10	7	$1,375.00	$9,625.00
3	L/S 35 Tubing (20-35 psi) (.31" id)				$200.00
4	Tygon LFL	P-06429-35	1	$93.00	$93.00
5	Solenoid Valve (brass, ½")	P-98500-20	14	$85.00	$1,190.00
6	3-Way Solenoid Valve (SS,0-70psi,24v)	P-98601-85	1	$173.00	$173.00
3	**OPERATION and CONTROL**	**Alan Bradley**			
	PLC Components				
1	ML 1500 BASE 120V AC IN / RELAY OUT / AC POWER	1764-24AWA	1	$ 418.00	$418.00
2	ML 1500 RS-232 PROCESSOR	1764-LRP	1	$ 286.00	$286.00
3	16 POINT 120 VAC INPUT MODULE	1769-IA16	1	$ 165.83	$165.83
4	8 POINT 120/240 VAC OUTPUT MODULE	1769-OA8	2	$ 158.46	$316.91
5	4 CHANNNEL ANALOG CURRENT/VOLTAGE INPUT MODULE	1769-IF4	2	$ 302.17	$604.34

6	2 CHANNEL ANALOG CURRENT/VOLTAGE OUTPUT MODULE	1769-OF2	4	$ 302.17	$1,208.68
7	1FT (305 MM) RIGHT-TO-RIGHT BUS EXPANSION CABLE	1769-CRR1	1	$ 99.50	$99.50
8	LEFT END CAP/TERMINATOR	1769-ECL	1	$ 25.80	$25.80
9	PWR SUPPLY 120/240 VAC INPUT 2 AMP @ 5 VDC OUTPUT	1769-PA2	1	$ 165.83	$165.83
10	AIC+ ADVANCED INTERFACE CONVERTER	1761-NETAIC	2	$ 154.00	$308.00
11	M-SYSTEM DUAL OUTPUT SIGNAL TRANSMITTER	W2VS-AAA-M2	6	$ 320.00	$1,920.00
	Programming Software and Data Server				
1	RSLOGIX 500 STARTER (ENGLISH) CD-ROM	9324-RL0100ENE	1	$ 499.00	$499.00
2	RSLINX FOR ALEN-BRADLEY, CD DDE/OPC SERVER	9355-WABENE	1	$ 1,450.00	$1,450.00
	Optional - Display Terminal, UPS				$0.00
1	PANELVIEW 600 COLOR KEYPAD TERMINAL	2711-K6C16	1	$ 1,795.00	$1,795.00
2	PANELBUILDER CONFIGURATION 32 BIT SOFTWARE ON CD	2711-ND3	1	$ 295.00	$295.00
3	Sola 2000 Series UPS 470 VA	S2700	1	$ 304.00	$304.00
4	**DATA ACQUISITION**	**Dell Computer**			
1	IBM-Compatible PC with modem		1	$800.00	$800.00
	GRAND TOTAL				**$28,651**

7. Conclusions

As a part of the restoration of the Florida's Everglades ecological system, changes will have to be brought about in the current water quality, quantity, distribution, and timing of flows through the system. The nutrient loading, especially phosphorus has had an adverse effect and necessity for reducing the loading is evident. Station S-5A, since it is located in EAA, plays a vital role in obtaining accurate estimated of current and future loadings. Hence there is a need for a system capable of accurately determining the loading through the station discharge.

The proposed auto-sampler, in addition to being flow-proportional also takes into account the total discharge from the station i. e., it is a total flow sampler. The samples that are collected accurately represent the discharge at all times and hence can be used to precisely calculate the loading. The sampling system has also been shown to be robust to errors in the measuring instruments like the metering pumps and in flow estimation. The automatic design of the sampler requires minimal personnel time for operation and maintenance.

The proposed auto-sampler will be used in parallel with the current auto-sampler. By implementing the two systems simultaneously, the results of the two auto-samplers can be used to compare the extent of spatial variability in concentration. The installation of the proposed auto-sampler will also demonstrate the effectiveness of using a custom-designed auto-sampler.

References

[1] N. Bhandari, N., R. Srivastava, S-5A Sampler Design, HCET-2000-T010-002-08, Hemispheric Center for Environmental Technology, December 2000.

[2] N. Bhandari, E. Shea, A. Awwad, and R. Srivastava, Conceptual Design of Total-flow Auto-sampler for Structure S-5A, Hemispheric Center for Environmental Technology, HCET-2000-T010-003-08, June 2001.

[3] J. M. Otero, Computation of Flow-through Water Control Structures. Technical Publication 95-03 (WRE #328), Hydrologic Data Management Division, SFWMD, 1995.