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Application of the SCADA system in wastewater treatment plants

Ba Dieu

City of Houston, Public Works and Engineering Department, Wastewater Operations Branch, 4545 Groveway, Houston, TX 77087, USA

Abstract

The implementation of the SCADA system has a positive impact on the operations, maintenance, process improvement and savings for the City of Houston's Wastewater Operations branch. This paper will discuss the system's evolvement, the external/internal architecture, and the human-machine-interface graphical design. Finally, it will demonstrate the system's successes in monitoring the City's sewage and sludge collection/distribution systems, wet-weather facilities and wastewater treatment plants, complying with the USEPA requirements on the discharge, and effectively reducing the operations and maintenance costs. © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

Prior to 1998, the City of Houston's wastewater operations branch monitored the city's over 200 pump stations from the control-center with an old SCADA system named SETCONPC. Since this system was a text based operating system, it was a difficult and tedious task for the control-center operators to monitor the pump stations across the city. The control-center also had a separate small SCADA system named LOOKOUT. It monitored the chlorination and dechlorination (disinfection) processes at 27 medium size wastewater treatment plants. This system was a window-based operating system and utilized the HMI graphic design; therefore, the operators found it very user friendly and easy to work with. In the larger wastewater treatment plant, the plant operators were on site 24 hours a day and monitored the plant with its own small SCADA system. In the smaller wastewater treatment plant, at least one plant operator was required to be on site at least 8 hours a day. At night, the plant operators were scheduled to check different plants every few hours to make sure the plants were operating normally.

In an effort to centralize the monitoring and controlling processes, i.e. to have the control-center be able to monitor and control everything from the pump stations to the wastewater treatment plants, the city had started to implement a new SCADA system in early 1998. After about 8 months, the control-center at 4545 Groveway was able to monitor the city's 220 pump stations, 3 wet weather facilities, 4 sludge transfer systems, and 43 wastewater treatment plants, which produce a combined discharge of nearly 250 million gallons per day.

E-mail address: bdieu@pwe.ci.houston.tx.us

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Nomenclature

SCADA	Supervisory control and data acquisition
PS/LS/UP	Pump station/lift station/under pass
WWF	Wet-weather facility
WWTP	Wastewater treatment plant
LAN	Local area network
DEC	Digital equipment corporation
WAN	Wide area network
CSU/DSU	Channel service unit/data service unit
CMX	Control and measurement executive
XIS	Extended information system
XOS	X-window based operator station
PLC	Programmable logic controller
IP	Internet protocol
HMI	human-machine-interface
USEPA	United States Environmental Protection Agency
TNRCC	Texas Natural Resource and Conservation Commission
MGD	Million gallons per day
PPM or mg/l	Part per million
WWO	Wastewater operations

2. System architecture

2.1. External (hardware)

The city's SCADA system is a WAN of DEC servers and workstations. It consists of one main system (master) located in the control-center and 14 supplemental systems (submasters) located in the 14 mid size wastewater treatment plants (Fig. 1).

The master is a LAN of 5 servers (CMX, XIS, HDS, DOS, PLC), 6 workstations (N-XOS, S-XOS, VID1, DEV1, DEV2, EOC), 7 terminal servers (XYPLEX), 3 routers (CISCO), 6 network hubs (ACCTON), 2 multiplexers (ADTRAN, function as CSU/DSU), 14 monitors, 2 projections, 5 printers and loggers, 4×16 modem (MICROCOM) racks for dial-up lines, 14×9.6K circuit lines, 13×56K circuit lines, and a spread-spectrum radio. The essential components of the master system are the CMX and XIS servers; they both have the redundant units for fail-safe operations. Whenever the primary (hot or host) unit fails, the standby (secondary or backup) unit will automatically become hot and resume normal operations. After the problems of the failed unit are investigated and solved, it will be started and put in the standby mode. The master system's primary functions are:

1. to gather real-time information from the field's PLCs (PS/LS, WWTP, WWF, etc...),
2. to display real-time information on the computer screens and projections,
3. to create real-time historical trending for the field's process variables,
4. to collect and store the information in a relational database for future retrieval,
5. to display alarms generated from field's devices or variables such as no-reply communication, pump's failure status, chlorine residual violation, high/low wet-well level, blower/clarifier status, etc...
6. to print out alarms, graphics displays when needed,
7. to provide weekly and monthly reports on effluent flow, total flow, wet-well level, etc...

The submaster consists of a workstation, a monitor, a printer, a terminal server, a router, a network hub, a CSU/DSU unit (CRAY), and a phone circuit line. The plant's PLCs will be connected to the terminal server and/or the network hub for data acquisition from the Submaster. Besides performing the same 7 functions as of the master, the submaster will send all of its collecting data to the master at mid-night for long term storage.

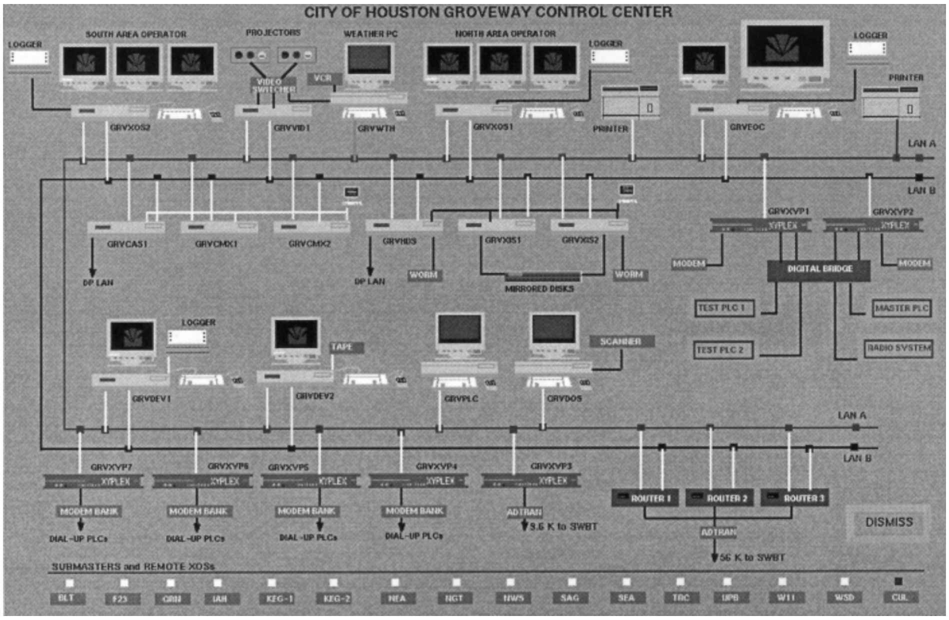


Fig. 1. SCADA overall hardware architecture.

2.2. Internal (software)

The city's standard SCADA software is manufactured by Neles Automation. It runs under the UNIX operating system. This software incorporates three major subsystems: (1) CMX: a real-time database and programming package for real-time data processing, (2) XIS: a relational database for historical data processing, and (3) XOS: a human-machine-interface package for graphics display processing.

For security purposes, the city's SCADA system utilizes an independent IP addressing (class C network) for its equipment's identification and networking. In order to get into the SCADA system, an outsider needs to get through a gateway with the proper user-name and password. There are also different levels of security for the SCADA users such as viewer, operator, supervisor, programmer, engineer, and manager. For example, an operator can acknowledge the alarm from the field but he cannot modify the graphics or the database program.

Adding new sites (PS/LS, WWTP, and WWF) into the SCADA system is simple thanks to the user-friendly configuration menu. The configurations of the remote, communication line, status, analog, rate, and collect databases reside in the master's CMX server. In order to perform functions that are not available in the standard SCADA software, the advanced users can add these new functions into the SCADA system using the DataBasic program offered by the CMX. To communicate with various types of field (remote) PLCs distributed across the city, the CMX triggers different poll tasks and communication protocols such as TASKCODE, MODBUS, and SY/MAX. The CMX also offers the real-time trending for data analysis, transfers data into the XIS server for historical data archiving, initiates and logs alarm messages into the alarm and event summaries, etc...

Upon receiving data from the CMX server, the XIS will store the information in its internal hard-drive and external mirror disks for processing. Due to the limited space on the XIS's hard-drive, only data (alarms, events, analogs, rates, etc...) of the last 4 months can be accessed directly from the XIS. For older data, it is necessary to retrieve the information from the optical drive. Every midnight, the XIS transferred the data from its hard-drive into the optical drive. The data were then saved into the optical disk for future retrieval. Each optical disk can store about 5 months of data.

It is the XOS package that makes the SCADA system dynamic, real-time, and user-friendly. The city engineers utilize the XOS package to design and produce the HMI graphics displays of the field sites to be monitored. The goals of these displays are to make the control-center and plant operators feel comfortable and efficient while using the SCADA system.

The SCADA now monitors a total of 12,300 field data points in which 10,000 are status, 2,200 are analogs, and 100 are rates. It requests information from a total of 380 remotes (field PLCs) via spread-spectrum radio, 9.6–56 K digital circuits and analog dial-up lines. It collects and archives about 1,000 analog and rate data points for weekly, monthly, and future retrieval. These collect points are the wet-well level, effluent flow-rate, effluent totalizer, and chlorine residual, etc... (Fig. 2).

Description	Real-time trend (day)	Historical archiving interval (min)
Wet-well Level (Feet)	2	10
Effluent Flow (MGD)	2	10
Effluent Totalizer (MG)	2	60
Chlorine Residual (mg/L)	2	10

Fig. 2. Real-time trend and historical archiving interval.

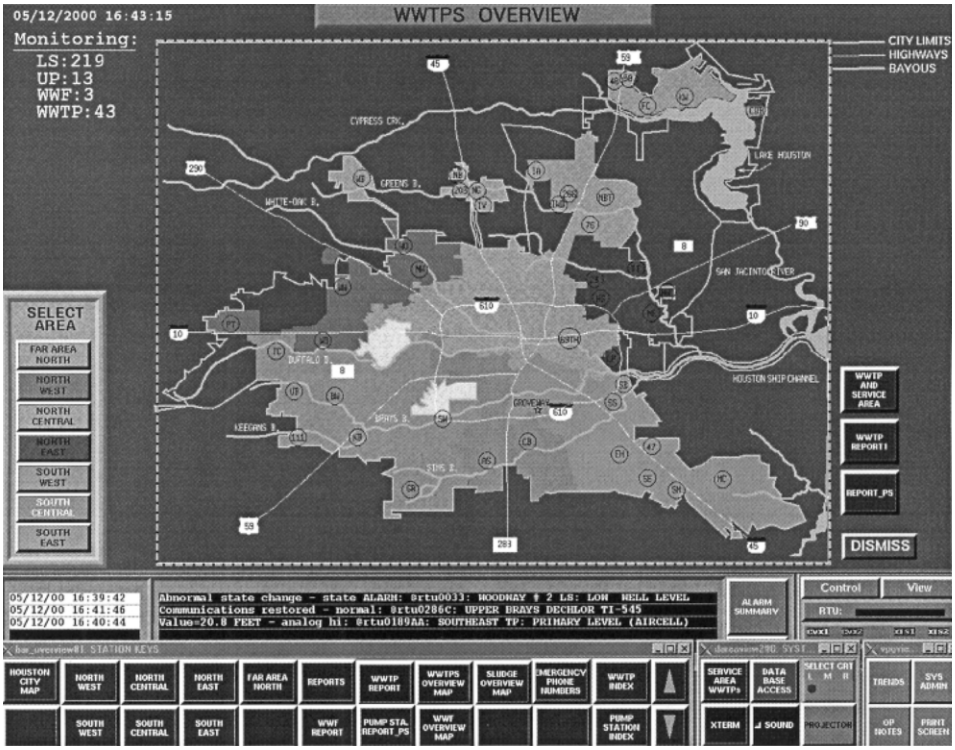


Fig. 3. SCADA WWTP overview.

Besides being accessible by the control-center and plant operators, the SCADA system can also be accessed by the managers, engineers, and supervisors from their remote offices on their own personal computers. These PCs are connected to the SCADA system on an intranet network. The Hummingbird-Exceed software is required for the PC to access the SCADA system.

3. HMI graphical designs

3.1. Basic design

With the concerns on helping the control-center operators monitor the city's sewage collection/distribution systems and wastewater treatment plants in an effective and efficient way, the city engineers designed various schemes and graphical displays for the new SCADA system.

After logon into the SCADA system, the "WWTPS OVERVIEW" display (Fig. 3) will appear on the computer screen. It is the map of the city with 7 different service areas and corresponding wastewater treatment plants.

The SCADA user has a wide variety of selections by moving the mouse pointer to:

- one of the 43 circled WWTP inside the map to get the WWTP overview display,
- one of the 7 boxes in the 'SELECT AREA' column to get the service area display,
- one of the named boxes in the bottom two rows to get the specific function as named, etc...

When the user moves the mouse pointer to a circled WWTP and clicks, the overview plant layout of that WWTP will appear on the screen. For example, when clicking in the 'TC' circle (in the top left-hand side of the green service area), the plant layout of Turkey Creek WWTP (Fig. 4) will be displayed on the screen.

Fig. 4 shows the actual real-time operating conditions at the TC WWTP as: 3 clarifiers running, 1 clarifier stopped, 3 blowers off, 2 blowers on, 1 submersible pump in the on-site LS running, etc...

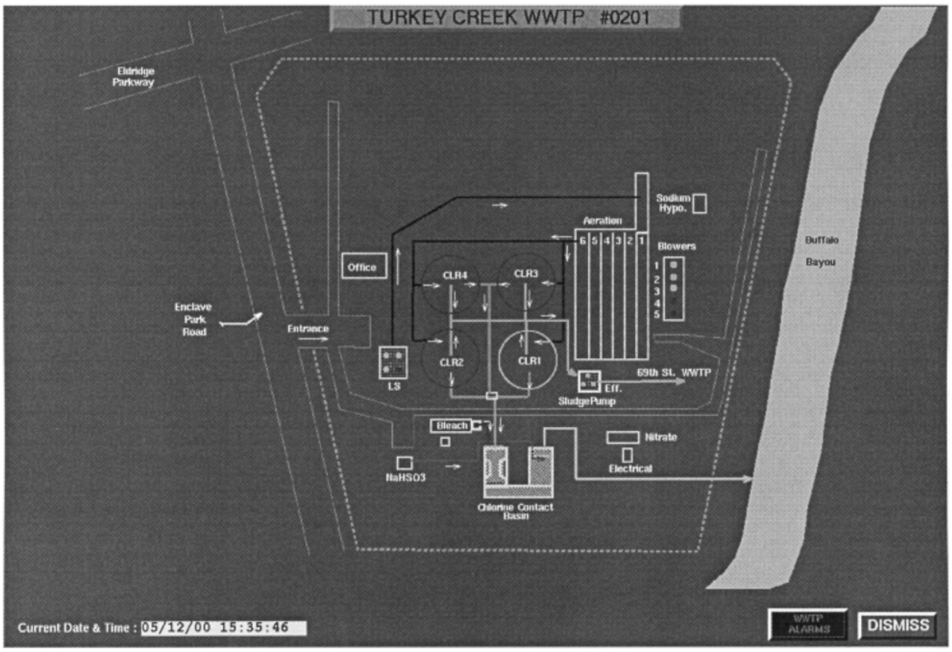
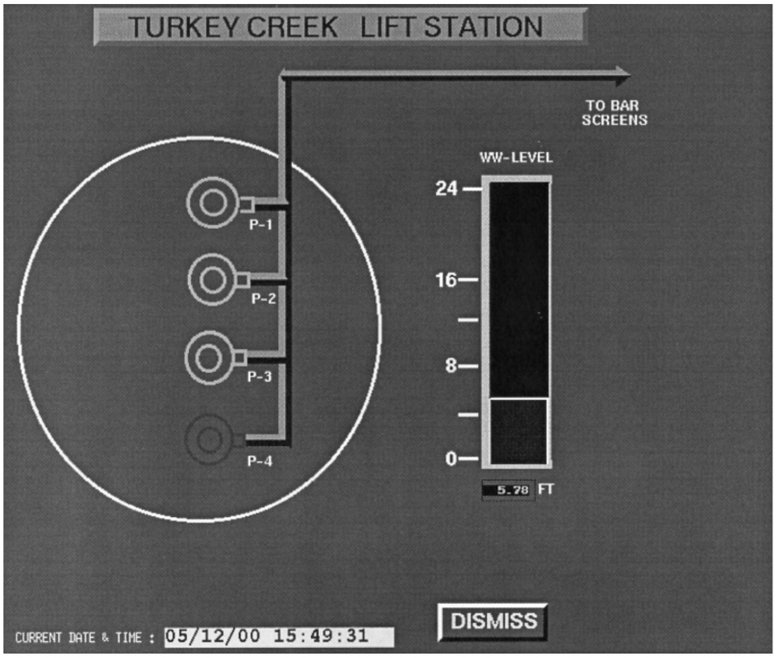


Fig. 4. Turkey Creek WWTP overview.

From this display, the user can get into the details of the specific operation or process. Clicking the mouse pointer in the 'LS' box will display the TC WWTP on-site lift station (Fig. 5), clicking in the 'chlorine contact basin' box will display the TC WWTP chlorination and dechlorination processes

(a)



(b)

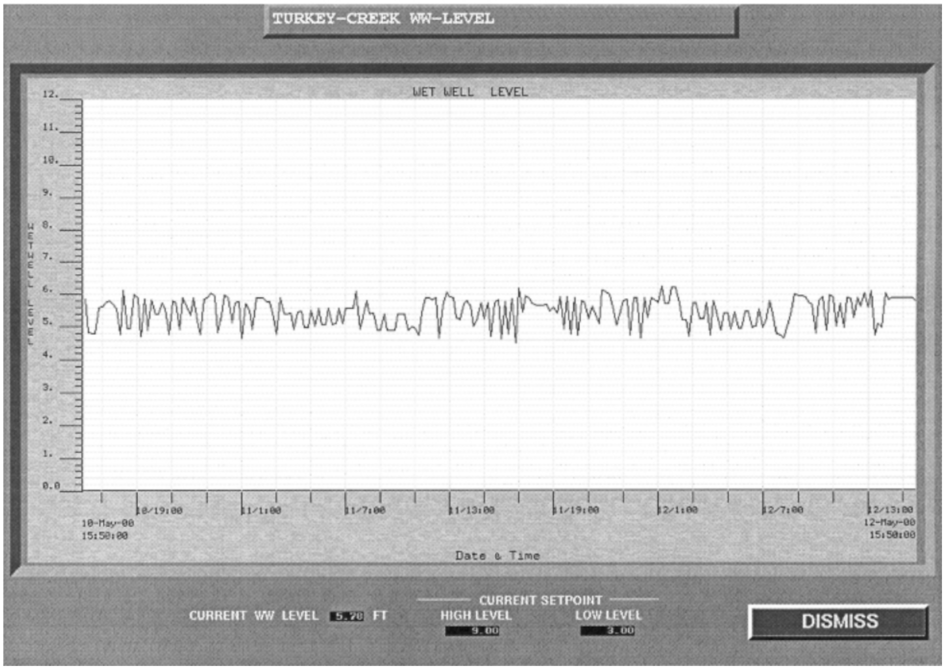


Fig. 5. (a) TC WWTP on-site lift station; (b) TC WWTP on-site wet-well level trend.

(Fig. 6). Additionally, clicking the mouse pointer inside the WW-level column (inside Fig. 5) will display the trending curve of the wet-well level (Fig. 5b) in the last 2-day. Clicking in the 'TRENDS' box (inside Fig. 6) will display the trending curves of the effluent flow-rate, pre-weir

(a)

(b)

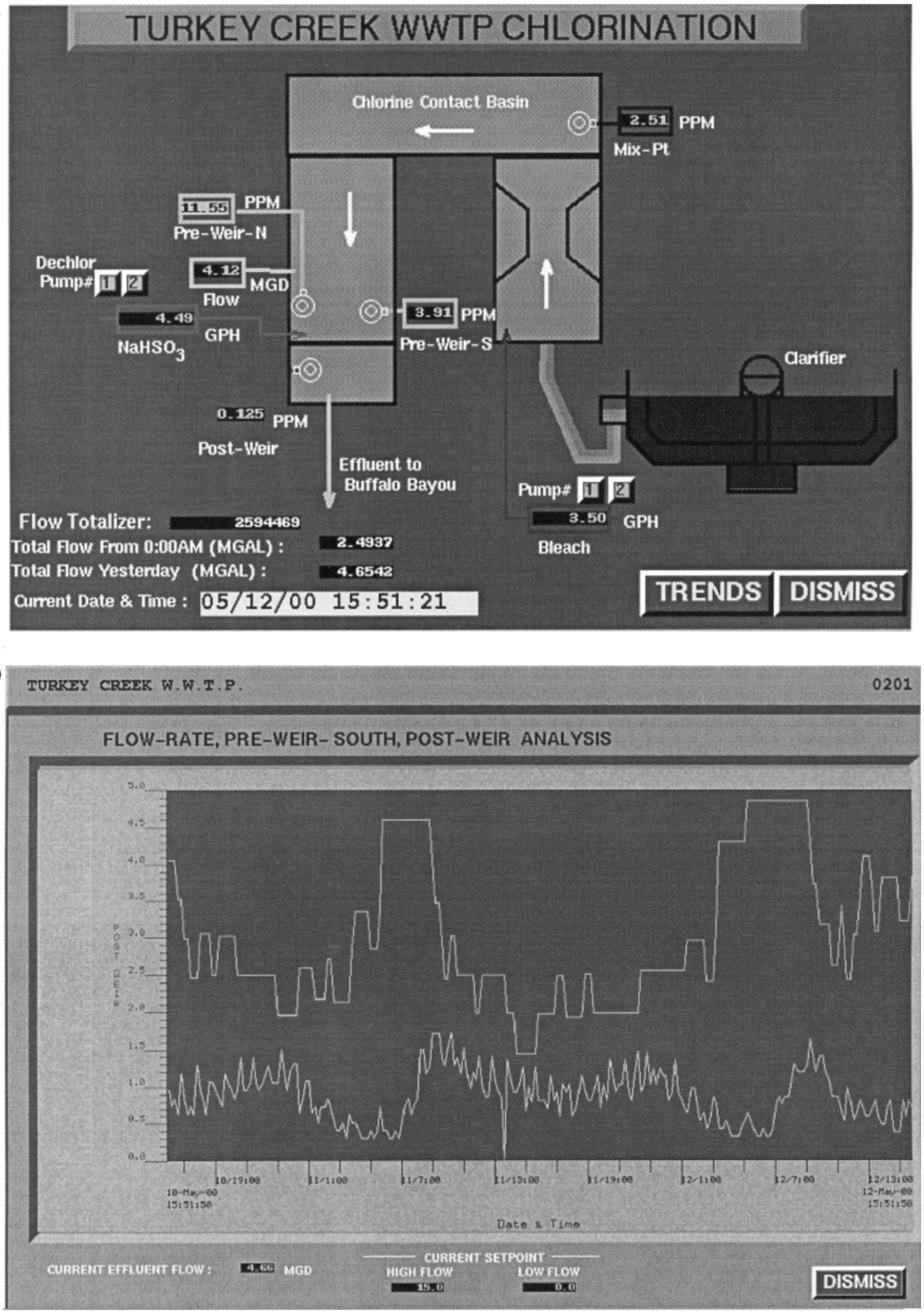


Fig. 6. (a) TC WWTP chlorination and de-chlorination (dis-infection) contact basin; (b) Turkey Creek WWTP effluent flow-rate, pre-weir and post-weir chlorine residuals trend.

and post-weir chlorine residuals (Fig. 6b) in the last 2-days.

3.2. Extended design

Prior to the implementation of the new extended graphic design, the control-center operator had to navigate through 3 or 4 static screens such as overview, area, and service area maps in order to view the real-time operating conditions at a specific site. This navigation process from the basic graphical design was cumbersome and inefficient for the control-center operators during the hectic time. During the heavy rain or storm events, a lot of alarms were generated in the fields such as high wet-well level, pump failure, no communication, etc... To alleviate the control-center operators from this time consuming navigation task, the city engineers developed an extended graphic design in which the operators could watch the operations for 5–15 remote sites simultaneously with one click of the mouse (Fig. 7).

This single display shows the real-time information such as wet-well level, effluent flow, blower and clarifier status, chlorine residual, and totalizer readings at 6 WWTPs. Clicking the mouse in the 'F/G/H' box will pop up another similar display containing WWTPs starting with F, G, and H. Clicking the mouse in the 'P.S.' or 'WWF' box will pop up the "pump station report — real time" display (Fig. 9a) or "Wet-Weather Facility Report — Real Time" display, respectively. Clicking the mouse in the 'BW' box will pop up the overview plant layout of BeltWay WWTP. Click the mouse in the 'FLOW' or 'WWL' box will pop up the 2-day trend of the plant's effluent-flow or wet-well-level, respectively.

4. Operations

One of the main objectives of the city SCADA system is to monitor the LS, WWTP, and WWF from the control-center so that any potential

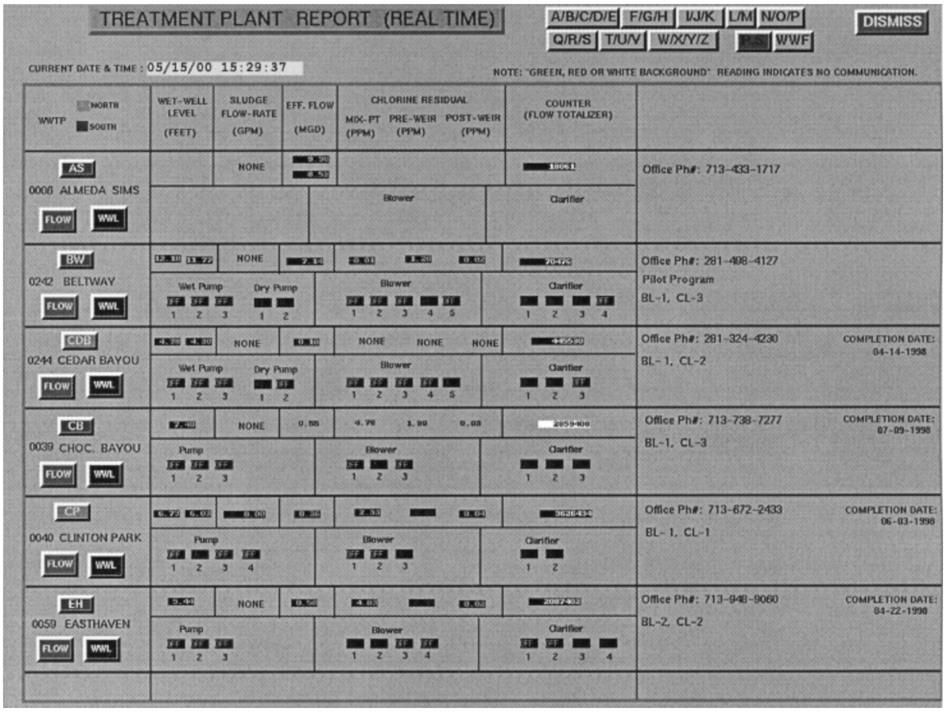


Fig. 7. Extended graphical display for WWTP's operating conditions.

excursion in the wet-well level and effluent discharge can be identified and corrected as soon as possible. The high wet-well level might cause sewage overflow into city streets; the low pre-weir or high post-weir chlorine residuals might cause insufficient disinfection or toxicity of the plant's discharge, respectively. These excursions are costly and can be fined heavily by the USEPA and TNRCC. Following are some of the most important tasks performed daily by the control-center operators:

- Detect and minimize the number of the remote PLCs with "NO REPLY" communication. If the communication is lost between the control-center SCADA system and the remote PLC, then the control-center operator cannot know what is happening at the remote site such as wet-well level, pump/blower/clarifier status, chlorine residuals, etc... After the detection of the "NO REPLY" PLC, the operator will check whether the problem is from the remote PLC modem, the phone line, or the SCADA system (least likely). If the problem is from the remote PLC modem (most likely) then the operator will dispatch the site electrician to check and replace/reset the modem. If the phone line is bad then the operator will inform the phone company. Fig. 8a shows a list of "NO REPLY" PLCs, in which DURHAM PS had bad modem, CROSSTIMBER UP and NORTHBOROUGH WWTP DECHLOR

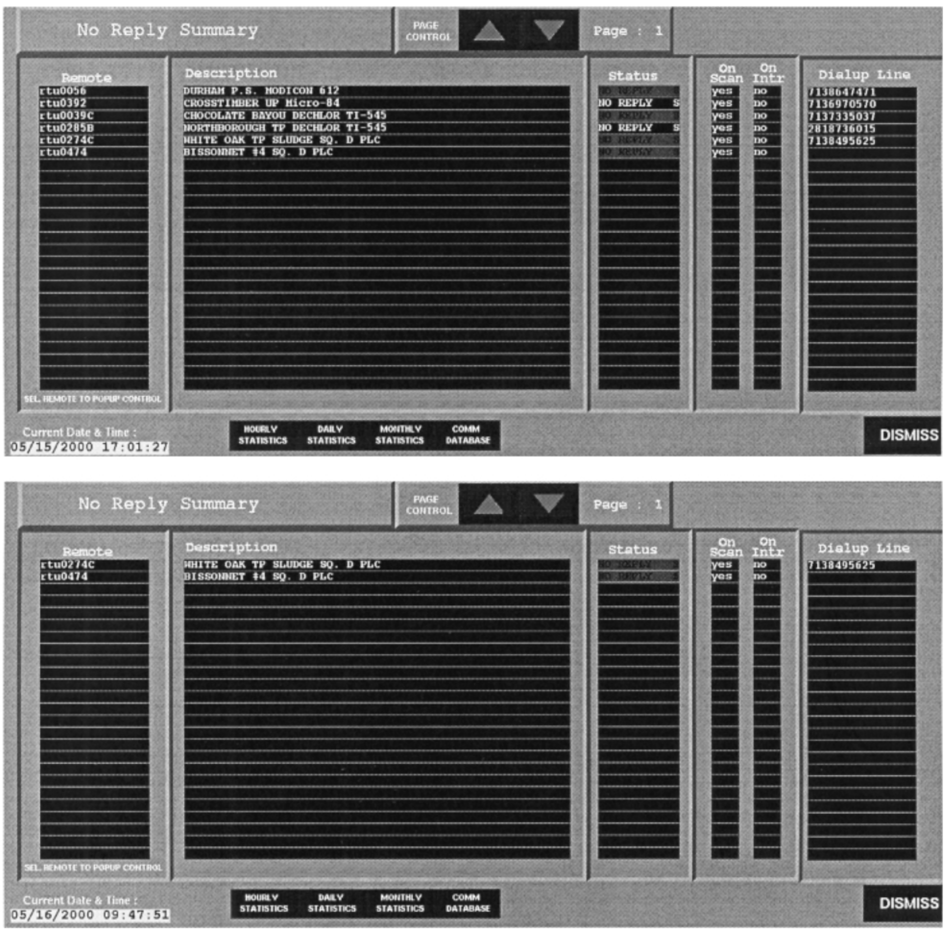
(a)
(b)


Fig. 8. (a) "NO REPLY" PLC list prior to problems fixed; (b) "NO REPLY" PLC list after problems fixed.

had bad phone lines, CHOCOLATE BAYOU DECHLOR phone line was severed accidentally by the contractor, WHITE OAK WWTP SLUDGE had bad connection, BISSONNET No. 4 PS had bad circuit line. Fig. 8b shows the list of update "NO REPLY" PLCs in the next morning after problems fixed.

- Detect the high wet-well level in time so that appropriate action can be made to prevent sewage overflow. For example, while

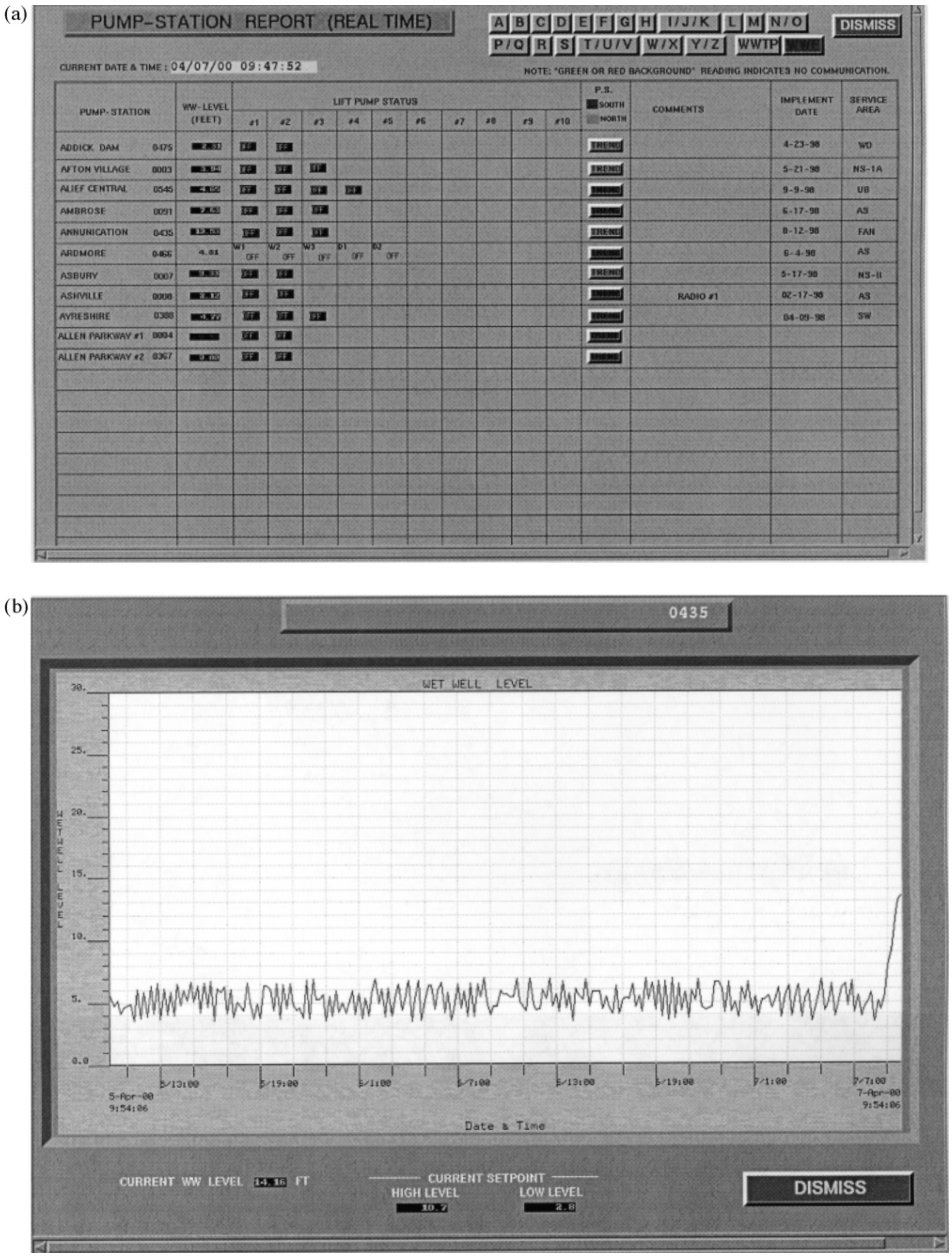


Fig. 9. (a) Extended graphical display for PS/LS/UP's operating conditions; (b) wet-well level 2-day trend for annunciation LS.

navigating through the real-time pump-station reports (Fig. 9a), the operator clicked on the "TREND" box for 2-day wet-well level trending and found the high wet-well level (Fig. 9b) in the Annuciation LS (Facility #0435). The display showed a wet-well level of 14.16 feet and no pump is running! The operator informed the site supervisor of this event. The site electrician was dispatched to investigate the problem. He found out that the power to the LS was off due to the recent storm. The power was restored in time for turning on the pumps so that no sewage overflow occurred at the site.

- Detect the abnormal chlorine residuals in the disinfection process to prevent permit violation. For example, when the SCADA system triggered the pre-weir chlorine residual low at Upper Brays WWTP, the control-center operator navigated to the chlorine residual 2-day trend (Fig.10) display. He found that there was a problem with the pre-weir chlorine reading. The problem might be due to the chemical pump malfunction, the chlorine analyzer got clogged, or low bleach tank level. He informed the plant operator to check the process. After the plant operator fixed the chlorine analyzer problem, the chlorine residual reading returned back to normal. The city could have violated the permit had the problem not corrected in time.
- Detect and inform the plant operator whenever all the blowers or all the clarifiers at the WWTP stop running. If these problems were not detected in time, the processes in the treatment plant could be upset, and permit violations in dissolved oxygen (DO) and total suspended solid (TSS) concentrations would be inevitable.
- Detect the pump failures, pump seal failure, pump phase unbalance, pump high temperatures for important pump stations.
- Create the "OPERATOR NOTE PAD" that lists all important telephone/fax/pager/radio numbers as well as addresses and retrieve information quickly when requested.
- Monitor the wet-weather facilities during the heavy rain or storm events.
- Monitor the sludge facilities when requested.
- Provide field people the real time informa-

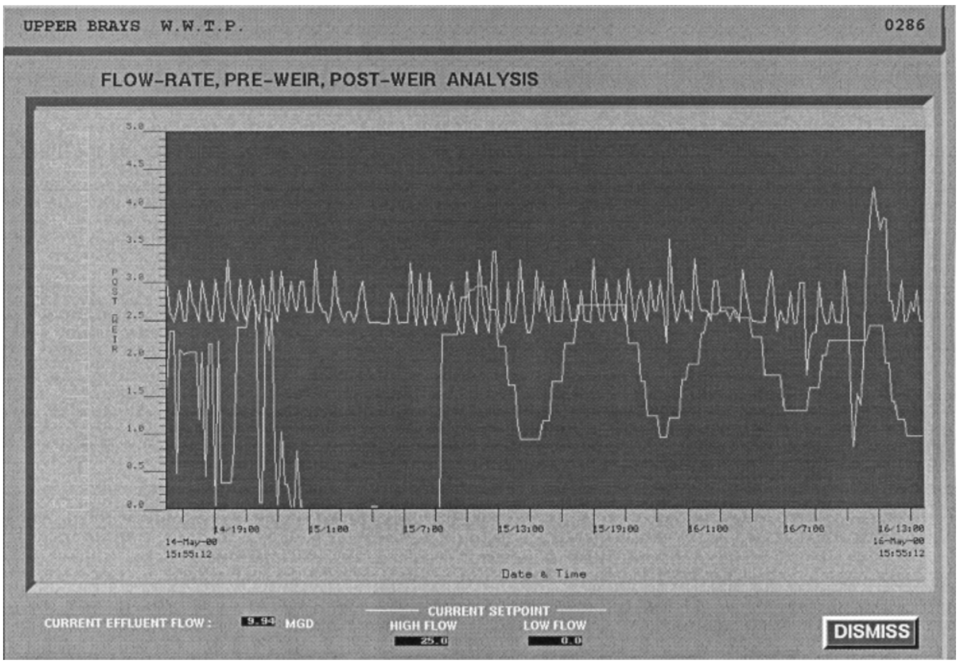


Fig. 10. UB WWTP effluent flow-rate, pre-weir and post-weir chlorine residuals 2-day trend.

tion so that they can calibrate and verify field instrument variables to match those in the SCADA system.

- Provide address (Fig.11) and print out service area (Fig. 12) of facilities when requested.

5. Data analysis and process optimization

The SCADA system also benefits the instrumentation technicians who work on the automatic control and optimization of the chlorination and dechlorination processes. The USEPA and TNRCC require that the chlorine residuals for the plant's discharge be more than 1.0 PPM (after 30 min contact time) at the pre-weir location, and be less than 0.1 PPM at the post-weir location. Due to the fluctuation in the influent flow and chlorine demand of the sewage, it is not an easy task to control and optimize these processes. By analyzing the pre-weir chlorine residual data from the 2-day trend at Turkey Creek WWTP, a site instrumentation technician tried to modify the PLC program that controlled the chlor/dechlor processes. He switched the set-point control to the mix-point (location where chlorine solution was injected into the contact basin) instead of at the pre-weir (location about 30–50 min downstream from the mix-point). The result (Fig. 13) showed that after the modification, the pre-weir residual reading (green curve) was much better than before. This modification not only improved the chlorination process but also eliminated the pre-weir chlorine violations and associated alarms in the SCADA system. This trend also showed that


WWTP INDEX – ALPHABETICAL

NUMERIC DISMISS

SELECT

SERVICE AREA	WWTP OVERVIEW	FACILITY NUMBER	FACILITY NAME	AREA MAP	FACILITY ADDRESS @ ZIP-CODE	KEY MAP	OFFICE PHONE #
		0006	ALMEDA SIMS	SC	12319 1/2 ALMEDA ROAD @ 77045	572-S	713-433-1717
		0242	BELTWAY	SW	10518 BELLAIRE @ 77072	529-G	281-498-4127
		0244	CEDAR BAYOU	FAN	2804 HUFFMAN EASTGATE @ 77535	339-G	281-324-4230
		0039	CHOCOLATE BAYOU	SC	9600 MARTIN LUTHER KING @ 77048	574-J	713-738-7277
		0040	CLINTON PARK	NE	9030 CLINTON DRIVE @ 77024	495-T	713-672-2433
		0059	EASTHAVEN	SE	8545 SCRANTON @ 77075	575-G	713-948-9060
		0565	FOREST COVE	FAN	729 HAMBLEN RD. @ 77339	336-J	
		0083	FWSD #023	NE	8219 KELLETT @ 77078	455-G	713-636-8209
		0240	GREENRIDGE	SW	6301-#1 FUQUA, W. @ 77489	571-X	281-437-6239
		0107	HOMESTEAD	NE	5565 KIRKPATRICK @ 77028	455-N	713-675-3910
		0482	HUNTERWOOD	NE	6230 S. LAKE HOUSTON PKWY @ 77013	456-R	N/A
		0268	IMPERIAL VALLEY	FAN	15500 COTILLION @ 77060	373-W	281-448-4226
		0238	INTERCONTINENTAL	FAN	2450 RANKIN @ 77032	373-H	281-233-2572
		0241	INTERWOOD	FAN	4722 ALDINE BENDER @ 77032	374-Y	N/A
		0250	KEEGANS BAYOU	SW	9400 WHITE CHAPEL LN. @ 77074	530-S	713-272-3699
		0518	KINGWOOD CENTRAL	FAN	3928 KINGWOOD DR. @ 77345	337-F	281-358-7171
		0397	METRO CENTRAL	SE	12815 GALVESTON ROAD @ 77062	617-C	713-488-3571
		0451	MUD #048	FAN	SORTERS ROAD @ 77365	295-V	281-358-6885
		0452	MUD #058	FAN	22405 LOOP 494 @ 77339	296-W	N/A
		0243	MUD #203	FAN	1215 GEARS ROAD @ 77060	372-P	281-825-8124
		0407	MUD #266	FAN	15021 CROSSWINDS @ 77032	374-U	N/A
		0252	NORTHBELT	FAN	14506 SMITH @ 77396	375-Y	713-441-8554
		0285	NORTHBOROUGH	FAN	13131 NORTH FREEWAY @ 77060	372-L	281-875-4802
		0146	NORTHEAST	NE	655 MAXEY ROAD @ 77015	496-C	713-453-2946
		0270	NORTHGATE	FAN	303 BENMAR @ 77060	373-N	281-875-5551
		0145	NORTHWEST	NW	5423 MANGUM @ 77091	451-C	713-683-6789
		0245	PARK TEN	NW	16500 PARK ROW @ 77084	447-Y	281-646-6606
		0171	SAGEMONT	SE	11700 SAGEARBOR @ 77089	576-Z	281-922-2308
		0183	SIMS BAYOU	SE	9500 LAWNDALE @ 77019	535-H	713-926-1040
		0283	SIMS SOUTH	SE	3005 GALVESTON ROAD @ 77017	535-L	713-847-5158 / 5159
		0189	SOUTHEAST	SE	9610 KINGSPOINT @ 77075	576-W	713-731-6003
		0190	SOUTHWEST	SW	4211 BEECHNUT @ 77096	531-P	713-662-8031
		0498	TIDWELL TIMBER	NE	10155 TIDWELL @ 77396	416-A	N/A
		0201	TURKEY CREEK	SW	1147 ENCLAVE PARKWAY @ 77077	488-G	281-558-8465
		0286	UPPER BRAYS	SW	13525 OLD WESTHEIMER @ 77082	529-A	281-752-2231
		0225	WCID #047	SE	7410 GALVESTON @ 77587	576-F	713-948-9057
		0485	WCID #76	FAN	13535 RIVER TRAIL DRIVE @ 77396	374-U	281-590-6219
		0279	WCID #111	SW	10601 HUNTINGTON POINT @ 77099	528-Y	281-568-7598
		0237	WEST DISTRICT	NW	255 ISOLDE @ 77079	489-L	713-468-0875

Fig. 11. Facility's address.

something was wrong with the de-chlorination process because the post-weir chlorine residual reading (orange curve) was frequently higher than 0.1 PPM. This was due to the sodium-bisulfite chemical pump malfunction or the chemical tank running low, etc... The detection of this problem helped to solve the problem and kept the chlorine residuals within the permit requirements.

The ideal automatic control and optimization for the chlorination/dechlorination processes is where the chlorine residual for the pre-weir is about 1.5 PPM and for the post-weir is about 0.02 PPM all times. This ideal condition not only meets the permit requirement but also is best for the chemical savings and chemical pump workload. A historical trend for the chlor/dechlor processes

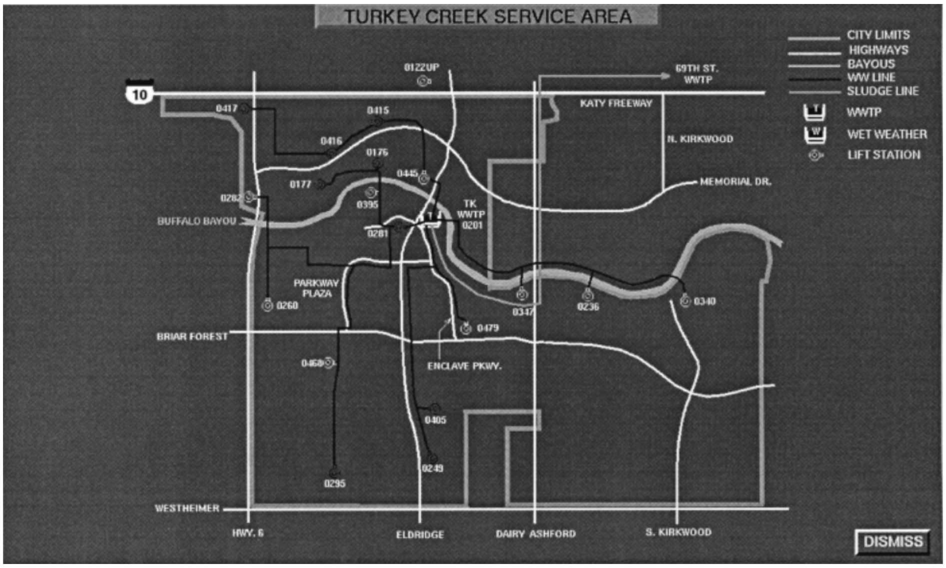


Fig. 12. Facility's service area.

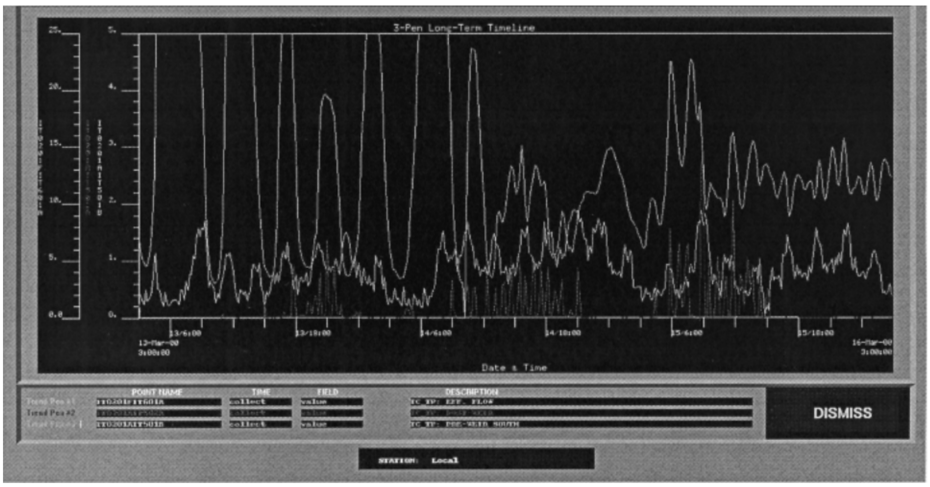


Fig. 13. Pre-weir chlorine residual (green curve) prior and after changing set-point parameter.

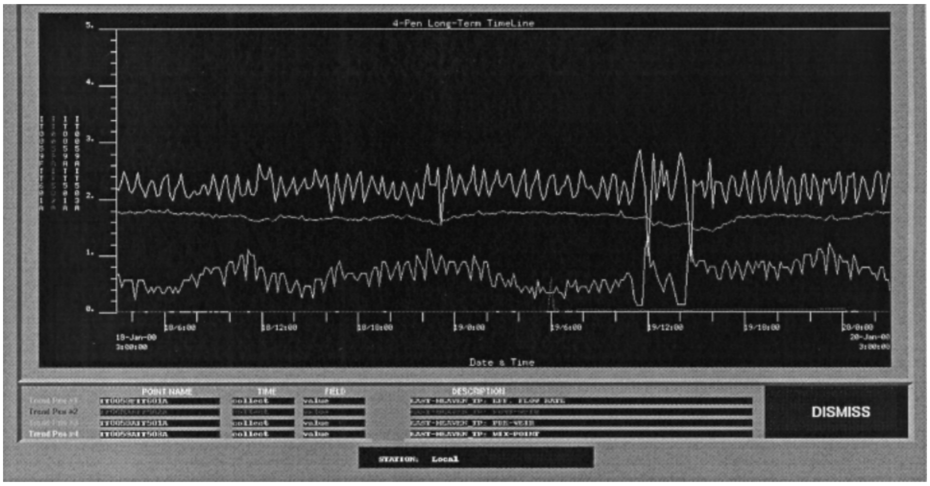


Fig. 14. East Heaven WWTP: chlorination/dechlorination trend for data analysis.

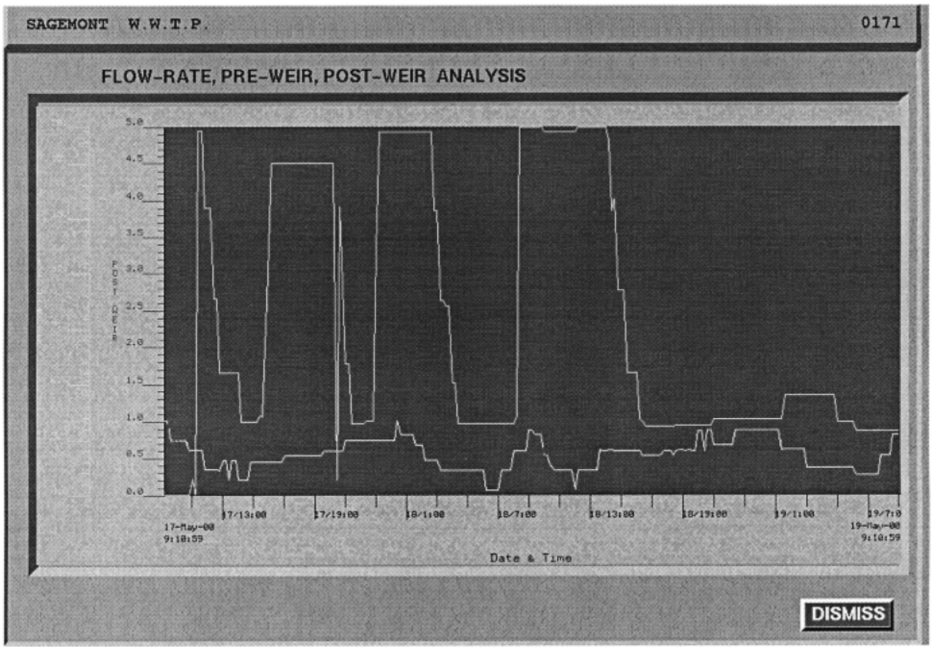


Fig. 15. Sagemont WWTP: chlorination/dechlorination trend for data analysis and process optimization.

(Fig. 14) at East-Heaven WWTP showed that this ideal condition could be attained at this facility and it should be a goal for other wastewater treatment plants.

Another recent chlorination process optimization was implemented at Sagemont WWTP. The plant experienced a highly fluctuated pre-weir chlorine residual. By analyzing the data from the SCADA 2-day trend, an instrumentation technician had decided to modify the PLC program by switching the set-point control from the pre-weir location to the mix-point location. As expected, after the change was made at 2:00 PM on 18 May 2000, the pre-weir chlorine residual reading smoothed out at about 1.0 PPM. Further data analysis from the trend (Fig. 15), the technician would make some more minor adjustments in the PLC program in order to keep the pre-weir residual at 1.5 PPM. When compared the results between the pre-weir control and the mix-point control, it is obvious that the mix-point control was better than that of the pre-weir control. This process optimization showed a reduction in chemical consumption (both sodium chloride and sodium-bisulfite), a reduction in the pump's workload and a subsequent reduction in the plant's operations and maintenance costs.

6. Summary

The application of the SCADA system in the wastewater treatment facilities not only has helped the Wastewater Operations Branch to monitor effectively the city's sewage collection/distribution systems, wastewater treatment plants, and wet-weather facilities but also helped the city to comply with the USEPA/TNRCC permit requirements. With the SCADA trending tool, the city can continue to optimize the plant's processes for savings in operations, chemical, energy, and maintenance expenditures.

The success of the city's SCADA system was a result of the team effort and dedication from all employees. The author would like to acknowledge Harold Kidder, a project manager of EMA Services Inc for his contribution in the system administration; Kenny Smith, a technical consultant of MPI for his contribution in database implementation; all employees in WWO branch for their contributions in managing project, developing graphics displays, setting up communication to remote PLCs, verifying data points in the fields, etc; and especially Teresa Battenfield, the branch director, for her vision, encouraging, and full support in the SCADA project.

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