USACERL Technical Report EP-94/01
November 1993
Microcontroller Technology for
Water and Wastewater Treatment

US Army Corps
of Engineers
Construction Engineering
Research Laboratories

An Evaluation of Technologies To Automate U.S. Army Water and Wastewater Systems

by
Byung J. Kim
Robert G. Skrentner

The U.S. Army currently faces reductions in budget and personnel that support and operate its domestic and industrial water and wastewater systems. It may be possible to maintain required levels of service at Army wastewater treatment plants (WWTPs) by installing and using automated systems at the plants. Automation technologies have been successfully applied at municipal and industrial water and wastewater treatment plants, and collection and distribution systems. The Army, however, has automated relatively few of its water and wastewater systems, even though the technology to do so is both economically practical and immediately available. Automation offers a promising alternative to labor-intensive operations, especially for the Army, which has a shortage of skilled workforce.

This study investigated and evaluated the Army's needs to automate its water and wastewater systems using off-the-shelf technology. Representative Army installations were visited to interview plant personnel and review current operating and maintenance practices. Areas that could be automated were located, and several alternative control system approaches were identified. Each alternative system was judged against a set of predetermined criteria, and an approach for implementing automation was recommended.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
November 1993

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
An Evaluation of Technologies To Automate U.S. Army Water and Wastewater Systems

5. FUNDING NUMBERS
4A162720
A896
NN-TY2

6. AUTHOR(S)
Byung J. Kim and Robert G. Skrentner

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Construction Engineering Research Laboratories (USACERL)
P.O. Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
TR EP-94/01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Center for Public Works (USACPW)
ATTN: CECPW-FU-W
Bldg 358
Fort Belvoir, VA 22060-5516

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The U.S. Army currently faces reductions in budget and personnel that support and operate its domestic and industrial water and wastewater systems. It may be possible to maintain required levels of service at Army wastewater treatment plants (WWTPs) by installing and using automated systems at the plants. Automation technologies have been successfully applied at municipal and industrial water and wastewater treatment plants, and collection and distribution systems. The Army, however, has automated relatively few of its water and wastewater systems, even though the technology to do so is both economically practical and immediately available. Automation offers a promising alternative to labor-intensive operations, especially for the Army, which has a shortage of skilled workforce.

This study investigated and evaluated the Army's needs to automate its water and wastewater systems using off-the-shelf technology. Representative Army installations were visited to interview plant personnel and review current operating and maintenance practices. Areas that could be automated were located, and several alternative control system approaches were identified. Each alternative system was judged against a set of predetermined criteria, and an approach for implementing automation was recommended.

14. SUBJECT TERMS
Army facilities
wastewater treatment plants
water treatment plants
automation

15. NUMBER OF PAGES
64

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

FOREWORD

This study was conducted for the U.S. Army Center for Public Works (USACPW), Fort Belvoir, VA, under Project 4A162720A896, "Environmental Quality Technology"; Work Unit NN-TY2, "Micro-controller Technology for Water and Wastewater Treatment." The USACPW technical monitor was Malcolm McLeod, CECPW-FU-W.

This research was performed by the Environmental Engineering Division (EP), of the Environmental Sustainment Laboratory (EL), U.S. Army Construction Engineering Research Laboratories (USACERL). Dr. Byung Kim was the USACERL principal investigator. Robert Skrentner is associated with EMA Services, Inc., St Paul, MN. At the time of this report preparation, Mr. Brian Emery, a graduate research associate from the University of Illinois, reviewed and revised this report to reflect sponsor's comments. Dr. Dean Smith is Acting Chief, CECER-EP and Dr. Edward Novak is Acting Chief, CECER-EL. The USACERL technical editor was William J. Wolfe, Information Management Office.

LTC David J. Rehbein is Commander of USACERL and Dr. L.R. Shaffer is Director.

CONTENTS

FIGURES

TABLES

AN EVALUATION OF TECHNOLOGIES TO AUTOMATE U.S. ARMY WATER AND WASTEWATER SYSTEMS

1 INTRODUCTION

Background

The U.S. Army currently operates more than 100 small wastewater treatment plants (WWTPs), of which 75 percent use trickling filters, 15 percent use an activated sludge process, and 10 percent use other treatment methods. Army WWTPs range in capacity from 0.003 to 8 million gallons per day (MGD),* with an average capacity of about 1.0 MGD. The physical size and complexity of Army WWTPs generally parallel the systems' treatment and distribution capacities, i.e., larger capacity systems are bigger and more complex than relatively smaller capacity systems.

As in many other areas, the Army is currently facing reductions in budget and personnel that support and operate its domestic and industrial water and wastewater systems. One way to maintain required levels of service at WWTPs despite such cuts is to increase efficiency by using automated systems at the plants. Many different automation technologies have already been successfully applied at municipal and industrial water and wastewater treatment plants, and collections and distribution systems. The Army, however, has automated relatively few of its water and wastewater systems, even though the technology to do so is both economically practical and immediately available. Simple control automation that uses durable equipment offers the Army a promising alternative to labor-intensive operations, especially in light of the Army's shortage of skilled work force. The installation and use of simple, reliable automated controls can make plant operations more cost-effective by using the available workforce more effectively and by reducing the use of energy and chemicals. The Army can expect to gain substantial savings by automating its more than 100 facilities.

A first step in beginning to automate Army water and wastewater systems is to review and evaluate the systems themselves, their needs, and available technologies. This 2-year study focused on selected water and wastewater systems as a part of an ongoing water and wastewater automation project being conducted by the U.S. Army Construction Engineering Research Laboratories (USACERL).

Objectives

The objectives of this study were to: (1) review the processes at Army water and wastewater facilities and identify those that could be automated to achieve a cost benefit, (2) review available, off-the-shelf technologies appropriate to automate the candidate processes, (3) determine criteria for evaluating the technologies, and from that assessment, to recommend specific technologies that can help reduce operating costs at those Army facilities by automating the candidate processes, and (4) outline a strategy to successfully begin automation at Army water and wastewater facilities.

*A metric conversion table is included on p 61.

Approach

On-site interviews were conducted at representative Army water and wastewater facilities to review their work processes, and to assess the current state of the automation and identify areas where automation would be cost beneficial. Facilities included:

- Anniston Army Depot, AL
- Fort Bragg, NC
- Fort Gordon, GA
- Fort Huachuca, AZ
- Fort Meade, MD
- Fort Lewis, WA
- Holston Army Ammunition Plant, TN
- Lone Star Army Ammunition Plant, TX
- Red River Army Depot, TX
- Watervliet Arsenal, NY
- West Point Military Academy, NY.

A literature search was performed to identify appropriate technologies that might be applied to the identified processes. Criteria were derived to rate each technology for its potential for successful application to Army water and wastewater plants. The technologies that best met the criteria were recommended, and a strategy for implementing those technologies was outlined.

Scope

This study assessed automation technology that may be applied in any Army facility. The facilities surveyed in this study were considered to be representative of Army facilities. The concept developed by this study has been validated by partial automation at Fort Meade, Watervliet Arsenal, and West Point Military Academy. Detail for the demonstration will be discussed in a forthcoming report.

Mode of Technology Transfer

It is anticipated that the results of this study will be incorporated into an Engineer Technical Note (ETN).

2 REPRESENTATIVE ARMY WATER AND WASTEWATER SYSTEMS

Anniston Army Depot

The Anniston Army Depot is about 8 mi west of Anniston, AL. Two wastewater treatment plants are located on the Depot, one for domestic wastewater and one for industrial wastewater. The industrial wastewater plant consists of five different liquid trains to treat various waste streams. Water is supplied to the Depot by the City of Anniston. Water meters are read daily.

A staff of five operators is responsible for the domestic wastewater treatment plant operation. The plant is staffed 24 hr/day, 7 days per week even though there is little influent on weekends. A staff of five operators is responsible for the industrial plant.

Domestic Wastewater Treatment Plant

The wastewater plant treats an average of 0.25 MGD and serves a population of about 4700. It can receive about 0.03 MGD from a nearby weapons plant when the plant is operating. All flow is pumped to the plant by one of two pump stations. Flow enters an aerated grit chamber at the plant and flows into two aerated equalization basins. An air-operated pinch valve regulates flow to a splitter box that divides flow into two parallel aeration basin/clarifier trains. A rotary strainer is located ahead of each aeration basin.

Alum is added manually at the head end of the aeration tank to lower pH from about 10 to 7. About 300 mL per minute of polymer is added just before the clarifier as a settling aid. One of two 50-hp, constant speed blowers runs continuously to provide air for the equalization basin and aeration tanks.

Waste sludge from each train is pumped to aerobic digesters. One constant speed blower operates continuously for each of the two digesters. Digested sludge is pumped to one of nine drying beds about once every 15 days.

Three aeration effluent pumps force clarified effluent through five upflow sand filters. The pumps cycle on/off based on level. Whenever a pump is on, chlorine is added at the pump discharge. Four filter effluent pumps convey the effluent about 6 mi to a creek. A rather complex, relay and timer-based control panel sequences filter backwashes. However, the controls lack the ability to detect valve failures. A pump sequence equalizes run time on both the aeration pumps and the filter effluent pumps.

The grit collector is not used. Plastic media trickling filters located upstrem of the aeration basins are also not used.

Wastewater Collection System

The wastewater collection system has four lift stations and two pump stations. One pump station has two 50-hp pumps and the other has three 50-hp pumps and a bar screen. The four lift stations are small sumps. One of the 2-day shift operators checks the pump and lift stations everyday. This requires about 1 hr per day.

Stripper Wells

Fifteen stripper wells serve four ground water decontamination sites. Groundwater is pumped to carbon filters and air strippers. Treated groundwater is applied back to the surface to percolate down and provide additional soil decontamination.

The lift and pump station operator checks the four sites every day and records pressure and changes strainers every other day. It takes about 2 hr per day to check all the sites.

Industrial Waste Treatment Plant

The industrial waste plant has five continuous process trains, one to treat phenol wastes, one for steam-cleaning wastes, one for general industrial wastes and two batch plants, one to treat cadmium/cyanide, and one for chrome. The plant contains a common lime slurry and alum system. Acid is added individually at each process using metering pumps. The entire plant was constructed to be fully automatic, using a panel with discrete relays and timers. However, the interlocking scheme was so complex that control was abandoned shortly after startup. All controls are run manually.

<u>Chrome Process</u>. Chrome laden wastewater is pumped into one of three tanks where sodium sulfite or sulfuric acid are added to lower pH. The operator reads a pH meter and after several minutes raises the pH by adding lime. Treated waste flows to a clarifier. Effluent flows to the general waste treatment plant.

Sludge is pumped to a holding tank where it is mixed with the steam-cleaning sludge. Sludge is periodically dewatered with a plate-and-frame filter press.

<u>Cadmium/Cyanide Process</u>. The cadmium/cyanide plant processes 10,000 gal per batch. A batch is run once per week and takes about 8 hr. Chlorine is added at the source to lower pH from 11 to 8. Influent is stored in a holding tank and lime is added. To begin a batch, the operator starts a transfer pump. Wastewater is pumped to a flocculation tank where sodium sulfite or metabisulfite is added. The waste passes through a clarifier and charcoal filter for cyanide removal to a second flocculator where lime and polymer are added. The effluent is clarified and passes through an ion exchanger for cadmium removal. Effluent then flows to the general waste treatment process train. Sludge is pumped to a storage tank. The sludge amount is so small the tank has never been emptied.

<u>Steam Cleaning Process</u>. One of two sump pumps lifts flow to an equalization tank where it is agitated. A third pump further lifts the wastewater to a splitter box that feeds two parallel trains. In each train the flow passes through three tanks in series. Alum is added in the first tank, lime in the second tank, and polymer in the third tank. Effluent is clarified and discharged to the domestic wastewater plant. Sludge is pumped to the chrome sludge holding tank.

<u>General Waste Process</u>. The general waste process is similar to the steam-cleaning process. One of two sumps lifts flow to an equalization tank where lime is added. The wastewater is then pumped to a splitter box that feeds two parallel trains. In each train, the flow passes through a mixing tank (where sodium bisulfite and polymer are added), a clarifier, and a sand filter.

Sludge is pumped to a holding tank. Periodically the sludge is dewatered in the plate-and-frame press. Effluent is mixed with the steam-cleaning flow prior to discharge to the domestic plant. Lime and acid can be added to adjust pH if necessary.

Phenol Process. Phenol is treated biologically. From an equalization tank, wastewater is pumped to an aeration tank. One of two positive displacement blowers provides air and mixing. Aeration effluent is clarified and discharged to the domestic wastewater plant.

Potential Automation Areas

Domestic Wastewater System. Areas where automation could improve operations include:

1. Equalization basis air flow control
2. Flow equalization to plant
3. Alum and polymer addition
4. Filter backwashing and control
5. Chlorine control
6. Replacing existing control panel to monitor and record run times and alarms
7. Lift stations, well pumps, and strippers monitoring.

Equalization Basin Air Flow Control. Operators must manually adjust the equalization basin air flow to maintain a flow rate of 600 scfm as the basin fills or drains. Adjustments are made as often as every hour.

Flow Equalization to Plant. Flow to the plant is intermittent. Almost no flow arrives during evenings and weekends. To not upset the biological process, operators must estimate what flow rate to set and then manually adjust the flow control valve. Automation could perform some simple calculations to calculate the rate of fill or drain in the equalization basin, current level, current plant flow, and day of week to predict a plant flow setpoint.

Alum and Polymer Addition. As the plant flow setpoint is changed, operators must adjust the alum and polymer addition. Pacing chemicals to plant flow could reduce chemical costs and provide more uniform treatment.

Filter Backwashing and Control. The existing relay and timer based panel should be replaced with a more modern automation system. Operators must closely monitor the existing automatic controls since the controls do not account for valve failures or filters out of service.

Chlorine Control. The plant averages 5 to 6 lb per day of chlorine. Operators check the residual every 2 hr. The plant has no permit requirements relative to chlorine or toxicity. Since there are no permit limits and since the plant uses so little chlorine, automation in this area should be a very low priority.

Replacing Existing Control Panel. An existing control panel contains lights to display the on/off status of 16 devices, 24 alarms, and 15 elapsed time meters. Operators manually transcribe run time readings. An automation system would eliminate the need for operators to record alarms and run times.

Lift Stations, Well Pumps and Strippers Monitoring. Monitoring lift station and well pump status would free up an additional 8 to 10 hr of operator time per week. Strainers at the strippers would still have to be changed manually every other day as is currently done.

Industrial Waste Treatment Plant. Areas where automation could improve operations include:

1. Scheduling and sequencing batch operations
2. Chemical addition.

Batch Operations. The complex control panel was abandoned because operators could not easily get around its interlocks. For example, if a valve failed to open somewhere, the batch operation stopped. The operator had to go to the valve, fix it, and then return to the panel to restart the process. It was found to be easier to run everything manually.

For automation to be successful, all valves must be working properly. Apparently, several of the valves are subject to sticking and valve status is unknown. This must be corrected.

Chemical Addition. All chemical feeds were adjusted manually. Operators made rounds and observed pH and ORP sensor readings, and adjusted feed rates as necessary.

Automatic control designs should permit operators to use pH and ORP sensors for automatic control. However, when sensors fail, the automation must allow operators to control the dosage rate manually through the control system, or to use a flow-paced control based on their experience.

Fort Bragg

Collection System

A 6-year old Intrac 2000 system monitors the seven existing lift stations. Plant staff calls Motorola to repair the system. The system logs each pump start/stop and produces large amounts of paper printouts. The printed information is rarely used. The system is unattended and unused unless a station alarm occurs. Staff cannot reprogram the system to make it more effective.

Wastewater Plant

The Fort Bragg primary and trickling filter plant is being completely replaced with an oxidation ditch plant. The existing gravity thickener will be converted to an aerobic digester/thickener. The existing anaerobic digesters will be abandoned.

Maintenance was performed primarily on top priority essential functions. At the time of the site visit, there was a hiring freeze and maintenance on equipment to be abandoned was minimal. Although atypical, in one case an instrument repair took 10 months.

Potential Automation Areas

Wastewater Treatment Plant. The new oxidation ditch plant will be typical of Army plants using this technology. Five areas were identified as candidates for automation:

1. Surface aerator control
2. Sludge pumping
3. Chlorination control
4. Report generation
5. Lift station monitoring.

Surface Aerator Control. Each oxidation ditch has two dissolved oxygen probes and two 125-hp, two-speed surface aerators. Using lower speeds or even turning one aerator off will be the largest energy saver.

The new oxidation ditch plant will have five dissolved oxygen monitors, two pH monitors, three Palmer-Bowlus flumes with sonic level/flow transmitters, and one residual chlorine analyzer. Instrument maintenance will be important if dissolved oxygen control and chlorine control are to be operated effectively.

Sludge Pumping. The primary and secondary clarifier sludge withdrawal valves are pneumatic with solenoid operators. Drum programmers were provided to sequence valves, but are not used. Replacement of the drum programmers function by digital controls similar to Fort Gordon would permit better control.

Digester charging/discharging valves were also equipped with a drum programmer that is also not used. Software timers would be more effective.

Chlorination. The plant attempted to pace chlorine addition to influent flow. Process lags and dead times resulted in erratic residuals. The chlorine is adjusted manually. Feed forward, flow-paced chlorine control will provide good control. Adding residual feedback control can provide excellent control.

Report Generation. The Fort Bragg laboratory supervisor acquired a personal computer to produce the operating reports for both the wastewater and water plant. The PC has no hard disk or graphics/trending capability. Additional benefit would result if daily operator- and lab-entered data were transferred automatically to the monthly reports. Reports and lab tests are similar to those done at Fort Gordon.

Lift Station Monitoring. The existing system should be left in place, but it should be relocated to the plant control room. As equipment fails, it can be converted to the new system.

Water Treatment Plant.

Chemical Feed Control. The Fort Bragg plant uses alum, phosphate, carbon, lime, fluoride ammonia, polymer, and chlorine since its water is classified as highly corrosive (Law Environmental 1989). At 6 MGD, Fort Bragg's chemical costs are about $250 per day. Automation to use flow-paced addition, chlorine residual analyzers, pH probes, and streaming current detectors could reduce costs up to 20 percent. These changes will also reduce operators' errors or personal preferences in determining chemical feed requirements.

Filter Backwashing. Filter backwashing sequences are prone to operator error. There is no set backwashing time, so each operator backwashes differently. On occasion, valves are not operated in the correct sequence, or the filter is left in an inoperable state. One major upset occurred when an operator left a drain valve partially open. Other filters began to drain and the washwater tank was close to overflowing before the error was corrected.

Automation of filter backwashing would ensure that filters were backwashed consistently and that sequences were correct, and would also free operators to monitor other processes and systems and to do routine cleaning of the filter area.

Filter Effluent Flow Control. Flow rate-controllers are used to set flow through each filter. Flow rates are determined by predicting water use requirements. In most plants, flow rates are set individually, making it difficult to balance or change flow if all rate controllers are not functioning properly. This is a chronic problem at the Fort Bragg Water Treatment Plant.

Water Distribution System—Expert System for Water Demand. Several times per shift, operators will review the status of the water plant and distribution system and make adjustments to plant flows. The operator observes elevated tank levels and the rate of level change, the raw water pumping rate, and the finished water pumping rates. In addition, the operator considers time of day, weather conditions, and personal preferences and experience.

At Fort Bragg, the operator must manually start raw water and finished water pumps as well as manually adjust filter flow rates and chemical feeds. Pumps and chemical feeds are widely scattered in different buildings. As a result, changes are minimized, especially on off-shifts and during stormy weather. If power fails, the operator must restart all equipment manually. This happens about once a month at Fort Bragg.

One operator interviewed during the site visit said it took several years to learn how to predict flows. A much more consistent flow prediction scheme and plant control would be possible if experienced operators' decision processes were modeled to predict plant settings. A simple expert system could be programmed into the plant control system.

Swimming Pool Monitoring. At Fort Bragg, there are eight pools. Chemicals are checked daily (including Saturdays, Sundays, and holidays). At some pools, soda ash tanks must be filled daily. Chlorine tanks usually last 2 to 4 days. However, unusually hot weather or heavy demands, such as troop survival training, will use chemicals faster. Because of the number of pools, a plant maintenance person is dedicated almost full time to pool maintenance. Base personnel become very upset if a pool must be closed because of chemical or temperature control failures.

By remotely monitoring chemical feed status, chlorine leaks, and temperatures, and sometimes by increasing chemical tank size, pool visits could be reduced from seven to two times a week. Maintenance personnel could be freed to improve plant operations and more quickly respond to emergencies.

Fort Gordon

Fort Gordon is approximately 12 mi southwest of August, GA. Engineering personnel from the Directorate of Installation Support have contracted domestic wastewater collection and disposal operations and maintenance responsibilities to Pan American World Services, Inc., a division of Johnson Controls, Inc.

Collection System

Separate storm and sanitary sewer systems serve Fort Gordon, and minimal fluctuations in treatment plant flow rates after heavy rainfalls indicate that infiltration and inflow to the sanitary lines are not a problem. The sanitary collection system consists of 22 lift stations that boost pressure through force mains followed by a network of gravity mains to the Fort Gordon WWTP.

Wastewater Plant

The WWTP, designed and built in the early 1940s and upgraded by the addition of a recirculating system in 1962, treats nearly all the raw domestic sewage and the small amounts of oil/water separator effluents from installation wash racks. About 20 septic tanks with tile drainage fields continue to serve remote areas.

The influent flows through a grit chamber, bar screen, comminutor, and a 12-in. Parshall flume before treatment in primary clarifiers. Primary effluent is applied to four rock-media trickling filters and is then chlorinated as it enters the final clarifiers. This early chlorination provides adequate contact time to reduce fecal coliforms counts. Coliforms cannot be effectively controlled in the undersized chlorine contact chamber. The effluent flows through a 9-in. Parshall flume into McCoy Creek.

Discharges from the Fort Gordon WWTP are regulated by National Pollution Discharge Elimination System (NPDES) Permit #GA0003484 that expires in 1992. The average flow may not exceed 4 MGD. Average weekly and monthly effluent BOD and TSS limits are 45 and 30 mg/L. The monthly average BOD and TSS removal efficiencies must be 85 percent or greater. Average weekly and monthly fecal coliform counts may not exceed 400 and 200 per 100 mls. The dissolved oxygen concentration in the effluent must always be maintained at or above five mg/L.

Potential Automation Areas

Wastewater Treatment Plant. Fort Gordon was assumed to be typical of all Army trickling filter wastewater treatment plants. Five areas where automation could improve operations were identified:

1. Primary sludge pumping
2. Secondary sludge pumping
3. Chlorine control
4. Report generation
5. Lift station monitoring.

Primary and Secondary Sludge. An optimum sludge blanket should be maintained in the primary and secondary clarifiers. To accomplish an optimum blanket, sludge should be pumped frequently, but for short durations, to maintain a blanket depth of 1 to 2 ft. Automation of the valve and pump operation frees the operator to optimize sludge pumping to plant flow. To automate this process, the following equipment modifications are required: (1) add electric valve operators to the clarifier sludge valves, and (2) add control relays to the sludge pump starters. Future optimization could use sludge blanket level detection to prevent over- or underpumping of sludge.

Chlorine Control. Chlorine gas is used for final disinfection of the plant effluent, in a process identical to that used in the activated sludge plant. Operators manually adjust chlorine dosage. A control strategy similar to the one used at the West Point wastewater treatment plant should be used in the trickle filter plants.

Report Generation. Data management at the trickle filter plant is a time-consuming activity of making 7500 entries per month. A personal computer would help operators generate reports and track plant performance. The time savings from automated data management would allow operators to devote more time to plant operations and maintenance activities.

Lift Station Monitoring. Signals from the existing lift station monitoring panel could be connected to the control system to record and date stamp alarms.

Fort Lewis

Fort Lewis is south of Tacoma, WA. All water is supplied from surface springs and wells. The wastewater treatment plant serves both Fort Lewis and McCord Air Force Base. Effluent from the wastewater plant is discharged into the ocean.

A staff of six operators is responsible for the water distribution system. The operators check the well sites, three swimming pools, and the golf course. A staff of 11 is responsible for operating the wastewater plant and the approximately 20 lift stations. The state of Washington requires 24-hr per day, 7 day per week staffing for the wastewater facilities.

Water Production/Distribution System

The production/distribution system has 1 water plant, 12 wells, 1 elevated tank, and 12 reservoirs in 6 locations. The water plant consists of four pumps at a surface spring and supplies about half of the water demand. The surface spring is being covered to keep contaminants out of the water supply. Well #12, rated at 3200 gal per minute, can supply much of the remaining demand. All wells pump directly into the distribution system. Altitude valves at the reservoirs open and close as needed to balance system pressures when demand changes. The elevated tank feed pumps operate based on level in the tank. Occasionally reservoirs have overflowed due to faulty altitude valves or overpumping.

The plant contains a control panel that displays levels at the reservoirs and allows remote pump operation at 7 of the 12 wells. Remote operation was not being used, however. The pumps' sand traps must be cleaned every shift. Pump changes are infrequent and performed manually at the site.

Chlorine and fluoride is added at each site. The chlorination equipment is about a year old. Chlorine addition is set manually for each site based on the well pump capacity. Chlorine residual is monitored, but not used for control.

Fluoride in the form of sodium silica fluoride is added through a dry feed system at each site. Fluoride addition is set manually based on well water flow.

The water is very corrosive, with a pH of about 6.5. Most of the pipes are being relined. A treatment plant is being designed to remove $C0_2$. Construction should begin in the near future.

Wastewater Collection System

The collection system has about 20 lift stations and 2 stormwater treatment systems. A new 1-MGD lift station and pipe are being installed to replace an old line that was subject to surcharging and infiltration. Lift stations are checked about twice a week to clean basket strainers. Crews are dispatched if complaints are received.

The stormwater treatment systems consist of oil flotation units that clean runoff from the motor pool area prior to discharge at one of the ocean outfalls.

Wastewater Treatment Plant

Fort Lewis has a trickling filter plant rated at about 3.5 MGD. Influent flows through one of two fine screens to a grit chamber. One of two grit pumps and one grit separator remove grit based on time. Two of the four primary tanks were in service and the two primary sludge pumps run continuously to pump very dilute sludge to a gravity thickener. Primary effluent is pumped to two 90-ft diameter plastic media trickling filters. Sludge pumps associated with each secondary clarifier, pumped dilute sludge continuously to the thickener. Chlorinators were set to manual operation.

Two thickened sludge pumps ran about 5 minutes at 40- to 60-minute intervals to pump thickened sludge to a primary digester. Sludge and supernatant overflowed into a second primary digester in series with the first. Overflow from this digester flowed into the secondary digester with a floating cover. Digested sludge flows by gravity to drying beds.

A control panel in the main building displayed the on/off status of about 44 motors, 14 alarms, 2 trickling filter flows, and effluent flow, pH, temperature, conductivity, and dissolved oxygen.

Potential Automation Areas

Production System Control (Wells and Springs). Each shift, operators check the well sites. The operators clean sand traps; record flow, and chlorine and fluoride dosage; and check general site conditions.

A panel was installed at the water plant to display levels in six reservoir pairs and the elevated tank. From this panel, 7 of 12 well pumps could be controlled. Well pumps were not controlled remotely since the pumps tend to accumulate sand and the sand traps must be cleaned each shift.

Automation of the sand trap blow out and the pump operation could reduce visits to once per day. At one site, the fluoride probe line had an entrapped air bubble that caused a bad reading. Monitoring chemical dosage and residuals would permit alarming failures. In addition, intrusion alarms should be installed to increase security.

Distribution System Monitoring. Reservoir and elevated tank level monitoring will locate stuck altitude valves or unusual conditions in the system. Data will also be used to do demand calculations.

Demand Calculations. The elevated tank has emptied during peak demand. As additional personnel transfer to the base, capacity will be taxed. Prediction of water demand, current use, and current water in storage by the automation system will help operations meet expected demand at minimum cost.

Swimming Pool Monitoring. Operators check the three swimming pools twice per shift. Automatic monitoring could reduce the need for checking to once per day.

Domestic Wastewater System.

Primary and Secondary Sludge Pumping. Sludge pumps were operated continuously. If this operation continues, automatic control may not be required. However, intermittent sludge pumping should be considered to reduce the quantity of supernatant which returned to the head of the plant.

Chlorination. Chlorinators were set to manual operation. The plant effluent flow meter is a propellor meter that constantly plugs. Flow paced control could significantly reduce chlorine use.

Digester Operation. Primary digester charging and transfer to secondary digester could be automated. Monitoring of gas production would help to verify digester performance.

Lift Station Monitoring. Lift stations are checked twice per week. If plugging or other failures occur, the staff relies on complaints from base personnel. Monitoring pump status and high level alarms at each lift station would eliminate unwanted customer complaints and reduce the checking to once per week.

Stormwater Treatment Facilities Monitoring. Two oil separator units should be monitored. These units are important to help meet discharge permits for the two ocean outfalls.

Water and Wastewater Systems Monitoring. The control room at the wastewater treatment plant displays the status of 44 items, 14 alarms, 2 trickling filter flows and plant effluent flow, pH, temperature, conductivity, and dissolved oxygen. An automation system for both the water and wastewater systems could be installed in this location to permit monitoring and operation of both systems from a single location.

Fort Meade

Detail discussion will be in a forthcoming report. Areas of automation included the pit control for nitrification/denitrification and chlorine control.

Fort Huachuca

Fort Huachuca is in the western portion of Cochise County in the southeastern quadrant of Arizona. All water is supplied from deep wells. Effluent from the wastewater treatment plant is applied to a golf course, parade field, and to evaporation ponds.

The water and wastewater systems are operated commercially under contract to the Army. Both the water and wastewater systems are staffed full time. One water system operator and one wastewater system operator are on duty at all times.

Water Production/Distribution System

The system has nine production wells. Eight wells are used regularly to meet demand. The ninth well, located on the east range, is operated only when the range is being used. In general, well sites contain a well pump, surge tank, booster pump, chlorinator, and fluoride metering pump. Wells seven and eight share facilities. Well two has two booster pumps, one is connected to well one. Well pumps start and stop automatically to maintain water in the surge tank.

Ground elevation at the Fort rises about 800 ft from northeast to southwest. To account for this elevation, three pressure zones are used. Zones are isolated either by terminating lines or using gate valves. A few pressure-reducing valves are used at lower ends of some zones.

Booster pumps at wells 1 and 2 can pump to a 1.5 million gallon (MG) reservoir in Zone B or a 3 MG reservoir in Zone C. Booster pumps at wells 3 through 6 pump to the Zone C reservoir. A 0.5 MG elevated tank in Zone C also receives water from these wells. Booster pumps at wells 7 and 8 pump to either the Zone C or Zone B reservoir using an in-line booster station. In addition to the well site booster stations, the Wherry Booster Station transfers water from the Zone C reservoir to the Zone B reservoir. A booster station at the Zone B reservoir transfers water to two interconnected 0.2 MG, Zone A reservoirs.

At one time, all control could be performed from a central location. However, underground lines became unreliable and the system was abandoned. Operators now make rounds every 3 hr and, when needed, manually operate booster pumps to pump water into the system. The system is very labor intensive. Underfilling or overfilling reservoirs is common. Energy use is high, since it is easier to pump to Zone C and then to Zone B rather than directly to Zone B.

The daily operation of the wells and pressure zones is manual. Wells and booster stations are turned on or off to meet current and short-term projected demands.

Wastewater Treatment Plant

Fort Huachuca has a trickling filter plant rated at about 2.7 MGD. Influent flows through a screen and grit channel. Grit is removed manually by diverting flow through a parallel channel. The wastewater passes through a barminutor and into an aerated mixing basin where final clarifier sludge is returned. Wastewater flows to two primary basins and then to a trickling filter and final clarifier. About 30 to 40 percent of the plant effluent is used for the golf course and parade field irrigation. The effluent is pumped to a pond near an abandoned treatment plant. Prior to application, it is chlorinated. Remaining effluent flows by gravity to evaporation ponds.

Primary sludge is removed every 3 hr and pumped to the primary digester. Secondary sludge is pumped back to the aerated mixing basin on a timed basis. Primary digester sludge overflows into the secondary digester. Secondary digester supernatant is returned to the aerated mixing basin. Digested sludge is applied to land. All digester gas is wasted.

In the future, it is anticipated that the base population will increase when the planned expansion is implemented. The primary and secondary clarifiers will be doubled in size. Tertiary filtration will be added to meet water reuse standards. Groundwater monitoring wells are also needed around the evaporation ponds.

Potential Automation Areas

<u>Production System Control (Wells)</u>. Every 3 hr, operators check the well sites, record flow and chlorine and fluoride dosage, and check general site conditions. The operators start and stop booster pumps at each site to meet system demands. The well pumps cycle on and off automatically to maintain the proper level in the surge tank.

Distribution System Control. The operation of the system is quite complex. Automation of the booster pumps from a central location could reduce site visits to once per day.

Demand Calculations. The power demand charge is currently $7 per kilowatt. About one half the Fort's power bill relates to demand charges. The utility is proposing a $20 per kilowatt demand charge in the future. Operating the system to minimize average and peak power use will significantly reduce the Fort's power bill.

Prediction of water demand, current use, and current water in storage by the automation system will help meet expected demand at minimum cost.

<u>Domestic Wastewater System</u>. The trickling filter plant operation is very simple. Addition of a timer to the primary sludge pump is one of the few automation areas for this system.

<u>Irrigation Water Supply</u>. Plant effluent is pumped to the irrigation water holding ponds. The operator at the wastewater plant does not know how much water is in the ponds. If too much effluent is pumped to the ponds, it overflows back to the evaporation ponds, wasting energy.

Even including the costs of operating the transfer pump, the irrigation systems, and the water distribution system, automation would be cost effective. Pond level monitoring, chlorination control, and effluent pump control would save energy and eliminate the need for the wastewater plant operator to travel to the ponds.

Holston Army Ammunition Plant

The Holston plant is located just west of Kingsport, TN. Holston is divided into two sites, connected by a 5 mi. corridor. The facility contains one 7.5 MGD industrial wastewater treatment plant, a very small domestic wastewater plant, and two filtered water plants in Area B. It has a small pretreatment plant and a filtered water plant in area A. All drinking water is provided by the City of Kingsport, although the filtered water plants meet drinking water standards. All plants are operated by the Holston Defense Corporation.

Process Water Treatment Plants

Area B Treatment Plant. A pump house rated at 50 MGD provides water from the Holston River to the filter plants and cooling water systems. The older filter plant flow averages about eight MGD. The newer plant, rated at 7.5 MGD, was not in use. The plant is staffed with 2 operators, 24 hr per day.

The plant is divided into two parallel trains. Alum and chlorine are added upstream of the splitter box. Each train has two flocculation basins, four primary settling basins, and two secondary settling basins. Sludge is removed by manually operating telescoping valves. This takes about 90 minutes each day for the primary basins, and 60 minutes for the secondary basins.

Settling basin effluent from each train flows to five sand filters, each with two sides that operated independently. All valves are manual. Normally three filters are backwashed each day based on run time. Head loss and flow rate controllers have not worked in 15 years.

Area A Treatment Plant. The Area A plant treats about 7.5 MGD. It is slightly smaller, having six sand filters. The plant is staffed with one operator per shift.

Domestic Wastewater Treatment Plant

The domestic wastewater treatment plant is a typical trickling filter plant that operates unmanned and treats a population of about 1000. A roving operator checks the plant twice per shift. Influent flows by gravity and is split into three rectangular primary clarifiers. Primary effluent is lifted to the trickling filter by two automatically controlled pumps. The effluent is clarified and chlorinated. Primary sludge is pumped to a digester once per day. Secondary sludge is pumped to the head of the plant. Digested sludge is pumped to drying beds about once every 3 months.

Industrial Wastewater Collection System

There are two lift stations in Area A and one in Area B. These are checked when the operator makes rounds twice per shift.

Industrial Wastewater Treatment Plant

Flow from Area A and Area B enters the plant through dedicated flow meters. The streams are combined and the wastewater passes through two in-series neutralization tanks where either sodium hydroxide (NaOH) or hydrochloric acid (HCl) can be added to adjust pH. Flow passes through four anoxic upflow filters for denitrification. Effluent passes through two more in-series neutralization tanks to further adjust pH.

Each filter is equipped with five telescoping valves for recycle flow to a wet well, from where effluent is pumped back to the neutralization basin. Sludge is removed through an automatic system and pumped to the solids handling area.

Neutralized effluent flows to a wet well where it can either be pumped up to a trickling filter, or bypass the trickling filter and go directly to six aeration basins. Surface aerators provide oxygen for biological growth. Two positive displacement blowers aerate the influent channel flow. Mixed liquor flows to a splitter box and then to two clarifiers. Return sludge from each clarifier is metered and two screw pumps lift the return sludge. Waste sludge is pumped to the solids handling area using two waste sludge pumps.

Clarified effluent is lifted by two screw pumps to four multimedia sand filters. Effluent flows to the river, and can also be diverted to the water plants.

Waste-activated sludge flows to a pre-thickener. Thickened sludge is pumped to two aerated digesters. Supernatant flows back to the aeration basin. Digested sludge flows to two post-thickeners. Supernatant flows back to the neutralization basins. A third post-thickener receives alum sludge from the filter plant. The alum sludge and thickened sludge are dewatered in a plate-and-frame press. When thickened sludge is dewatered, ferric chloride and lime are added. Occasionally, alum, fly ash, or sulfuric acid is also added.

Potential Automation Areas

Process Water Plants. The 2 operating water plants required a staff of 3 operators, 24 hr per day. Since the plants do not supply drinking water, full automation should be considered. The fully automated plant will require less manpower.

Areas to automate include remote pump house operation, plant flow control, alum addition, prechlorination, sedimentation basin sludge withdrawal, and filter backwashing (including washwater systems), and high lift pumping. To accomplish this, the plants would require major renovation to replace existing manual valves. The plant supervisor reported that this may be done for safety reasons since several operators had been injured when operating the manual valves.

Domestic Wastewater Treatment Plant. The wastewater plant has been operating unattended for about 6 months. A roving operator checks the plant twice per shift. This requires 30 to 45 minutes each time including travel time. Remote monitoring of the plant operational status could reduce the number of visits to once per day, saving about 3 to 4 hr per day. Time-based automation of primary sludge pumping would be necessary.

Industrial Wastewater Systems. A control room contains a control-panel mounted PLC that controls filter backwashing. The control panel also displays 160 alarm status points and permits control of return activated sludge (RAS) and waste activated sludge (WAS) flow. Areas to further automate include:

1. Influent neutralization
2. Return sludge screw pumps and sludge withdrawal
3. Aeration tank dissolved oxygen
4. Chemical inventories and usage
5. Plant operational status monitoring
6. Production area monitoring.

Influent Neutralization. Automatic control of chemical addition to control pH will provide more consistent control and save chemicals.

Return Sludge Screw Pumps and Sludge Withdrawal. Return sludge screw pumps are run continuously. Modulating RAS valves to control sludge withdrawal from the clarifiers were set to manual operation.

Automatic control of these valves would provide more consistent loading on the aeration tanks. During the site visit, the operator indicated that intermittent pumping of RAS could be implemented to save power. Sludge could accumulate and consolidate in the clarifier during this time.

Aeration Tank Dissolved Oxygen. Automatic on/off control of the surface aerators could be tried. It appeared that the aerators were overaerating. If settling is not a problem, aerators could be cycled on and off to save power costs.

Chemical Inventories and Usage. The operators recorded a lot of information on chemical use and chemical inventories. Automatic monitoring and recording could reduce operator recording time and provide better information on chemical use.

Plant Operational Status Monitoring. At this large plant, operators record about 50 items on a morning report. Much of this information is then manually entered into a Sperry computer system through a terminal. An automated system could automatically transfer data to the Sperry computer.

Production Area Monitoring. Monitoring pH and nitrates in the production area would provide an early warning, up to 4 hr, for the plant operators. This would allow time to adjust the plant process in anticipation of abnormal pH or nitrate wastes approaching.

Lone Star Army Ammunition Plant

The Lone Star Ammunition Plant is just east of the Red River Depot. The ammunition plant and seven wastewater treatment plants are operated by Day-Zimmerman under contract to the Army. One wastewater plant treats chrome waste, one treats lead, and the remaining five treat explosive-contaminated pinkwater. Only two pinkwater plants are currently in use. Plants are operated manually by two operators who work 10 hr per day, 4 days per week.

Chromium Treatment Plant

The chromium plant uses a batch process. Each batch is about 2000 gal. A sump pump pumps wastewater to one of two, 2000-gal holding tanks. From the holding tank, wastewater passes through an electrolysis unit to reduce chromium and add ferrous ions as a flocculation aid. Wastewater flows to a holding tank where settling occurs. The holding tank effluent is prefiltered and then ultrafiltered. The filtered wastewater is pumped through a carbon column to remove organic contaminants. From the carbon column, wastewater flows into a holding tank. It is held until tested and then discharged to the sanitary sewer. Sludge from the holding tank and filter sludge is stored in drums prior to disposal.

Lead Treatment Plant

The lead plant is very similar to the chromium plant. Each batch is about 8000 gal. The lead plant differs from the chromium plant in that: (1) sulfuric acid is added to the holding tank to adjust pH,

(2) polymer is added to the effluent of the electrolysis unit as a further settling aid, and (3) sludge from the holding tank is dewatered in a plate-and-frame press prior to storage in 55-gal drums.

Pinkwater Treatment Plants

Three pinkwater treatment plants treat 20 gal per minute (gpm), one can treat 40 gpm, and one can treat 80 gpm. All use the same treatment methods. Currently, the two plants in service are operated every other day.

Explosive-contaminated wastewater is collected in settling pits. Wastewater is pumped into the plant and mixed with diatomaceous earth. The slurry is then filtered. Filtered wastewater passes through carbon columns to remove dissolved contaminants.

Grit that settled in the pits is periodically removed. Diatomaceous earth waste sludge and spent carbon is sent in 55-gal drums to earth-covered igloos for storage and subsequent offsite disposal.

Potential Automation Areas

All Lone Star plants use batch processes and no major potential automation areas are identified. Each is operated once or twice per week depending on production schedules. Two operators operate the plants.

The pinkwater plants are rated as Class I, Division I. All equipment must be explosion proof. A rather complex pneumatic control system was abandoned at the pinkwater site because corrosion and impurities in the air supply caused early failure.

Sump levels, storage tank levels, and effluent flow could be transmitted to a central location for monitoring and alarming. At pinkwater plants above 100 gpm, automation may reduce diatomaceous earth and spent carbon wastes sufficiently to make automation cost effective.

Red River Army Depot

The Red River Army Depot is about 15 mi west of Texarkana, TX. The water treatment plant and the domestic wastewater treatment plant serve both the Red River Army Depot and the adjacent Lone Star Army Ammunition Plant. Effluents from the seven industrial wastewater plants at Lone Star are conveyed through the sanitary sewers to the Red River domestic wastewater treatment plant. Effluent from the two industrial wastewater plants at Red River are discharged directly to the receiving stream.

A staff of 10 operators is responsible for all water and wastewater facilities at Red River. The domestic wastewater plant is attended on the day shift. The two industrial wastewater plants are operated on two shifts. The water plant is operated on two shifts. Roving operators check on the lift stations, swimming pools, and plants during off shifts. (Shifts last 10 hr.)

Water Treatment Plant

The water treatment plant process is typical of many Army plants. Low lift pumps pump raw water from a reservoir to the flocculation and settling basins. Chlorine is added at the low lift pumps to control algae. Alum and lime are added for pH control and settling. Settled water is filtered using gravity sand filters. Filtered water is chlorinated and flows to a clearwell before high lift pumping.

The plant is divided into two parallel trains that operate independently. On weekdays, flow averages about 1 MGD to Red River and about 0.6 MGD to Lone Star. Flows are very low on weekends.

Two Square D programmable logic controllers (PLCs) are used to automatically backwash filters. Each PLC controls three filters. A third PLC consolidates plant data for the operator display station. A personal computer with the Screenware software package displays plant status, logs alarms, and prints operating reports. In terms of automating the water plant, this plant is ahead of most Army installations.

Water Distribution System

The distribution system has two elevated tanks, one at Red River and one at Lone Star. Tank levels are transmitted to the water plant over dedicated telephone lines. Level signals are incompatible with the PLC system. Levels are displayed on circular charts in an area next to the control room.

Wastewater Collection System

The collection system has eight lift stations. One is a prepackaged unit. The others are a mix of wet pit and dry pit stations. Infiltration/inflow occurs. Plant flows increase significantly during rain events.

Domestic Wastewater Treatment Plant

The wastewater plant is typical of many Army trickling filter plants. Influent flows through a comminutor to a primary clarifier. Primary effluent is applied to a rock media trickling filter. Secondary clarifier effluent passes through a flume to a chlorine contact chamber for disinfection. Primary and secondary sludges are pumped to one of two digesters. Digested sludge flows by gravity to drying beds. All control is manual.

The plant NPDES permit limits the plant to the following capacities:

Average daily flow:	1.5 MGD
Maximum 24-hr average flow:	3.0 MGD
Daily average BOD and TSS:	20 mg/L
Daily maximum BOD and TSS:	45 mg/L
Minimum chlorine residual:	1.0 mg/L

Currently, flow averages about 0.8 MGD. Effluent BOD and TSS are between 5 and 10 mg/L.

Phosphate Rinsewater Treatment Plant

The phosphate plant is a continuous process plant operating at about 0.6 MGD, 20 hr per day. For the remaining 4 hr, rinsewater is stored in equalization lagoons. Two submersible sump pumps lift the rinsewater to two API oil separators that remove both oil and grit. Flow is manually routed to one of three equalization lagoons. The oil separators operate continuously.

Each morning, operators start pumping stored rinsewater from the lagoons to a rapid mix tank where lime is added to raise the pH to about 11. Two flocculator/clarifiers are used to remove phosphates. Carbon dioxide is added to the effluent to lower pH to between 6 and 9. The effluent is routed to a final holding lagoon where it is held until it is tested. Approximately 0.12 tons of lime and 500 lb of CO_2 are used each day.

Waste oil is conveyed to a holding tank that has not been emptied in several years. Grit is pumped to sludge dewatering bed one and two. Phosphate sludge is routed to dewatering beds three through six. After drying, it is hauled off site for land application.

Chromate Rinsewater Treatment Plant

The chromate plant is a batch process. Each batch is about 4800 gal and requires 20 to 30 minutes to treat. Each day, from 28 to 32 batches are processed.

Two submersible sump pumps lift rinsewater to three 20,000-gal storage tanks. From the storage tank, rinsewater flows to a sump and is pumped to two small holding tanks. Operation is fully automatic based on tank level switches.

The operator manually initiates the batch process by pumping from one of the holding tanks to the mix tank. While the mix tank is filling, sulphur dioxide is added to lower the pH to between 2.7 and 2.9. The operator manually samples and tests pH and adjusts the SO_2 as required. After about 10 minutes, lime is added to bring the pH up to 11. Again, the operator manually tests pH and adjusts the lime feed if necessary. Treated rinsewater flows to four settling tanks. Settling tank effluent flows to an effluent lagoon for temporary storage until the effluent is sampled and tested. It is then pumped to the final holding lagoon and mixed with the phosphate rinsewater plant effluent.

Chromate sludge is pumped to a 10,000-gal holding tank and then to sludge dewatering beds. Dried sludge is hauled off site as a hazardous waste.

Potential Automation Areas

Water Supply System. In addition to the existing low lift pump automation, filter backwash automation and automatic report generation, other plant operations could be improved by automation.

1. Alum and lime addition
2. Pre- and postchlorination
3. Distribution system monitoring
4. Plant demand and flow setpoint calculations
5. High lift pumping
6. Swimming pool monitoring.

The control system is under warranty by the vendor. The vendor performs all repairs as well as program modifications. Staff have not been trained in hardware or software maintenance.

Alum and Lime Addition. Alum is adjusted via metering pumps. The operator adjusts the pump speed based on jar test results. Lime is adjusted via a lime slurry system based on pH sensor readings. Pacing alum from a streaming current detector could save as much as 25 percent of the alum. Lime pacing for pH control could save up to 15 percent of the lime.

Pre- and postchlorination. Automatic control of prechlorination based on plant flow will reduce chlorine use. A future optimizing strategy could include a link to the streaming current detector and alum pacing signal as a means to account for variances in influent turbidity. Automatic control of post chlorination based on flow pacing with residual trim will reduce chlorine use. A future optimizing strategy could include filter effluent turbidity in the pacing calculation.

Distribution System Monitoring. The two elevated tank levels are recorded on circular charts near the control room. The signal system needs to be upgraded to be compatible with the control system.

Plant demand and flow setpoint calculations. Both the Red River and Lone Star facilities operate 10 hr per day, 4 days per week. Water demand on off-shifts and weekends is very low.

Prediction of water demand, current use, and current water in storage should be programmed into the control system. For those plants that can negotiate lower electric rates during off times, automation could result in lower power costs.

High Lift Pumping. An electric low lift pump pumps to each train. A third pump operates as a standby. In addition, the plant has a diesel pump for emergency operation during power failures. The operator can start and stop pumping from the computer.

Three of the six electric high lift pumps pump to Red River and the other three to Lone Star. A seventh high lift pump is diesel powered. High lift pump automation will require automation of the discharge valves with electric or pneumatic actuators.

Swimming Pool Monitoring. Operators check swimming pools four times per day. Each check requires about 30 minutes excluding travel time. Checks include measuring pH, temperature, and free chlorine, and checking for filter plugging. Remote monitoring of water quality, filter performance, and chlorine leak detection could reduce the number of visits to once or twice per day.

<u>Domestic Wastewater System</u>. Areas where automation could improve operations include:

1. Primary and secondary sludge pumping
2. Chlorine control
3. Plant and lift station monitoring.

Primary and Secondary Sludge Pumping. Sludge should be pumped frequently, but for short durations to maintain optimal blanket levels and to prevent sludge from becoming septic. Currently, sludge is pumped once or twice per day. Automation of the two sludge pumps and two sludge routing valves will produce more consistent sludge. This will improve digester performance.

Chlorine control. At the Red River plant, chlorine residuals must be kept above 1 mg/L by permit. To ensure permit is met on off-shifts, chlorine gas flow is set to maintain 2 mg/L. Pacing chlorine to plant flow would reduce chlorine costs. If the permit is changed to restrict chlorine residual, chlorine control can be supplemented with feedback from a chlorine residual analyzer.

Plant and Lift Station Monitoring. Operators check the eight lift stations twice per day. Each of the two checks requires at least 2 hr. Monitoring of pump status and high level alarms at each station could reduce the visits to once or twice per week. Plant operations status and lift station status should be monitored at the water treatment plant.

<u>Chromate Plant</u>. The chromate plant is partially automated. Automation consists of level switches and interlocks between sump pumps and the associated tanks. The chromate treating operation is manual. A level sensor should be added to the storage/equalization tanks to allow operators to view how much storage capacity remains.

Automation of the chromate treating operation will require a pH probe and automatic control of the SO_2 and lime addition. Because this is a batch operation, design of the pH probe mounting must include a washwater system to prevent fouling. The savings in operator time can be used for the future H_2SO_4 addition and routine maintenance. The control system should produce operating reports on the chromate in storage and free volume, holding tank volumes, batch operations data, sludge production, and chemical use.

Phosphate Plant. The plant influent sump pump, oil separator, equalization lagoons, and transfer pumps are located on a hill about 200 yd from the main plant. Remote monitoring and control of these facilities will provide for better startup. In addition, the control system can better track the status of the lagoons and perform recordkeeping. Other areas for automation include lime and CO_2 addition. Normally operators test pH once an hour and adjust lime feed. Sometimes, pH tests are run every 20 minutes. Lime use is approximately 0.12 tons per day. CO_2 use is about 500 lb per day.

Watervliet Arsenal

The Watervliet Arsenal is in Watervliet, NY, just North of Albany. Potable water is provided by the City at five different metering points. Water use is about 10 million gal per month. Domestic wastewater flows back to the city through either of two sewage meters.

The arsenal has one industrial wastewater treatment plant with three different liquid waste treatment processes, one for acid wastes, one for oily wastes and one for cyanide. Effluent is discharged to the Hudson River. In addition, five stormwater outfalls also discharge to the River.

Waste Collection System

Separate underground collection systems exist for acid wastes, soluble oils, and cyanide. Acid waste is generated in nine buildings. Soluble and combustible oil wastes are generated in 18 different buildings. Cyanide is generated in one building.

Combustible oil flows into 10 underground tanks. Each tank is equipped with leak detectors and level sensors. When a tank is full, a pumper truck collects the oil for commercial use.

Acid Waste Process

The process treats about 140,000 gal per day. Acid waste flows into a receiving well, from where it is automatically pumped into one of two holding tanks. The process is usually continuous, but it can be run as a batch process.

Sulfur dioxide, or sulfuric acid if necessary, is injected into the wastewater as it is being pumped into a reaction tank. This lowers the pH to about 3 to convert hexa-valent chromium to tri-valent chromium. The reaction tank has two compartments. Sodium hydroxide is added in the second compartment to raise pH to about 8. The wastewater flows into a blending tank where lime is added to raise pH to 8 to 9. Alum is added to aid flocculation. The blended wastewater is pumped to two clarifiers. Polymer is added upstream of the clarifier. Clarified effluent passes through a final pH adjustment tank. Sludge is manually pumped to the sludge drying beds. Private contractors haul the dried sludge to an industrial waste landfill.

Oily Waste Process

The oily waste treatment is a batch process. The plant processes two 6500-gal batches per day, each taking about 2 hr.

Soluble oil flows into a receiving well. A pump automatically pumps the waste into one of two 6700-gal treatment tanks. The pH is normally around 3.5. When full, sodium hydroxide is added to raise the pH to about 8.5, and alum and polymer are added to aid in settling. The batch is allowed to settle for 45 to 60 minutes.

Sludge is removed based on operator observations and pumped to drying beds. Skim oil is discharged to a holding tank and is removed by the combustible oil pump truck. The treated wastewater flows to the acid waste process receiving well.

Cyanide Waste Process

The cyanide process is a batch process that treats about 5000 gal per month. Batches are run twice per month and take about 6 hr. An influent sump pump routes flow to one of two tanks. When the tank is full, a batch is processed and the second tank is allowed to fill.

Sodium hydroxide is added to the tank to raise the pH to 11. After 3 or 4 hr, chlorine is added to lower the pH to 8.5. When the oxidation reduction potential (ORP) is between 400 and 500, a sample is taken and sent to a lab for analysis. If the cyanide is less than 0.01 mg/L, the batch is pumped to the acid waste plant receiving well. If not, the batch operation is repeated.

A control panel is located next to the process and allows full control. The automatic pH controls for NaOH and Cl_2 addition were out of service, as was the pH probe.

Potential Automation Areas

<u>Industrial Wastewater Systems</u>. The industrial plant has two main control panels for the acid plants. In addition, smaller control panels exist for oily waste influent pumps, oily waste sludge pumps, and the cyanide process. Automation of the plant would permit consolidating these panels into one main monitoring area.

The panels contained controllers for pH and ORP, which were not working during the site visit. Several other pH controllers were in automatic operation. In addition to replacing the existing panels, additional areas for automation include:

1. pH control prior to acid tank and alum dosage control
2. Acid sludge pumping
3. Oily waste sludge pumping
4. Production area monitoring.

Acid Sludge Pumping. The sludge blanket interface in the acid waste clarifier is very pronounced. An optical sludge blanked probe to control sludge pumping would be ideal in this application. A productive area for a research project would be designing a streaming current detector to automate polymer addition.

Oily Waste Sludge Pumping. The sludge blanket/supernatant interface in the oily waste tank is very difficult to observe. The interviewed operator reported that he often cannot tell how much to pump. The installation of a density meter or density switch would help determine when the optimal amount of sludge had been removed.

Production Area Monitoring. Monitoring pH in the production area would provide an early warning for the plant operators. This would permit them to adjust the plant process in anticipation of abnormal pH wastes approaching.

West Point Military Academy

Collection System

The wastewater collection system at West Point consists of six lift stations, and clay, cast iron, and concrete pipe lines varying in size from 4 to 24 in. The wastewater enters the plant at two points, bringing the raw sewage from North and South ends of the facility.

The South Site Pump Station pumps wastewater from the South end of West Point. The pump station has two 1875 gal per minute, 50-hp, variable speed pumps. The Stony Lonesome Pump Station pumps wastewater from 20 sets of quarters in Stony Lonesome Housing area. The pump station has two 100 gal per minute, 5-hp pumps. The three stations in buildings 609, 627, and 767 are underground pits equipped with identical equipment. Each station has two submersible pumps. The Howze Field Pump Station pumps wastewater from Michie Stadium. It has two 300 gal per minute, 5-hp pumps.

South site and buildings 609, 627, and 767 pump stations have alarm systems that transmit to the wastewater treatment plant whenever there is a malfunction in the system. Stony Lonesome and Howze Field Pump Stations have alarm systems on site that indicate when there is a malfunction in the system.

Wastewater Treatment Plant

The construction for the Secondary Wastewater Treatment Plant began in August 1971 and the plant went into operation in October of 1973. The plant is rated at two MGD. An auxiliary generator can operate the plant in a power outage.

Headworks. There is one bar screen at each point where the wastewater enters the plant. The screens are cleaned manually and the collected debris is disposed in a landfill. Following the bar screens are four grit chambers, which remove sand and gravel. The grit is removed by mechanically operated revolving chains and is disposed in a landfill. Two comminutors follow each grit chamber. The comminutor is a rotating drum type device with teeth that shred up or break solids to such size that they can remain in the wastewater without damaging pumps, clogging pipes, or affecting any other operations or treatment devices.

Pump Station. Flow from the chambers combines in the wet well and is pumped to primary settling tanks. The pumps are operated alternately. An auxiliary gasoline engine drive is provided to operate one of the pumps in a power outage.

Primary Treatment. Three rectangular tanks remove settleable solids by sedimentation. Most of the settleable solids and about 35 to 45 percent of the suspended solids are separated or removed. At the rate of 2 MGD, the total retention period in the tanks is 1.5 hr. The settled solids are moved by mechanically operated scrapers to the sludge hopper located at the inlet end of the tanks. The solids are pumped to the primary digesters twice per day. The floating solids, grease, and oil are pushed by the scrapers to a scum collector at the outlet end of the tank. The scum is also pumped to the primary digesters for further treatment.

Activated Sludge Treatment—Aeration. From primary settling tanks, the primary effluent flows into two aeration tanks for secondary treatment. The detention time in the aeration tanks is 7 hr. The facility is designed for step-aeration, a modified version of a conventional activated sludge process. Mean cell residence time is used to monitor the activated sludge process. Other control or lab tests performed to control the performance of aeration process are:

1. Dissolved oxygen
2. Mixed liquor suspended solids
3. Microscopic analysis of micro-organisms
4. 30-minute settleability test.

Activated Sludge Treatment—Final Settling. From the aeration tanks, the mixed liquor flows into the three rectangular final settling tanks. The liquid flows over weirs to the chlorine chamber for disinfection. The settled solids are moveu continuously by mechanically operated scrapers to the sludge hopper located at the inlet end of the tanks. From the hopper, solids are either pumped back into aeration tanks as return sludge or pumped to the thickener as waste sludge. At rated capacity, the total detention time is 2.5 hr.

Chlorination. The final settling tank effluent flows into the chlorine contact chamber where it is disinfected by chlorine gas. A minimum of 30 minutes contact time passes before the effluent is discharged into Hudson River.

Thickening. Waste sludge is concentrated in the dissolved air flotation thickener. Air bubbles adhere to or are trapped within solid particles, increasing the buoyancy of the particles and producing positive flotation. Polymer, a flocculating chemical, is added ahead of the inlet chamber to increase the efficiency of the solids removal and to increase the concentration of the float. The sludge is pumped to primary digesters. Subnatant flows by gravity to the aeration tanks.

Digestion. Anaerobic digestion of sludge occurs in four digesters (two primary, two secondary). The sludge is fed to the primary digesters. The temperature of the sludge is maintained at 85 to 95 °F and the sludge is mixed continuously. The sludge in primary digesters becomes more soluble, and acid and methane form. The normal residence time is three weeks. Digested sludge is then transferred to the secondary digesters. The supernatant flows back to the wet well by gravity.

Quality control lab tests are performed to evaluate or control the performance of the digesters. The tests performed are: pH, volatile acids, and alkalinity.

Dewatering. A belt press dewaters the digested sludge from the secondary digesters. The filtered liquid flows back to the wet well. The dewatered sludge is sent to a landfill.

Reports and Lab Control

The raw wastewater and final effluent are monitored for the parameters specified in the permit, and a report is submitted quarterly to the New York State Department of Environmental Conservation.

Potential Automation Areas

Wastewater Treatment Plant. At West Point's Target Field Wastewater Treatment Plant, seven areas where plant operations may be improved by automation were identified:

1. Plant influent pumping
2. Primary sludge pumping

3. Aeration tank dissolved oxygen
4. Return activated sludge
5. Waste sludge pumping
6. Chlorination control
7. Report generation.

Plant Influent Pumping. The raw wastewater is pumped by four pumps from a wet well to the primary clarifiers. Pumps cycle on/off based on wet well level floats. During low flow periods, the duty pump cycles on/off three to four times per hour causing flow shocks in the primary clarifiers.

The plant intends to install variable speed drives on the pump motors to eliminate the flow shocks and to allow a more consistent plant flow. Automatic controls would vary pump speed and start and stop pumps to minimize flow changes. The wet well level would vary between upper and lower limits.

Primary Sludge. The operator uses a piston pump to pump primary sludge on a daily basis to a selected primary digester. The operator has to open or close up to eight valves to route sludge to the proper digester. The operator must open and close an additional five valves located 150 ft away on the primary clarifier deck to withdraw sludge from each of the three primary clarifiers. The operator manually operates the valves and starts the pump. Sludge quality is monitored in the digester building.

Sludge withdrawal control should remove small quantities of sludge at frequent intervals. In addition, the amount of sludge removed should be based upon maintaining a sludge depth of approximately 1 to 2 ft in each clarifier. To automate this process, the following equipment modifications are required:

1. Add electric valve operators to digester and primary clarifier sludge valves
2. Add control relays to the sludge pump starters.

Automatic controls would operate valves and start/stop the sludge pump. The operator would set the sludge pumping interval in either time or accumulated plant flow and set the withdrawal time for each clarifier. This allows customizing sludge pumping to seasonal or daily sludge withdrawal schemes.

As a future optimization, high and low sludge blanket level sensors could be installed to prevent over- or underpumping sludge.

Aeration Tank Dissolved Oxygen. Three manually operated blowers provide oxygen to the aeration tanks. Normally, two blowers run continuously and dissolved oxygen varies. Design minimums for dissolved oxygen (DO) in an aeration tank are typically 0.5 mg/L with 1-2 mg/L the normal operating range. The aeration tank dissolved oxygen varies from 1-10 mg/L (Figures 1 and 2).

Continuous reading DO probes are mounted in the effluent of each process train. An operator records the aeration tank DO profile one to three times per week with a hand-held DO probe.

The north aeration tank dissolved oxygen chart (Figure 2) illustrates a waste of energy by overaerating the tank. Power would be saved by pace controlling blower operation to the oxygen demand of the aeration tanks. To automate this process, the following equipment modifications are required: (1) add variable speed drives to the blowers, and (2) add control relays to blower starters.

Return Activated Sludge. Return activated sludge is pumped continuously by three (two duty, one standby) centrifugal pumps from the secondary clarifier wet well to the aeration tanks. As originally designed, each pump was capable of operating at variable capacity. However, the variable speed drive

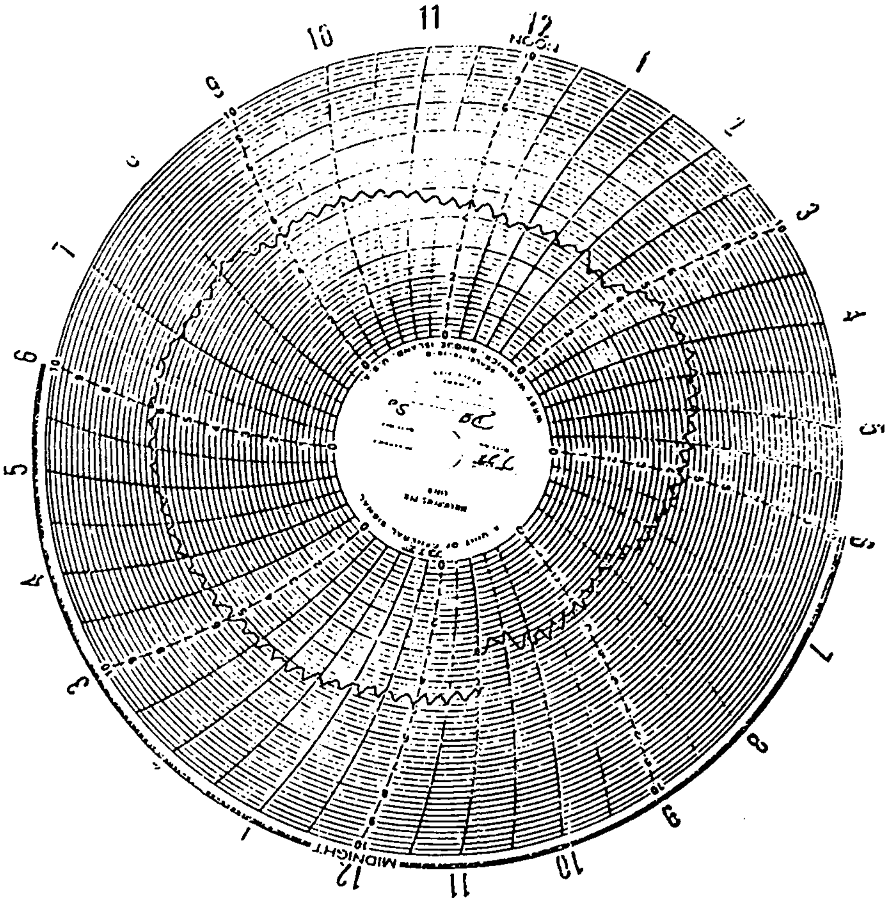


Figure 1. Dissolved Oxygen Variation (7-22-90).

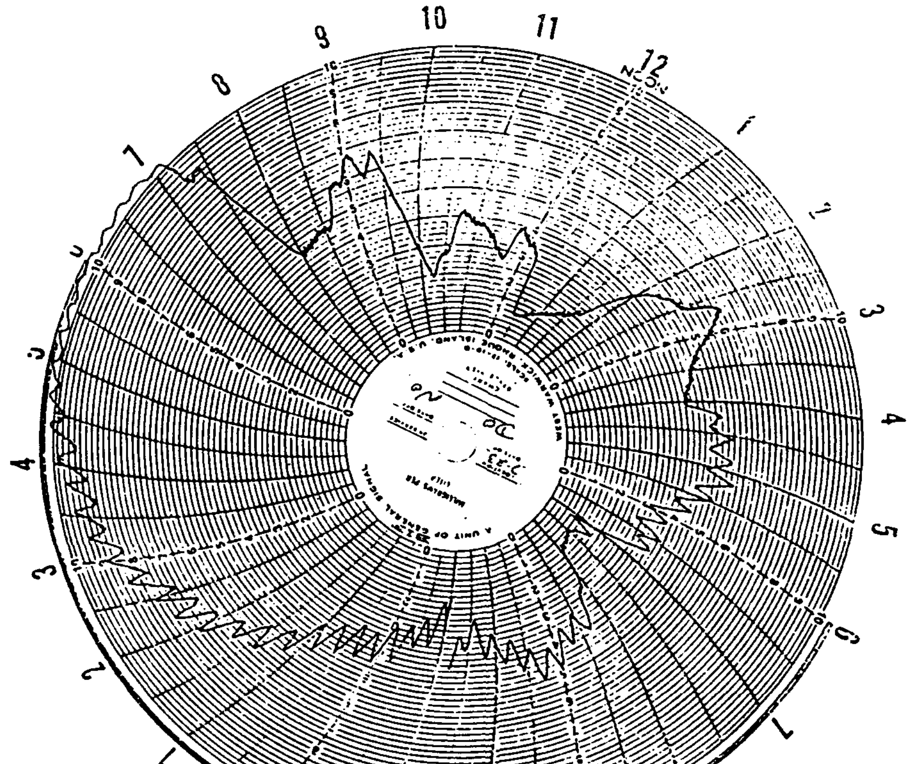


Figure 2. Dissolved Oxygen Variation (7-23-90).

units were removed from each unit (Law Environmental 1989). The RAS flow to the aeration tanks is controlled by manual valve adjustments.

RAS flow from the secondary clarifiers to the RAS wet well is controlled by adjusting telescoping valves located on the reactor decks. RAS flow out of the wet well is based upon mean cell resident time (MCRT) calculations. The telescoping valves are adjusted to equalize sludge blanket level if needed.

Balancing mixed liquor suspended solids is very difficult since the RAS is returned in a common header. Automating the RAS pumps and making some minor piping changes would greatly improve operations. Variable speed drives should be reinstalled on the RAS pumps along with two additional isolation valves. The speed control and isolation valves would allow each aeration tank to be fed from a dedicated RAS pump. The flow rate to each aeration tank could be customized to match the tanks' mixed liquor suspended solids and hydraulic flow.

For future optimization, sludge blanket level should be monitored and controlled in the secondary clarifiers. The sludge blanket high/low levels need to be monitored to accomplish this control. Position controlled actuators on telescoping valves would equalize the blanket levels.

Waste Activated Sludge. Waste activated sludge (WAS) is pumped daily to the dissolved air flotation (DAF) unit for thickening. The operator, using a worksheet, hand calculates the amount of WAS to pump based on mean cell residence time and waste sludge density. The operator manually performs the following sequence to pump WAS to the DAF unit:

1. Open valve in DAF Building, mix polymer
2. Walk 100 ft to Blower Building to start WAS pump
3. Return to DAF Building to start DAF unit
4. Return to the Blower Building to adjust WAS pump speed.

Automating this process and placing an operator interface unit in the DAF Building would allow the operator to monitor the DAF unit more closely. If the DAF unit overflows, it takes 2 hr to clean up the spill. Through an operator interface unit, the operator would control WAS pump speed. The lab data could be entered and the WAS amount calculated automatically for the operator.

For future optimization, a RAS/WAS density sensor could be used to calculate pounds of waste sludge processed, and to turn off the waste pump when total daily limit is reached.

Chlorination Control. Chlorine gas is added for final disinfection. Periodically operator manually adjusts chlorine addition rate. Chemical use would be reduced by an automatic adjustment to the chlorine feed rate. Several control schemes could be used to accomplish this:

1. Chlorine flow could be paced to plant influent flow
2. Chlorine flow could be paced to plant influent flow with dead time compensation
3. Flow could be paced with chlorine residual feedback trim.

All three plants indicated that state agencies were closely monitoring chlorine residuals and may require dechlorination at some future time. Tight chlorine control could allow plants to defer a major capital expenditure for dechlorination facilities. A future optimizing strategy could include pacing chlorine to plant solids loading with residual trim.

Report Generation. The WWTP has 25 forms including worksheets, logs, and reports. Over 8000 entries are made on these forms each month. In addition, numerous hand calculations are performed to complete reports and worksheets. The use of a personal computer would reduce workforce requirements for data management and would allow plant operators to devote more time to process control and maintenance activities. A personal computer using statistical process control software could assist the operator in monitoring plant processes that are slow to change but could potentially cause permit violations and require long periods of time to correct. Graphic displays with alarm limits would warn the operator that a process is moving out of normal operating limits. This monitoring would allow the operator to make adjustments to the plant process to optimize plant operation.

Water Treatment Plant Filter Backwashing. Operators spend about 30 minutes backwashing a filter. Operators generally stay at the filter during this operation. If they leave, they sometimes forget that a filter is out of service. On off-shifts, the single operator does not monitor other plant systems or the distribution system. Alarms can go unanswered for up to an hour.

Automation of filter backwashing would ensure that filters were backwashed consistently and that sequences were correct, and would free operators to monitor other processes and systems and to do routine cleaning of the filter area.

Filter Effluent Flow Control. Flow rate-controllers are used to set flow through each filter. Flow rates are determined by predicting water use requirements. In most plants, flow rates are set individually, making it difficult to balance or change flow if all rate controllers are not functioning properly. This is a chronic problem at the Stony Lonesome plant at West Point.

Distribution System. Elevated tank levels are monitored at the water plant. Usually, remote transfer pumps and altitude valves are not monitored. Operators watch tank level changes to detect equipment problems. However, fires and main breaks can cause unusual changes in tank levels. In such cases, operators are not sure what is happening and must dispatch someone to the site. Pump and valve status should be monitored.

Summary of Potential Automation Areas

Table 1 summarizes plants and functions with a potential for cost-effective automation, for each visited installation.

Table 1

Summary of Potential Automation Areas

Installation	Plant	Function
Anniston Army Depot	Domestic wastewater system	Equalization basis air flow control Flow equalization to plant Alum and polymer addition Filter backwashing and control Chlorine control Monitor and record run times and alarms Monitor lift stations, well pumps, and strippers
	Industrial waste treatment plant	Scheduling and sequencing batch operations Chemical addition
Fort Bragg	Wastewater treatment plant	Surface aerator control Sludge pumping Chlorination control Report generation Lift station monitoring
	Water treatment plant	Chemical feed control Filter backwashing Filter effluent control
	Water distribution system	Expert system for water demand
	Swimming pool	Chemical monitoring Temperature monitoring
Fort Gordon	Wastewater treatment plant (trickling filter)	Primary sludge pumping Secondary sludge pumping Chlorine control Report generation Lift station monitoring.
Fort Huachuca	Production system control (wells)	Distribution system control Demand calculations
	Domestic wastewater system	Add timer to primary sludge pump
Fort Lewis	Irrigation water supply	Monitor pond level Control chlorine Control effluent pump
Fort Meade	Wastewater treatment plant	pH control chlorine control
Holston Army Ammunition Plant	Process water plants	Remote pump house operation Plant flow control Alum addition Prechlorination Sedimentation basin sludge withdrawal Filter backwashing High lift pumping
	Domestic wastewater treatment plant	Remote monitoring of plant status Monitor primary sludge pumping

Table 1 (Cont'd)

Installation	Plant	Function
Holston Army Ammunition Plant (cont'd)	Industrial wastewater systems	Influent neutralization Return sludge screw pumps and sludge withdrawal Aeration tank dissolved oxygen Chemical inventories and usage Plant operational status monitoring Production area monitoring.
Lone Star Army Ammunition Plant	Pinkwater plants	Monitor sump levels Monitor storage tank levels Monitor effluent flow
Red River Army Depot	Water supply system	Alum and lime addition Pre- and postchlorination Monitor distribution system Plant demand and flow setpoint calculations High lift pumping Monitor swimming pool
	Domestic wastewater system	Primary and secondary sludge pumping Chlorine control Plant and lift station
	Chromate plant	Add level sensor for storage/equalization tanks
	Phosphate plant	Remote monitoring/control of lagoons Recordkeeping Lime and CO_2 addition
Watervliet Arsenal	Industrial wastewater systems	Consolidate control panels Control acid sludge pumping Control oily waste sludge pumping Monitor production area monitoring
West Point Military Academy	Wastewater treatment plant	Plant influent pumping Primary sludge pumping Aeration tank dissolved oxygen Return activated sludge pumping Waste activated sludge pumping Chlorination control Report generation.
	Water treatment plant	Filter backwashing Control filter effluent flow
	Distribution system	Remotely monitor elevated tank pump and valve status

3 ASSESSMENT OF WATER AND WASTEWATER SYSTEMS

General Characteristics

Water and Wastewater Treatment Plants

The Army uses several different processes for its domestic wastewater treatment plants. Most facilities generally use trickling filters while some plants use an activated sludge process. Industrial wastewater plants use predominantly chemical treatment processes. In contrast, all of the water plants visited use the same processes–flocculation and sedimentation followed by filtration and chlorination.

Most of the facilities are more than 20 years old. Only one facility, the Fort Gordon Water Treatment Plant, was less than 10 years old. Older facilities will cost more to automate since most manual control valves will need to be replaced with electrically or pneumatically operated valves. For pumps and motors, electrical work must meet current codes, and old equipment must be updated. This will also affect costs.

Life cycle costs often make automation less attractive in smaller plants. The installed cost of analytical instruments such as pH, dissolved oxygen, and suspended solids remains constant regardless of the application. Thus, while automation will reduce chemical costs by the same percentage in a large and a small plant, the total cost saving at the small plant is much less.

Existing Level of Automation

Many of the facilities contained some automation. The Fort Gordon Water Treatment Plant was about 75 percent automated using single-loop controller technology. The Red River Army Depot Water Treatment Plant automated filter backwashing using PLCs. However, high lift pumping was manual because there were insufficient funds to replace the old, manually operated pump isolation valves.

Many industrial plants have automated individual chemical feed loops. In some plants, the automatic loops were no longer used due to the extensive maintenance required to keep control valves and pH probes operating.

Staff Utilization

None of the plants had completely centralized monitoring of either the plant or the associated collection or distribution system. Several plants had control panels that showed portions of the plant operation. Most of the water plants displayed elevated tank levels at the plant, but little other information on the status of the system. Wastewater lift station monitoring was practically nonexistent. As a result, operators must make rounds once or twice per shift to take readings, record information, and make process adjustments. This is a very time-consuming check of the collection and distribution systems.

Many of the smaller plants were staffed on off-shifts. At several sites, plants were unmanned during off-shifts. Several of the trickling filter plants were totally unmanned. Operators from other facilities made rounds.

Automation Areas

Automation Philosophy

Operation and maintenance capabilities play a major role in realistically identifying automation needs. The plants are small and, in general, cannot afford sophisticated maintenance staff, equipment, and repair facilities. Operations and maintenance staff has been reduced to the lowest levels ever at most plants, even where additional plant processes are being added and operator responsibilities are increasing.

The first step in identifying automation areas was to look at processes that use the greatest percentage of energy or chemicals. Next, labor-intensive processes were examined. Areas were explored where the quality of the effluent could be improved, and finally, future optimization areas were identified.

All of the sites visited had the following common automation needs:

1. A combination of in-plant control, and control and monitoring of remote sites
2. A combination of analog control and discrete control
3. A need for automation to include failure operations and operator guidance.

In-Plant and Remote Site Control

Operators at most facilities spent from 2 hr per day to 4 hr per shift making rounds to remote sites. These sites included water wells, ground water treatment wells, water reservoirs and altitude valves, swimming pools, wastewater lift and pump stations, and outfalls.

At industrial plants, operators expressed the need to monitor conditions at the industrial processes to detect changes in wastewater characteristics. Remote monitoring of pH was the most common need.

Analog (Continuous) Control

Analog control is characterized by variables that can be continuously observed and represented. For most water and wastewater plants, variables are represented by 4 to 20 mA or 3 to 15 psig signals.

In an open control loop, continuous measurement of the variable to be controlled is not connected to automatic controls. There is no assurance that the control objective is actually being achieved. Satisfactory control occurs only if the final control element is properly set and no disturbances occur. If the original conditions are disturbed, operator intervention will be required to maintain balance within the process.

In a closed control loop, continuous measurement of the process variable is routed to a controller. The controller compares this measurement (the feedback signal) with the desired value (the setpoint). If there is any difference between desired and actual, the controller outputs a corrective action to the final control element. This is often called feedback control.

A feedforward control loop predicts how much corrective action will be required because of a disturbance. Feedforward control measures one or more inputs to the process. Any change in input causes a corresponding change in the output to the final control element.

Closed loop control of chemical addition and dissolved oxygen can save a minimum of 10 percent in energy and chemical costs compared to open loop control. For smaller plants with relatively constant effluent quality, feedforward control often provides a similar savings over open loop control without the need for additional sensors. For example, feedforward controls can pace chlorine addition to plant flow without relying on a chlorine residual analyzer instrument.

Discrete (Sequential) Control

Discrete control is characterized by on/off or open/closed type control actions. These actions are in response to a predefined program of events, elapsed time, or an analog value reaching some preset limit.

Discrete control includes simple on/off control of a single device such as a sump pump, sequential startup/shutdown of a complex device such as a filter press, and a sequence of operations such as a filter backwash operation.

Many water and wastewater processes combine discrete and analog control. These controls enable security, safety, and optimum performance. Startup and shutdown logic, failure detection, and process characteristic tracking can help minimize dependence on operator-directed corrective actions.

Failure Operations and Operator Guidance

Most of the site visits were less than a half day for each plant. In this short time interval, several operational problems were observed that could have been prevented with automation.

At one site, the water treatment plant clear well overflowed. It was early afternoon and the elevated tanks were full. In this particular plant, the system should have been near empty rather than completely full at that time of day. Energy and chemicals were being wasted.

An automation system would generate a high level alarm when the clear well was nearly full. At the same time, it could be programmed to recommend the appropriate course of action to the operator, i.e., to stop low lift pumping. Additionally, it could be programmed to predict water demand for the day and more closely match production to use. This would have prevented the problem.

At another site, an operator had to predict the next day's demand and adjust the plant accordingly. The operator had to walk a quarter mile to adjust low lift pumps, then walk back to the office area to adjust all the chemical feed pumps, then adjust the high lift pumps. Two hours later after making these adjustments, the operator discovered that someone had left a filter drain valve open. An automation system would not have placed the filter back in service if the drain valve failed to close. All of the plant adjustments could have been done automatically.

Impact of Automation on Organizations

Managing Change

When new ideas, such as automation, are introduced into an organization, people resist. Often the resistance is not so much to the automation itself, but to the way it affects their lives. Change management is a process of following a comprehensive plan to introduce a change. Introducing change consists of technical and social activities. The technical activities may be installing a sensor or an automation system. The social activities include getting people to adopt the change, training them how to use it, and making sure they use it over time. One study reported that 95 percent of the problems in introducing change is due to poor management of the social activities (Carr and Littman 1991).

People cannot simply be ordered to adopt automation. Although orders hold persuasive force, they are best combined with the planned use of other forces for change. Sound approaches to introducing a complex change, such as automating an entire facility, have the following criteria:

- The sponsors (i.e., sanitation branch chief, utilities division chief, plant supervision, or operator) of the change know and plan the direction the organization needs to take.
- The change supports going in that direction.
- The sponsors understand the nature of the automation change and the effect on its users.
- The sponsors know the level of all involved parties commitment to the change.
- The sponsors prepare a written plan for managing change.
- The sponsors allow staff to experiment with the change in a nonthreatening environment.
- Staff participates in the change rather than having it imposed upon them from outside.

Staff Capabilities

Operations staff at all plants were quite knowledgeable about the operation of the plants and collection/distribution systems. But many of the staff at both the water and wastewater plants had less than 5 years' experience. Training budgets are limited, so it is more difficult to place new equipment in operation.

It takes time for operators and managers to adapt to the change from manual to automatic control. Therefore, it is better to start with simple control systems. As the plant staff becomes more familiar with automation and instrument maintenance, additional sensors can be added to optimize plant operations. In addition, the staff can test sensors to meet their particular needs.

Maintenance Practices

Although the scope of this study did not include the operations and maintenance organizations as such, current maintenance practices significantly affect the type of technology recommended. In most plants, mechanical and electrical maintenance was fair to good. Instrumentation and controls maintenance was generally poor. When an instrument or control device broke, control often reverted to manual.

Difficulties in obtaining the right part in a timely manner was a common complaint. Often the Supply Division is understaffed and delays occur in obtaining parts. Competitive bidding occasionally results in parts that are not exact replacements. The Operation and Maintenance Division then has to modify them to fit or trade with other groups. Even though there is only one supplier, often the bidding process must be followed.

The Supply Division is not part of the Operations and Maintenance Division. At some facilities, centralized maintenance staff gave lower priority to the water and wastewater plants.

For automation to be successful, repairs must be made quickly. Reduced staffs will not have time to control devices manually while waiting for repairs; they will instead revert to control practices that waste energy and chemicals or require overtime. On the other hand, automation must fit in to existing practices. This balance assures success.

4 APPLICABLE AUTOMATION TECHNOLOGY

Overview of Digital Control Systems

There are many different digital control systems, including those based on: (1) distributed controllers, (2) programmable controllers, (3) remote terminal units, (4) personal computers, and (5) single loop controllers.

Distributed controller-based systems are most applicable in larger plants with more than 1000 input/output points and more than 40 percent continuous control loops. They operate in a networked environment over high speed data highways. Operator interface units are connected directly to the data highway. They do not lend themselves to pump station monitoring. Manufacturers include Bailey Controls, Bristol Babcock, Fisher Controls, Fischer and Porter, Honeywell, Johnson Yokogawa, and Westinghouse. These would not be applicable to the Army plants.

Programmable controller-based systems are very flexible. They can range in size from fewer than 10 input/output points to several thousand points. They range in application from standalone relay replacers to networked control systems. Operator interface units can vary from alphanumeric message displays to complex minicomputer-based systems. They are used both in in-plant control applications and for telemetry systems. Manufacturers include Allen Bradley, General Electric, Siemans, Square D, Texas Instruments, and Westinghouse.

Remote terminal unit-based systems can range from very large to very small. Systems such as those manufactured by Rexnord/TI, Sentrol, Trans-Dyn, and Turbitrol use minicomputers and programmable remote terminal units designed for large supervisory control and data acquisition (SCADA) systems and large telemetry systems. These systems would not be applicable to the Army plants. Vendors such as Autocon offer small, specialized systems that are very cost-effective in certain applications. These systems use personal computers for the operator interface and many have preprogrammed remote terminal units. They work best in small telemetry system applications, but are weak for in-plant controls.

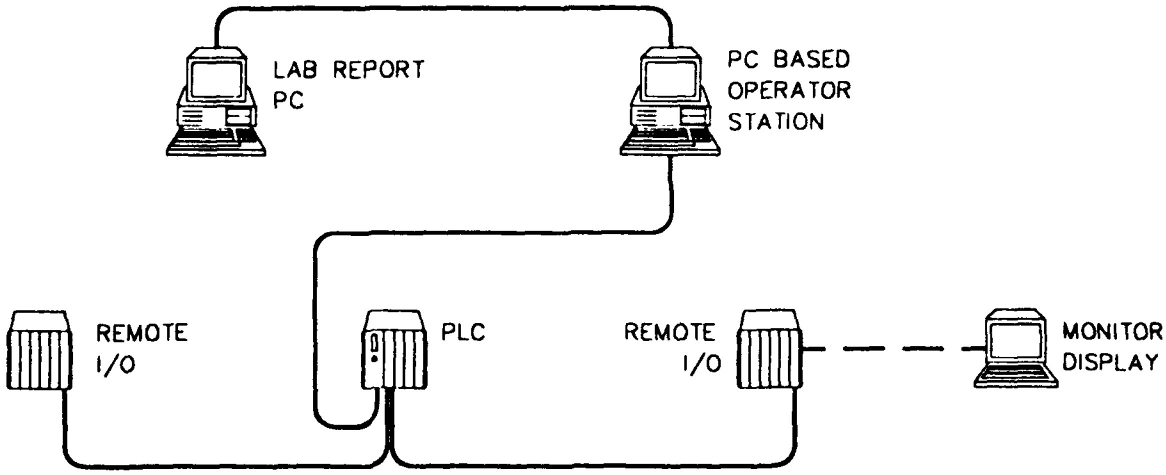
Personal computer-based systems use special cards mounted in the personal computer or connected to it through one of the personal computer's ports. The personal computer performs the monitoring and control. These systems are used mainly in laboratories to interface with analytical equipment. This market is expanding quickly and offers cost effective solutions for small, noncritical control applications such as those at a trickling filter plant. They are not well suited to telemetry applications or complex process control applications.

Single loop controller networks are excellent in small plant applications with fewer than 1000 input/output points. The controller performs all monitoring and control. Both sequence controllers and cascade controllers are available. A self-tuning capability is a standard feature in many of the controllers. A personal computer can be added for operator interface and can use the same type of software as PLC operator stations.

Comparison of Digital Control Systems

Programmable Controller with Remote I/O

Figure 3 shows the configuration for a centrally located PLC with remote input/output (I/O). Remote I/O racks are located near the process equipment. Control commands and data are transmitted



Digester Building

PRIMARY SLUDGE PUMPS	4 DI 4 CO
DIGESTER VALVES	15 DI 10 CO
COVER LEVEL	4 AI
DIGESTER TEMPERATURE	4 AI
FILTER PRESSURE	3 DI
TOTAL I/O COUNT	22 DI 14 CO 8 AI

Blower Building

BLOWERS	3 DI 6 CO 3 AI 3 AO
D.O. PROBES	2 AI
RAS PUMPS	3 DI 6 CO 3 AI 3 AO
RAS VALVE	9 DI 6 CO 3 AI
WET WELL	1 AI
SLUDGE BLANKET	2 DI
WAS PUMP	2 DI 2 CO 2 AI 2 AO
PLANT EFFLUENT	5 AI
TOTAL I/O COUNT	19 DI 20 CO 19 AI 8 AO

DAF Building

CHLORINE	2 DI 4 CO 2 AO
WATT METER	1 AI
DAF	8 DI 4 AI
TOTAL I/O COUNT	10 DI 4 CO 5 AI 2 AO

Note:
DI: Digital Input
CO: Control or Digital Output
AI: Analog Input
AO: Analog Output

Figure 3. Programmable Logic Controller With Remote I/O.

on a serial communications link between the PLC and the remote I/O racks. All control logic resides in the PLC.

Advantages	Disadvantages
Parts are stocked locally by independent distributors	
PLCs are very reliable even in adverse environments	Not specifically designed for supervisory control
Easy to program by electricians versed in ladder logic	All plant monitoring and control in one device
Will support a variety of operator interface units	
Excellent for sequence control	

Distributed PLCs

Figure 4 shows a configuration for distributed PLCs. This alternative places PLCs near the process equipment. The PLCs are networked to share information between process areas and with the operator interface unit. Control logic for a process area resides in the local PLC.

Advantages	Disadvantages
PLC failure affects only the area where the failure occurs	Smaller distributed PLCs do not have processing power of larger, central PLCs
Parts are stocked locally by independent distributors	More difficult to interface operator interface unit
PLCs are very reliable even in adverse environments	Not all vendors can network smaller PLCs
Easy to program by electricians versed in ladder logic	Harder to keep track of programming since each PLC is programmed independently
Excellent for sequence control	
Not specifically designed for supervisory control	

Personal Computer With Distributed I/O

Figure 5 shows a personal computer with distributed I/O. This alternative uses optically isolated I/O blocks connected to a personal computer. Communications between the I/O and the personnel computer occurs through the parallel port. All control logic resides in the personal computer, although some I/O modules can contain limited control logic.

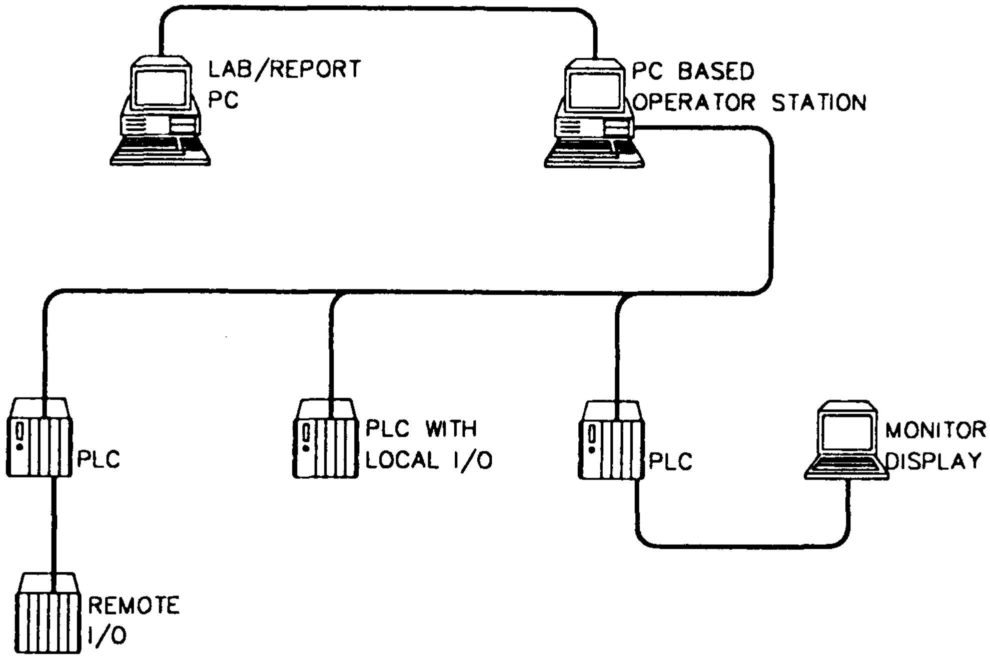


Figure 4. Distributed Programmable Logic Controllers.

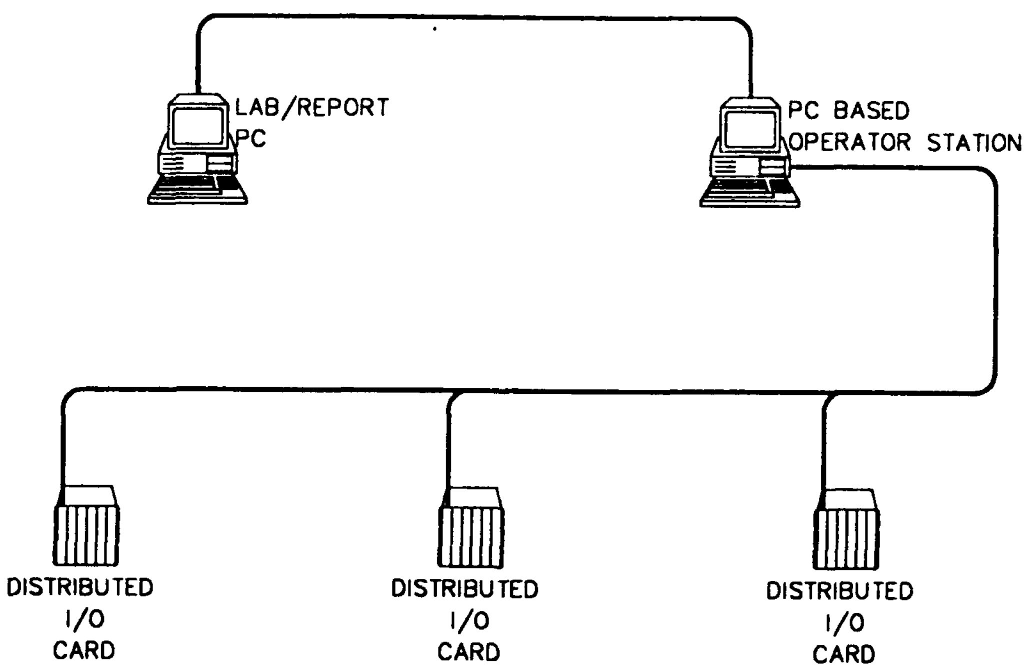


Figure 5. Personal Computer With Distributed I/O.

Advantages	Disadvantages
Individual I/O blocks permit matching application exactly	Requires customized programs
Very flexible	Reliability of personal computer questionable
Easy to maintain I/O	Not industrially hardened. Disk is weak point
Excellent for labs and research applications	Too easy to stop control with personal computer, i.e., ctrl/alt/del

Single Loop Controller

Figure 6 shows a single loop controller configuration wired in a network. Each controller monitors and controls a process loop. Control logic resides in each controller. A personal computer attached to the network provides the operator interface.

Advantages	Disadvantages
Best for continuous control loops	Cannot be used for remote site telemetry
Can do limited sequence control	Difficult to configure without special configuration panel
Can configure with self-tuning PID control algorithm	
High process control reliability since only one loop fails	
Parts stocked locally by independent distributors	
Programming by supervisors or engineers using fill-in forms or programmer panel	

Remote Terminal Units

Figure 7 shows a remote terminal unit configuration. This alternative uses intelligent or dumb devices. The intelligent unit will function without communications from a central area. The dumb units act like remote I/O. If the central processing unit fails, controls hold the last state.

Advantages	Disadvantages
Designed for wastewater applications	Programming is more difficult
Boards inexpensive	Boards less rugged

Operator Interface

Each of the above alternatives can use a personal computer as the operator interface for announcing alarm, process monitoring, and entering control commands. They may also become part of a network.

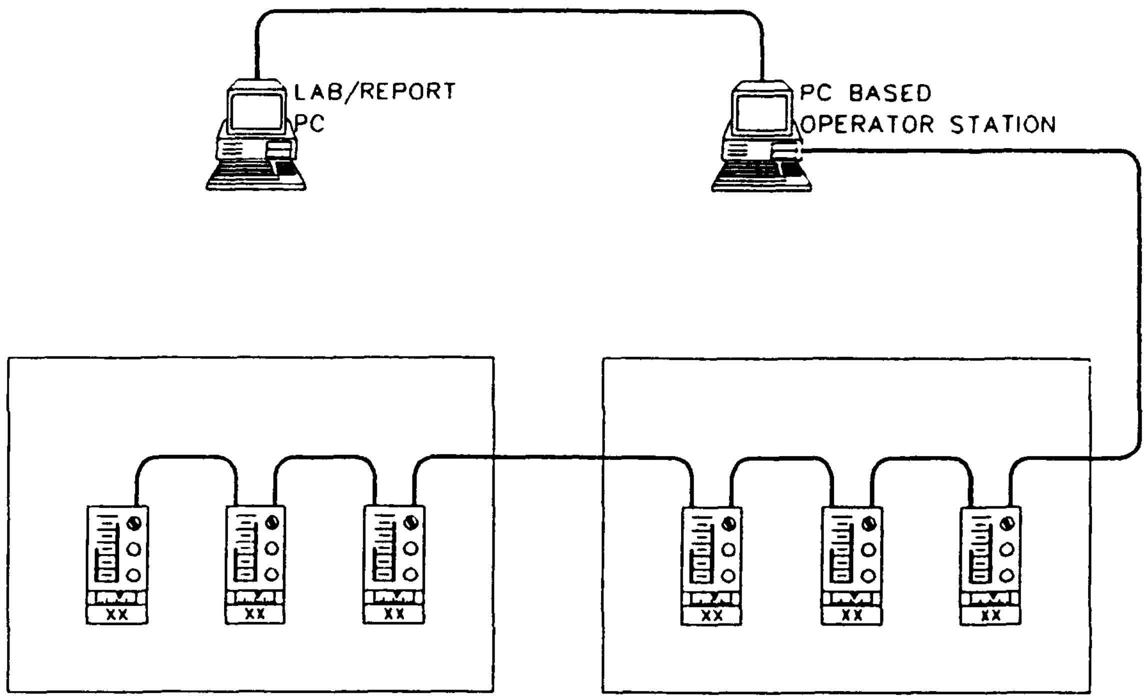


Figure 6. Single Loop Controllers.

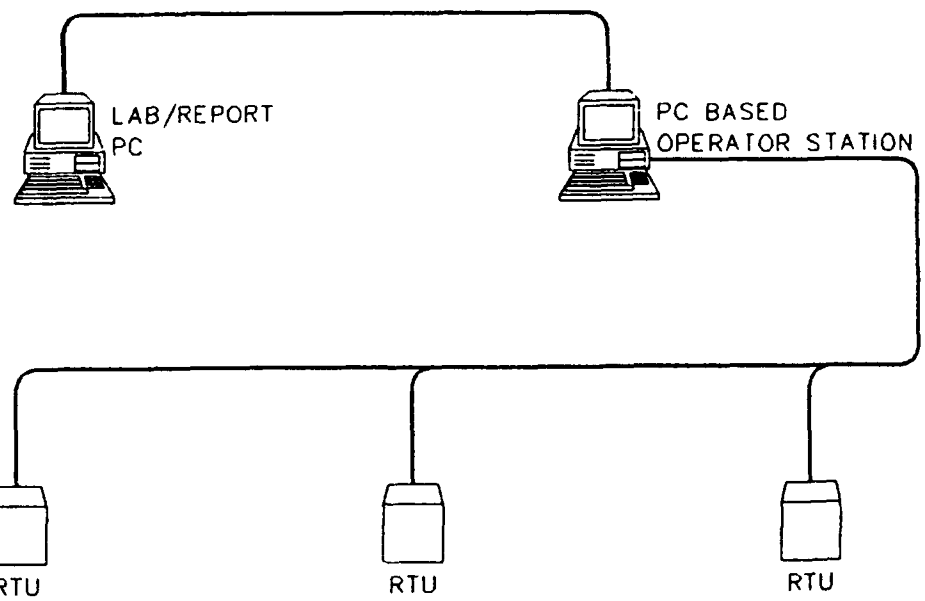


Figure 7. Remote Terminal Units.

Other personal computers on the network could be used for laboratory management, maintenance management, statistical process control, and expert systems as the users become more sophisticated.

For some systems, less expensive operator interface devices can be used, including:

1. Panel type modules, containing lights and membrane pushbuttons, that connect directly to the PLC ASCII ports

2. Message display panels that can display one to four lines of alphanumeric data, used in conjunction with the panel modules

3. CRT-based operator terminals that have small monochrome or color displays. Operators use function keys or touchscreen to enter commands. Units are limited to about 64 kilobytes of memory.

Telemetry Systems

Water distribution and wastewater collection systems vary greatly. Most variations are due to site geography. Sites with large variance in level terrain generally have few or no wastewater lift stations, but several water booster stations and reservoirs to compensate for elevation differences. Sites with relatively flat terrain have more lift stations and few or no water booster stations.

Wastewater collection systems usually contain from 2 to 30 lift stations. Facilities with many lift stations usually have a mix of small submersible pumps in manholes and small package type lift stations. On the other hand, facilities with fewer lift stations generally have larger pumps in buildings. Many of the lift stations have manually cleaned bar screens that must be cleaned periodically.

Water distribution systems usually contain one or four elevated tanks or ground level reservoirs. Some sites have one or two booster stations.

Most facilities have some telemetry. Usually, elevated tank levels are returned to the water plant over telephone lines or dedicated wires. Several sites reported problems with noise on the lines affecting operation and generating false alarms.

For most facilities, remote site monitoring should be included as part of the automation. Installation and startup could be done by plant staff to reduce costs.

Radio-based telemetry systems could replace telephone line systems to improve reliability and noise immunity. For municipal systems, there is little cost difference between purchasing radios and leasing telephone lines. Military installations, on the other hand, usually have their own communications systems. As long as noise is not a problem and cables are nearby, radio systems may not be cost effective.

Sensors

A USACERL report on the use of programmable controllers contains a good discussion of the type of sensors that could be used in Army wastewater plants (Kim et al. 1991). Another recent work describes many of the same instruments and describes manufacturer options, design considerations, and maintenance and calibration procedures (Skrentner 1988).

Two instruments not described in these two references are streaming current detectors and sludge blanket measurement. Since these apply to water, wastewater, and industrial plant operation, they will be further described here.

Streaming Current

Streaming current technology is used to control coagulant dosing. In water plants, it is most often used for alum addition. In wastewater plants, it can be used anywhere polymers are added to improve settling. The technology has been applied to belt filter presses and flotation thickeners to control polymer addition. In industrial plants, it can be used to clarify raw water for the process or to control polymer or alum feeds for settling.

Theory. The streaming current monitor is a charge measuring device. Streaming current is the electrokinetic phenomenon of ionic and colloidal surface charges being physically moved in a liquid and quantitatively measured by a pair of electrodes.

Operation. The sample flows into a cell and is drawn into a piston chamber. As the sample is moved back and forth, mobile counterions surrounding colloids are sheared near the surface of the walls and are moved past electrodes. An ac signal is generated proportional to the charge density.

Performance. Accuracy +/- 1 percent of full scale

Range. -15 to +15 streaming current units

Installation. The unit is wall mounted and requires 1.5 to 3 L per minute flow rate at about 2 psig. Power is 115 VAC.

Maintenance. Inspect, clean sample chamber as needed.

Reliability. Long term reliability is excellent in water plants. One unit was in continuous operation for over 2 years with virtually no maintenance.

Vendors.	Chemtrac Norcross, GA 30092 (404) 449-6233	Milton Roy Ivyland, PA 18974 (215) 441-0800	L'eau Claire Systems, Inc. Kenner, LA 70062 (800) 341-4288

Sludge Blanket

Sludge blanket sensor technology is used to control the sludge blanket level in solid/liquid separators such as sedimentation basins and clarifiers. In water plants, it is most often used for sedimentation following alum addition. In wastewater plants, it can be used for primary and secondary clarifiers, sludge thickeners, and similar applications where a solids/liquid interface exists. In industrial plants, it can be used for batch reactors and clarifiers where control of a solids/liquid interface is important.

Operation. Two types of sensors are available, optical and ultrasonic. Optical sensors use infrared emitting diodes and photodetectors mounted in probes with a narrow gap. Ultrasonic sensors use ultrasonic impulse across a probe. The electronics can be adjusted to sense concentrations from 0.1 to 10.0 gm/L.

Sludge blanket sensors can provide discrete outputs or continuous outputs. Both discrete optical and ultrasonic probes and cable can be mounted on a spool that is driven by a direct current gear motor. The probe is positioned at the solids/liquid interface and the level is derived from a potentiometer mounted on the spool. Another vendor stacks diodes and photodetectors at 3/4 in. on center and converts the discrete readings to a continuous output.

Performance. Accuracy +/-0.05 grams/L

Response time. 5 - 30 seconds

Repeatability. +/- 1% of full span

Installation. Probes are suspended in tanks where scraper arms can pass unrestricted at desired high and low sludge blanket level positions.

Maintenance. Inspect and clean probe head as needed.

Reliability. Long term reliability is excellent in applications where the probe head is not fouled.

Vendors.

BTG, Inc.
Lausanne, Switzerland
(02) 201161

Markland Specialty Engineering Ltd.
Etobicoke, Ontario, Canada M9C 4V2
(416) 625-0930

Monitek Technologies, Inc.
Hayward, CA 94544
(415) 471-8300

Raven Manufactured Products, Inc.
Cincinnati, OH 45216
(614) 292-6717

Royce Instrument Corporation
New Orleans, LA 70129
(800) 347-3505

Final Control Devices

Control Valve Actuators

Control valve actuators are available in a variety of types and sizes. They are used both for full open and full close valve operation, and for modulating valve operation. Actuators are manufactured by Alma Actuators, Rotork, and Limitorque.

Electro-Mechanical Actuators. The electro-mechanical actuator uses an electrically operated reversing motor-driven gear train or screw to position the valve stem. These actuators are available for a wide range of speeds and torque outputs. They are compatible with all types of valves.

In open/close operation, the motor drives the valve either full open or full close and then stops. This type of operation applies to filter backwash control and similar batch operations. In modulating operation, the motor starts, stops, and reverses direction as needed to maintain any desired valve position. This type of operation applies to filter effluent flow control, tank level control, and similar continuous control operations.

Pneumatic Diaphragm Actuators. In a diaphragm actuator, a compressible fluid, usually air, acts on a flexible member, the diaphragm, to provide linear motion to the actuator stem. Diaphragm actuators can be equipped with a spring on one side of the diaphragm. Spring-return actuators provide a fail-safe type operation. If pressure fails, they will always return to a known position. Common applications for pneumatic diaphragm actuators are for digester valve control and munition plant valve control where explosive gases or dusts are present.

Motor Speed Controllers

Variable speed drives are used for pumping or driving other mechanical functions that cannot be properly accomplished with a reasonable number of constant speed units. Variable speed drives offer increased flexibility in control. Process efficiency can be improved where periodic changes in the demand allow operating at reduced horsepower to save energy.

Variable frequency drives and silicon controlled rectifier drives are available from Westinghouse, Square D, Allen-Bradley, and Siemans. Pulley drives are available from the pump manufacturers.

Variable Frequency Drives. A variable frequency drive (VFD) uses an electrical inverter to adjust both voltage and frequency to an induction motor to adjust the motor's speed. Frequency changes affect motor speed, while voltage adjustments affect the motor's output power.

Motor sizes from 1/8 to 500 hp can be controlled. Multiple motors can operate off one common VFD simultaneously. Also, one VFD can be switched between motors to provide a combination fixed-speed and variable-speed system.

Silicon-Controlled Rectifier. A silicon-controlled rectifier (SCR) drive is a variable speed drive that uses a direct current motor. The SCR rectifies constant alternating current voltage to variable direct current voltage. SCR drives are often used on chemical metering pumps and positive displacement sludge pumps.

Variable Pulley Drives. Variable pulley drives are electromechanical units connected between a pump and a motor that use a varible belt drive system to vary the speed of the pump. The drive sheave diameter is adjusted using a reversing gear motor. As the diameter increases, the pump speed increases. Variable pulley drives are often used in sludge pumping applications.

Chemical Feeders

Gas Feed Systems. Chlorinators and sulfonators (dechlorinators) are the most common gas feed systems in water and wasterwater treatment. These units heat liquid chlorine or sulphur dioxide, and meter the gas flow to the process. The units can be equipped with automatic controls to pace the gas flow to any incoming 4 to 20 mA signal.

The incoming signal can be from a flow meter for flow pacing control, a residual analyzer or probe for feedback control, a summer for feedforward-feedback control, or any other source the user may choose.

Dry Feed Systems. Lime slakers and similar dry chemical feed systems are used mostly in Army water treatment plants. These systems convey dry chemicals to the process using screw conveyors or vibrating hoppers. They are usually maintenance intensive since the humidity often causes the dry chemicals to cake and plug equipment.

The feeders can be equipped to vary speed or hopper opening based on a 4 to 20 mA signal for control. The user chooses the source of the feed signal, which may be a flow meter, a streaming current meter, turbidity meter, etc.

Liquid Feed Systems. Alum, ferric, and polymer systems are normally furnished by the chemical manufacturers. The systems can consist of mix tanks, conditioning tanks, storage tanks, and metering feed pumps. The 4 to 20 mA metering pump control signal can have any source.

State-of-the-Art Technologies

Self-Tuning Controllers

Self-tuning proportional/integral/derivative (PID) controllers can help achieve optimum control. Self-tuning control is particularly useful in batch applications where process characteristics can vary from batch to batch. Self-tuning is triggered by set-point changes or on demand. The self-tuning functions measure the process response and derive equivalent process parameters and corresponding optimum PID tuning values. Self-tuning controllers can be used as stand-alone controllers, or as a part of a control system. For a programmable logic controller-based system, the controller would receive its setpoint from the PLC.

HART Field Bus Protocol

For years, the standard means to transmit analog signals was 4 to 20 mAdc over twisted pair wires. With the advent of microprocessor technology, many instrument vendors included this capability in their instruments to improve reliability and accuracy. A natural extension of the technology was to replace the 4 to 20 mAdc output with a digital output. Digital signals are more immune to noise than are analog signals. In addition, one pair of wires could handle several instruments; sensor maintenance and diagnostics could be performed remotely; and sensor calibration could be performed easily.

Unfortunately, vendors were unable to agree on a standard digital communications protocol. Each vendor had its own proprietary instruments. Recently, the Rosemount Company developed and made public their field instrument digital communications protocol. The HART user group was formed to support the growing number of companies using smart field instruments. The basic goals of the group are to promote the use of the HART protocol until some other standard is developed, to ensure the interchangeability of devices, and to provide an open forum for exchange of information. The Instrument Society of America SP-50 Committee is attempting to develop an international field bus standard.

Interconnectivity—MMS

The Manufacturing Message Specification (MMS) is an internationally accepted standard communications protocol for integrating heterogeneous automation devices. MMS operates on networks based on the Open System Interconnect (OSI) seven-layer stack model. MMS resides in layer seven of the stack. MMS consists of messages that travel across a network. These messages are in a specific format that can be understood by all MMS-compatible devices. Benefits of MMS include:

- better communications among automation devices
- reduced development cost required to add new devices to networks
- lower software maintenance cost
- easier overall Army-wide integration
- smaller vendors are enabled to create innovative products.

MMS is endorsed by major companies such as Allen-Bradley, AEG/Modicon, Burr-Brown, Cincinnati Milacron, Digital Equipment Corporation, GE Fanuc Automation, Giddings and Lewis, Hewlett Packard, IBM, Johnson Yokogawa, Moore Products, Siemens, Square D Company, and TI Industrial

Automation. These represent the major programmable logic controller companies and some of the machine tool companies.

Expert Systems

Expert systems technology is a branch of artificial intelligence that uses computers to match or exceed the decisionmaking capability of human experts. Expert systems are useful to solve problems where no mathematical or algorithmic solution exists because data is inexact, uncertain, or based on probabilities.

Rule-based expert systems use groups of rules to perform consistent control actions. The system can monitor processes continuously to diagnose alarm conditions and prompt the operator on how to deal with them. An expert can automatically implement corrective action.

Expert systems are appropriate when:

1. The current methods are too slow, inaccurate, or inconsistent.
2. The problem is small enough that it can be solved by a human expert in a matter of hours.
3. A human expert exists.
4. Only one or two experts exist when many are needed.
5. There is an identifiable benefit.

A USACERL study concluded that AI/expert systems technology is not yet economically practical for use in the operation and maintenance of the Army's wastewater treatment plants (Kim et al. 1988). That study used a LISP-based workstation and knowledge engineering environment (KEE), a very powerful combination. A simpler approach could use a personal computer and a rule-based expert system shell software package. An ideal application would predict water plant flows to meet anticipated demand. This type of application may prove somewhat more economical.

Statistical Process Control

The use of control charts to distinguish between normal and abnormal operations is part of Statistical Process Control (SPC) or Statistical Quality Control (SQC). A control chart plots data over time with statistically determined upper and lower limits drawn on either side of the process average. Control charts help detect trends in operation. The upper and lower limits define the normal process variation. Variation results from many small causes including the capability of the process, clarity of operations procedures, etc.

Malfunctions or upsets usually show up as points outside the limits. Control charts can be used for monitoring so as to immediately detect when something goes wrong. Operators can take action before major permit violations occur. Although used extensively in manufacturing, SPC is infrequently used in water and wastewater applications. Most personal computer-based operator display software includes an SPC capability as an option.

5 DESIGN GUIDELINES

Recommended Automation Technology

To decide between competing technologies, criteria were developed by completing the following statement: "Whatever technology is chosen should . . ." with the criteria that would satisfy the needs of the facilities identified during the site visits. Based on this process, the chosen technology should:

- be easy to use
- be easy to learn
- be easy to maintain
- be easy to program
- be reliable
- be applicable to water plants as well as wastewater
- be applicable to pump station monitoring
- be easy to expand and modify
- be available throughout the United States
- have easily accessible distributors
- have established training programs and centers
- include self-diagnostics
- minimize capital cost
- minimize operating and maintenance costs
- allow rapid implementation
- have some expert system capabilities.

Each criterion was rated by its relative importance to the others. The most important criteria was given a weight of 10 and the least important a weight of 1. Each technology was rated for how well it satisfied the criteria. Table 2 shows the scoring.

The technology with the highest weighted score is best able to achieve the criteria and represents the tentative choice. This technology gives the most of what is wanted with the fewest disadvantages. The tentative choice was reviewed for adverse consequences. The weights and values in Table 2 were determined based on operator interview results and authors' experience. The central PLC technology with remote inputs and outputs received the highest score, followed by the single loop controllers, distributed PLCs, remote terminal units, and personal computer with remote inputs and outputs respectively.

To account for the somewhat subjective quality of these criteria, any technologies with scores within 10 percent of each other were considered essentially equal. Based on the scoring, either the single loop controller or central programmable logic controller technology would meet the Army's needs.

Programmable Logic Controllers

A recent USACERL report contains a thorough discussion of the application of programmable controllers in the Army's wastewater treatment plants (Kim et al. 1991). The report includes an extensive vendor list and a comparison of the sizes and features of the various manufacturer's equipment.

Programmable logic controllers can be applied equally as well to the water plants, water distribution systems, wastewater collection systems, and industrial wastewater treatment plants. PLCs have already been used extensively in municipal water and wastewater systems and in many industrial applications.

Table 2

Comparison of Technologies To Automate U.S. Army Wastewater Treatment Plants

		Central PLC W/ Remote I/O		Distributed PLCs		PC W/Remote I/O		Single-Loop Controller		Remote Terminal Units	
Criteria	**Weight**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**
Easy to learn	8	7	56	6	48	10	80	10	80	7	56
Easy to use	8	8	72	6	54	8	72	10	90	6	54
Easy to maintain	7	8	56	5	35	4	28	10	70	5	35
Easy to program	5	7	35	8	40	10	50	8	40	6	30
Reliance	10	8	80	9	90	2	20	10	100	6	60
Applicable to water plants	5	9	45	9	45	7	35	7	35	9	45
Applicable to p.s. telemetry	9	8	72	6	54	0	0	0	0	9	81
Easy to expand and modify	6	9	54	7	42	5	30	9	54	7	42
Available throughout U.S.	3	10	30	10	30	6	18	8	24	6	18
Distributors near bases	1	10	10	10	10	5	5	2	2	4	4
Established training program	5	9	45	9	45	5	25	4	20	8	40
Has self-diagnostics	8	9	72	9	72	2	16	6	48	7	56
Minimum capital costs	4	3	12	1	4	9	36	10	40	3	12
Minimum O&M costs	7	8	56	6	42	4	28	10	70	6	42
Allows rapid implementation	4	8	32	8	32	6	24	9	36	6	24
Includes some ES features	5	10	50	8	40	4	20	1	5	6	30
Total			777		683		487		714		629

Single Loop Controllers

At the smaller plants such as Fort Gordon and many of the industrial waste treatment plants, single loop controllers without operator stations could be installed and operated as panel-mounted devices for individual loop control of chemicals such as chlorine. As valves are replaced and other areas for automation are identified, a personal computer-based operator station could be added.

There are few risks in using single loop controller-based technology. These systems are in use extensively at smaller wastewater and water treatment plants throughout the world, and have a long history of successful operation. The cost of single loop controllers is so small that even if they did not perform as expected, they could easily be replaced. A personal computer could be used with both PLCs and single loop controllers.

The single loop controller technology provides an inexpensive, flexible, reliable technology. Plants that begin with a small "trial" system can easily expand the system as they gain operational experience. In many cases, local private resources will be available to assist plant staff with learning the new system, solving operational problems, or expanding the system.

One major limitation of the single loop controllers technology is the pump station monitoring. For plants with existing remote terminal units such as Fort Bragg, it may be possible to write drivers so that the operator station can scan the remotes. For plants with annunciator systems such as Fort Gordon, a single loop controller could receive the inputs from the alarm panel.

Most facilities will require monitoring of lift stations, wells, or elevated tanks and reservoirs. If these signals do not already exist at the plant site, single loop controllers would be inappropriate.

Design Considerations

Additional criteria were required to determine other candidates for automation.

Monitoring Needs

Once the desired control for each process is defined, monitoring needs can be established. Monitoring includes:

- alarm detection and annunciation
- equipment status and run time
- trending of analog type variables such as flow
- flow totaling
- performance calculations
- operational reporting
- historical data acquisition and storage.

Control Philosophy and Failure Operations

The control philosophy affects the instrumentation systems selection. Control philosophy considerations include:

- manual or automatic operation
- momentary versus maintained pushbuttons and switches
- controls located near devices or remote from equipment
- how many loops each PLC will control
- type of backup control for each device.

Resource Constraints

Resource constraints that will affect the selection of the process control system include:

- operation and maintenance staff skills
- time and budget limitations
- geographic location of plant for hot or cold weather protection
- political issues such as using local suppliers, union agreements, community acceptance, etc.

Physical Constraints

Physical constraints that will affect selection of the process control system include:

- temperature and humidity
- airborne contaminants such as dust or corrosive gases
- power reliability and quality
- lightening, earthquakes, etc.
- plant layout and size
- distances between process areas.

Life Cycle Cost Analysis Examples

Life cycle costing should be used to develop all significant costs of the proposed technology. Life cycle costing is important because the initial construction cost is often not the dominant cost in owning and operating a system. Life cycle costing is the preferred method in Value Engineering analysis (USEPA 1975). It equalizes all costs to a common baseline no matter the year or expenditure or interest rate. Life cycle costing places more weight on the use of quality products of reasonable initial costs having low maintenance and operating costs.

For each plant area or function, the initial capital cost is shown along with the projected operation and maintenance costs. Operation and maintenance costs are subdivided into two categories: (1) labor and material, and (2) power and chemicals. Reduction in costs (savings) are shown as negative. Tables 3 and 4 show an example analysis for West Point and Tables 5 and 6 give an analysis for Fort Gordon.

The savings benefits are both tangible and intangible. Intangible benefit value are quantified by equating them to personnel or equipment costs. For example, the value of a manager's or operator's

Table 3

West Point Cost/Benefit Example (Present Worth Cost Analysis)

Recommendation	Initial Cost*	Lab & Matl Yearly Costs or Savings**	Pwr & Chem Yearly Costs or Savings	Notes
Plant Influent				
Change on/off pump control to continuous control:			-$5,000	Better process operation with level flows; Currently being done by plant
1. Install VFDs on pumps	$20,000	$0		
2. Instruments	$2,000	$0		
Primary Treatment				
Sludge withdrawal and routing:		-$4,688	-$1,500	Save 1 operator-hr per day;
1. Motorize 12 valves	$60,000	$3,600		12 at $5000
2. Control 2 sludge pumps	$2,000	$24		
Secondary Treatment				
Dissolved oxygen control:		-$4,688	-$8,830	15% power savings +1 operator hr;
1. Dissolved Oxy probes exist	$0	$0		VFDs to be installed by plant
2. Blower VFDs to be installed	$0	$0		
RAS Pumping:		-$4,688		Save 1 operator hr per day;
1. Add VFDs to pumps	$0	$0		Currently being done by plant staff
2. Control 3 pumps	$3,000	$36		
3. Misc piping modifications	$5,000	$0		
Clarifier sludge withdrawal:				
1. Motorize telescoping valves	$0	$0		Not recommended at this time
Waste sludge control:		-$4,688		Save 1 operator hr per day
1. Control 1 pump speed	$0	$0		
Chlorination				
Chlorine addition:			-$300	Save 10% annual chlorine;
1. Instruments	$0	$0		Residual probe being installed
Management Information				
Operator calculations	$0	-$4,688		Save 1 operator- hr per day;
Report Generation	$0	-$1,973		Save 8 manager- hr per month
Control System:				
1. PLC	$18,000	$1,080		1 large plc
2. Remote I/O	$31,200	$1,872		64 DI, 40 DO, 32 AI, 10 AO
2. Operator station	$16,000	$960		25% of hardware cost
3. DAF operator station	$2,000	$120		33% of hardware cost
5. Engineering & design	$16,800	$0		50% of hardware cost
4. Programming	$22,176	$0		15% of hardware cost
5. Installation	$33,600	$0		
6. Vendor training	$10,080	$0		
TOTAL	$241,856	-$17,721	-$15,630	

Payback period (total savings): $241,856/$17,721 + $15,630 ≈ 6 years

*Evaluation period: 10 years.
**Savings is shown negative.

Table 4

Example Life-Cycle Cost Analysis—West Point

Parameters	Measure	Estimated Cost	Present Worth in 10 Years
Initial cost			$241,856
Replacement and salvage costs			
Year	5	$6,046	$4,115 Replace 2.5%
Year	8	$6,046	$4,115 Replace 2.5%
Salvage	10	–$35,000	-$16,212
Total present worth			-$ 7,892
Annual benefits including escalation			
Labor & materials	5%	-$17,721	-$152,247
Power & chemicals	6%	-$15,630	-$141,234
Total present worth			-$293,481
Net present worth savings in 10 years			
$241,856 - $7,892 - $293,481 =			-$59,517

Note:	
Equipment life	20 yrs
Controls life	10 yrs
Interest rate	8%

Table 5

Fort Gordon Cost/Benefit Example (Present Worth Cost Analysis)

Recommendation	Initial Cost*	Lab & Matl Yearly Costs or Savings	Pwr & Chem Yearly Costs or Savings	Notes
Primary Treatment				
Sludge withdrawal:		–$4,688		Save 1 operator hr per
1. Motorize 4 valves	$20,000	$1,200	$100	day; extra power cost;
2. Control 2 sludge pumps	$2,000	$120		upgrade electrical
Chlorination				
Chlorine addition:		–$4,688	–$1,000	Save 1 operator hr per day
1. Instruments	$5,000	$300		
Management Information				
Operator calculations	$0	–$4,688		Save 1 operator hr per day;
Report Generation	$0	–$1,973		save 8 manager-hr per mo.
Control System				
1. Programmable logic controller	$10,000	$600		Medium size
2. Remote I/O	$6,000	$360		4 AI, 24 DI, 10 DO
2. Operator station	$12,000	$720		
3. Engineering & design	$7,000			
4. Programming	$9,240	$0		25% of hardware cost
6. Vendor training	$4,200			33% of hardware cost
5. Installation	$14,000	$0		15% of hardware cost
				50% of hardware cost
	$89,440	–$12,737	–$900	

Payback period (total savings): $89,440/$12,737 + $900 = 7 years

*Evaluation period: 10 years.

Table 6

Example Life Cycle Cost Analysis—Fort Gordon

Parameter	Measure	Estimated Cost	Present Worth	
Initial Cost			$89,440	
Salvage & replacement cost:				
Year	5	$894	$609	Replace 2.5%
Year	8	$894	$483	Replace 2.5%
Salvage	10	-$11,000	-$5,095	Valves (20yr) + Controls (10yr)
Total present worth			-$4,003	
Annual benefits including escalation				
Labor and materials	5%	-$12,735	-$109,429	
Power and chemicals	6%	-$900	-$8,132	
Total present worth			-$117,561	
Net present worth costs in 10 years				
$89,440 - $4,003 - $117,562 =			$32,125	

access to plant operating information equates to the time needed to record and review operational data. The present worth analysis assumes that:

1. An interest rate of 8 percent was used to calculate the present worth.

2. The control equipment life is estimated at 10 years and valve and pump life at 20 years. The analysis allows replacement to occur. The example shows some equipment replaced in years 5 and 8.

3. Labor and material cost was escalated at 5 percent per annum. Power and chemical cost was escalated at 6 percent. This type of cost escallation can have a major impact on the total present worth.

Based on the present worth analysis, a single programmable controller at West Point would have a breakeven period of about 6 years. In 10 years, the present worth analysis shows an $81,000 saving. Most vendors report a minimum of 5 years mean time between failures. In 6 years, it is unlikely that the plant will have experienced one failure. At Fort Gordon, after 10 years, the present worth savings would be about $31,000.

The cost of replacing the sludge valves was included in the cost analysis for both West Point and Fort Gordon. This could be considered a normal maintenance item, and not part of the automation. If these costs are deducted, automation becomes even more attractive.

Automated System Maintenance

Maintenance is the cleaning, calibration, adjustment and repair of instrumentation and control equipment to ensure optimal performance. Maintenance of automated systems will include some hardware, software, and telecommunications equipment support.

Simple process instruments for well established physical measurements such as pressure, level, temperature, and flow can be maintained by competent electronics technicians using vendor furnished maintenance manuals. More complex instruments to measure dissolved oxygen, sludge density, chlorine residual, etc., may require special training. Usually a 1/2 day on-the-job training course conducted by the manufacturer's factory-trained service representative is adequate.

Panel mounted control circuit devices such as relays and switches and programmable controllers are maintained by electricians or electronics technicians. In some cases, electronics technicians are not allowed to work on the 120 volt control circuits commonly found in control panels and programmable controller input/output cards. If programmable controllers are purchased locally, programming and maintenance courses generally are offered by the local supplier. Most courses are 3 to 5 days in length and are geared toward electricians and electronic technicians.

Telecommunications equipment, local area networks, and personal computers are best maintained through support agreements with local suppliers unless the installation has a large installed base of this type of equipment.

The operator station software residing in the personal computer can be "maintained" by a computer literate operator, secretary, plant manager, or maintenance technician. Maintenance involves changing the input/output point database, operator displays, historical database, and reports. Maintenance of the operating system software should be performed through support agreement with the supplier. Most courses are 1 to 2 weeks long and are geared toward programmers, engineers, and general computer users.

6 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Site visits and interviews indicate that many of the processes at Army water and wastewater facilities may be automated for more cost-efficient operation (Table 1). All the visited facilities had automated their processes to some degree; however, none had completely centralized monitoring of either the plant or of the associated collection or distribution systems. All of the visited sites had the following automation needs:

1. A combination of in-plant control, and control and monitoring of remote sites
2. A combination of analog control and discrete control
3. A need for automation to include failure operations and operator guidance.

These common needs represent a unique opportunity for the Army to modernize its facilities both to gain the economies of more efficient operation, and to better meet water and wastewater requirements. Automation of Army wastewater treatment plants may help the Army reduce costs and increase the operational effectiveness of existing staff in several ways. Where staff levels are below minimum, automation can maximize the effectiveness of available personnel. At some facilities, staff could be redeployed or reduced by using automation to eliminate off-shift staffing and to centralize and consolidate the operation of the water and wastewater systems.

Appropriate off-the-shelf technologies that can meet these needs are digital control systems based on: (1) distributed controllers, (2) programmable controllers, (3) personal computers, and (4) loop controllers.

Distributed controller-based systems are most applicable in larger plants with more than 1000 input/output points and more than 40 percent continuous control loops, since they operate in a networked environment over high speed data highways. However, they do not lend themselves to pump station monitoring.

Programmable logic controller-based systems can range in size from fewer than 10 points to several thousand input/output points, and range in application from standalone relay replacers to networked control systems. They are used in both in-plant control applications and for telemetry systems.

Personal computer-based systems can monitor and control operations, and offer cost effective solutions for small, noncritical control applications such as those at trickling filter plants. They are not well suited to telemetry applications or complex process control applications.

Single loop controller networks are excellent in small plant applications with fewer than 1000 input/output points. The controller performs all monitoring and control, and are available as both sequence and cascade controllers.

Recommendations

A set of criteria to rate automation technologies applicable to water and wastewater plants was determined, and it was found that central PLC technology best satisfied the criteria, followed closely by single-loop controller technology. It is recommended that these technologies be implemented where appropriate in water and wastewater applications. PLCs, for instance, are recommended for application in water plants and distribution systems, and wastewater collection systems and treatment plants. Single-loop controllers are recommended for use with smaller water and wastewater treatment plants, such as the Fort Gordon plant.

It is recommended that, as installations upgrade their technologies, both water and wastewater systems at each site be automated as a single project to ensure that automation equipment for the entire project is the same, and to reduce long-term operation and maintenance costs.

Strategies

Each treatment plan is unique and each automation project must be properly engineered. Automation should focus on labor and chemical intensive processes. A phased approach to automation will allow plant staff to grow in knowledge and experience appropriate to their skills and capabilities. In general, each plant should install a personal computer-based operator station and programmable logic controller and interface to existing instruments and control equipment. Over time, more complex instruments can be added and additional processes can be automated. The technical strategies that follow are recommended to help plants make the transition to automation:

1. Whenever possible, use sensors and control equipment from the same manufacturer at both the water and wastewater plants.

2. Minimize the use of new instruments at first. Focus on chlorine control, pH control, and dissolved oxygen/blower control at wastewater plants, and chlorine control and filter backwashing at water plants. To achieve chlorine control, use simple instruments such as chlorine probes and thermal mass flow sensors rather than chlorine analyzers and ring balances.

3. Use sludge blanket probes, suspended solids sensors, and similar maintenance-intensive instruments only after plants have effectively implemented more basic automation. Meanwhile, use time-based or accumulated-flow based control strategies.

4. Evaluate each plant for placement and sizing of flow meters. Almost all visited sites had insufficient upstream and downstream pipe lengths to permit accurate (1 to 2 percent) measurement. In many cases, flow meters were oversized.

5. Use a centralized programmable logic controller with distributed inputs and outputs and personal computers to automate both wastewater and water systems. Specify PLCs that incorporate MMS technology.

6. Ensure that personal computer software is designed to run in a networked environment. This will allow linking with other computers both within the plants and base-wide, and even Army-wide if needed. Equip personal computers with a modem port to permit addition of pump station monitoring and of dial-in capability for others to retrieve plant data from the computer.

7. Use phone line-based pump station-monitoring systems, or radio-based systems where communications reliability is critical (e.g., the link between the two water plants at West Point).

Concept Field Evaluation

It is recommended that research and development in water and wastewater plant automation continue. One result of all automation-related concept field evaluations should be design standards and guides for various sensors, automation systems, and plant types. As plants are upgraded or as equipment is replaced, plant maintenance personnel or contractors can use these standards to automate the plant. Without clear guidance, support, and standards, automation will be haphazard and will fail to reduce costs or increase operational effectiveness.

Future Work

Parallel short-term field evaluations are planned to demonstrate the validity of applying the various types of automation described in this study. Three demonstrations will be conducted at: Fort Meade, MD, Watervliet Arsenal, and West Point Military Academy. At Fort Meade, chlorination and pH control will be automated; at Watervliet Arsenal, pH will be automatically adjusted before effluent reaches the reaction tanks; and at West Point, a PC will be used for data management. Longer term concept evaluation is recommended to demonstrate whether plants should remain automated permanently.

METRIC CONVERSION TABLE

1 in.	=	25.4 mm
1 ft	=	0.305 m
1 sq ft	=	0.093 m^2
1 mi	=	1.61 km
1 lb	=	0.453 kg
1 gal	=	3.78 L
1 hp	=	7.47 W
°F	=	(°C x 1.8) + 32

REFERENCES

Carr, David K., and Ian D. Littman, *Excellence in Government, Total Quality Management in the 1990s* (Coopers & Lybrand, June 1991).

Kim, Byung J., James E. Alleman, Chai S. Gee, and John T. Bandy, *Use of Programmable Logic Controllers To Automate Control and Monitoring of U.S. Army Wastewater Treatment Systems*, Technical Report (TR) N-91/27/ADA241372 (U.S. Army Construction Engineering Research Laboratory [USACERL], July 1991).

Kim, B.J., J.T. Bandy, K.K. Gidwani, and S.P. Shelton, *Artificial Intelligence for U.S. Army Wastewater Treatment Plant Operation and Maintenance*, Technical Report (TR) N-88/26ADA200434 (USACERL, September 1988).

Law Environmental, *Summary Reports, Operator Assistance Program* (January 1989).

Skrentner, Robert G., *Instrumentation Handbook for Water and Watewater Treatment Plants* (Lewis Publishers, 1988).

U.S. Environmental Protection Agency (USAEPA), Office of Water Program Operations, *Procedural Handbook for Value Engineering*, EPA-430/9-75-020 (USEPA, December 1975).

USACERL DISTRIBUTION

Chief of Engineers
ATTN: CEHEC-IM-LH (2)
ATTN: CEHEC-IM-LP (2)
ATTN: CECG
ATTN: CERD-M
ATTN: CECC-P
ATTN: CERD-L
ATTN: CECW-P
ATTN: CECW-PR
ATTN: CEMP-E
ATTN: CEMP-C
ATTN: CECW-O
ATTN: CECW
ATTN: CERM
ATTN: CEMP
ATTN: CERD-C
ATTN: CEMP-M
ATTN: CEMP-R
ATTN: CERD-ZA
ATTN: DAEN-ZCM
ATTN: DAEN-ZCE
ATTN: DAEN-ZCI

CECPW
ATTN: CECPW-F 22060
ATTN: CECPW-TT 22060
ATTN: CECPW-ZC 22060
ATTN: DET III 79906

US Army Engr District
ATTN: Library (40)

US Army Engr Division
ATTN: Library (13)

US Army Europe
ATTN: AEAEN-EH 09014
ATTN: AEAEN-ODCS 09014
29th Area Support Group
ATTN: AERAS-FA 09054
100th Support Group
ATTN: AETT-EN-DEH 09114
222d Base Battalion
ATTN: AETV-BHR-E 09034
235th Base Support Battalion
ATTN: Unit 28614 Ansbach 09177
293d Base Support Battalion
ATTN: AEUSG-MA-AST-WO-E 09086
409th Support Battalion (Base)
ATTN: AETTG-DEH 09114
412th Base Support Battalion 09630
ATTN: Unit 31401
Frankfurt Base Support Battalion
ATTN: Unit 25727 09242
CMTC Hohenfels 09173
ATTN: AETTH-DEH
Mainz Germany 09185
ATTN: BSB-MZ-E
21st Support Command
ATTN: DEH (10)
US Army Berlin
ATTN: AEBA-EH 09235
ATTN: AEBA-EN 09235
SETAF
ATTN: AESE-EN-D 09613
ATTN: AESE-EN 09630
Supreme Allied Command
ATTN: ACSGEB 09703
ATTN: SHIHB/ENGR 09705

INSCOM
ATTN: IALOG-I 22060
ATTN: IAV-DEH 22186

USA TACOM 48397
ATTN: AMSTA-XE

Defense Distribution Region East
ATTN: DDRE-WI 17070

HQ XVIII Airborne Corps 28307
ATTN: AFZA-DEH-EE

4th Infantry Div (MECH)
ATTN: AFZC-FE 80913

US Army Materiel Command (AMC)
Alexandria, VA 22333-0001
ATTN: AMCEN-F
Installations:
ATTN: DEH (19)

FORSCOM
Forts Gillem & McPherson 30330
ATTN: FCEN
Installations:
ATTN: DEH (23)

6th Infantry Division (Light)
ATTN: APVR-DE 99505
ATTN: APVR-WF-DE 99703

National Guard Bureau 20310
ATTN: Installations Div

Fort Belvoir 22060
ATTN: CETEC-IM-T
ATTN: CECC-R 22060
ATTN: Engr Strategic Studies Ctr
ATTN: Australian Liaison Office

USA Natick RD&E Center 01760
ATTN: STRNC-DT
ATTN: DRDNA-F

TRADOC
Fort Monroe 23651
ATTN: ATBO-G
Installations:
ATTN: DEH (20)

US Army Materials Tech Lab
ATTN: SLCMT-DEH 02172

USARPAC 96858
ATTN: DEH
ATTN: APEN-A

SHAPE 09705
ATTN: Infrastructure Branch LANDA

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

HQ USEUCOM 09128
ATTN: ECJ4-LIE

AMMRC 02172
ATTN: DRXMR-AF
ATTN: DRXMR-WE

CEWES 39180
ATTN: Library

CECRL 03755
ATTN: Library

USA AMCOM
ATTN: Facilities Engr 21719
ATTN: AMSMC-IR 61299
ATTN: Facilities Engr (3) 85613

USAARMC 40121
ATTN: ATZIC-EHA

Military Traffic Mgmt Command
ATTN: MTEA-GB-EHP 07002
ATTN: MT-LOF 20315
ATTN: MTE-SU-FE 28461
ATTN: MTW-IE 94626

Fort Leonard Wood 65473
ATTN: ATSE-DAC-LB (3)
ATTN: ATZA-TE-SW
ATTN: ATSE-CFLO
ATTN: ATSE-DAC-FL

Military Dist of WASH
Fort McNair
ATTN: ANEN 20319

USA Engr Activity, Capital Area
ATTN: Library 22211

Norton AFB 92409
ATTN: Library

US Army ARDEC 07806
ATTN: SMCAR-ISE

Engr Societies Library
ATTN: Acquisitions 10017

Defense Nuclear Agency
ATTN: NADS 20305

Defense Logistics Agency
ATTN: DLA-WI 22304

US Military Academy 10996
ATTN: MAEN-A
ATTN: Facilities Engineer
ATTN: Geography & Envr Engrg

416th Engineer Command 60623
ATTN: Gibson USAR Ctr

USA Japan (USARJ)
ATTN: APAJ-EN-ES 96343
ATTN: HONSHU 96343
ATTN: DEH-Okinawa 96376

Naval Facilities Engr Command
ATTN: Facilities Engr Command (8)
ATTN: Division Offices (11)
ATTN: Public Works Center (8)
ATTN: Naval Constr Battalion Ctr 93043
ATTN: Naval Civil Engr Service Center (3) 93043

8th US Army Korea
ATTN: DEH (12)

US Army HSC
Fort Sam Houston 78234
ATTN: HSLO-F
Fitzsimons Army Medical Ctr
ATTN: HSHG-DEH 80045
Walter Reed Army Medical Ctr 20307

Tyndall AFB 32403
ATTN: HQAFCESA Program Ofc
ATTN: Engrg & Srvc Lab

USA TSARCOM 63120
ATTN: STSAS-F

American Public Works Assoc. 60637

US Army Envr Hygiene Agency
ATTN: HSHB-ME 21010

US Gov't Printing Office 20401
ATTN: Rec Sec/Deposit Sec (2)

Nat'l Institute of Standards & Tech
ATTN: Library 20899

Defense Tech Info Center 22304
ATTN: DTIC-FAB (2)

285
11/93

This publication was reproduced on recycled paper.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1994—3510-S/00003