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Reduced-budget Approach to Central Monitoring and Control of Water and Waste Water Systems

by

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Water systems, typically, consist of pumping stations, reservoirs, and treatment plants scattered over a relatively large geographical area. It is often necessary to monitor the status of various parameters at the remote stations. Furthermore, it may be necessary to control pumps and valves. Traditionally, these tasks have been done by staff who either visit remote stations periodically or monitor the stations continuously. A centralized monitoring and control system has several advantages:

Status of the entire system can be monitored from a single central location.

Information in one part of the system can be used to control pumps and valves at a separate location. For example, a reservoir level can be used to determine which pumps will run.

Alarm situations are brought to the attention of the operation immediately.

Staff are freed for more productive duties.

The system can operate unattended if desired.

Collected data can be analyzed and presented in a meaningful form automatically by the computer. The need for chart recorders is eliminated.

To achieve a reduced budget system, the approach is not to cut costs on system components by using lower-quality parts. The approach is to examine alternative designs, taking particular advantage of ways in which recent technology can be incorporated to replace older, less-effective designs. A general description of such a system is presented in this paper which exploits mini- and micro-computer developments and advances in programmable controllers and remote terminal units. These standard products, with a few customized components, can provide a control system that meets all the desired characteristics of a control system as described below.

A well-designed central monitoring and control system requires to have the following characteristics:

It does the job it was intended to do.

It is reliable.

It is easy to use.

It is easy to maintain.

It should be easily modifiable to accept changes in the system.

It should be easily upgradable.

It must provide adequate protection for personnel and equipment.

It should be the lowest-cost solution that satisfies all the above.

Figure 1 shows the principal components and layout of an effective monitoring and/or control system which meets or surpasses performance specifications of systems many times the cost. The concepts presented in this paper have been proven practical in existing systems in North America. Each portion of the system will be discussed in the following sections.

TRANSDUCERS

Every monitoring system needs transducers to translate physical parameters such as electrical current, flow rate, well level, etc., into signals which can be used by the rest of the system. The transducers should be of high quality and reliability, since reliable data is mandatory. If the transducers are inferior, then no amount of monitoring equipment attached to them will improve the quality of the measurements made by the transducers.

A standard should be adopted in a system for analog signals. Typically, 4-20 mA or 1-5V is used. Adopting a standard simplifies interfacing and maintenance. If one type of analog signal is used throughout a system, then fewer types of spare parts need to be kept on hand and maintenance personnel need be concerned with fewer different types of components.

It is very useful for the designer of the monitoring system to have some control over the station design also. Some designs lend themselves more readily to remote monitoring and control than others. If the proper points at the station are accessible, a great deal of remote troubleshooting can be done.

CONTROL

The control of a remote station may be as simple as starting or stopping a pump. Other times it may be a much more complex control strategy with Proportional Integral Derivative (PID) loops for such things as chlorine control.

Unmanned remote station control can be divided into two categories; local control and remote supervisory control. The argument for this strategy lies in inherent limitations in communication links. By placing intelligent local control at the station, a reduction in control information to be passed over the communication link is achieved. This is practical for all controls that do not depend upon parameters which occur outside the station, for example, pump-starting (shutdown) delays and chlorine addition to water. Reduction of transmitted information leaves the communication channel open for necessary information. Having local control also has a great advantage in protecting upsets in another part of the system from affecting the station adversely. For instance, if the communications link fails, then the station is still as functional as it can be without external information.

With local control, responses to alarm situations are immediate and not dependent upon a central computer and a communication link. The local control also relieves the central computer of much of the burden of the station control, which leaves open the possibility of using a much smaller and less-expensive central computer. Often, a standard microcomputer will do the job, normally requiring a minicomputer. All these advantages can be achieved by adding intelligent control to the remote terminal unit (RTU) at very little extra cost to the RTU.

In addition to the automatic control, the station must have a manual override on each control. Not only does this act as a backup, but it also ensures that when a piece of equipment is shut down there is nothing that the automatic control can do to turn it on again. This provides safety for maintenance personnel working on equipment.

RTU OR PROGRAMMABLE CONTROLLER

An RTU (Remote Terminal Unit) is an input/output device used primarily for data acquisition, telemetry and remote control. With current microprocessor technology, adding a stand-alone control capability to such a device is very inexpensive.

There are two reasonable choices for such a device. One option is to use a standard programmable controller in conjunction with a special communication interface. Another is to use even more modern devices which combine the features of a programmable controller and a communications interface.

The programmable controller has as its advantage a wide range of options and peripherals. This may not be a significant advantage when theprogrammable controller is used as an RTU. An intelligent RTU designed specifically for the job is more efficient in communicating and at a lower cost. Both units are modular with various I/O cards available making replacement and maintenance very simple.

The RTU should be addressable so that all remote stations can share the same communication channel. Using this scheme, the stations can be scanned at rates up to 100 per minute. This rate is usually much higher than necessary for water and waste-water systems whose parameters change on a much longer time scale. The need for faster scan rates is further reduced by the use of intelligent controllers at each station.

COMMUNICATION LINK

The communication link can be any voice-quality channel. The use of higher bandwidth channels is not necessary for systems in which events occur on a minute-by-minute time scale rather than in fractions of a second. This is another area where costs can be reduced without sacrificing performance.

Generally, a land line (twisted pair) rented or leased from the telephone company or off-the-shelf VHF or UHF radios serve as practical communication links in such systems. All stations can be accessed by the same communication link which is more cost-effective than having a separate link to each remote station.

Radio transceivers can often give a long-term cost-saving when compared with renting land lines. The initial cost of using radios is higher. Radios can also be a more reliable communication link because there are no lines to be damaged. Replacing a defective radio is a much faster and simpler process than having lines repaired.

Other communication links are possible and practical in certain instances. If all the monitoring and control is within a plant (sewage-treatment plant, desalination plant, etc.) then a coaxial-cable communication link ("data highway") can provide higher-speed data transfer over a relatively short distance (less than 3000m). The data-transfer rate using this method can be up to 50 times faster than by radio or land line.

A fourth alternative for communications is to use autodial and autoanswer modems in conjunction with the standard telephone system. This method becomes practical only for special circumstances where the remote site is too far away to be reached practically by radio or land line. The most useful example of where this technique could be used is when the remote system is self-contained and does not require continuous monitoring. For example, assume there is a remote self-contained system which is several hundred kilometers from where its performance information is needed. It may be necessary only to have a summary of this information once per day. In this case, a computer could automatically call the remote system each day (perhaps when telephone rates are lowest) and receive the data for that day. This technique can be used to monitor a system from any point in the world. When the proper status points are monitored, this can be a very valuable tool for remote troubleshooting. More detail on this concept is given later.

The protocol which is used for communication has a great effect upon system performance and reliability. With the system described in this paper, one protocol works particularly well. The mode of data transfer is FSK (Frequency Shift Key) at rates between 110 and 1200 bits per second in an asyncronous format. The frequencies used are either Bell or CCITT standard frequencies. The data is transferred in half duplex (only one direction at a time) which is compatible with radio transceivers. Data should be coded with a high degree of error detecting capability to eliminate false signals. This is especially important in control systems where undetected corrupted data could start or stop equipment. It may even be desirable to use an error-correcting code to enable correction of commonly-occurring errors. Two commonly-used codes for this purpose are Hamming codes and BCH codes.

The sequence of events which occur to access data at the remote stations is as follows:

> A command is transmitted by the central computer. This command consists of the address of the data at the remote stations along with the addresses of the stations from which data is requested.
>
> The remote stations are in a receive mode until they receive a command. When the stations in the addressed group receive a command, they transmit their data one station after another. This can be via standard radios or land lines.

The central computer receives the data transmitted by the remote stations.

If any errors are detected in the data received from a station, then the computer will request the same data again from that station.

After all the data is received from the remote stations, then the computer can send control information out to the stations. If there is no control information, then the computer can request more data from the stations for monitoring purposes.

To initiate a control command to a station or a group of stations, the central computer transmits the command to all the stations. Only those stations whose address is specified in the command will respond to the command. Each station specified will respond and send an acknowledgement back to the central computer.

If an acknowledgement is not received from a station, then the control command is retransmitted to that station.

After all control commands have been completed, the computer will return to the first step.

The above sequence requires, typically, one minute to complete.

CENTRAL SITE COMMUNICATION INTERFACE

To handle the details of interfacing between the communication link and the central computer, a special microprocessor-based device can be used.

An RS-232 interface on this device would allow it to be readily connected to almost any standard computer. Another interface on this device would allow it to be connected to the communication link to the remote stations.

In a typical system, the device would;

Receive data from the computer via the RS-232 interface.

Add the error-detecting and/or correcting codes to the data.

Set the radio transceiver into the transmit mode and wait a brief time to allow the radio to reach full output power (approximately 0.1 sec.).

Transmit the encoded data in FSK asynchronous format.

Place the radio transceiver into the receive mode if a radio is used.

Wait for response from remote stations.

Receive data from remote stations transforming FSK tones into digital format.

Decode the encoded data checking for errors and correcting where possible.

Pass received decoded data to the computer via the RS-232 interface.

Notify the computer if uncorrectible erroneous data was received.

Wait for more data from the computer.

CENTRAL SITE COMPUTER:

The central site computer serves as a supervisory control computer, report generator and operator interface.

The computer chosen for this job can be a standard minicomputer or microcomputer. The model used can be chosen to suit the particular job. There are several criteria which this computer should meet regardless of the job.

Due to the distributed computing power which exists in the rest of the system and the face that high-speed control is not necessary in water and waste-water systems, a relatively-low-speed computer with corresponding low cost can be used successfully. Modern microcomputers such as the IBM XT or minicomputers such as the Hewlett-Packard 1000 are ideal choices for controlling medium-to low-speed systems. These machines are available with colour graphics monitors for presentation of system information. Hard disks allow storage of system data for later generation of reports. Printers and plotters allow reports to be presented in hard-copy format without the need of conventional chart recorders. Other features such as a battery back-up on the system clock are useful for improving system performance.

The computer chosen should be well supported in the marketplace. A computer for which it will be difficult to find spare parts in a few years is not a good choice. Maintenance for the computer should be minimal and should be limited to tasks as simple as changing the paper in a printer. Wherever possible, high reliability components should be used. With certain components, consideration should be given to keeping spare parts on hand.

Certain hardware options enhance the ease of operator interface. One common and very useful enhancement is user-definable keys on the computer keyboard. Various operations can be assigned to each of the keys.

A touch screen allows the operator to control the system by just pointing the various options on the screen. This can be a very natural way for operators to use the computer. Frequent touching of the screen can result in the constant need to clean the screen. A "light pen" can give the same features as a touch screen without the need for constant screen cleaning. A light pen is a pointer attached by a wire to the computer. The computer can detect which part of the screen the light pen is pointing to.

Another operator interfacing device is called a "mouse". A mouse is a small device which can be moved around on a table top. The computer can detect the position of the mouse. Movement of the mouse produces a corresponding movement of a cursor or pointer on the screen. A button on the mouse can be pressed to allow selection of the item which the cursor is pointing to on the screen.

All the above operator interfaces are inexpensive and available for small computer systems.

SOFTWARE

Software is the key to a good control system. Software is the term used for all computer programs used in the system. It determines the way in which the system will function. All the displays, control strategy, and report generations, are the result of the software. The fact that the system characteristics are determined by software gives the system tremendous flexibility. Using the same hardware can give vastly different systems for different applications with the use of different software. This also means that changes to a system can often be done in minutes by changing the software without making any hardware changes.

The following sub-sections discuss the various sections of software usually found in a monitoring and control system.

GRAPHIC DISPLAYS

Presenting the information retrieved from remote stations in an easily-understood and easily-interpreted manner is a major aim of the system software. One very effective way of doing this is to use colour graphic displays representing the system schematically. The various system components can be drawn on the screen with colours used to distinguish various sections. For example, fresh water could be blue, chlorine green, pumps and valves grey. Red can be used to highlight locations of alarms.

Displays should be updated dynamically as the data is received from the remote stations. On/off status of pumps, motors, etc., can be shown by simply displaying "on" or "off" next to the device on the screen. Alternatively, the status can be shown by changing the colour of the device on the screen. For instance, green could indicate on, yellow could indicate off, and red could indicate an alarm condition with that device. This method helps reduce problems caused by different languages.

Physical changes in the system can be represented easily on a computer display. Well or reservoir levels can be shown by having a bar change height on the screen in proportion to the level. Typically, a reservoir would be drawn as a tank with blue (representing the water) filling the interior of the tank drawing up to a point which corresponds to the actual level in the reservoir at a remote site. Similarly, valve positions drawn on the screen can represent the actual valve position of the valve.

The use of graphic displays does not have to be confined to one display per system. On the contrary, a system generally consists of one or two dozen such displays with each one representing a different portion of the system at various levels of detail. The operator can switch from one display to another at any time. In this way, one monitor can replace a room full of mimic panels and instrumentation at a small fraction of the cost. It has an additional advantage of being very flexible allowing changes to be made without changing wires or disrupting system operation.

Normally, the displays are arranged in a heirarchy. A summary display shows the overall system status giving indication of the important status points and locations of alarms. Detail is not shown on the summary display but is usually left to other displays. Typically, each section of the system shown on the summary display has a display of its own. For instance, each remote station may have its own display indicating most of the details pertaining to that station including alarms associated with that station.

A further level of detail may be employed on displays that show sub-systems at a station. A ladder diagram for each pump can show the present status of the control circuit for each pump. If colour is used to indicate the presence or absence of power at various points in the circuit, then faults can be diagnosed in seconds. This has the same effect as having an electrician go to the remote station and check the status of the various points in the circuit with a meter. The advantages of using the computer are that time is saved allowing maintenance personnel to bring the proper tools and spare parts before the station is visited and no one has to test live control circuits in high-voltage panels resulting in a higher degree of safety.

Another type of graphic display which can be useful in some situations presents dynamic bar graphs of various system parameters. These bar graphs can replace traditional indicators at a substantial savings.

CONTROL SOFTWARE

Control software can be broken into two categories - automatic control and operator-directed control. Automated control sends out commands to remote stations in response to changing conditions in the system such as a changein reservoir level. Operator-directed control allows the operator to have direct control over devices at the remote stations. Operator-directed control usually overrides automatic control.

For automatic control, the operator often has the ability to adjust the control parameters. For instance, set points can be entered and modified for a reservoir level or for a PID loop.

Operator-directed control can be used to start or stop pumps upon demand regardless of the state of the automatic control provided that it is safe to do so.

DATA LOGGING

It is usually desirable to record the information collected from the remote stations. This information includes running hours, flow rates, well levels, alarms, etc.

Events such as equipment start or alarms should be recorded on the mass storage device immediately when they occur. Usually, a hard disc is used to record the information. Typically, an event file for alarms would record the time of occurrence, the time cleared and the nature of the alarm. A file holding 32000 alarm messages is common.

Other analog values can be stored at regular intervals of perhaps one minute. Typically, a year's worth of data can be stored at one time. With all data files, the most recent information is always accessible. Therefore, when the file is full, only the oldest information is overwritten when new data is added.

REPORT GENERATION

Report generation goes together with data logging. Reports are created from historical data saved in files.

Reports are generally in two formats - graphical and tabular. Graphical reports are very useful for visualizing trends in analog values. Tabular reports give a more quantitative presentation of the data. Tabular reports are useful for status-type signals such as alarms.

The computer can be used to generate reports based upon calculations using logged data. Average flow rates or minimum well levels over a period of time are examples of this.

Reports can be generated to cover any arbitrary period of time. For example, reports for an hour, day, week, month or year are common. It is feasible to allow the operator to select the start time and the end time for each report.

The computer can handle details of generating the reports by doing such things as automatically choosing the scale to fill best the graph. Graphs can be displayed on the computer screen, printed on a graphic printer or plotted on a high-quality multicolor plotter.

By having these report generation capabilities in the computer, the need for chart recorders is eliminated. The computer has additional flexibility allowing statistical analysis of the data which chart recorders cannot give. The saving in chart recorders alone can often pay for the computer.

EXAMPLES OF EXISTING SYSTEMS

Charlottetown Central Monitoring and Control System

Charlottetown is a small city located in eastern Canada. The water system for Charlottetown is monitored and controlled from an office in the city.

There are two separate well fields having a total of nine pumps. At each pumping station is an Allen Bradley programmable controller which does all the local station control. The reservoir site also has a programmable controller which is used for monitoring only. The three remote sites communicate with the central site by a UHF radio.

At the central site is an IBM XT computer equipped with a colour display, graphics printer, 10 million character hard-disk drive, battery-backed-up clock, and tape back-up unit.

Figures 2 and 3 show the general layout of the Charlottetown system. A third pumping station is shown in these diagrams. This station is not presently connected to the system but may be added sometime in the future. Addition of this station can be done with almost no disruption to the current system.

The central computer scans the remote stations once each minute. Data are recorded on the hard disk every two minutes for the most recent 410 days. The most recent 32767 alarm messages are also recorded.

Figure 4 gives a black and white representation of the colour summary display for this system. This display shows the status of each pump, the station flows and currents and the reservoir level. The pumps start and stop as determined by the reservoir level. The system is capable of unattended operation and runs in this mode during non-business hours. If a serious alarm occurs when the operator is absent, the computer sends an alarm to the fire station. Personnel at the fire station call the water-system personnel to notify them of the alarm situation.

Figures 5 and 6 show typical reports generated by the system. The operator can generate these reports at any time without disrupting system operation.

One useful feature of the system is the ability to generate a display showing the control circuit for a pump. Energized portions of the circuit are shown in yellow and de-energized portions in white. With this display, it is very easy to diagnose faults without every having to leave the central site.

The system can be monitored by telephone from any point in the world. Using a similar IBM computer together with a telephone allows viewing of the status of the system without going there. The implications of this are that troubleshooting can be done by a consultant at a fraction of the cost of a field trip.

The system has many more features which are too numerous to mention in detail here. More information is readily available from the author.

Millidgeville Wastewater Treatment Plant

The Millidgeville Wastewater Treatment Plant is a centralized monitoring system. The control of the plant is accomplished with an Allen Bradley programmable controller. An IBM XT computer is used to present information on plant status and to generate reports.

The status of pumps, valves, and levels are scanned by the computer every five seconds. The programmable controller and computer are located in the same room allowing the fast data transfer.

The system has fourteen colour graphic displays representing various sections and systems in the plant. The computer can also display sixteen bar graphs which replace traditional indicators.

This system has much the same hardness as the Charlottetown water system; but because of the different software, it gives a totally different function to the system.

REMOTE TROUBLESHOOTING

The ability to monitor the status of remote stations can give a great deal of troubleshooting capability from the central site especially if the proper parameters are monitored in the system Using ladder diagrams to represent the control circuits can be very useful in analyzing problems. Displaying the ladder diagram on a computer screen can be done if all the points in the control circuit are monitored by the RTU at the remote station. Having this capability displaces the need for personnel to test live circuits in a high-voltage control panel.

Another concept for remote troubleshooting is to have the capability to connect a computer by a regular telephone to the remote system. The connection can be made either to the central computer or to the RTU at the station. With the connection established, the status of the system or station can be monitored with a very brief telephone call. If it were desirable, control of the system could be done by telephone also.

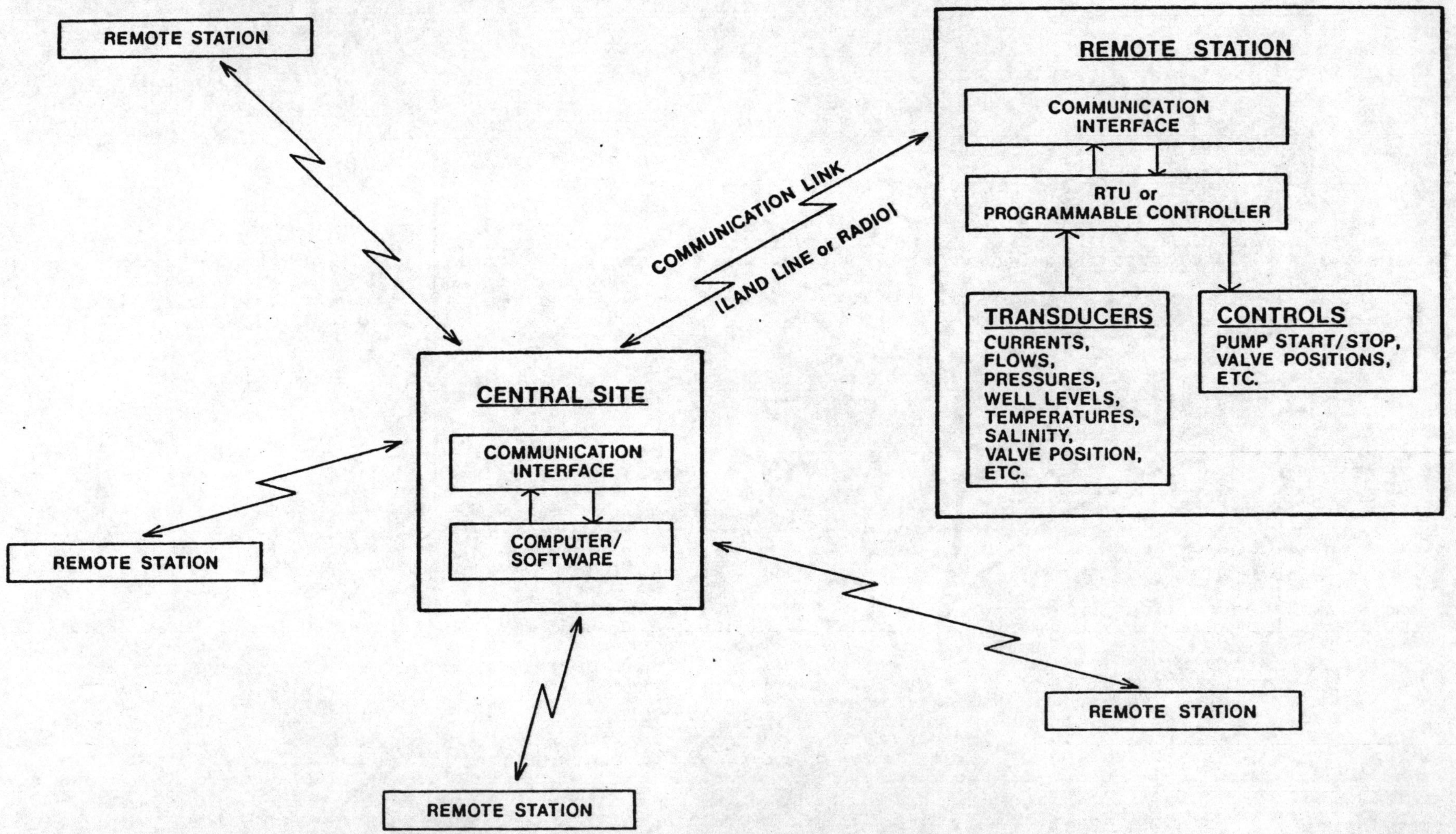
This capability has implications for troubleshooting systems which can be at any location in the world that can be reached by telephone. Other standalone systems can be monitored routinely from a point many hundreds of kilometers away. A great deal of time and expense can be saved if the problem is known before a service trip is made. It is even possible to make modifications to the system software from a very distant location.

CONCLUSIONS

With the use of recent technology and proper design strategy, centralized monitoring and control systems have become practical for small-scale systems at an affordable price. Incorporating small computers, audio bandwidth communication channels, and programmable controllers or RTU's (Remote Terminal Units) into the design results in a highly efficient, functional and reliable system. Such systems have been proved to be effective in North America in monitoring and control or water and waste-water systems. The concepts could be readily applied to other systems such as irrigation.

The ability to monitor, economically, a system by telephone from any point in the world opens a whole range of possibilities. One practical use for this capability is to diagnose a problem before a service trip is made, thus saving time and money.

FIGURE NO.1 CENTRALIZED CONTROL SYSTEM LAYOUT



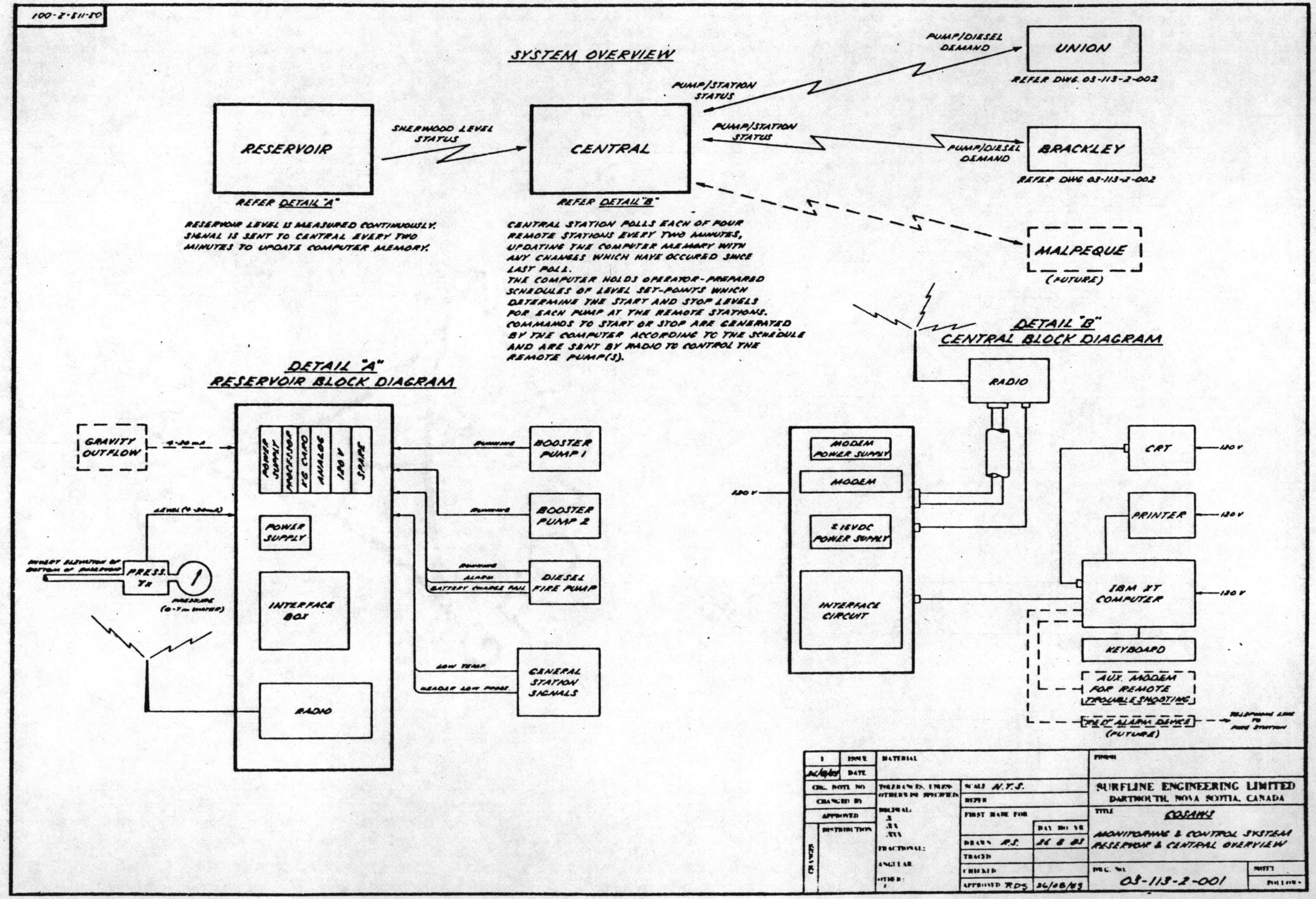


FIGURE 2 CHARLOTTETOWN WATER SYSTEM OVERVIEW

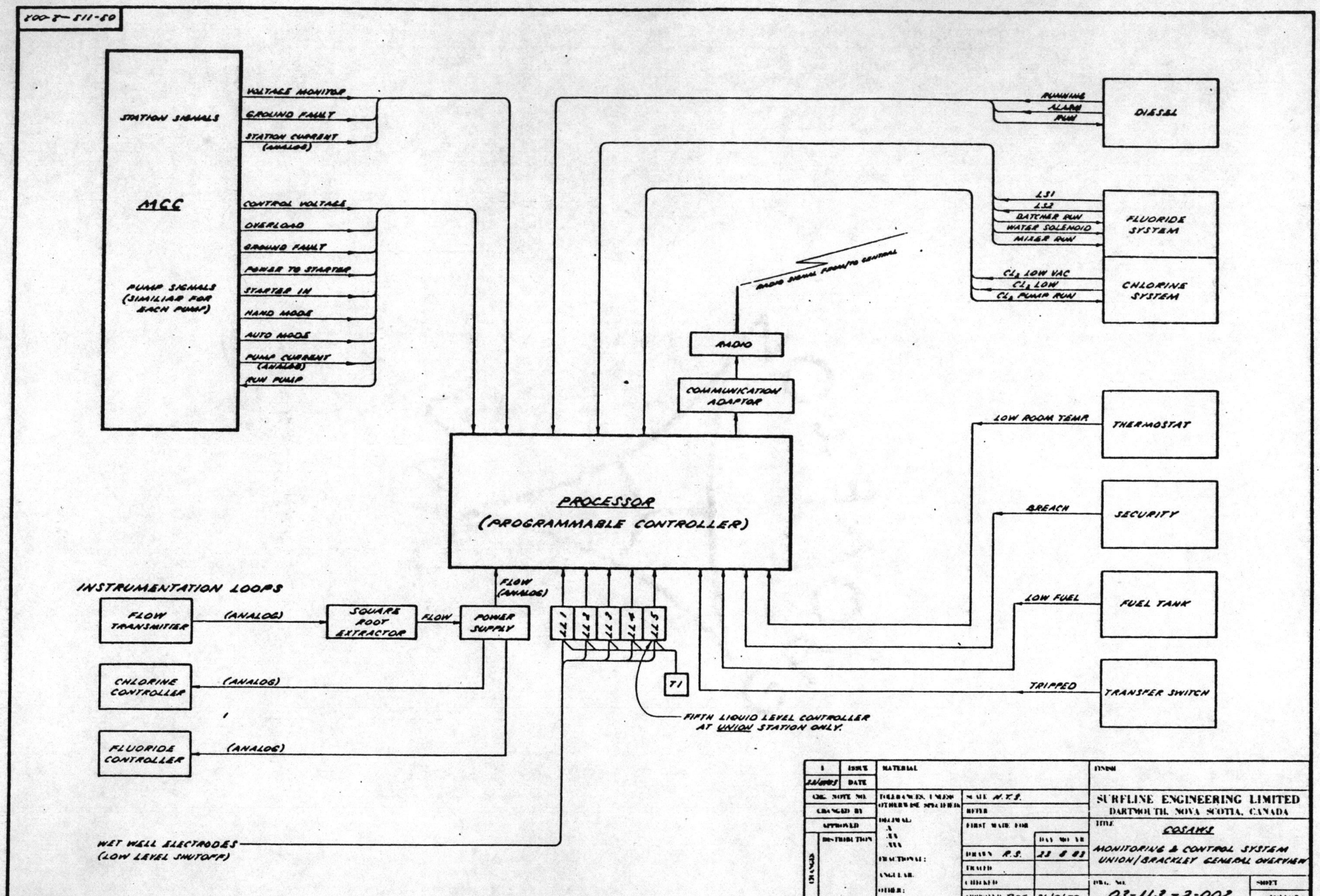


FIGURE 3 CHARLOTTETOWN WATER SYSTEM PUMPING STATION LAYOUT

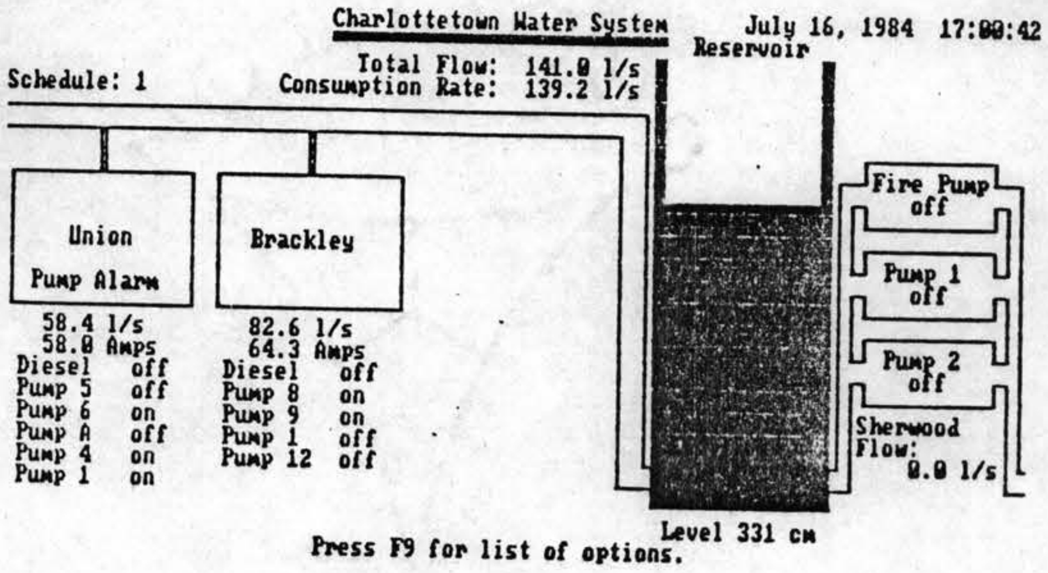
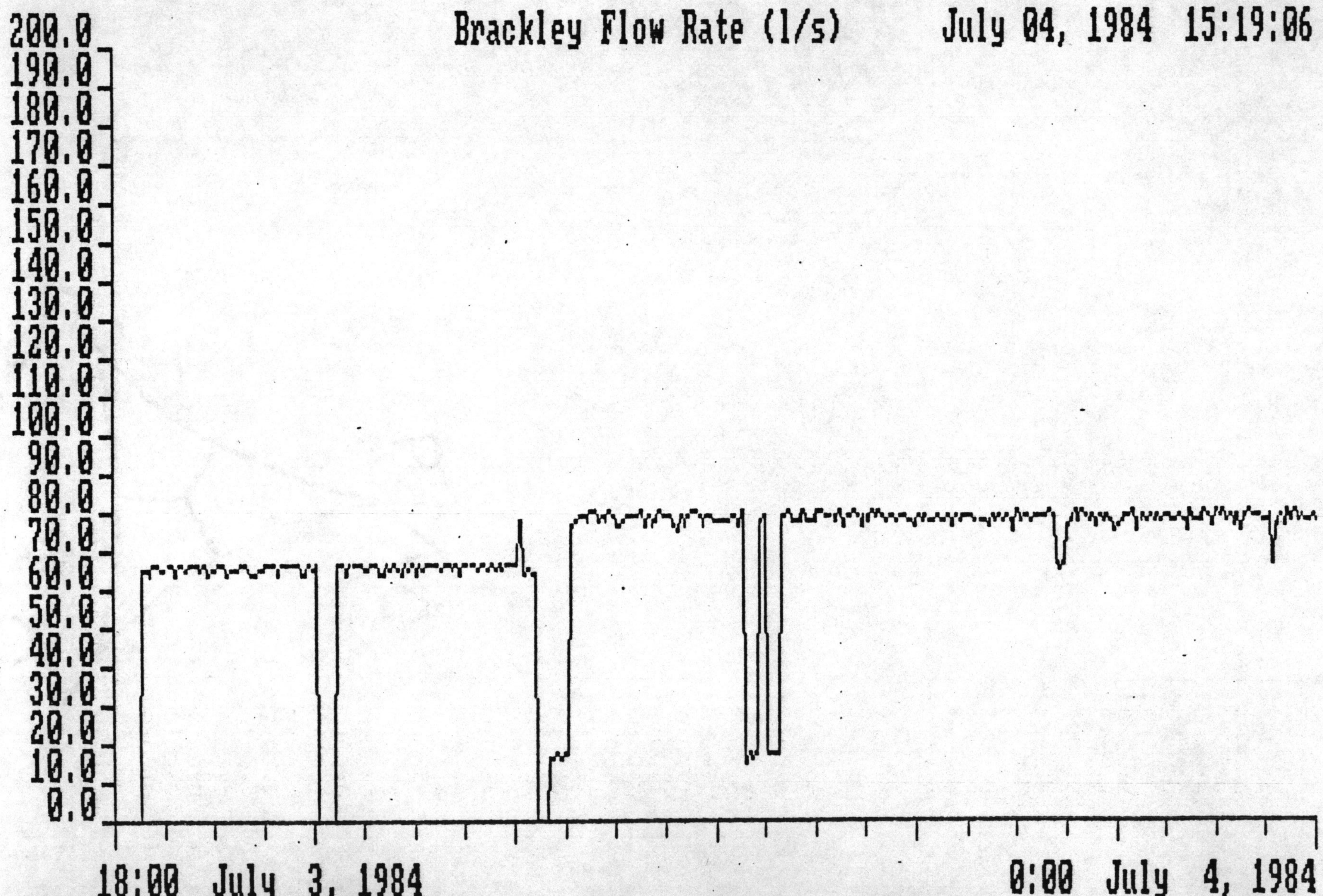


FIGURE 4 COMPUTER DISPLAY SHOWING OVERVIEW OF CHARLOTTETOWN WATER SYSTEM



Minimum: 0.0 at 18:00 July 3, 1984 Average: 68.3 l/s
Maximum: 80.1 at 20:21 July 3, 1984 Total water: 1475 thousand liters

FIGURE 5 SAMPLE GRAPH OF PUMPING STATION FLOW

Union Station Current (Amps) Page 1

Time			Average	Minimum	Maximum
July	3, 1984	18:00:00	55.3	40.8	61.2
July	3, 1984	18:20:00	60.7	43.9	61.2
July	3, 1984	18:40:00	45.9	23.5	61.2
July	3, 1984	19:00:00	61.2	61.2	61.2
July	3, 1984	19:20:00	61.2	61.2	61.2
July	3, 1984	19:40:00	54.6	40.8	61.2
July	3, 1984	20:00:00	44.6	40.8	61.2
July	3, 1984	20:20:00	61.2	61.2	61.2
July	3, 1984	20:40:00	51.0	40.8	61.2
July	3, 1984	21:00:00	67.9	43.9	78.4
July	3, 1984	21:20:00	78.4	78.4	78.4
July	3, 1984	21:40:00	65.2	58.0	78.4
July	3, 1984	22:00:00	74.0	58.0	78.4
July	3, 1984	22:20:00	78.4	78.4	78.4
July	3, 1984	22:40:00	70.2	58.0	78.4
July	3, 1984	23:00:00	70.2	58.0	78.4
July	3, 1984	23:20:00	78.0	61.2	78.4
July	3, 1984	23:40:00	62.8	58.0	78.4
July	4, 1984	0:00:00	78.4	78.4	78.4
July	4, 1984	0:20:00	78.4	78.4	78.4
July	4, 1984	0:40:00	78.4	78.4	78.4
July	4, 1984	1:00:00	70.7	58.0	78.4
July	4, 1984	1:20:00	78.4	78.4	78.4
July	4, 1984	1:40:00	66.3	61.2	78.4
July	4, 1984	2:00:00	64.4	61.2	78.4
July	4, 1984	2:20:00	72.8	43.9	78.4
July	4, 1984	2:40:00	75.6	43.9	78.4
July	4, 1984	3:00:00	78.4	78.4	78.4
July	4, 1984	3:20:00	78.4	78.4	78.4
July	4, 1984	3:40:00	78.4	78.4	78.4
July	4, 1984	4:00:00	78.4	78.4	78.4
July	4, 1984	4:20:00	78.4	78.4	78.4
July	4, 1984	4:40:00	66.3	58.0	78.4
July	4, 1984	5:00:00	78.4	78.4	78.4
July	4, 1984	5:20:00	78.4	78.4	78.4
July	4, 1984	5:40:00	74.7	61.2	78.4
July	4, 1984	6:00:00	78.4	78.4	78.4
July	4, 1984	6:20:00	78.4	78.4	78.4
July	4, 1984	6:40:00	66.4	40.8	98.8
July	4, 1984	7:00:00	51.0	40.8	61.2
July	4, 1984	7:20:00	31.7	3.1	61.2
July	4, 1984	7:40:00	34.1	3.1	40.8
July	4, 1984	8:00:00	40.8	40.8	40.8
July	4, 1984	8:20:00	24.9	3.1	40.8
July	4, 1984	8:40:00	36.1	23.5	40.8

Instantaneous Minimum: 3.1 at 7:34 July 4, 1984
Minimum Average : 24.9 at 8:20 July 4, 1984
Instantaneous Maximum: 98.8 at 6:41 July 4, 1984
Maximum Average : 78.4 at 21:20 July 3, 1984
Average: 65.2 Amps
Total power consumed: 915.4 kWh

FIGURE 6 SAMPLE REPORT FOR PUMPING STATION ELECTRICAL CURRENT