Real-Time Remote Monitoring of Drinking Water Quality

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Abstract
Over the past eight years, the U.S. Environmental Protection Agency's (EPA) Office of Research and Development (ORD) has funded the testing and evaluation of various online "real-time" technologies for monitoring drinking water quality. The events of 9/11 and subsequent threats to the nation's infrastructure have expanded the focus of this research. Currently, EPA's National Homeland Security Research Center (NHSRC) is funding additional research to evaluate a variety of remote water quality monitoring (RWQM) technologies. The evaluations focus on the ability of the commercially available technologies to be used as a tool to detect deliberate or accidental contamination of water supply and water distribution systems. This paper highlights some of the lessons learned from the past and ongoing research related to RWQM conducted by EPA at the EPA's Test and Evaluation (T&E) Facility in Cincinnati, Ohio, and other field locations.

Disclaimer
This paper has been reviewed in accordance with the EPA's peer and administrative review policies and approved for presentation and publication. The mention of trade names or commercial products in this paper does not constitute endorsement or recommendation for use by the authors, or by their respective employers. The trade names have been included to accurately represent the equipment used for the purpose of testing and evaluation.

Introduction
In 1997, EPA-ORD initiated a field program to install three real-time RWQM stations at various locations in Washington D.C. (DC), and three real-time RWQM stations in rural West Virginia (WV). Subsequent to the successful implementation of these

studies, EPA funded the limited use of RWQM in other field tests in California and Ohio. These field tests were performed for short durations, lasting anywhere between a few days to a few weeks and were limited in scope (from a remote monitoring perspective). Therefore, in these studies, local data loggers were used for the test-specific instruments. Panguluri et al (2005) discuss the use of continuous monitors and data-loggers for conducting tracer studies. Starting in 2003, EPA's NHSRC has collaborated with ORD and funded the testing and evaluation of other commercial RWQM technologies at the T&E Facility. Shaw Environmental, Inc. (Shaw) provides the lead technical support to EPA in the selection, design, installation and/or maintenance of these RWQM stations and associated monitoring and/or control hardware.

As a number of online sensors and data acquisition systems have now become available, it is important to understand how to select and implement an appropriate system to achieve optimal results based on the objectives of the implementation. This paper presents a brief historical overview of the aforementioned implementations as case studies along with a summary of selection/implementation criteria and lessons learned (related to remote monitoring).

Case 1: West Virginia Remote Monitoring Initiative

This EPA test site is located in Coalwood (McDowell County), WV. The water source was an abandoned coal mine. Prior to 1994, an aerator combined with a slow sand filter was used for water treatment at this site. This combined unit had been operational for over 30 years and needed substantial repairs. The volume of water from the mine was sufficient for the small rural community (of about 50 people). The EPA investigated various alternative economically feasible technologies. The investigations concluded that a packaged ultrafiltration (UF) system was ideally suited for this location. Therefore, in 1994, a packaged (UF) water treatment system was purchased and installed at this site using EPA funding. Figure 1 shows the Coalwood UF system.

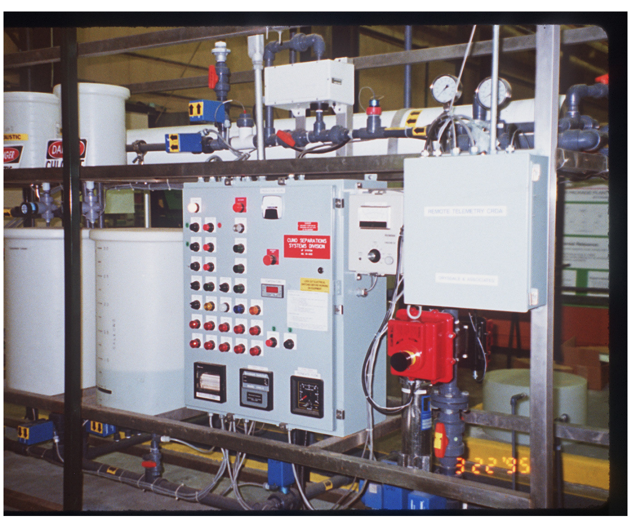


Figure 1. UF System installed at Coalwood, West Virginia

The packaged UF system as initially installed used a programmable logic controller (PLC), along with PLC-controllable hardware for automation. The UF system also included several instruments and sensors including an online pH sensor, online chlorine sensor, pressure gauges, etc. Initially, operational and water quality parameters for the UF system were manually logged and recorded from the instrument's analog/digital displays. In 1996, the EPA developed, installed, and tested a remote monitoring system at the site. This system used commercially available hardware, along with proprietary EPA-developed software. The software was a MSDOS -based system that was hardware-specific, not very user-friendly, and the overall cost of ownership (for EPA to continually upgrade the hardware/software based on market changes) was not practical. Therefore, in 1998, EPA updated the UF system with a commercially available off-the-shelf user-friendly Windows-based Supervisory Control and Data Acquisition (SCADA) system. The PCM400 series controller manufactured by Integrated Systems and Control, Inc. (www.isacinc.com), was used as the SCADA controller along with their IWATCH, IDRAW, ILISTEN and ITERM software utilities. The inputs/outputs (I/O) to the SCADA controller were either binary digital or analog 4-20 milli-ampere (mA) signals. Figure 2 shows an operator screen shot for the IWATCH interface.

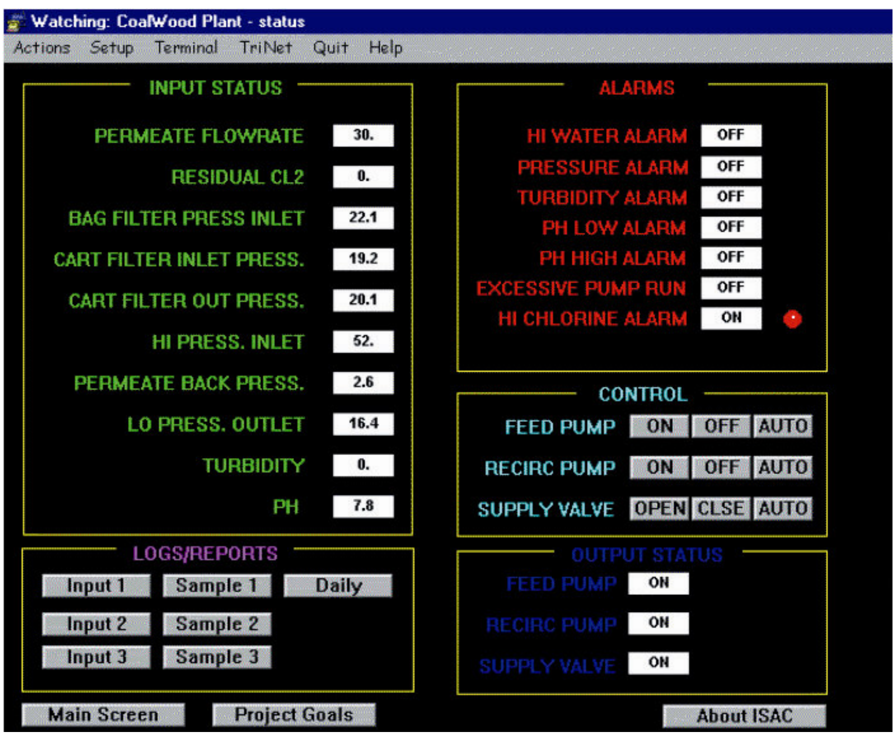


Figure 2. IWATCH System Operator Interface

After this unit was operational for over a year, two other locations (Berwind and Bartley) were equipped with SCADA-based RWQMs. The monitored parameters included temperature, pH, Oxidation Reduction Potential (ORP), free chlorine and turbidity at each location. The EPA funding support for the remote monitoring effort lasted for the period of 1996 to 2001.

Case Study Summary: The SCADA system selected was fairly inexpensive, smart, user-friendly and scalable. For the Coalwood site implementation, the capital cost for SCADA hardware/software was less than $2,000. The total cost was approximately $33,000, including the instrumentation (~ $10,000) and on-site technical support, training, and set-up. The subsequent implementations at Berwind and Bartley were much lesser in total cost. For each of these sites, a phone line was available for remote modem-based communications. The system was periodically monitored, and the logged water quality (and operational data for the Coalwood location) was downloaded on a monthly basis from the SCADA controller.

The study revealed that the implemented SCADA system worked very well. However, the maintenance and calibration of the instrumentation was not performed on a routine basis and was poorly documented. Besides automation, the study objectives included an assessment of the acceptance of this data by the WV Department of Health (DOH) to satisfy their routine monitoring and reporting guidelines. The DOH required the treatment unit operator to maintain daily records of the monitored water quality parameters at these locations. However, the lack of historical instrument maintenance records prevented EPA from aggressively pursuing this objective.

Case 2: Washington D.C. Remote Monitoring Initiative

Following a number of "coliform" violations, EPA's Region 3 office directed the DC Water and Sewer Authority (DCWASA) to implement a number of corrective actions to its water distribution system (Clark, et al 1997). "Real-time" remote monitoring of water quality parameters within the distribution system was identified as one possible method to identify potential water quality problems within the system. In July 1997, EPA initiated a research study to install remote monitoring system(s) at various locations in DC to monitor the water quality within the distribution system. DCWASA staff coordinated with EPA and Shaw Environmental, Inc., to select appropriate location(s) within the distribution system for the installation of online sampling stations.

For the purposes of remote monitoring, EPA selected the following parameters: free chlorine, pH, temperature, and turbidity. These parameters were selected because they are considered to be common indicators of water quality. Additionally, these water quality parameters could be monitored continuously with good reliability and limited maintenance using commercial off-the-shelf instrumentation. Although other water quality parameters such as nitrate-nitrogen and ORP were considered, there was insufficient information available regarding interpretation of this data with respect to bacterial growth within the distribution system. Shaw built the customized online sampling system(s) that contained various instruments, piping and control valves used for measuring the water quality parameters at each location.

At the time of this implementation, DCWASA owned and operated a SCADA system manufactured by DAQ electronics (www.daq.net). The I/O to the SCADA controllers were either binary digital or analog 4-20 mA signals. The main purpose of this DAQ-SCADA system was to monitor and control water distribution to the city. Shaw evaluated various available options for selecting an appropriate SCADA/RTU system for the proposed real-time on-line monitoring system. During Shaw's evaluation, it was clear that use of this existing DAQ-SCADA system to manage the monitored data provided clear advantages (such as on-site support, secure data transfer, existing communication and other electronic hardware) over other available systems.

The remote monitoring network system in DC was implemented in three phases. In the first phase, a remote monitoring system was installed at the Fort Reno # 2 tank. This site provided security and easy access to the distribution system. Subsequently, based on initial success at this location, two other sites (Bryant Street and Blue Plains) were selected and added to the remote monitoring network in the second phase. Figure 3 shows the overall layout of the DC remote monitoring network. The third phase involved the development of a Web-based application to publish the real-time data to enhance consumer confidence. Figure 4 shows the web interface.

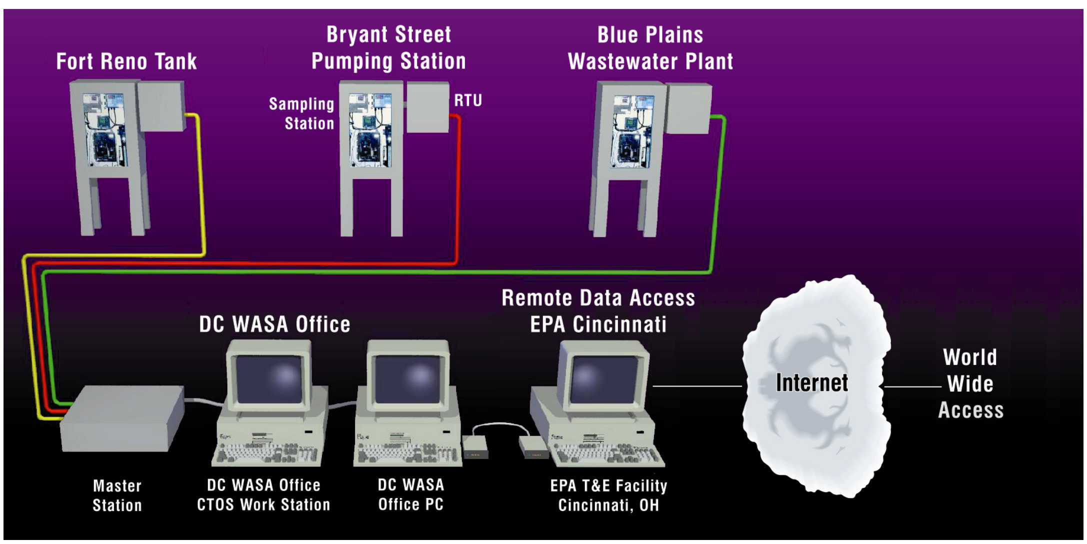
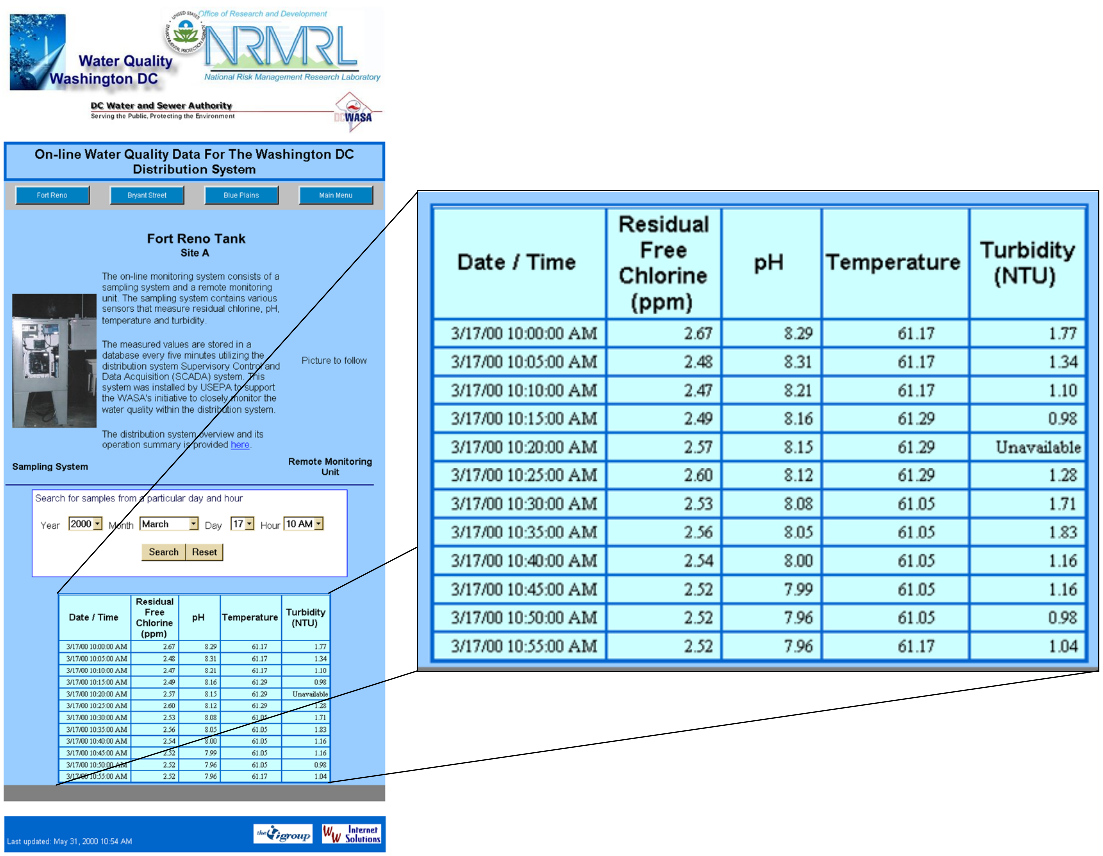


Figure 3. Washington, DC Remote Monitoring Network Layout



Date / Time	Residual Free Chlorine (ppm)	pH	Temperature	Turbidity (NTU)
3/17/00 10:00:00 AM	2.67	8.29	61.17	1.77
3/17/00 10:05:00 AM	2.48	8.31	61.17	1.34
3/17/00 10:10:00 AM	2.47	8.21	61.17	1.10
3/17/00 10:15:00 AM	2.49	8.16	61.29	0.98
3/17/00 10:20:00 AM	2.57	8.15	61.29	Unavailable
3/17/00 10:25:00 AM	2.60	8.12	61.29	1.28
3/17/00 10:30:00 AM	2.53	8.08	61.05	1.71
3/17/00 10:35:00 AM	2.56	8.05	61.05	1.83
3/17/00 10:40:00 AM	2.54	8.00	61.05	1.16
3/17/00 10:45:00 AM	2.52	7.99	61.05	1.16
3/17/00 10:50:00 AM	2.52	7.96	61.05	0.98
3/17/00 10:55:00 AM	2.52	7.96	61.17	1.04

Figure 4. Washington, DC Remote Monitoring Web Interface

Case Study Summary: The average capital cost for implementation of the remote monitoring unit was estimated to be approximately $20,000 per location. This included purchase of instrumentation, additional SCADA hardware, custom web application development, and installation/setup.

Periodically, there were accidents and malfunctions which rendered the monitoring systems to be inoperative. In addition, during the initial phases, frequent changes in DCWASA support personnel adversely affected some of the troubleshooting activities. Also, the initial data obtained from the remote monitoring network could not be validated due to the lack of calibration records. However, once the personnel issue was resolved and a recordkeeping checklist was developed, the data stream was more consistent. Meckes, et al. (1998) presents a more detailed account of this implementation.

Case 3: T&E Facility Sensor Network Initiative
After 9/11, there has been a tremendous increase in the availability of technologies that are related to RWQM. EPA is in the process of evaluating the use of commercial sensors to determine which monitoring parameters are best suited for rapid contaminant detection in a drinking water distribution system. For this purpose, a suite of sensors have been connected to a distribution system simulator (DSS), test

"contaminants" are injected into the system and the specific sensor responses are evaluated. The pilot-scale DSS system is located at the T&E Facility in Cincinnati, Ohio. Hall, et al (2005), presents in detail the ongoing EPA-NHSRC's research on monitoring parameters for rapid contaminant detection in drinking water distribution systems.

Cooperative research and development agreements (CRADAs) allow vendors to access EPA laboratories, personnel, equipment or services for testing and evaluation. During 2003 and 2004, EPA acquired, through CRADAs or outright purchases, a variety of sensors for water quality monitoring. For the purposes of testing and evaluation, it was essential that the suite of sensors be integrated into a centralized data collection unit. The I/O interfaces of these sensors were either analog 4-20 mA signal or digital RS232 standard signals. Shaw selected NexSens (www.nexsens.com) iSIC data logger and iChart software for integrating the data from these sensors. The iChart software came with a suite of readily available drivers for many of these sensors, which made the integration process easy. Each sensor suite is connected to the iSIC datalogger and to the receiving computer either directly or via radio modem depending upon the location. Figure 5 shows an operator screen shot for the iChart interface.

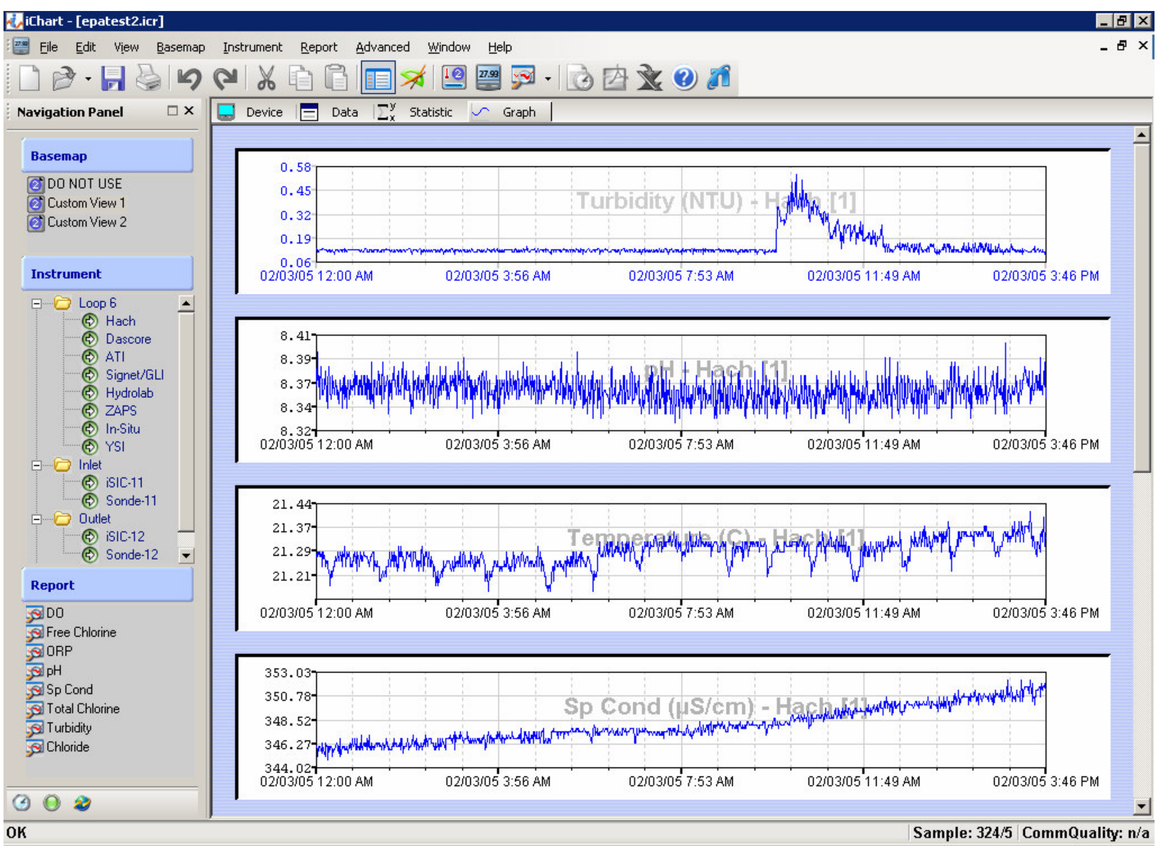


Figure 5. iChart Operator Interface

Case Study Summary: The capital cost for purchasing and implementing the monitoring system (excluding the cost of instrumentation and the setup of the various instruments) is approximately $25,000. Since the T&E Facility is a well staffed and maintained facility, the system has worked flawlessly since implementation. Keeping all the instruments properly calibrated for frequent testing has been the biggest challenge. Soon after the testing began, it was apparent that the management of the data was becoming fairly complex. Therefore, EPA funded the vendor to develop an Open Database Connectivity (ODBC) driver for iChart software so that the data could be directly transported to a relational database. Also, additional graphing capability had to be built for test data manipulations. This highlights the fact that data processing needs should be evaluated prior to making appropriate software selection.

Case 4: PureSense CRADA Initiative
In 2004, EPA initiated a CRADA effort with PureSense (www.puresense.com). Under this CRADA, EPA is evaluating the PureSense technology at the T&E Facility in Cincinnati, Ohio. The PureSense system consists of four key components: the PureSense iNode™, the PureSense iWatch™, the PureSense iServe™ and PureSense AlertNet™. The Puresense system collects data in real time and continually performs analysis to deliver the programmed system information. The PureSense iNode™ is a remote data communication device that uses cellular and Wi-Fi services to both collect monitoring data and send commands to remote sensors. The PureSense iWatch™ is an Internet-based hosted data management system that enables the integration of disparate data sets, including data from other remote online sensors. The PureSense iServe™ performs the automated analysis of real-time data to generate the information that users may need to manage their systems. The PureSense AlertNet™ sends automated alerts to communicate critical and actionable information to the users. Figure 6 depicts the iNode unit.

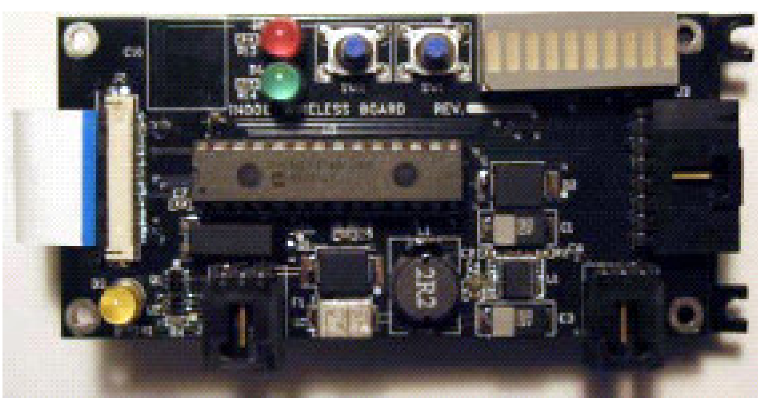


Figure 6. iNode unit

The PureSense system at the T&E Facility is configured as follows: a single multi-sonde probe is connected directly to an iNode unit. The iNode then transmits the data using Very High Frequency (VHF) radio modems to a local gateway where the data is then transmitted via an Internet connection to the PureSense iWatch system. The use of VHF in this application was necessary as the initial installation using a cellular service was not stable due to weak signal strength. However, this configuration provides an added benefit since the two-way communication between the sensor and the iNode can be directly observed from the locally installed gateway (computer) interface. Real-time data from other sensors rack collected through the NexSens system is transmitted separately to the iWatch node (via the existing Internet connection).

Case Study Summary: At the time this manuscript was written, the system had just become fully operational. There is not enough information available at this time to present any evaluation.

Summary & Conclusions

The case studies illustrate the fact that each site may require a different monitoring solution, depending upon the study objectives, existing infrastructure, instrument requirements and available funding. Haught and Panguluri (1998) discuss the various selection and implementation criteria for RWQM in small drinking water systems. Panguluri, et al., 1999, present an overview of site-specific needs that should be evaluated for implementing a RWQM in a distribution system. Real-time RWQM is a very helpful tool to effectively detect and respond to water quality changes. However, it is important that the instruments are well maintained and integrated into a network to realize the full potential of RWQM.

Real-time RWQM can also be used to fulfill some of the routine monitoring requirements of the Safe Drinking Water Act and its Amendments. Proper implementation and maintenance of these systems would enhance their ability to detect water quality changes and effectively control the impact of such an event. The overall expected benefits from an appropriately designed and successfully deployed RWQM include:

- enhanced security and control,
- improved water quality,
- regulatory compliance, and
- reduced overall maintenance costs

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References

Clark, R.M., Rizzo, G.S., Belknap, J.A., Cochrane, C. 1999. “Water quality and the replacement and repair of drinking water infrastructure: the Washington, DC case study,” Proceedings of the Journal Water SRT – Aqua Vol48, No. 3, pp.106-114, 1999.

Hall, J., Zaffiro, A., Haught, R., Herrmann, J., Krishnan, R., Kefauver, P., Marx, R., 2005. “Parameters for Rapid Contaminant Detection in a Water Distribution System,” Proceedings of AWWA 2005 Water Security Congress, Oklahoma City, Oklahoma, April 2005

Haught, R. C., and Panguluri, S., 1998. “Selection and management of remote telemetry systems for monitoring and operation of small drinking water treatment plants,” Proceedings of NSF International Symposium on Safe Drinking Water in Small Systems, Washington, DC, May 1998.

Meckes, M. C., Mattingly, J. S., Papadopoulos, G. J., Dosani, M. and Panguluri, S., 1998. “Real time water quality monitoring of a water distribution system using remote telemetry,” Proceedings of AWWA Distribution System Symposium, Austin, Texas, September 1998.

Panguluri, S., Haught, R. C., Meckes, M. C., and Dosani, M.,1999. “Remote water quality monitoring of drinking water treatment systems.” Proceedings of AWWA Water Quality Technology Conference, Denver, CO, November 1999.

Panguluri, S., Krishnan, R., Garner, L., Patterson, C., Lee, Y., Hartman, D., Grayman, W., Clark, R., Piao, H., 2005. “Using Continuous Monitors for Conducting Tracer Studies in Water Distribution Systems,” Proceedings of EWRI World Water & Environmental Resources Congress, Anchorage, Alaska, May 2005.