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Remote Monitoring of Hydroprojects: Design, Installation, and Verification of Remote Monitoring Systems

by John W. Lemons, Michael C. Vorwerk, Joe H. Carroll, and William E. Jabour

Purpose

This technical note describes methods for monitoring water quality at hydroprojects. A water quality manager can apply the techniques described herein to design a site-specific water quality monitoring system that provides information for water quality problem-solving.

Background

Remote monitoring systems are important tools for lake managers, hydropower operators, and others concerned with hydroproject-influenced water quality. Remote, automated water quality monitors provide temporal data sets that are used for determining water quality trends under various operational and seasonal conditions. Data collected via remote monitors can be used to identify areas of management concern and are valuable for developing and calibrating predictive models.

The usefulness of data collected by remote monitors depends on how effectively the sampled water represents the parameters of concern for the area. Many variables affect the representativeness of monitoring locations, including lateral, longitudinal, and vertical heterogeneities in the water; equilibration times of the water quality instruments; and hydrological, biological, and physicochemical processes within the sample areas.

This technical note describes the processes involved in designing and deploying automated, remote monitoring systems and analyzing the data they generate. It is not intended as an exhaustive review of the subject, but highlights the more critical steps in developing monitoring systems. Where appropriate, case studies are cited.

Although the primary purpose of this technical note is to describe the installation and maintenance of *automated* remote monitoring systems, the ideas presented have application to manual sampling programs as well. The ultimate goal of any monitoring program should be to collect pertinent, representative data. The flow diagram presented as Figure 1 is a generic guideline for implementing a monitoring program. It is meant to organize the ideas that are discussed in this technical note, and not as a “recipe” for designing and installing automated monitors.

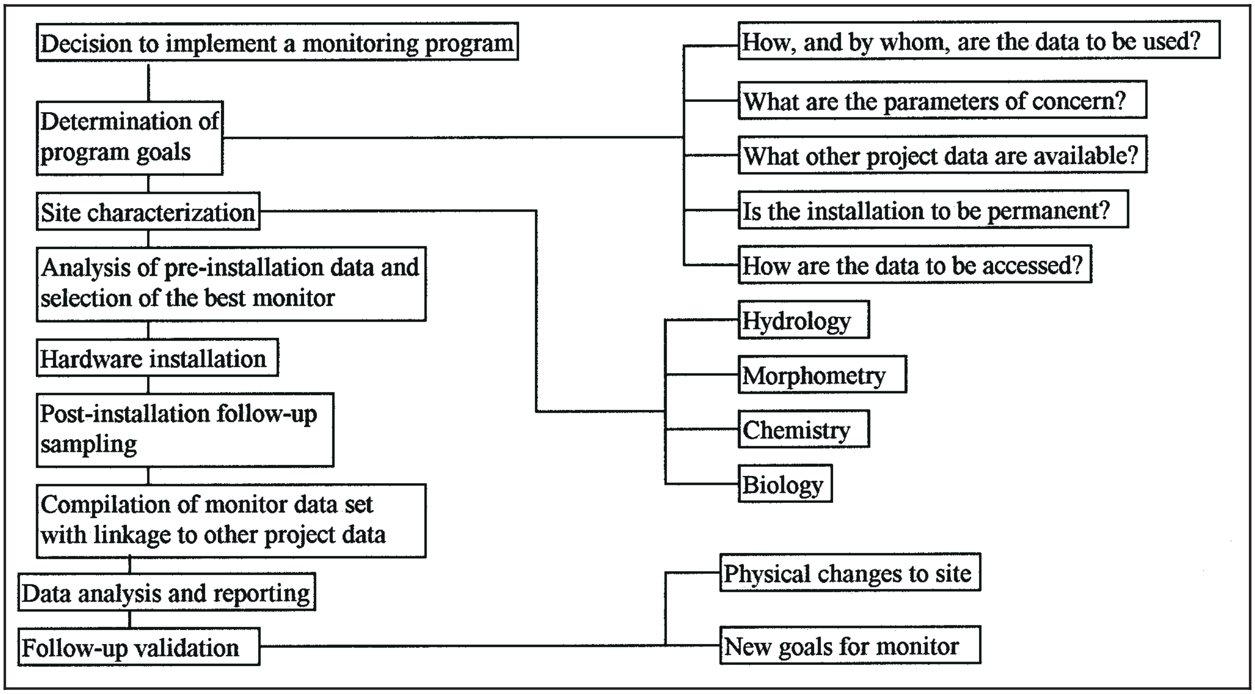


Figure 1. Flow diagram for water quality automated monitor system design

Preinstallation

Goals

The first step in implementing any monitoring program is to determine its goal. Potential questions may include the following:

- Why are the data needed?
- Who will need access to the data?
- Are the data needed real-time or at some other level of frequency?
- What type of sampling interval will be required?
- What is the time frame from data collection to data reporting?

The objective at this stage is to determine what will be expected of the monitoring program. The answers to these questions influence subsequent decisions regarding equipment and location, and are necessary to prevent the implementation of what has been characterized as a “data-rich but information-poor” monitoring program (Ward, Loftis, and McBride 1986).

The answers to questions such as those listed above help managers determine if automated monitoring is needed to attain the goal of the program. Grab sampling may be better suited to a temporary monitoring program or one having a long sampling interval. In a lengthy or permanent installation or one requiring a short sampling interval, grab sampling quickly becomes cost prohibitive, and automated, remote monitors are both more appropriate and effective.

Site Characterization

After the decision to install an automated monitor has been made and the water quality parameters to be measured have been identified, the next step in the preinstallation process is to characterize the study area. This may be accomplished with short-term manual sampling. A working knowledge of the parameter(s) to be measured is essential to identify the most representative deployment site. In addition, the hydrology, morphometry, flow patterns, climate, chemistry, and biology of the site determine the optimum monitoring location. Characterization of the area should include identifying any lateral, longitudinal, and vertical heterogeneities. Sampling should be conducted under the conditions that will be experienced by the monitor; that is, if the monitor is to measure hydropower release water quality, then preinstallation sampling should be conducted during release periods.

Four general areas need to be considered in deploying hydroproject monitors: the forebay, the area within the hydroproject's physical structure, the tailrace, and the tailwater. Preliminary areas of study would depend on the monitoring objective. For example, the preliminary study area for a release water quality monitor for a hydropower dam may be the tailrace. An installation for monitoring the effectiveness of water quality improvement measures may be located upstream for pretreatment conditions and downstream for posttreatment conditions. A monitor for evaluating hydroproject operation on downstream habitat may be located in the tailwater some distance downstream of the project.

Regardless of the monitoring program's goal, certain locations will probably be apparent as logical starting points for consideration. Secondary consideration may focus on accessibility for calibration and maintenance; however, the most convenient location is not always the most representative one, and greatest emphasis should be placed on data quality.

Many relatively inexpensive water quality instruments that are capable of internally storing data are commercially available. These instruments allow project planners to experiment with various site locations via short-term deployments. These data can then be combined with grab data to provide temporal and spatial representations of the daily and seasonal variations for the area. Careful analysis of the available data is crucial during the preliminary stages of developing a monitoring program, to prevent future problems regarding data validity and defensibility. Often, a logical location for the monitor may be apparent; however, peculiarities of the site, particularly with respect to flow patterns, may preclude installation of the monitor in this area. The logical location provides a starting point for the validation stage of the preinstallation process.

Conservative water quality measures (such as temperature or specific conductance), which are not easily affected by biota, may be used as "tracers" to track parcels of water. Comparing conservative parameters cannot conclusively validate the representativeness of a potential location but can eliminate a nonrepresentative one. Several case studies will be presented to further develop these ideas.

Ice Harbor Example

Ice Harbor Dam is located on the Columbia River immediately upstream of McNary Dam and immediately downstream of Lower Monumental Dam along the Oregon/Washington border (Figure 2). Spilling operations conducted for fish passage, as well as flood control, often lead to dissolved gas concentrations that are supersaturated with respect to the atmosphere. Supersaturation of dissolved gases in water may have severe detrimental impacts on fish. As a result, extensive studies to measure dissolved gas concentrations and dynamics have been conducted at the U.S. Army Corps of Engineers projects in the Columbia River Basin.

Data gathered during transect studies in support of the total dissolved gas monitoring program illustrate how data gathered for other purposes can be used to plan an automated monitor installation. The results from these lateral transects are displayed in Figure 3. Two monitors were previously installed in the Ice Harbor tailwater (indicated as the labeled points in Figure 3); however, they were neither designed nor intended to reflect the extent of the variation in total dissolved gas concentrations in the area.

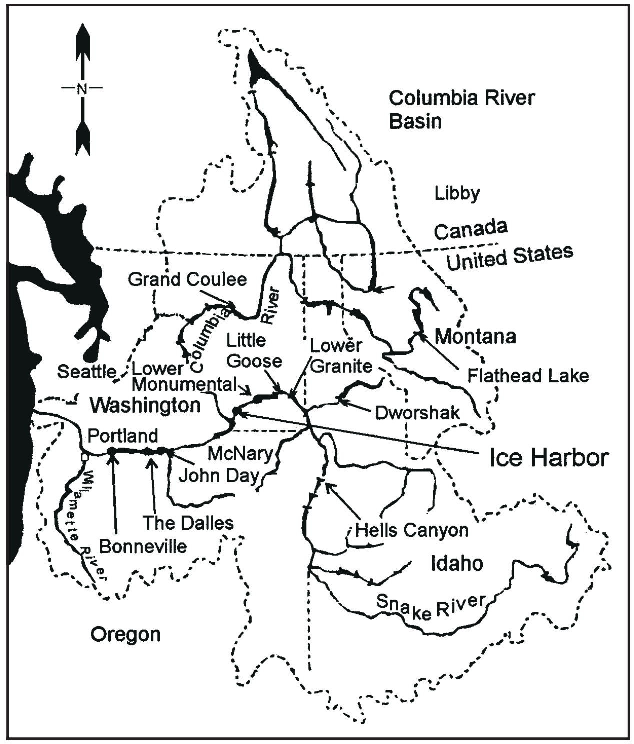


Figure 2. Columbia River basin

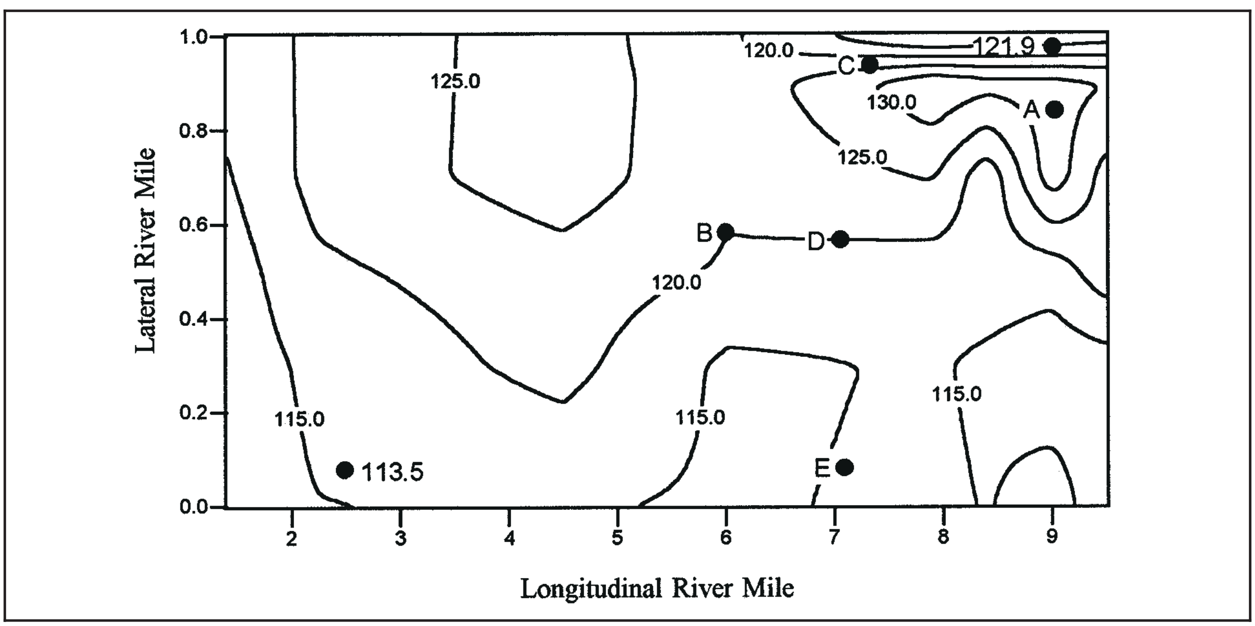


Figure 3. Contour plot of Ice Harbor total dissolved gas transect data

The goal of the monitoring program dictates the deployment design. If the goal of the program were to measure critical total dissolved gas concentrations, then a single monitor near the area of highest total dissolved gas concentrations may be sufficient (point A, Figure 3). If concerns were for the mean total dissolved gas concentrations for the area, a single monitor located near midchannel may be appropriate (point B). However, if the program's goal were to map the total dissolved gas concentrations for the tailwater, a single fixed monitor would be inappropriate, and an alternate plan would have to be developed, involving numerous fixed positions (for example, points C, D, and E in Figure 3). This example highlights the need for good planning and preinstallation sampling in the early stages of developing a monitoring program.

Monitor Equipment

Hardware

Data requirements and available funding will dictate the hardware selected for the monitor installation. Water quality instruments equipped to measure most parameters of concern are commercially available. However, these instruments vary with respect to accuracy, precision, data presentation, and expense.

Consideration should be given to the design limitations of the instrument when selecting water quality equipment. For example, if the purpose of the monitor were to record dam release dissolved oxygen (DO) concentrations for mitigation and the requirement was to remain within 0.5 mg/L of a target DO concentration of 5.0 mg/L, then oxygen probes with an accuracy of less than ±0.5 mg/L would be inadequate.

Deployment/retrieval monitoring is used for thermal monitoring and special studies at Richard B. Russell Reservoir on the Savannah River. For this application, water quality instruments with data logging capabilities are deployed, and the data are retrieved later. If data are needed real time, a computer/modem system can be used. Relatively inexpensive, reliable water quality sondes interfaced with a personal computer/modem can be obtained for less than $5,000 (1996). Commercially built data collection platforms are available, and most can be tailored to fulfill the design requirements of the site. With computers and other data platforms, the operator achieves greater flexibility with respect to how the data are stored and accessed.

As a general rule, equipment should be selected based on the following factors:

- Instrument accuracy, precision, and resolution desired.
- Instrument deployment requirements.
- Deployment method (deploy/retrieval, computer/modem, incorporation with existing equipment, etc.).
- Fouling concerns and required calibration and maintenance regimens.
- Instrument expense and monitoring program budget constraints.

Software

Off-the-shelf data collection platforms include software or programming instructions that allow them to be configured to communicate with a variety of instruments. Additionally, personal computer communications packages can communicate with water quality equipment and store and transmit data; however, design flexibility is generally less. BASIC software programs (Microsoft Corporation) can be developed as an alternative to off-the-shelf communications packages and afford the user control over communication protocol and data storage format (Vorwerk, Moore, and Carroll 1996). The data storage format is an important design consideration because it facilitates integration of the final monitor data set with other pertinent data sets (for example, hydroproject operation data) and allows real-time data presentation to better fit project requirements.

Location Validation

Postdeployment data validation is a crucial final step in the monitor installation process, as this evaluates the representativeness of the monitor location. Although postvalidation may seem unnecessary if care was taken during preinstallation sampling, the installation itself may have a measurable impact on how the water quality is represented by the equipment. A dam release monitor could be installed in the tailrace of a project, with water pumped to it from an area determined to reflect the area of management concern during generation periods. Subsequent calibration visits may confirm that the sensors are operating well within the manufacturer's specifications. From this, it may be assumed that the monitor is accurately representing the parameters of concern. If, however, the water were being warmed as it passed from the tailrace through the pipe to the monitor, it would actually reflect the water within the sample chamber and not the tailwater. Likewise, changes in the physical structure of a site or introduction of water quality improvement measures may alter the representativeness of an established monitor. These concerns must be addressed via postdeployment verification studies.

Data Interpretation

After the monitor is in place and recording representative water quality data, the next concern is how the data should be used. Raw monitor data are of little use if they are not presented in a manner that facilitates interpretation. Off-the-shelf spreadsheet and database programs such as Excel (Microsoft Corporation), SAS (SAS Institute, Inc.), and SPSS (SPSS, Inc.) expedite data analysis and reporting by facilitating the linkage of monitor data with other project data. Data must undergo vigorous error-detection and filtering processes prior to analysis. Raw monitor data must be edited to remove machine characters, usually artifacts of the data collection software, before they can be properly imported into analysis software packages.

Water quality sensors typically exhibit some degree of response drift as a result of the sensors' chemical reactions (for example, oxidation of DO probes). Sensor drift can also result from biological activity. For example, algal growth on DO probes may decrease the reported DO concentrations by inhibiting oxygen diffusion across the sensors' membranes. Routine calibration may reduce the degree of sensor drift; however, postdeployment corrections for sensor drift can further improve data accuracy.

For the Savannah River monitors where dam release DO concentrations are the primary concern, frequent calibration visits (at least once a week) during summer months reduce the degree of drift resulting from biological activity. Calibration drift is assumed to be linear, which allows corrections to be based on the degree of drift per hour for the period between calibrations. Each reading is then corrected for drift by adding or subtracting this value to it, with the drift at the time of the first calibration being equal to zero. The causative factors leading to drift vary depending on the site, the parameters being measured, and the equipment being used. (The instruments used for monitoring the Savannah River hydroprojects have a resolution of ±0.2 mg/L; therefore, drift must be >0.2 mg/L before corrections are made.) Drift must be determined for each site and should be factored into the data set prior to its incorporation with other project data (Whitfield and Wade 1993).

Data should be incorporated with other project data prior to final analysis. By combining the available data into a comprehensive project data set, "windows of reflectiveness" can be better identified and data interpretation will be more accurate. For example, the release monitor at Hartwell Dam, a Corps project located on the Savannah River (Figure 4), is deployed in the tailrace (Figure 5). It consists of a submersible pump and pipeline to pass water from the tailrace to a water quality sonde in a nearby building. Because it samples water from the tailrace, the monitor represents release water quality only during periods when Hartwell Dam is releasing water. Data for periods of nonrelease reflect the tailwater conditions only in the area localized around the sample intake line.

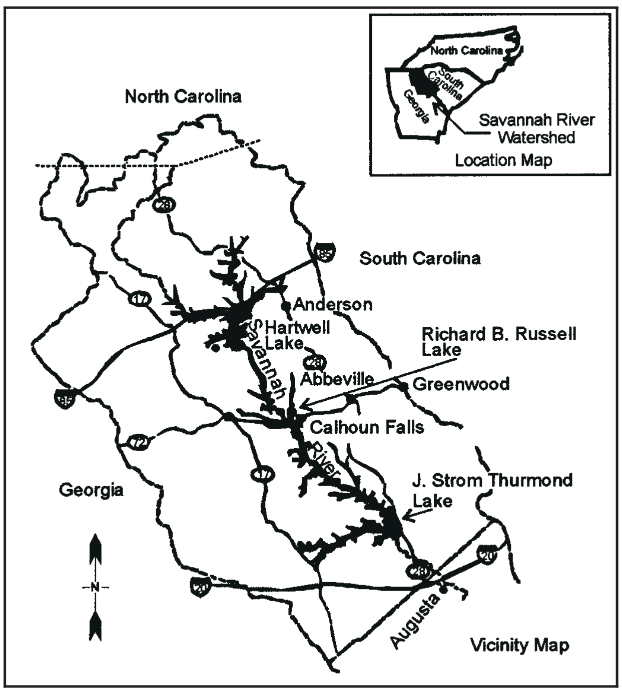


Figure 4. Savannah River basin

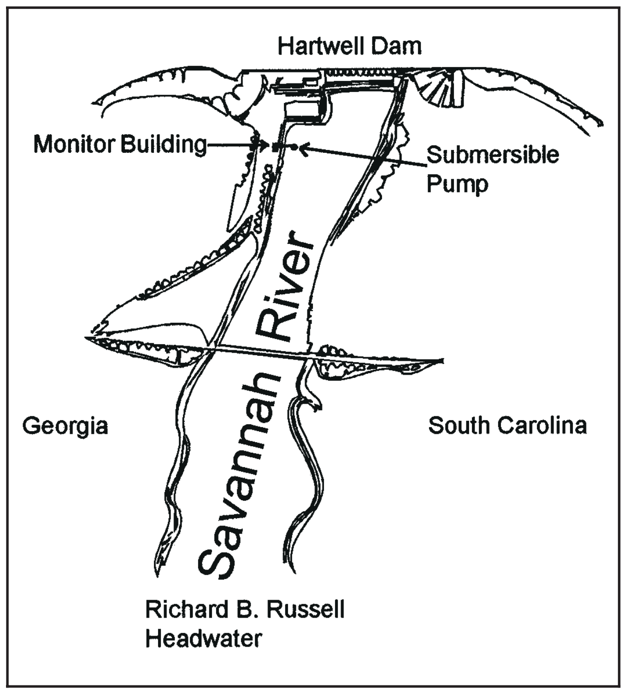
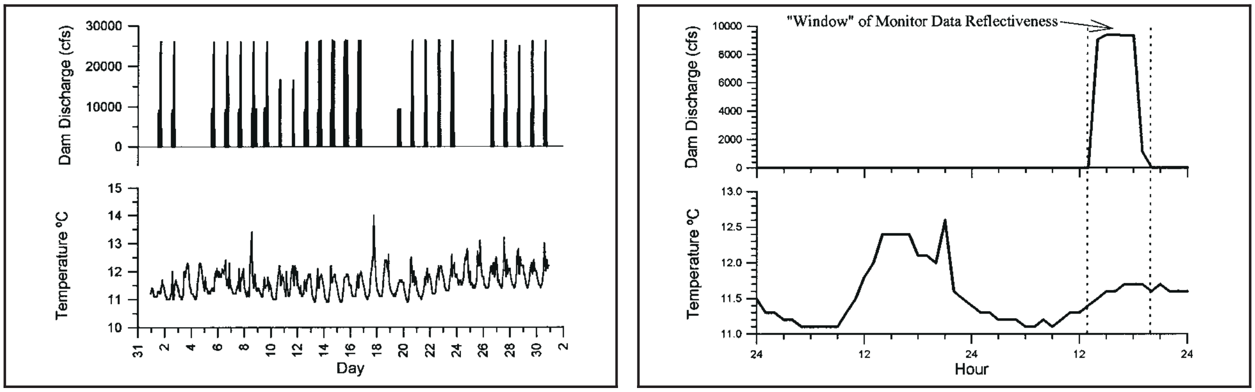


Figure 5. Hartwell Dam release monitor

Representative periods are readily apparent when both the monitor and operations data are incorporated (Figure 6). Data falling outside the "window" that defines representative periods, generally resulting from changes in project operations, are not included in final reporting as they are not reflective of the parameters of concern.



a. May 31-June 30, 1995 **b. June 18-19, 1995**

Figure 6. Hartwell Dam operation and release temperatures

A large equilibration period (longer than 20 minutes) may be required by some instruments before accurate measurements are possible. This is especially true for gas measuring instruments such as DO or total dissolved gas sensors. Instrument and design limitations such as these should be considered during the final analysis, particularly in situations where rapid changes are experienced.

Case Studies

Continuous, automated monitors are presently being used by the Corps to monitor the release water quality of the hydropower projects on the Savannah River forming the Georgia/South Carolina border, the tailwater conditions during periods of no release at St. Stephen Dam on the Cooper River in South Carolina, the effectiveness of turbine venting procedures at Bull Shoals Dam on the White River in Arkansas, the total dissolved gas concentrations at various projects throughout the Columbia and Snake River systems, and at other projects throughout the United States. The monitoring goals, parameters of concern, and available funding vary significantly from project to project; however, the overall goal—to collect representative data—is common to all. The case studies discussed below demonstrate some of the techniques that have been used to ensure sample reflectiveness at various projects.

Richard B. Russell Dam

Richard B. Russell Dam is a Corps generation/pumped storage project located on the Savannah River between the Corps reservoirs of Hartwell and J. S. Thurmond (Figure 4). The Russell monitor measures release water quality for the purpose of maintaining a release DO concentration of 6.0 mg/L. The Corps operates an oxygen injection system in Russell forebay to maintain this concentration during the summer months when hypolimnetic DO concentrations approach anoxia. The 6.0 mg/L DO concentration requirement applies to the release and not to the tailrace or tailwater conditions; therefore, the sampled water must reflect the Russell release and not the conditions of the Thurmond headwater.

The monitor was originally located in the tailrace, where follow-up studies later demonstrated that flow patterns caused the monitor to be less reflective of Russell Dam release water than the ambient tailwater conditions (Figure 7). Temperatures and DO concentrations were measured at various points in the tailrace and the dam, and were compared with the temperatures of the water sampled by the original tailrace monitor. For comparison, temperature was selected over DO, since it was a more conservative parameter and as such was deemed to be less susceptible to exterior influences (Vorwerk and Carroll 1994).

The lacustrine tailwater region at the Russell project prevented the deployment of the tailrace monitors that had been successful for other Savannah River monitors. A mixing chamber system containing a water quality sonde was implemented such that water passage was controlled by solenoid switches. The switches were configured to restrict water passage to periods of turbine operation. This system (Figure 8) allowed representative water to be sampled with a single in-dam unit. While the monitoring goal (to measure release temperatures and DO concentrations) was the same for the Savannah River monitors, specific characteristics unique to each site had to be considered in determining where to locate the monitors.

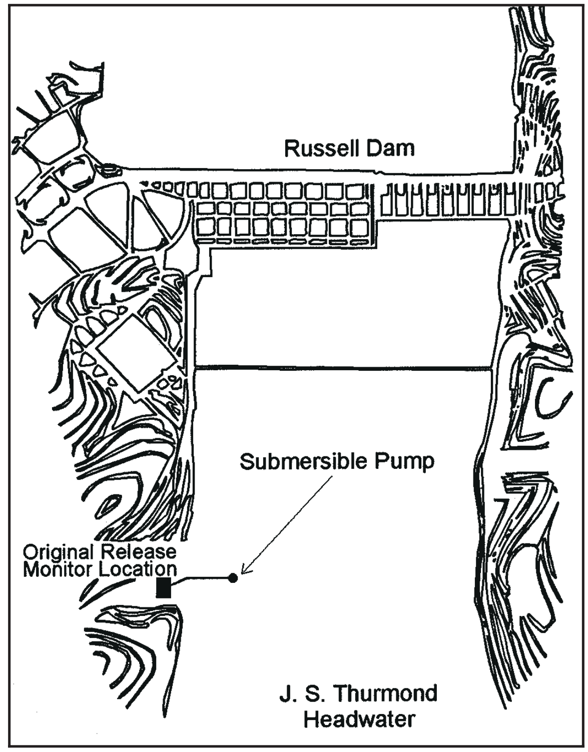


Figure 7. Richard B. Russell original downstream monitor

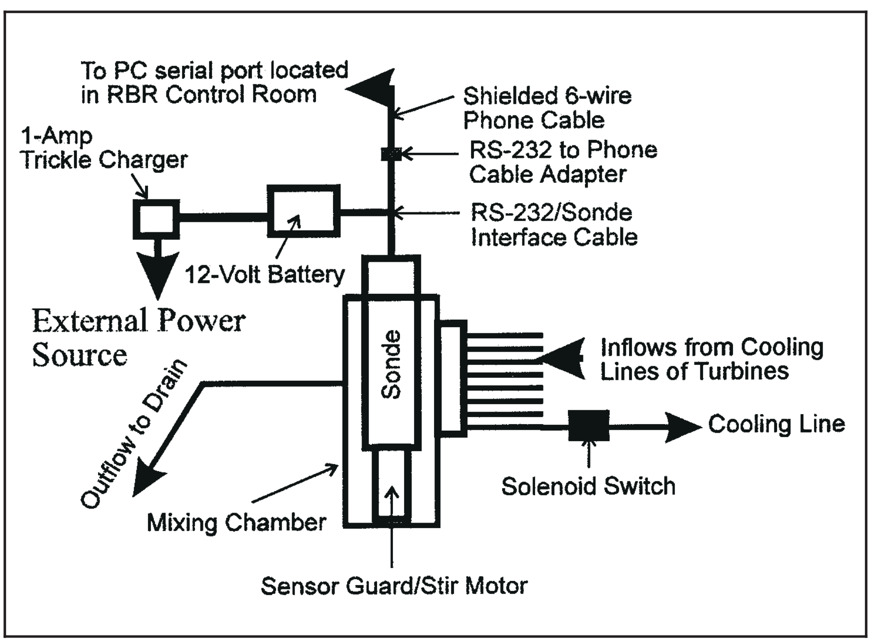


Figure 8. Richard B. Russell piping gallery monitor

Bull Shoals Dam

At Bull Shoals Dam on the White River, Arkansas (Figure 9), the goal for the monitoring program was to determine the efficiency of turbine venting operations conducted in order to increase downstream DO concentrations. Two of the seven Bull Shoals units had turbine venting capability, and penstock monitors had previously been installed to measure the pretreatment water quality. In situ sampling demonstrated that locating the posttreatment monitors in or near the draft tube exits would best represent the release water quality. The draft tube access ports were chosen for their proximity to the draft tube exits and because they afforded easy access for calibration and maintenance. The concern was to isolate the monitors from the release of the other units to accurately identify the DO increase resulting from individual turbine venting.

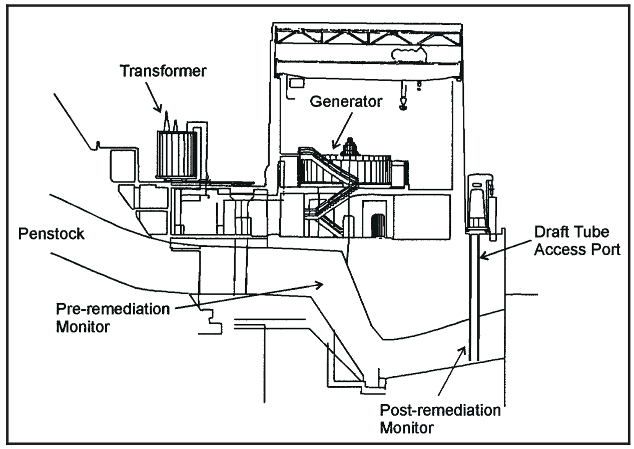


Figure 9. Bull Shoals powerhouse, White River, Arkansas

St. Stephen Dam

St. Stephen Dam is a Corps power project located near St. Stephen, SC. The dam rediverts water from Lake Moultrie back to the Santee River (Figure 10). A fish kill during spring 1991, which was attributed to insufficient DO concentrations during nonrelease periods, prompted evaluation of the DO dynamics surrounding the project. It was determined that releasing water when the DO concentrations were low caused dilution of the poorly oxygenated canal water with well-oxygenated reservoir water and prevented DO-related fish kills. The monitor program implemented at St. Stephen was designed to measure the tailrace DO concentration during periods of no release. Real-time monitoring data were used to indicate when critically low DO concentrations occurred so water could be released, thus minimizing the potential for a fish kill. Manual sampling indicated that the monitor should be placed near the bottom of the canal and near the dam, since anoxic conditions were realized in these areas first. A monitor attached to the wingwall downstream of the dam (Figure 11) represented “worst-case” conditions (Vorwerk and Carroll 1995).

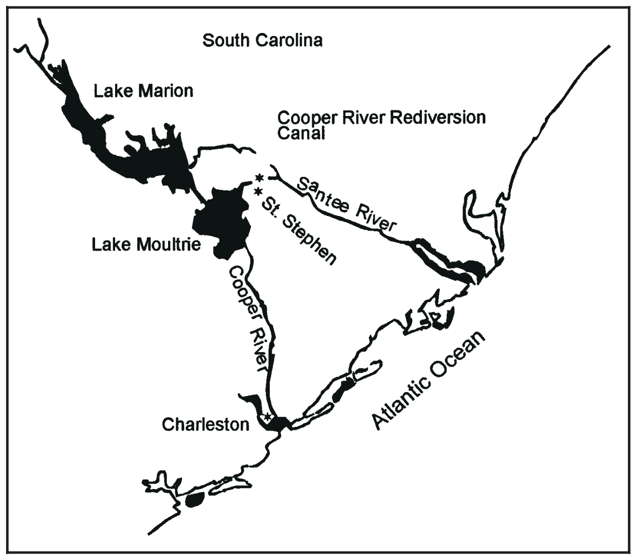


Figure 10. St. Stephen Dam vicinity map

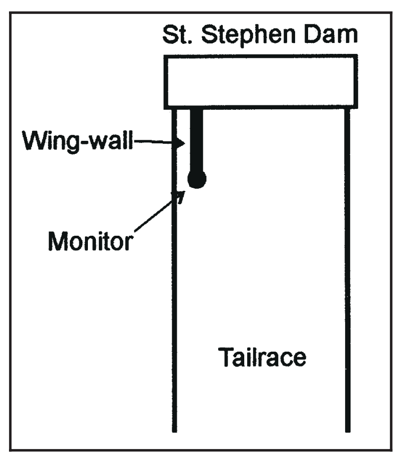


Figure 11. Schematic of the St. Stephen Dam tailrace monitor

Conclusions

Remote, automated monitors are valuable water management tools. Large gains continue to be made with respect to water quality instrumentation, which reduces the need for costly equipment and labor-intensive sampling regimes. Too often, however, the assumption is made that deployment of a fixed monitoring system is sufficient for generating the desired data with little (if any) forethought devoted to outlining the goals of the monitoring program. Without clear goals, it is impossible to design a preinstallation program to determine the most appropriate location for the fixed monitor. Data density without data quality is of no use to project managers.

By clearly defining the objectives of the monitoring program prior to beginning data collection, and characterizing the study site with respect to the physicochemical and biological attributes of the system, it becomes possible to design and install an automated, fixed location monitor that supplies data representative of the parameter(s) of management interest. Data should be analyzed as they are collected, especially during the critical preinstallation sampling, as it may be necessary to redesign the sampling approach to better address the questions to be answered or address new questions that arise during the study.

Incorporating all available data (including project operations, meteorological, and historical data for the project of concern) helps managers to address issues and collect data that may require intensive sampling efforts to obtain. Valuable information may be realized from historical data sets that may have been neglected otherwise. The monitoring program should remain focused on the objectives that were outlined at its inception.

Periodic evaluation of the monitor's performance should be a routine component of the analysis process, especially when structural or operational modifications to the project or monitor occur. Reevaluations of this nature are imperative for ensuring representative data collection.

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Point of Contact

For additional information, contact Mr. John W. Lemons (lemons@gorge.net), Dr. Michael C. Vorwerk, or Mr. Joe H. Carroll at the U.S. Army Engineer Waterways Experiment Station (WES), The Dalles Dam, (541) 298-6656, or Mr. William E. Jabour at the WES Trotters Shoals Limnological Research Facility, (864) 447-8561.

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