Water Quality Technical Note AM-01
January 1996

US Army Corps
of Engineers

Evaluation of Methods for In Situ Monitoring of Releases from Hydropower Projects

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Purpose

This technical note describes and qualitatively compares methods for in situ monitoring of release water quality from hydropower projects.

Background

The areas immediately downstream of hydropower projects are of extreme importance for water supply, recreation, navigation, and aquatic habitat. Increased environmental awareness and concern regarding the impacts of hydropower releases on downstream water quality have resulted in the need for increased monitoring. However, these same areas can present difficulties in effective and representative monitoring. To address these difficulties, a variety of specialized monitoring techniques are presently in use by the U.S. Army Corps of Engineers. The resulting data aid resource managers and hydropower operators in managing projects to minimize detrimental downstream environmental effects while maintaining optimum generation schedules.

Many factors must be considered when designing a hydropower tailrace sampling scheme. Sampling falls in two broad categories—manual and automated. Manual sampling, the most common type of data collection, includes all modes of sampling conducted by individuals with hand-operated equipment. Automated methods of sampling require equipment that can log real-time data independent of a human operator. A description and evaluation of both categories of sampling currently in use will be presented in this technical note.

These procedures have been used during evaluations of releases from Savannah River reservoir projects, St. Stephens Powerhouse, Bull Shoals Dam, sites within the Charleston, Little Rock, and Tulsa Corps districts, and other sites throughout the country.

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The first step in monitoring water quality is gaining an understanding of the gradients and dynamics of the parameter of interest. Some parameters, such as temperature, are relatively conservative and change relatively slowly. Others, such as dissolved oxygen, can change quickly as the result of mechanical aeration, moderately fast due to biotic activity and chemical oxygen demand, or slowly from diffusion and temperature-related effects. Thus, the effectiveness of a monitoring location in meeting the needs of a manager depends greatly on the dynamics of the parameter of interest.

Typically, the principal parameters of concern in hydropower release water quality are temperature and dissolved oxygen concentration. Other parameters sometimes of interest include specific conductivity, pH, and turbidity. Both manual and automated sampling methodologies are effective in monitoring each of these parameters. In many situations, both methods are necessary to fully evaluate the release from a project.

Other important considerations include safety of technicians during calibration and use of the system and cost. Ideally, the system should be constructed with minimal cost, take advantage of the natural features of the dam and tailrace, and incorporate readily available off-the-shelf equipment and supplies.

A number of manufacturers offer equipment designed for water quality sampling. Equipment ranges from a basic instrument measuring only temperature and dissolved oxygen concentration with no logging capability, to extremely sophisticated models offering multiparameter monitoring capabilities that can be deployed remotely and can log data for extended time periods.

Another critical decision is to determine whether a manual or remote sampling strategy will be most beneficial. Through an examination of both methods, one can decide whether one, or a combination of both, is most appropriate for the specific site and questions to be resolved.

Manual Sampling

Description

Manual sampling, whether done from the shoreline, bridge, or boat, is the method employed by most individuals and resource agencies in determining water quality conditions in lakes, rivers, and streams. Advantages of manual sampling include the possibility of examining many regions of questionable water quality within a large sampling area. Manual sampling can determine the origin of detrimental water quality, refuges of good water quality, and the vertical, horizontal, and longitudinal progression of water quality zones. Also, a single sampling instrument can be used to determine water quality throughout the entire study area, which is beneficial to those with financial restraints.

The equipment used for manual sampling can be as simple as a hand-held thermometer, but typically a multiprobe water quality sonde is used to provide greater information. A multiparameter sonde can be used to profile multiple depths and provide near-instantaneous measurements of temperature, dissolved oxygen, specific conductivity, and pH. Equipped with a waterproof cable, the sonde is used to sample releases, tailraces, tailwaters, and reservoirs.

Prior to actual fieldwork, development of a carefully designed sampling plan is of the utmost importance. The plan should include a general survey of the study area, with more detailed work to answer the questions being considered. One component of a hydropower release monitoring study is to collect information on conditions in the upstream reservoir, typically through vertical profiling of the water column immediately upstream of the power intake openings. This allows the manager to examine the water quality conditions of water entering the dam, prior to release. Profiles along the upstream face of the dam will reveal any lateral heterogeneities in the lake that might result in variance in releases from different units.

Downstream manual profiling of hydropower releases can require different sampling approaches, depending on the information needs of the resource manager. Fixed-location temporal sampling requires the collection of multiple samples at a given point over a period of time. This affords an opportunity to observe rapidly occurring or short-term changes at a fixed location. Fixed-parcel temporal sampling requires the observer to sample the same parcel of water over time. For releases, this typically involves deploying an inert marker in the stream, then drifting along with the marker in a boat, and repeatedly sampling the same parcel of water over a period of time.

Spatial sampling involves the selection of stations in a longitudinal or lateral arrangement so that spatial patterns of water quality can be identified. This spatial array can then be sampled simultaneously to show the distribution of water quality throughout the region (a "snapshot" of water quality) or temporally to show the change or travel of some water quality parameter.

Successful Example

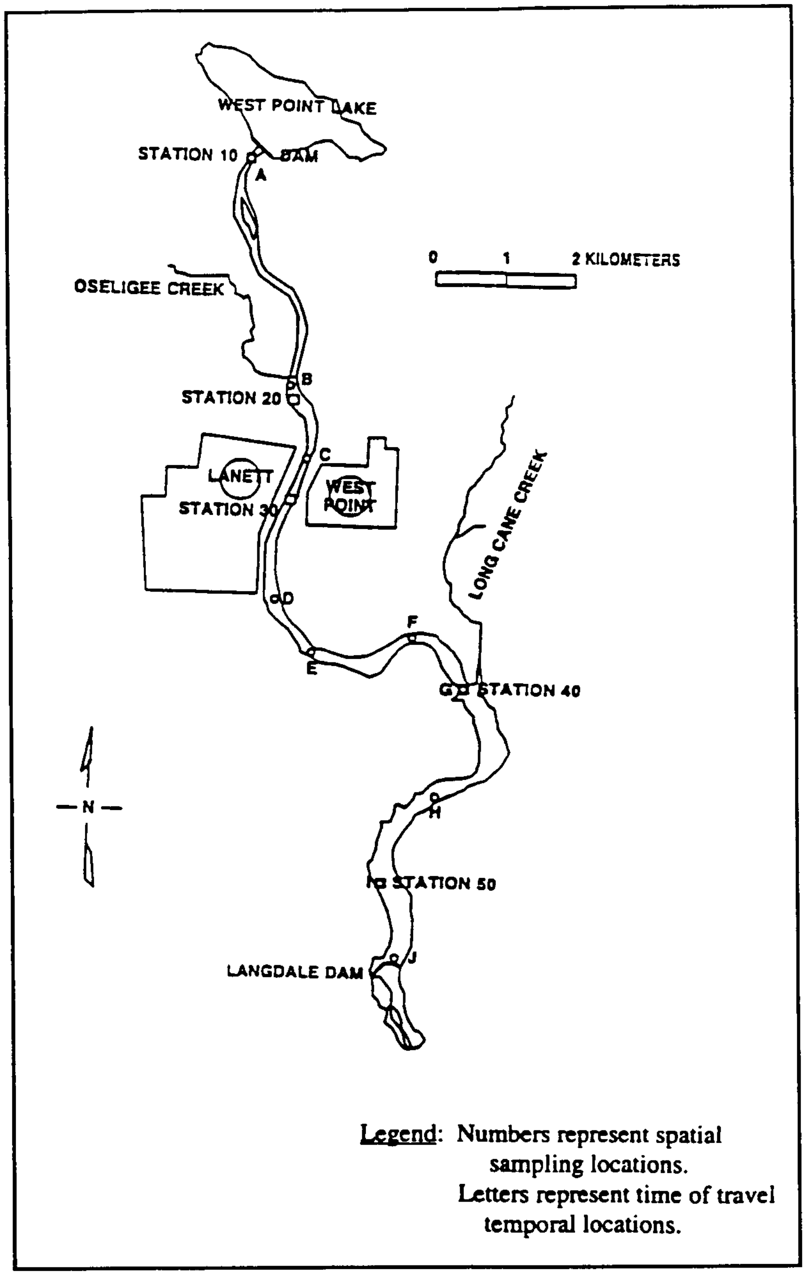
Work conducted in the tailwater downstream of West Point Dam, on the Georgia-Alabama border, illustrates the variety of sampling methodologies often necessary to answer release water quality questions (Figure 1). The study objectives were to determine the dynamics of water quality constituents in West Point Lake releases (Ashby, Kennedy, and Jabour 1992). Because of the variety and short time span of the studies required to explore the water quality of the release, it was determined that manual sampling was the best method for obtaining the required information. Automated sampling would be too costly and would not provide sufficient flexibility to conduct the various studies.

Vertical column water quality profiles of temperature, dissolved oxygen, pH, specific conductivity, and samples of other chemical parameters were collected in the West Point Lake forebay. These measurements provided information on inputs into the dam, and subsequently in the release and tailrace.

Individuals positioned at stations along the river sampled the tailrace prior to, during, and following release. Samples were collected at predetermined time intervals over the release cycle and included measurements of the above in situ parameters as well as water collection for chemical analysis. This sampling strategy provided "snapshot" records of water quality over the length of the tailrace, temporal records of change at each specific station with time, and temporal records of change of the spatial distribution of water quality. Thus, longitudinal and temporal trends in water quality were effectively monitored.

These samples showed the temporal and spatial degradation of water quality during release and the return to ambient conditions of water quality during release. The changes were primarily due to decreased dissolved oxygen concentrations in the water released from the dam, and subsequent re-oxygenation of water throughout the reach of the tailwaters (spatially) and throughout time (temporally).

A second team profiled surface-to-bottom water quality conditions along the downstream buoyline by boat, investigating lateral variability during release. Though the turbulent nature of tailwaters lends itself to being completely mixed, near-dam tailrace water quality often reflects lateral heterogeneities present in the forebay waters.



Legend: Numbers represent spatial sampling locations.
Letters represent time of travel temporal locations.

Figure 1. Manual sampling locations for Chattahoochee River below West Point Dam

Still another team conducted a time-of-travel study, drifting downstream at the same rate as a parcel of water. Through close interval sampling of in situ parameters and chemical constituents, changes within that parcel of water were recorded over time and distance.

The West Point Dam study illustrates several of the many release studies that can be undertaken using manual sampling techniques. The primary disadvantages of manual profiling are the labor-intensive nature of the sampling and the fact that the data are taken intermittently. Personnel must be present for data to be collected. When one is concerned with trends over a season, or a longer period, it is often difficult to obtain a sufficient number of manual observations. Manual sampling is of great value in determining water quality at multiple depths and locations, such as was desired in the above study. However, it is not the best tool if close-interval or nearly continuous sampling is desired.

Automated Remote Monitoring

Description

After determining the immediate area of concern within the tailrace through manual sampling, the resource manager will often require a continuous record of real-time water quality data as remedial procedures are employed to improve conditions. As these remedial procedures are implemented, a data set of ambient water quality conditions over time is required. Because of the close intervals required and the necessity of around-the-clock measurements, manual sampling techniques typically prove inadequate. In this situation, the best choice is an instrument that is capable of measuring the desired parameters and logs data remotely. The principal advantage to this design is in the ability of the instrument programmer to determine the desired sampling interval and the overall sampling period. Further, the operator can deploy and recover the data logger as a one-time occurrence, while still collecting a near-continuous data set. This freedom is extremely advantageous.

Successful Example

The tailrace of St. Stephens Powerhouse, located on the Cooper River Rediversion Canal in South Carolina, experienced midsummer fish kills during periods of nonoperation. These kills were believed to be caused by insufficient dissolved oxygen concentrations in the warm, nutrient-rich, and highly productive waters. Manual profiling was used to explore the dissolved oxygen dynamics in the tailwater. Data showed that anoxia developed within the near-dam bottom waters and progressed vertically and longitudinally, eventually encompassing the entire tailrace. This anoxia formation ultimately resulted in near-elimination of what had been a thriving tailrace fishery.

Analysis of the poor water quality conditions resulted in a monitoring and remediation plan. The tailrace was monitored daily via manual sampling from the wing wall near the powerhouse. When oxygen concentrations decreased to less than specified levels, the operator released the more highly oxygenated forebay water to flush the poor water from the canal. The volume of water released was equivalent to the volume contained in the canal, resulting in a near-complete replacement of water within the tailrace. The desired result was achieved; dissolved oxygen concentrations increased rapidly within the study area.

Manual sampling revealed that changes in dissolved oxygen concentrations followed a diel cycle, with concentrations reaching a maximum in midafternoon during peak photosynthesis and a minimum during the early-morning hours of minimal photosynthetic activity. Thus, the most critical periods occurred when personnel were unavailable for manual sampling. This resulted in the decision to install an automated remote monitor system.

The system was installed in a wet well on the wing wall of the powerhouse, with the water quality sonde approximately 1 m above bottom. The sonde was wired into the control room to a PC used to operate the sonde and to store data. Data were recorded at 1-hr intervals. Using this system, the nature of the diel fluctuations of dissolved oxygen dynamics was quantified. The resource manager found that daily fluctuations in dissolved oxygen concentrations were as great as 4.0 mg/L during periods of nonoperation, that is, periods where dissolved oxygen concentration was affected only by natural processes. This determination would have been difficult to achieve through manual monitoring techniques.

The continuous record of dissolved oxygen concentrations allowed the development of a remediation strategy dependent on the actual trends in dissolved oxygen and not on diel fluctuations. A plan was implemented to release lake waters when the dissolved oxygen concentration decreased to less than a specified concentration for a period of 8 hr or longer. This provided enough time for natural cycling to correct any deficit, while still remediating if a deleterious trend in water quality was detected. The details of this system are presented in Water Quality Technical Note CS-01 (Vorwerk and Carroll 1995).

This example shows how a single automated monitor system can be used to reflect the water quality of a large area. Because the area being sampled is at a fixed location and depth and comprises only a small percentage of the entire sample area, the utmost care must be used in determining the location and depth of the remote logger, that is, the representativeness of the sampling location. To determine trends over a larger areas, often more logging instruments must be used.

Representativeness of a Sample Location

Automated remote monitoring deployments inherently require a fixed sample location. Therefore, instrument location is critical to ensure that sampled water is representative of the body of water in question. Manual sampling procedures are most often used to determine this location.

Determining the representativeness of various potential monitoring locations is typically the most difficult task for a resource manager. Experience in manual monitoring provides much insight into finding representative locations. This technical note explores many possibilities, illustrating locations representative and nonrepresentative of releases. It is essential to collect data that are not biased, that is, data collected from water that is not release water but a mixture of release water and some other water. Some sources of this bias are listed below.

- Monitoring release from one unit when several are operating, with lateral heterogeneities existing in the forebay.
- Collecting water within the dam from a location that does not provide completely mixed sample water (heterogeneities caused by vertical stratification in the forebay).

- Collecting samples downstream of the dam which are affected by eddy currents returning downstream (not release) water to the monitor location.
- Monitoring the release from a location where all dam-induced processes are not complete (for example, turbine aeration and boil aeration).
- Monitoring the release from a location distant enough from the dam that photosynthesis and respiration influence the sample water. In shallow tailwaters, primary production can contribute large amounts of oxygen to the release.

In some cases, the optimum location (that which best represents the release or answers the question of interest) is not feasible for deployment because of limited access or equipment constraints. In these situations, careful consideration must precede the selection of an alternate location. The following discussion illustrates possible locations through short case studies and examples. The advantages and disadvantages of each deployment and equipment type are discussed. The locations include lake forebay, penstock, draft tube, and tailwater deployments (Figures 2 and 3).

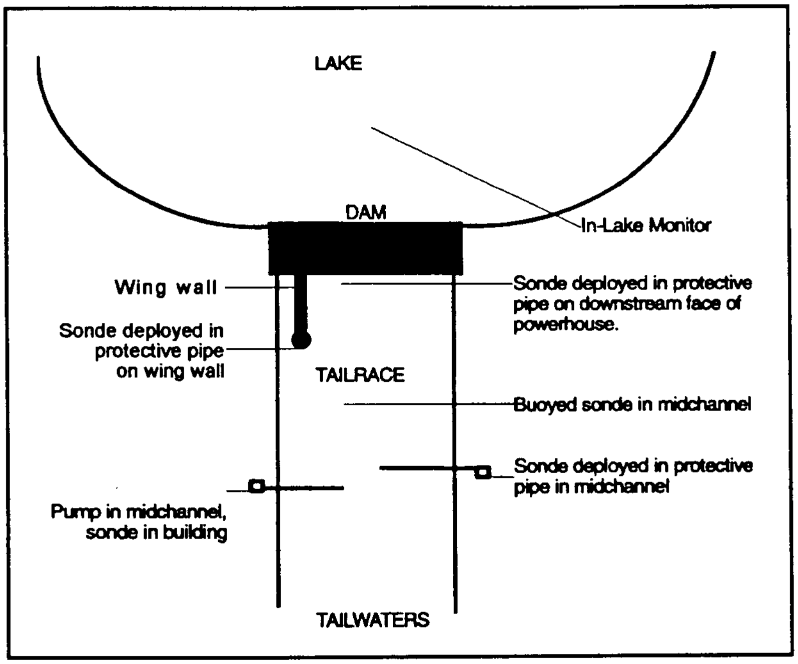


Figure 2. Plan view of dam monitoring locations

In-Lake Logging Units

In-lake logging units can be used to determine water quality conditions in the near-dam region of a lake. These data reflect water quality conditions prior to release and can be used to predict release values. A typical setup includes one or more water quality sondes measuring temperature, dissolved oxygen concentration, specific conductivity, and pH. The sondes are attached to a cable suspended from an anchored buoy. This system can provide a continuous record of water quality conditions in the forebay. However, one drawback is the lack of accessibility to the sondes for data downloading and maintenance, which results from the need for a boat and windlass large enough to retrieve the buoy, anchor, and sondes. Also, the operator cannot access real-time data.

Because in-lake water quality changes slowly (scale of days to weeks), it is typically adequate to use a boat crew and manual sampling to determine forebay conditions on a routine schedule. This manual system is used at Richard B. Russell Lake to provide data for predicting release dissolved oxygen concentrations. A more versatile but costlier alternative is to use a radio-linked data transmitting station mounted on a buoy. The water quality sondes can be connected to the radio transmitter, which allows the operator to view real-time information and to transfer data.

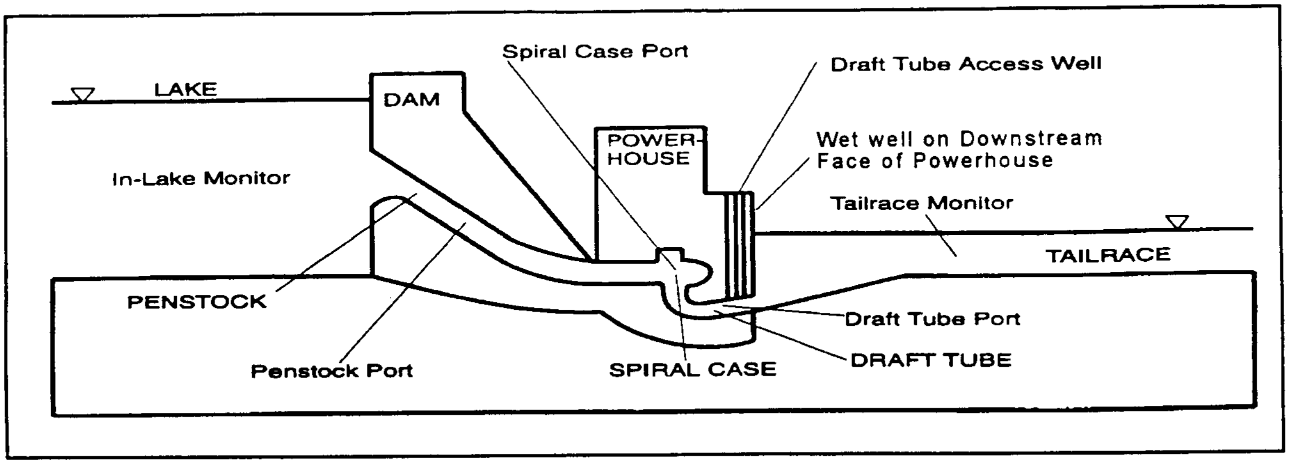


Figure 3. Cross section of dam monitoring locations

In-Lake Automated Profilers

In-lake automated profilers developed by Duke Power are presently undergoing testing (personal communication, John Knight, Duke Power, Huntersville, NC). These prototype units are self-contained lake-profiling, data-recording, and transmitting stations. These stations automatically lower a water quality sonde to specified depths and intervals, providing a continuous record of lake water quality conditions. The units are connected to cellular phones, allowing data to be downloaded remotely via modem. Thus, real-time in-lake water quality data are available. While this type system may become standard in the future, current drawbacks include no commercial production, significant initial purchase costs, and vandalism problems.

Tapping Water from Penstock

The first post-dam locations to consider for sampling are the dam's penstocks, if equipped with ports for sampling water. These ports can be plumbed to water quality sondes equipped with flow-through cells. This location is useful in determining penstock intake water quality conditions prior to any effects, such as turbine venting, that result in increased dissolved oxygen concentration in the downstream releases. However, some studies performed by Jim Ruane of the Tennessee Valley Authority and Steve Wilhelms of the U.S. Army Engineer Waterways Experiment Station have shown that if the forebay waters are not homogeneous, as is the case during stratified conditions, water sampled from the penstock may not be well mixed and thus not representative of the release. The taps are plumbed into a water quality sonde flow-through cell. The sonde can be connected to a data-recording and sonde control computer, or to a radio or satellite link if the dam is a remote site.

This type of monitoring system has been installed at Bull Shoals Powerhouse. It provides information about intake water quality prior to turbine venting. The access provided to real-time data is often critical in maintaining the downstream White River trout fishery.

Tapping Water from Spiral Case

Taps from the spiral case can provide information about near-turbine water quality. Often, cooling water for the generators is drawn from the spiral case. A typical installation directs water from a cooling line into a water quality sonde flow-through cell. Because of the mixing effect of the turbine and the additional travel time or distance from the face of the dam, water is assumed to be well mixed by this point and representative of the intake water. In the absence of turbine venting processes, this water should be representative of the release. However, if turbine venting is occurring, the effects of aeration are not complete by the time the water passes through the spiral case. This installation also provides easy real-time access to water quality information. This system was used at Richard B. Russell dam to monitor release dissolved oxygen concentrations.

Plumbing to Central Location

Water from the cooling line of each unit (as in the above example) is plumbed via solenoid-controlled valves to a central mixing chamber. The solenoid switches allow waterflow from each unit only during turbine operation. Because units contribute water to the mixing chamber only during respective turbine operation, a representative release can be sampled through this installation. Thus, any lateral heterogeneities present in the forebay are proportionally sampled. Drawbacks to this system are the cost and time necessary to install the piping, solenoids, and mixing chamber. Benefits, beyond the laterally representative sampling, include the ability to use a single sonde to monitor the release from all units. This eliminates any cross-calibration problems that could occur if multiple sondes were used to monitor multiple units. Installation costs, therefore, could be offset by moneys saved in purchasing a single sampling instrument. Further, since the operator must communicate only with one sonde, data collection and communication are minimized.

As in the above example, this method is not appropriate if any turbine venting or other water quality alteration occurs downstream of the turbine. This setup allows real-time data access and is presently in use at Richard B. Russell dam.

Tapping Water from Draft Tube

Water can be tapped from the draft tube, typically through ports immediately below the turbines. The water is plumbed to a sonde with a flow-through cell and passed to a drain. Because of the proximity of the turbine, travel time is insufficient for changes due to turbine action (for example, turbine venting in the water). This location is typically accessed in the penstock gallery, and thus the damp environment may be inhospitable to electronic equipment. Because of these drawbacks, this location, while allowing real-time access, is not recommended for most purposes.

Draft Tube Access Port

The draft tube access port is located on the draft tube deck. This port is designed to allow access to the draft tube after dewatering. Using a wet well, a sonde can be deployed in the access port and used to record water quality of the release. This location is sufficiently distant from the turbines so that most changes due to turbine venting can be detected. The sonde is typically wired directly into the powerhouse, where a data collection and sonde control computer is located. Thus, the operator has real-time access to information. The advantages of this location include ease of installation and access, representativeness of release water quality, and relatively low cost. Drawbacks are that aeration due to post-powerhouse processes, such as boil or weir aeration, is not measured. This system, in conjunction with a penstock monitor, is used at Bull Shoals Dam to determine the efficiency of turbine venting.

Downstream Face of Dam

Some post-powerhouse processes can be monitored by mounting a protective pipe vertically on the downstream face of the dam. The lower section of pipe is perforated to allow water access to the sonde sensors. Use of a pipe, instead of strapping the sonde to the face of the powerhouse, allows the sonde to be easily retrieved. In this installation, the sonde is lowered into the pipe and wired directly into the powerhouse, where a data collection and sonde control computer is located, allowing real-time data access. Drawbacks include a relatively difficult installation (divers must attach the wet well to the powerhouse face) and nonrepresentative data during periods of nonoperation of immediately adjacent units. When generation is composed of units not adjacent to the wet well, swirling eddy currents of tailrace or tailrace/release water may be measured. The tailrace of Richard B. Russell Lake is presently being monitored with a string of thermistor cables located in a wet well mounted on the downstream face of the powerhouse.

Sonde Deployed in Midchannel

A data logging sonde can be deployed, via buoy and anchored cable, in the full flow of releases. If a sonde is located downstream a sufficient distance, a representative portion of each releasing unit may be monitored. If the release does not fill the channel (plug flow), return currents can be entrained into the release causing the sonde to sample a mixture of release and other water, that is, the sonde monitors nonrepresentative water. Because of the midchannel location, this deployment necessitates a boat for retrieval and data downloading. Retrieval may be difficult or potentially hazardous during release, and real-time data access is not possible. The greatest advantages are ease of deployment and low installation cost, making this type deployment desirable for limited budgets and short-term studies.

Sonde in Protective Pipe on Wing Wall or Bank

A sonde can be deployed in a protective pipe mounted on a wing wall of the tailrace. This deployment allows the resource manager to monitor water in which most post-powerhouse effects (boil aeration, turbine venting) have occurred. The sonde communications cable is typically wired into the powerhouse, where real-time data can be accessed by the operator. This location can also be used to monitor tailwater conditions during periods of no release. One drawback of this location is that, if multiple turbines are present, the water quality of the unit nearest the wing wall may be the only one accurately monitored. Thus, any lateral heterogeneities in release would not be represented. This location can also be affected during generation by eddy currents when the unit nearest the wing wall is not operating. A wing wall deployment is in place at St. Stephens Powerhouse (as detailed earlier in this technical note) and at Norfolk Dam.

Sonde Deployed in Protective Pipe in Tailwaters

For this deployment, the sonde is placed in a near-horizontal protective pipe extending into midstream. The end of the pipe is perforated to allow water to flow across the sonde sensors, while protecting the sonde from physical damage. The data cable runs out of the pipe to a terminal that is housed in a weatherproof case. The terminal can be satellite or modem linked to a data-recording computer. Another option is to run the data communications cable directly to a computer that is housed in a nearby structure or building. The computer can be remotely accessed via modem for real-time data. The advantages of this deployment are that the sonde is deployed centrally in the current, and the water sampled is representative of the tailwaters. The disadvantages are difficulties in deploying the sonde, increased fouling of the probes, and risk of vandalism. Further, if return eddy currents are present or the sonde is not in full flow, sample bias will be recorded. This type of system is in place in the White River, below Bull Shoals Dam.

Sonde Deployed in Building—Water Plumbed to Unit from Midstream

This deployment involves a pipe extending into the tailwater with a submersible pump deployed at its base. The pump is plumbed into a building, where the sonde (fitted with a flow-through cell) and the data-recording computer are located. Sample water is pumped from a point in the channel assumed to be representative of the tailwaters. The drawbacks of this location are long-term pump maintenance and possible bias of sample water. Bias can occur if the pump location is nonrepresentative or if ambient conditions affect transported water prior to measurement by the sonde. This method is relatively secure from vandalism, and because the computer can be connected to a phone line, real-time remote data are available. This system is in use at J. Strom Thurmond Dam and Hartwell Dam on the Savannah River.

Communications for Automatic Remote Monitoring

Communications, relaying the collected data to the database, plays a central role in automated remote monitoring systems. Communication can be accomplished using either one- or two-stage processes. In one-stage communication, the data are transmitted via cable from the water quality sonde to the user. For two-stage communication, information is first transmitted from the water quality sonde to an interim data collection point, such as a computer or relay station. This information is in turn transmitted to users via modem, radio link, or satellite link.

Strategies

One-stage communication can be quite simple. A logging sonde or other water quality instrument can be deployed to log data. At the end of the study period, the sonde is retrieved and downloaded. This strategy is best employed for short-term studies. A second strategy is to connect a computer to a sonde using a data communications cable. This allows the computer to control the sonde and record the data. This computer might be located in the operator's office or control room where the operator can query the sonde for real-time data.

Two-stage communication allows greater versatility. If the data-recording computer is at a remote site, for example, a remotely operated dam, modems may be used to communicate from the monitor site to the central control room. Using this method, an operator can access real-time information, monitoring the releases from several remote sites from a central location.

Radio links can also be used for two-stage communications. Commercially available radio links can be used to control sondes and send data to a central receiving station, which stores the data. A similar method employs satellite linkages to transmit data to a central location. While these two methods are necessary for remote applications and applications having large amounts of electromagnetic interference (limiting the ability to use wire to carry the signals), their cost is substantially greater than modem communications discussed in the above paragraph.

Interference

When data transmission wires carry signals long distances (>15 m), electromagnetic interference can cause signal loss; weak, garbled signals; and incorrect information. This problem is often extreme in monitoring hydropower releases because signal transmission wires are often located near areas of high electromagnetic radiation (generators, switch yards, high-voltage transmission lines, and transformers). Several potential solutions exist, which vary in cost and installation difficulty.

A shielded cable can be used instead of the normal data transmission cable (typically telephone line). A greater degree of protection can be gained by enclosing the cable in grounded metal conduit. A second method is to use fiber optic cable and modems. With fiber optics, the signal is carried by light and thus is not susceptible to magnetic interference. A third method is to use commercially available radio links, which have built-in error correction capabilities in the software.

Depending on the severity of interference, one of these methods should be appropriate. A good strategy is to begin an application with shielded cable, the least expensive solution, and then employ a more expensive fix as necessary.

Conclusions

An ideal sampling plan for hydropower release monitoring would include both manual and remote methods. However, if a compromise must be achieved, the resource manager must determine whether the release water quality problem requires short-term intermittent or long-term continuous data sets. Manual sampling is valuable when used in an exploratory manner. Manual sampling can determine if a degradation of water quality exists, the location of the worst and best water quality, and any gross changes with time or operation schedule. While labor intensive, manual sampling affords the best overall view of a system while recognizing the limited nature of the data due to the number of measurements. Automated remote monitoring is the best choice when a continuous record of water quality is required. A more thorough analysis of hydropower release conditions can detect short-term changes (daily or during project operation), as well as long-term changes in water quality (over a season or year). However, due to the fixed nature of automated sampling, the responsible individual must be absolutely certain that the data logger is placed in a location where representative water will be measured. Many factors must be considered prior to proper implementation of a sound and appropriate hydropower release sampling strategy.

References

Ashby, S. L., Kennedy, R. H., and Jabour, W. E. (1992). "Downstream water quality responses to hydropower releases from West Point Dam, Georgia-Alabama," Miscellaneous Paper W-92-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Vorwerk, M. C., and Carroll, J. H. (1995). "Tailwater monitoring during periods of no release; Cooper River Rediversion Canal: A case study," Water Quality Technical Note CS-01, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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