Tools for Environmental Monitoring and Response at Hydro Projects

Managing a hydroelectric project for electricity production and environmental protection can be a delicate balancing act. This article highlights ways in which project owners are combining new and established technologies to meet the challenge.

Owners and operators of hydroelectric projects must be aware of, and responsive to, the natural environment in which their projects exist and the potential effects of project operation on that environment. Responsible stewardship of natural resources is not a new idea in the hydroelectric industry. However, in many cases, pressures from regulatory requirements and resource stakeholders are greater, and the stakes higher, than ever before. At the same time, because of the newly competitive electricity market, project owners feel the cost of environmental monitoring and mitigation more acutely than in the past.

But there is good news: through recently developed technologies and combinations of technologies, project owners are finding new and effective ways to collect, interpret, and make operational responses to environmental information.

This report describes applications of environmental monitoring technology for a number of different purposes. Several themes appear repeatedly across various applications, representing technological trends that can benefit almost all hydro project owners in some way. Important common elements of the applications include:

— Improvements in reliability, accuracy, and precision;

— Remote communication of data, which can dramatically reduce the personnel time required for environmental monitoring and compliance;

— Real-time processing and interpretation of data, making possible a prompt and appropriate operational response to a developing situation;

— User-friendliness and simplicity of data presentation;

— Interfaces with automated systems; and

— Interfaces with environmentally friendly equipment, such as aerating turbines and fish bypass devices.

Environmental monitoring and compliance always will involve vigilance and effort on the part of hydro project operators. But, as the following examples show, the industry and supporting technology providers are finding new ways to meet the dual objective of fulfilling environmental obligations and running an efficient, economical project.

This report was compiled by Ellen Faulkner, contributing editor to Hydro Review.

New Opportunities in Research, Design

The successful development of devices for environmental mitigation at hydro plants is based on accurate and reliable data acquisition. This is true at the general level, as in developing design guidelines for environmentally friendly turbines, and at the site-specific level, as when designing a fish diversion screen for a particular plant. Modern technologies for collecting and processing various types of data enhance the understanding of physical and biological phenomena at the design stage, which, in turn, reduces the probability of making environmentally and economically costly missteps at the implementation stage.

Sometimes, design improvements to devices for environmental mitigation have positive effects on the performance of the plant as a whole—for example, by re-allocating water or minimizing head losses. In one case, the Northern California Power Agency, operator of the 258.7-MW North Fork Stanislaus hydroelectric project, was able to benefit from a redesign of fish screens on one of its many diversion structures. Unevenly distributed water velocities across the face of the fish screens led to debris clogging, exceeding the capability of the automated screen cleaning system to clear debris from the face of the screens. Maintenance was required continuously to maintain the screens in good working order, and the clogging caused water normally diverted for generation to flow over the spillway.

The project operator called upon JBS Energy, Inc. to assist in the redesign of the screens by developing a detailed velocity profile at the existing screens. This task was accomplished with the use of an AquaCalc 5000, manufactured by JBS Instruments, attached to a Price "AA" current meter. The velocity profile data were supplied electronically to the design team for the screens.

As a result of the redesign, the operator was able to realize a substantial increase in the amount of water diverted for generation while maintaining downstream minimum flow requirements.

Accurate, reliable, and extensive field data are a necessity in the design of environmentally friendly hydroelectric equipment. As part of its program of improving fish passage through Kaplan turbines, the U.S. Army Corps of Engineers is conducting studies to identify the areas within an operating turbine environment that may contribute to physical injury to fish, develop design changes to minimize physical injury, and improve turbine performance that has been degraded by the presence of fish screens or other diversion devices.

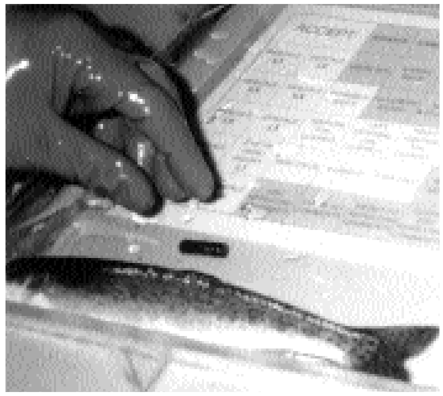
Turbine studies conducted at the Corps' 980-MW McNary Dam on the Columbia River focused on using field data to assess the effect of fish diversion screens on turbine performance. To obtain accurate measurements of absolute discharge through the turbines, the researchers used an acoustic scintillation flow meter (ASFM) supplied by

ASL Environmental Services of Sidney, British Columbia. The ASFM provides accurate measurements without the problems of space and flow interference associated with conventional mechanical flow meters.

At its 1,287-MW Rocky Reach hydroelectric project, Public Utility District No. 1 of Chelan County, Washington, has undergone intensive research and design efforts to improve survival of downstream-migrating salmonids at the project. Research at the project led to turbine runner replacement and the construction of a surface bypass collector, resulting in substantial improvements in fish survival. In conjunction with these efforts, the owner has conducted field research on the fine-scale movements of fish. Acoustic tags supplied by Hydroacoustic Technology, Inc. (HTI), of Seattle, were orally and surgically implanted into more than 400 juvenile salmonids, which were released upstream of the dam. As the tagged fish passed through the forebay and into the bypass and turbine intakes, HTI's acoustic instruments received signals from each fish every second, tracking the fish in three dimensions and to an accuracy within less than one meter. Viewing software developed by HTI allowed each fish's three-dimensional path to be displayed in a choice of perspectives and formats. The acoustic monitoring provided valuable information on swimming patterns of fish in the forebay over hours and days, and the three-dimensional fish tracks were merged with flow data to aid in refinement of the surface bypass design.

Environmental monitoring technology also is being used to enhance upstream fish passage in the Pacific Northwest. Structures for upstream passage of salmonids have existed at dams on the Columbia River for several decades. There is, however, still much to be learned about the utilization of these fishways by various species. For example, although biologists know that the upper limit of the water temperature range for migrating summer chinook salmon is 20 degrees Celsius, it is unknown how deviations from the optimum temperature affect migration and use of fish ladders.

To begin to answer this question, the Corps of Engineers established temperature monitoring programs in fish ladders at the 2,160-MW John Day, 1,093-MW The Dalles, and 1,147-MW Bonneville projects on the lower Columbia River. The monitoring, which began in 1994, employs high-resolution temperature probes and dataloggers provided by Unidata America, of Lake Oswego, Oregon. Temperatures are recorded at 15-second intervals and averaged hourly. The probes' capability to record temperatures within hundredths of degrees is significant in this study, because migrating salmon can detect temperature changes of less than 0.3 degree Celsius.



Tagging the Fish
Acoustic tags orally and surgically implanted in juvenile salmonids can provide valuable data on how fish move in the vicinity of a project. Data on fish swimming patterns are essential information in the design of devices, such as intake screens or bypass structures, for fish protection. (Photo courtesy Hydroacoustic Technology, Inc.)

As a result of the monitoring program, Corps biologists found that detectable differences existed between temperatures in the John Day fish ladder and the surrounding water. Although the effect of this difference on fish utilization of the ladder is not yet understood, the biologists expect that fish tracking data, combined with the temperature records, will shed further light on the role of water temperature in upstream fish passage.

In addition to research and design efforts related to fish passage in the Pacific Northwest, the Corps is investigating operational and equipment changes that will enhance water quality at its hydroelectric projects. As part of the Corps of Engineers' Operations and Maintenance Major Rehabilitation Program, the Mobile (Alabama) District is finding effective ways to increase dissolved oxygen in turbine discharges from several of its eight hydroelectric projects in the Alabama and Chattahoochee river basins. Although the projects share the problem of low dissolved oxygen, there is no common solution, due to the different equipment and physical configurations of the projects.

At the 86-MW Buford project on the Chattahoochee River, where turbine replacement is scheduled to begin in the summer of 2000, Reservoir Environmental Management, Inc. (REMI) and the Tennessee Valley Authority (TVA) worked with the Corps to identify the most cost-effective approach for aerating the project discharges. The team assessed historical water quality data, performed additional water quality sampling, collected water current data, and conducted powerhouse tests. On the basis of these studies and other considerations, the district has selected an auto-venting design for the replacement turbines.

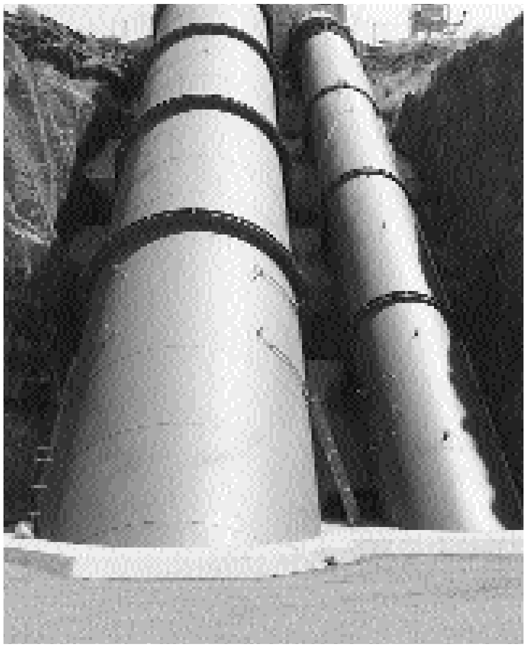
The 130-MW Walter F. George project on the Chattahoochee River also is scheduled for turbine replacement but the district, REMI, and TVA have determined that auto-venting turbines are not a feasible solution at the project. After a preliminary screening of alternatives, the study team will conduct feasibility analyses, design studies, and environmental assessments to evaluate the most promising alternatives. Possible measures include a tailrace weir, a reservoir curtain, oxygen diffusers, spillway modifications, operational changes, and surface water pumps.

Enhancing Operation, Compliance Through Routine Monitoring

Many hydroelectric project owners, particularly those with licenses recently issued from the Federal Energy Regulatory Commission (FERC), face increasing requirements for achieving and documenting compliance with environmental standards. Technologies now available for continuously monitoring variables such as streamflow, water level, water quality parameters, and fish movements provide data that are critical in making the right operating decision at the right time. These devices, by accumulating and storing digital data, also can provide a complete and credible record of compliance. Some project owners have taken the technology a step further, integrating environmental compliance into the operating routine by linking monitoring devices to automated control equipment.

Monitoring, Managing Plant Discharges

For Idaho Power Company, control of flows at its six Snake River hydro projects is critical, both for maintaining instream flows and for operating within the complex restrictions imposed by the allocation of water rights on the river.



Presenting a Flow Challenge
Two different-sized penstocks at Idaho Power's Milner Dam pose a challenge in flow measurement and control. The power company must maintain flows in the two penstocks such that the rate of change of the combined flow does not exceed 300 cubic feet per second in 20 minutes. Acoustic flow meters collect continuous flow data from the penstocks and transmit the data to Idaho Power's control system. (Photo courtesy Accusonic Technologies, Inc.)

At the 60-MW Milner hydroelectric project, for example, Idaho Power is required to maintain the rate of change of the combined flow through two penstocks (one 9 feet in diameter and the other 17 feet in diameter) at no more than 300 cubic feet per second (cfs) in 20 minutes. To help meet this requirement, the power company installed acoustic flow meter provided by Accusonic Technologies, Inc., Falmouth, Massachusetts, in the two project penstocks. Continuous flow data from the penstocks are transmitted to Idaho Power's control system and also to a river-wide SCADA system operated by the Bureau of Reclamation. The Milner plant's turbine-generator units are controlled by a Woodward 501 digital control system, which, in addition to controlling turbine flows, provides automatic control of the turbine bypass gate so that downstream flows are maintained even when the units trip off-line.

The rigorous management of flows on the Snake River appears to be yielding important ecological benefits. In a survey conducted in the fall of 1999, biologists from the power company observed a striking increase in the number of fall chinook salmon nesting beds on the Snake and other Pacific Northwest rivers relative to nests counted in 1997 and 1998. While a number of biological factors probably have contributed to the success, company biologists believe that the maintenance of stable spawning flows from the hydroelectric projects has played a key role in the observed increase.

Owners of other remotely operated plants also have made use of the capabilities of automated control systems to meet stringent requirements for instream flows. One such owner is the Eugene (Oregon) Water and Electric Board, which is required to ensure that water levels in the McKenzie River downstream of the 8.7-MW Trail Bridge hydroelectric project vary by no more than 2 inches per hour. The Woodward controls at the plant have been programmed to manage the turbine, the synchronous bypass valve, and the spillway gate to meet this criterion.

Monitoring for Water Quality

Routine operating procedures at many hydroelectric projects must be responsive not only to flow-related restrictions, but also to state water quality standards, most often concerning the dissolved oxygen content and temperature of water discharged from the plant.

To document the effect of plant operation on water quality in the Ohio River, operators at American Municipal Power-Ohio's 42-MW Belleville hydroelectric project collect dissolved oxygen and temperature data recorded at stations upstream and downstream of the plant. These water quality monitoring stations are equipped with multi-parameter water quality instrumentation supplied by YSI of Yellow Springs, Ohio, and also radio equipment that transmits the data to a base station near the plant. At the base station, the water quality data are processed and stored in a computer and regularly downloaded by plant personnel.

The Corps of Engineers, Seattle District, employs a single automated system for monitoring water quality, dam safety parameters, and reservoir conditions at the 2,457-MW Chief Joseph Dam hydroelectric project on the Columbia River. The system consists of 40 measurement and control units manufactured by Geomation, Inc., Golden, Colorado, that receive information from more than 450 sensors in the dam structures, the reservoir and tailwater, and the reservoir rim. Monitored environmental parameters include temperature, dissolved oxygen, conductivity, and redox in the tailwater. Temperature monitors installed adjacent to the reservoir also help the Corps establish seasonal patterns of ground-water flow in and out of the reservoir.

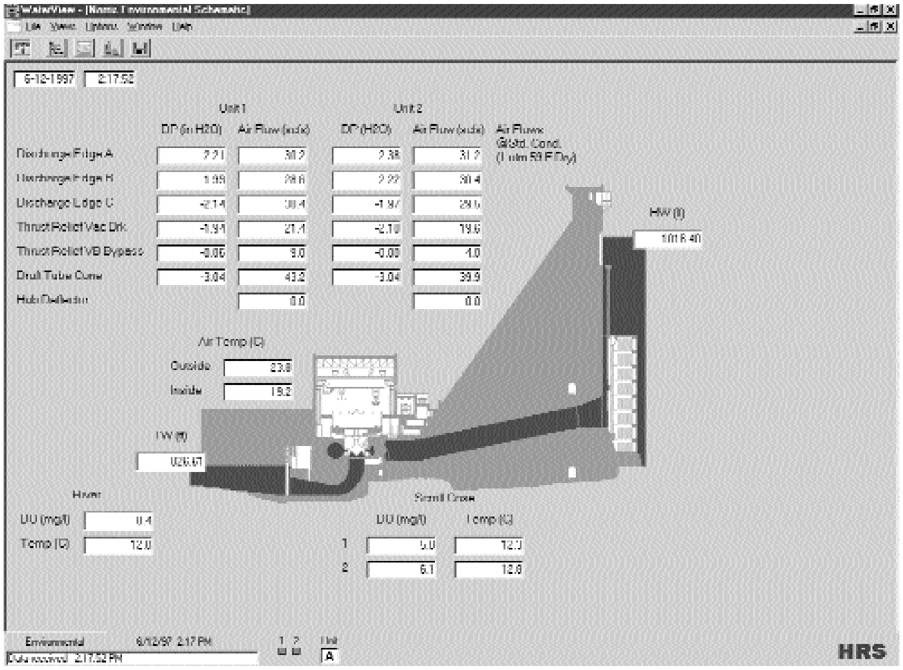
Water quality also is an important factor in fish survival through spillway bypasses. Although in some instances spilling can effectively transport downstream-migrating fish past a dam, at some dams the spillway discharges can become supersaturated with dissolved gas, a condition which is potentially lethal to fish.

In 1984, the Walla Walla District of the Corps of Engineers implemented a total dissolved gas monitoring system at six projects on the Columbia and Snake rivers. The system uses monitoring and telemetry instrumentation provided by Coastal Environmental Services, Inc., of Seattle. Total dissolved gas concentrations are measured hourly at 16 stations and transmitted by radio and telephone to computers at each of the district's projects. The district uses the data for scheduling spill at the projects, and also to document compliance with state water quality standards.

The use of telemetry and automated water quality data collection can result in substantial labor savings at a hydroelectric project. However, the monitoring systems still depend upon the close attention of the project operator to ensure that the sensors are calibrated, clean, and well-maintained. An automated system now being developed by Common Sensing, Inc., of Clark Fork, Idaho, will provide an alternative arrangement, in which the water to be sampled is pumped to a nearby secure enclosure housing the sensors. In this scheme, the sensors will be easily accessible, automatically checked for calibration, and protected from damage and fouling by debris. The designer expects to install the first system at a hydroelectric project late in 2000.

Keeping Track of the Fish

Hydroacoustic methods have been used extensively in research and licensing studies to develop an understanding of fish passage and behavior at hydroelectric projects. Once a project owner has



The WaterView® software system, developed by Hydro Resource Solutions LLC (a partnership of Voith Hydro and the Tennessee Valley Authority), displays and analyzes environmental and operating parameters simultaneously. Using these data, the software determines optimal turbine settings to achieve environmental and generation targets, and supplies the information to the plant control system.

learned how and when project operations can pose a risk to fish, a logical next step is to use the same technology to help mitigate the risk. Hydroacoustics are used for routine fish monitoring at several hydroelectric projects in the U.S., including the 203-MW Wells Dam project on the Columbia River and the 10.8-MW New York State Dam project on the Mohawk River. Both the Wells and New York State monitoring programs were developed and implemented by Biosonics, Inc., of Seattle, Washington.

At Wells Dam, intensive studies over a period of ten years led to the development of a fish bypass system. The bypass system is successful in bypassing about 90 percent of downstream-migrating fish. The system was installed and its performance verified between 1990 and 1992. The owner, Public Utility District No. 1 of Douglas County, Washington, then chose to continue to use hydroacoustic methods for routine monitoring of seasonal salmon runs. The routine monitoring application is much less labor-intensive than the design studies but is designed to provide almost immediate analysis of the acoustic data, enabling operators and fish managers to use the information in making real-time management decisions.

Acoustic techniques have been used since 1990 to monitor juvenile blueback herring at the Adirondack Hydro Development Corporation's New York State Dam during seasons when the fish were known to be moving. As the monitoring and mitigation program was first designed, operators would adjust bypass flows based on acoustic observations of fish in the turbine galleries. However, by 1993, it was apparent that the fish would be more successfully diverted if they were first detected approaching, rather than inside, the intakes. In redesigning the monitoring program, Biosonics also was able to take advantages of other technological advances that permitted complete automation of both the data collection and the bypass operation. The use of automated systems for hydroacoustic monitoring can result in substantial cost savings, relative to the very labor-intensive procedures used in the past.

When the acoustic system at the New York State project determines that fish abundance in the forebay exceeds a predetermined threshold, it sends a message from the computer via a relay switch to open a spill gate and bypass the fish. While the gate is open, the acoustic system continues to sample. When the abundance drops below the predetermined threshold, the spill gate is closed. The decision to open or close the spill gate also can be overridden by operating personnel.

Turning Knowledge into Power

A competitive energy market puts pressure on hydro project owners to optimize operations, using the water resource to generate just the right amount of electricity at just the right time. Responding to these pressures—while also scheduling operations to ensure minimum flows for habitat and recreation, to mitigate water quality effects, to comply with reservoir level restrictions, and to protect aquatic ecosystems—is a challenge that calls for the effective integration of new technologies for gathering, processing, and acting upon information.

The Tennessee Valley Authority (TVA) has implemented a modular system for monitoring and operation optimization at 25 of its hydroelectric plants, and one Corps of Engineers plant, in the southeastern U.S. The system, called WaterView®, includes environmental modules at nine TVA plants and the Corps of Engineers plant. WaterView, developed by Voith Hydro and TVA, is commercially available through Hydro Resource Solutions LLC, a jointly owned subsidiary of the two organizations. WaterView is designed to work in conjunction with hydro operators or automated control systems to optimize both the generating and environmental aspects of a plant's performance.

In a typical application, WaterView records numerous environmental parameters, including dissolved oxygen and temperature of water entering and leaving the project, total dissolved gases, air temperature, and air flow rates. The system also records operating data such as headwater and tailwater level, gate opening, flow rate, and cavitation level, and computes loss-adjusted performance curves and efficiencies. All of these data are recorded at five-second intervals and made available in real time throughout TVA's wide area network. The data are used to operate environmental systems, to monitor environmental compliance, and to provide input to environmental models and decision support systems.

At TVA's 57-MW Norris hydro plant, the WaterView system is fully integrated with the plant's Siemens automatic control system. The plant contains two self-aerating turbines, designed by Voith and TVA and installed in 1995 and 1996. The air flow in these turbines is delivered through central, distributed, and peripheral air outlets, with varying combinations of the aeration options chosen for varying operating conditions. The WaterView system monitors environmental conditions and receives load requests and other operating criteria from the automatic control system. For the current reservoir level and operating conditions, WaterView chooses the optimized combination of units to satisfy the system requests, to meet target dissolved oxygen levels, and to minimize aeration-induced efficiency losses. WaterView then returns the recommended unit loadings to the control system for execution.

Hydroelectric project owners, especially those who operate multiple plants, are turning increasingly to the technology known as decision support systems for making short- and long-term operating decisions. Although hydro plant decision support systems are built around analytic software for optimizing generation (or generation revenues), they incorporate many more elements, including the collection and transmission of data, simulation of economic or hydrologic scenarios, compliance with environmental constraints, and tools for identifying, ranking, and evaluating alternative actions.

Great Lakes Power, Inc. has used the *Vista* decision support system for several years for generation scheduling at its 12 hydroelectric plants in Ontario, Canada. In recent years, Great Lakes Power also has used the software's simulation capabilities for developing and negotiating with resource agencies a basin-wide water management plan. The *Vista* system, a product of Acres Productive Technologies of Ontario, Canada, incorporates historic and real-time hydrometeorologic data, physical data on the system and facilities, market data defining generation benefits, and operational constraints into the analytic process. Real-time data are acquired continuously and automatically through the internet and the owner's SCADA system. Using these data, the program ensures that generation benefits are optimized and environmental constraints (such as minimum or maximum flows, ramping rates, and reservoir elevation restrictions) are both incorporated into the optimization routine and met in full compliance.

PG&E Generating, which is not the same company as Pacific Gas and Electric Company, the regulated California utility, has also implemented the *Vista* decision support system for hydro generation scheduling for both the Connecticut River system and Deerfield River systems in New England. The two rivers host 15 hydroelectric plants and four additional storage reservoirs with a combined capacity of 1,158 MW. Long-term generation schedules, reaching over one year in duration, and short-term schedules with a one- to two-week focus are recursively produced by *Vista*, in order to maximize power revenues while still meeting extremely stringent environmental constraints and objectives. An early version of AUTO *Vista*, the planning module, also was instrumental in the fast-track settlement discussions associated with the relicensing of the 291-MW Fifteen Mile Falls Project on the Connecticut River.

Dataloggers for Small Hydro
The Mountain Energy 100 series dataloggers are designed for simplicity of use, durability, and reliability in the field. In this photograph, the downhole version of the logger, equipped with a radio data transmitter, is installed in a well at the 5-MW Big Creek project.

Monitoring, Datalogging Technology for Small Hydro

Small hydro operators have the same needs for accuracy, reliability, and credibility in collecting data as large project operators, but frequently are handicapped by limited funds and staff lacking in specialized technical expertise. As developers and operators of small and, in many instances, remote hydro facilities in the Pacific Northwest, the owners of Mountain Energy, Inc., Grants Pass, Oregon, know firsthand of the frustration and expense often involved in environmental monitoring at such projects.

After several years of unsuccessfully seeking suitable products for monitoring and data collection at its projects, Mountain Energy began to manufacture and market its own. Emphasizing field- and user-friendliness, versatility, simplicity, and reliability, Mountain Energy's line of products began with the 1999 introduction of the 100 Series dataloggers.

One of the dataloggers' first applications was at the 5-MW Big Creek Waterworks hydroelectric project in northern California, where the "downhole" version was used to record water levels in an earthen embankment. The downhole datalogger is a cylindrical device that fits inside a 2-inch pipe, eliminating concerns about vandalism or other damage occurring above ground (see photo on page 46). The datalogger also is equipped with an onboard display for either historical or real-time data, allowing staff to check data on site without the use of a laptop computer or other processing equipment. Alternatively, data can be downloaded via a serial port or a radio telemetry option.

The dataloggers at Big Creek provided cost-effectiveness, security, simplicity of operation and maintenance, and reliable and accurate data collection. Flexibility and adaptability also are central to Mountain Energy's design philosophy, meaning that the dataloggers may be used with almost any type of sensor and in a wide range of technical and environmental settings.

Building on Existing Technologies

Many of the basic sensing technologies described in this article, such as water quality sensors, pressure transducers, and hydroacoustic techniques, have been used at hydroelectric projects for many years. What is new, however, is the existing and potential enhancement of these technologies through combining them with increasingly sophisticated systems for communications, data management and analysis, plant control, decision support, and environmentally friendly operation. These systems, many of which would be in place at a hydroelectric plant even in the absence of environmental concerns, create opportunities for integrating environmental monitoring and response into project operations in ways that are consistent, rather than conflicting, with efficient and economical management of the project.