

MONITORING OXYGEN AT HYDROPOWER FACILITIES

A GUIDE TO UNDERSTANDING AND ESTABLISHING DISSOLVED OXYGEN AS A REAL-TIME MONITORING SOLUTION



FONDRIEST
ENVIRONMENTAL

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WHY MONITORING MATTERS

There are around 2500 hydropower facilities in the United States, generating approximately 7% of the US's electrical energy. In addition to being a renewable power source, these dams can also function as a water supply and flood control point. As a river obstruction, hydropower dams affect water flow, spawning migrations, and water quality.

To ensure that they have a minimal impact on the environment and natural stream flow, state and federal regulations are set in place for minimum water quality standards. One such regulation is dissolved oxygen monitoring. Dissolved oxygen is the leading factor in water quality, and hydropower dams can drastically alter normal levels. Water that is diverted through a hydropower facility is typically much lower in dissolved oxygen than the rest of ecosystem. When this under-aerated water is released downstream, it decreases the oxygen content of the rest of the river, threatening aquatic life below the dam. A dissolved oxygen monitoring system ensures that the dissolved oxygen levels above and below the dam are consistently similar.

The Federal Energy Regulatory Commission (FERC) and other federal and state agencies have established reporting procedures and dissolved oxygen limits for hydropower facility operations. These monitoring and reporting procedures work to minimize dam impacts on the local aquatic habitats. The FERC also suggests mitigation measures when dissolved oxygen concentrations fall below accepted levels. Dissolved oxygen monitoring efforts allow operations managers to immediately implement these mitigation measures and minimize ecosystem degradation.

REGULATORY APPROACHES

Overview of FERC Licensing

Nearly all non-federal hydroelectric facilities in operation are required to report to the Federal Energy Regulatory Commission (FERC). While FERC is responsible for issuing an operating license, detailed environmental regulations and requirements within that license are influenced by state and other federal agencies.

A state Department of Natural Resources (DNR) will often mandate a Section 401(a) Water Quality Certification under the Clean Water Act. This certification lists monitoring requirements to maintain compliance with state water quality standards. Any recommended or obligatory monitoring and mitigation efforts are generally incorporated into the FERC hydropower license.

The FERC license establishes facility-specific duties, conditions and measures for operation. These can include minimum flow, mitigation, measurement standards (such as dissolved oxygen minimums) and narrative criteria (habitat and aquatic life). These rules will vary from state to state and even from site to site based on the dam structure and potential for environmental degradation. Both compliance with and deviation from the established license articles must be reported.

Most FERC hydropower licenses are issued for a 30-50 year term. While periods of uncontrolled non-compliance (due to weather or natural events) must still be reported and corrected, penalties are not incurred. Deliberate or systematic non-compliance, however, may be assessed a penalty.

Impoundment-type hydroelectric facilities tend to face more licensing regulations than most. The creation of a reservoir or other deep impoundment can drastically alter the local landscape and aquatic habitats. In addition to the risks of flooding, erosion and dislocation, water quality above and below the dam can suffer. Still waters, like reservoirs, stratify easily, essentially creating two environments within the water: top and bottom. The bottom layer of water often becomes hypoxic (low dissolved oxygen levels) due to a lack of aeration and excess oxygen demand. When coupled with a deep hydro intake, the oxygen-depleted water is released downstream, lowering the dissolved oxygen content of the entire river.

To minimize this impact, FERC licenses may require dissolved oxygen monitoring upstream, downstream and within the impoundment. The frequency of this monitoring is dependent on state-specific regulations, but continuous or near-continuous monitoring is common for deep hydro intake dams. When monitoring dissolved oxygen at hydropower facilities, real-time availability of data is crucial to instigating timely mitigation efforts. Even when sampling intervals are on a weekly basis, the ability to respond quickly will minimize the adverse effects of low dissolved oxygen and re-establish compliance with FERC.



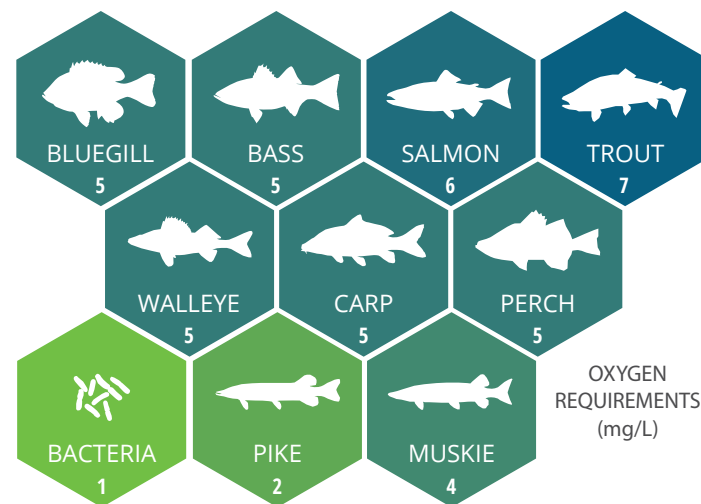
THE ESSENTIAL FACTOR

One of the biggest impacts that hydropower plants have on the local environment is reduced dissolved oxygen levels downstream. This consequence is one of concern, as dissolved oxygen (DO) is vital to the survival of aquatic organisms. Most freshwater organisms need levels above 5 mg/L for optimum growth, and species like salmon require even higher concentrations. When DO levels decrease, fish and other aquatic life may abandon the area or die.

While dissolved oxygen concentrations fluctuate naturally due to wind effects, underwater photosynthesis and organism respiration, hydropower dams may cause a far more sudden and steep change. As reservoirs are usually deep enough to stratify, the drop in DO levels is often due to released water from the bottom of the reservoir (low DO), as opposed to the top (higher DO). This low dissolved oxygen content can also be caused by an overgrowth of algae that consume the oxygen in the impoundment. To minimize any environmental risk from the dam, dissolved oxygen levels should be continuously monitored for atypical changes.

Why is Dissolved Oxygen Important?

Dissolved oxygen is necessary to survive for many forms of aquatic life including fish, invertebrates, bacteria and plants. These organisms use oxygen in respiration, similar to organisms on land. Fish and crustaceans obtain oxygen for respiration through their gills, while plant life and phytoplankton require dissolved oxygen for respiration when there is no light for photosynthesis. The amount of dissolved oxygen needed varies from creature to creature. Bottom feeders, crabs, oysters and worms need minimal amounts of oxygen (1-6 mg/L), while riverine fish need higher levels (4-15 mg/L). Even microbes such as bacteria and fungi require dissolved oxygen to decompose organic material at the bottom of a body of water.



Where does DO Come From?

Dissolved oxygen enters water through the air or as a plant byproduct. From the air, oxygen can slowly diffuse across the water's surface from the surrounding atmosphere, or be mixed in quickly through aeration. Dissolved oxygen is also produced as a waste product of photosynthesis from phytoplankton, algae, seaweed and other aquatic plants. As such, dissolved oxygen concentrations are constantly affected by diffusion and aeration, photosynthesis, respiration and decomposition. They are even affected by water temperature, salinity and pressure changes. That means that dissolved oxygen levels can range from less than 1 mg/L to more than 20 mg/L depending on how all of these factors interact.

For most healthy freshwater rivers and streams, DO levels seasonally range from 6 mg/L to 15 mg/L. Freshwater lakes may have slightly lower ranges due to the effects of stratification.

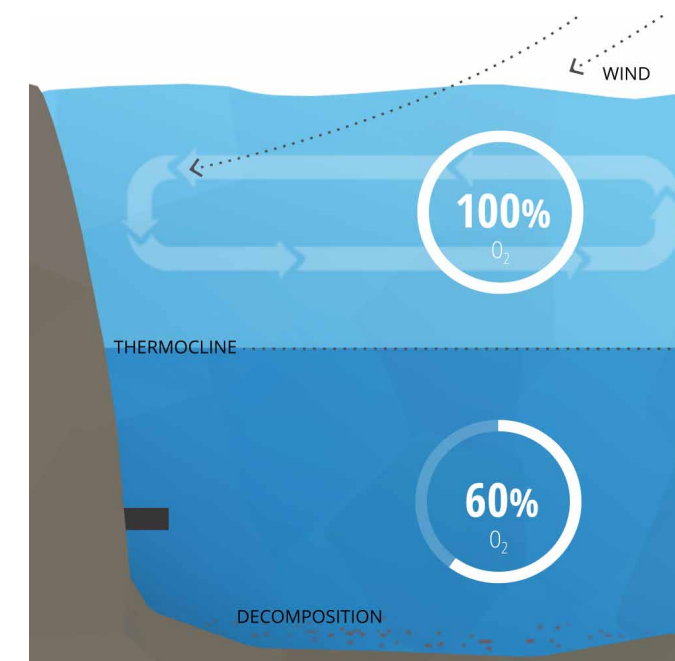
The Effects of Stratification

Stratification separates a body of water into layers. This layering can be based on temperature or dissolved substances (like oxygen) with both factors often playing a role. The stratification of water has been commonly studied in lakes, and frequently occurs in reservoirs and deep impoundments.

In a stratified impoundment, the top and bottom of a reservoir is divided by a boundary called the thermocline. This boundary keeps the layers of water from mixing, and there will often be a noticeable difference in temperature and dissolved oxygen levels between the two layers.

The uppermost layer of the impoundment is exposed to solar radiation and contact with the atmosphere, keeping it warmer and air-saturated. Due to the contact with the air, potential for aeration (wind) and the byproducts of photosynthesis, dissolved oxygen in the top layer usually remains near 100% saturation. The exact levels of DO vary depending on the temperature of the water, the amount of photosynthesis occurring and the quantity of dissolved oxygen used for respiration by aquatic life.

At the bottom of the impoundment, bacteria and fungi use dissolved oxygen to decompose organic material. This organic material comes from dead algae and other organisms that sink to the bottom. The dissolved oxygen used in decomposition is not replaced – there is no atmospheric contact, aeration or photosynthesis to restore DO levels in the lower strata. Thus the process of decomposition consumes all of the oxygen within this layer.



Oxygen Depletion

Oxygen depletion can come from two causes. First, oxygen is used by fish, bacteria and plants (at night) in a process called respiration. When respiration (oxygen consumption) is greater than the amount of oxygen received from the air or from photosynthesis, dissolved oxygen levels will decrease. Second, microbes at the bottom of a lake bed use oxygen to decompose the organic material. If there is an excess of decaying organic material (from dying algae and other organisms), the oxygen use increases. As there is no aeration and little photosynthesis in the lower layer of the water, this oxygen is not replenished. That means that in a stratified body of water, the oxygen at lower water levels will get used up, leaving an anoxic (no-oxygen) zone at the bottom of the water body. When the dam intake is below the stratified boundary, the released water will also be depleted of oxygen. This in turn can negatively affect water quality downstream.

DO Units and Percent Air Saturation

Dissolved oxygen is usually reported in milligrams per liter (mg/L) or as a percent of air saturation (%). However, some studies will report DO in parts per million (ppm). 1 mg/L is equal to 1 ppm, while the relationship between % air saturation and other units will fluctuate based on environmental factors such as water temperature, pressure and salinity. This is due to the definition of air saturation as a partial pressure, rather than a measured quantity.

In a stable body of water with no stratification, dissolved oxygen will be at 100% air saturation. 100% air saturation means that the water is holding as many dissolved gas molecules as it can in equilibrium. At equilibrium, the percentage of each gas in the water would be equivalent to the percentage of that gas in the atmosphere – i.e. its partial pressure.

It is important to note that while two bodies of water may both be at 100% air saturation, they do not necessarily have the same concentration of dissolved oxygen. The actual amount of dissolved oxygen (in mg/L) will vary depending on temperature, pressure and salinity.

How do environmental factors affect oxygen solubility? First, the solubility of oxygen decreases as temperature increases. This means that warmer surface water requires less dissolved oxygen to reach 100% air saturation than deeper, cooler water. For example, at sea level (1 atm or 760 mmHg) and 4°C (39°F), 100% air-saturated water would hold 10.92 mg/L of dissolved oxygen. But if the temperature were raised to room temperature, 21°C (70°F), there would only be 8.68 mg/L DO at 100% air saturation. Second, dissolved oxygen decreases exponentially as salinity increases. Third, dissolved oxygen will increase as pressure increases. This is true of both atmospheric and hydrostatic pressures. Water at lower altitudes can hold more dissolved oxygen than water at higher altitudes.

DISSOLVED OXYGEN TECHNOLOGY

The Winkler titration method has long been heralded as the standard for dissolved oxygen (DO) measurements. However, titrations are time-consuming and difficult to conduct in the field. Instead, dissolved oxygen sensors are used as they offer real-time results and have a proven accuracy rivaling the Winkler method. DO sensors can be used in real-time monitoring systems or for spot sampling and quality assurance. There are several types of dissolved oxygen sensors on the market, including polarographic, rapid-pulsing, galvanic and optical.

Hydropower facilities' dissolved oxygen monitoring systems typically use a submerged rapid-pulsing or optical sensor to measure DO. These sensors can continually monitor dissolved oxygen levels above and below the dam, providing instantaneous water quality data. Timely control measures can then be initiated based on a facility's impacts on the ecosystem.

Electrochemical Dissolved Oxygen Sensors

Electrochemical dissolved oxygen sensors are among the most economical DO sensors on the market. There are two types of electrochemical DO sensors: galvanic and polarographic. Both galvanic and polarographic DO sensors use two polarized electrodes, an anode and a cathode, in an electrolyte solution. The electrodes and electrolyte solution are isolated from the sample by a thin, semi-permeable membrane.

When taking measurements, dissolved oxygen diffuses across the membrane at a rate proportional to the pressure of oxygen in the water. The dissolved oxygen is then reduced and consumed at the cathode. This reaction produces an electrical current that is directly related to the oxygen concentration.

These sensors are only recommended for spot sampling as they are flow dependent and must be stirred in solution. When the oxygen is consumed, the sensors can produce an artificially low DO reading in no-flow situations. Electrochemical dissolved oxygen sensors should be stirred in the sample until the dissolved oxygen readings no longer increase.

Optical Dissolved Oxygen Sensors

Optical dissolved oxygen sensors measure the interaction between oxygen and certain luminescent dyes. When exposed to blue light, these dyes become excited (electrons gaining energy) and emit light as the electrons return to their normal energy state. When dissolved oxygen is present, the returned wavelengths are limited or altered due to oxygen molecules interacting with the dye. The measured effect is inversely proportional to the partial pressure of oxygen. While some of these optical DO sensors are called fluorescent sensors, this terminology is technically incorrect. These sensors emit blue light, not ultraviolet light, and are properly known as optical or luminescent DO sensors. Optical dissolved oxygen sensors can measure either the intensity or the lifetime of the luminescence, as oxygen affects both.

An optical DO sensor consists of a semi-permeable membrane, sensing element, light-emitting diode (LED) and photodetector. The sensing element contains a luminescent dye that is immobilized in sol-gel, xerogel or other matrix. The dye reacts when exposed to the blue light emitted by the LED. Some sensors will also emit a red light as a reference to ensure accuracy. This red light will not cause luminescence, but simply be reflected back by the dye. The intensity and luminescence lifetime of the dye when exposed to blue light is dependent on the amount of dissolved oxygen in the water sample. As oxygen crosses the membrane, it interacts with the dye, limiting the intensity and lifetime of the luminescence. The intensity or lifetime of the

returned luminescence is measured by a photodetector, and can be used to calculate the dissolved oxygen concentration.

At low concentrations, dissolved oxygen (as measured by its partial pressure) is inversely proportional to luminescence lifetime. At high concentrations, this measurement is non-linear. Most meters account for this by modifying their internal algorithms if a higher concentration is measured.

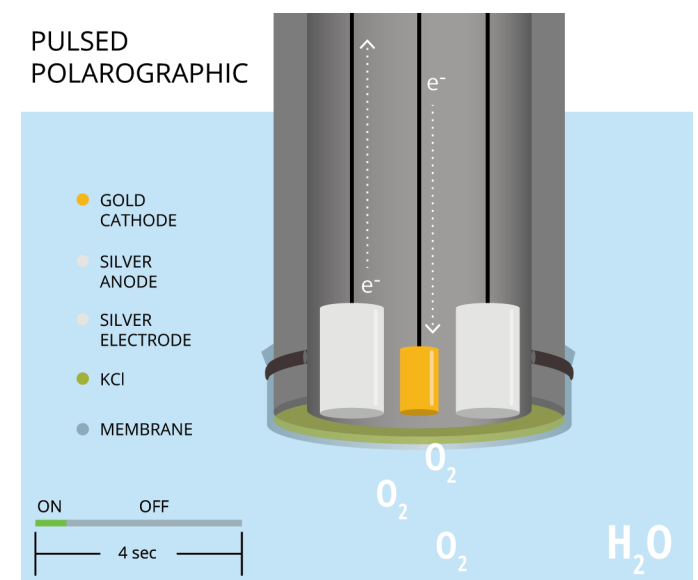
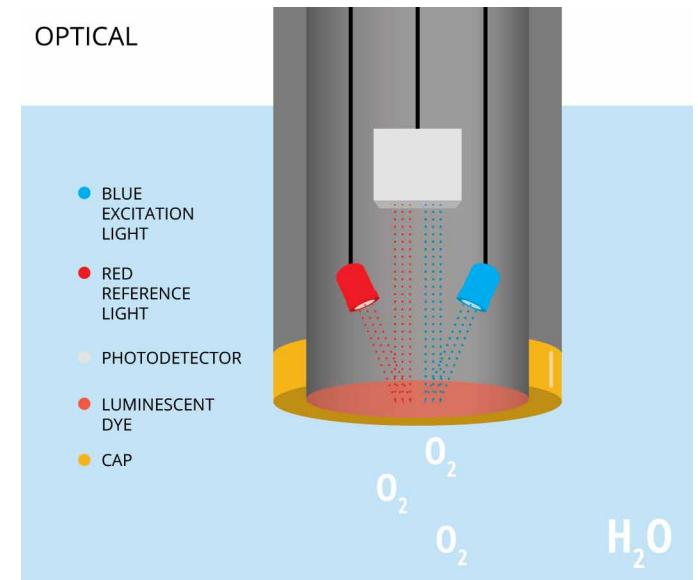
Optical dissolved oxygen sensors tend to be more accurate than their electrochemical counterparts, and are not affected by hydrogen sulfide or other gases that can permeate an electrochemical DO membrane. They are also capable of accurately measuring dissolved oxygen at very low concentrations.

Optical DO sensors are ideal for long-term monitoring programs due to their minimal maintenance requirements. They can hold a calibration for several months and exhibit little (if any) calibration drift. These dissolved oxygen sensors also do not require any warm-up time or stirring when taking a measurement. Over a long period of time, the dye degrades and the sensing element and membrane will need to be replaced, but this replacement is very infrequent compared to electrochemical sensor membrane replacement. Luminescence lifetime-measuring sensors are less affected by dye degradation than intensity-measuring sensors, which means that they will maintain their accuracy even with some photodegradation.

Pulsed Polarographic DO Sensors

Like optical sensors, pulsing polarographic dissolved oxygen sensors remove the need to stir a sample for accuracy when measuring dissolved oxygen. A rapid-pulse DO sensor is similar to a steady-state polarographic DO sensor as both utilize a gold cathode and silver anode. Both steady-state and rapid-pulse sensors also measure dissolved oxygen by producing a constant voltage to polarize the electrodes. However, these pulsing polarographic DO sensors turn on and off approximately every four seconds, allowing the dissolved oxygen to replenish at the membrane and cathode surface. This replenishing creates a flow dependence of almost zero. In order to consistently polarize and de-polarize the electrodes for these short time periods, a pulsing polarographic DO sensor includes a third, silver reference electrode, separate from the silver anode. The electrochemical reaction (silver oxidation and oxygen reduction) remains the same.

As rapid-pulse polarographic sensors reduce flow dependence when taking DO measurements, the water sample does not need to be stirred when using this sensor.



TYPICAL OXYGEN MONITORING SYSTEM

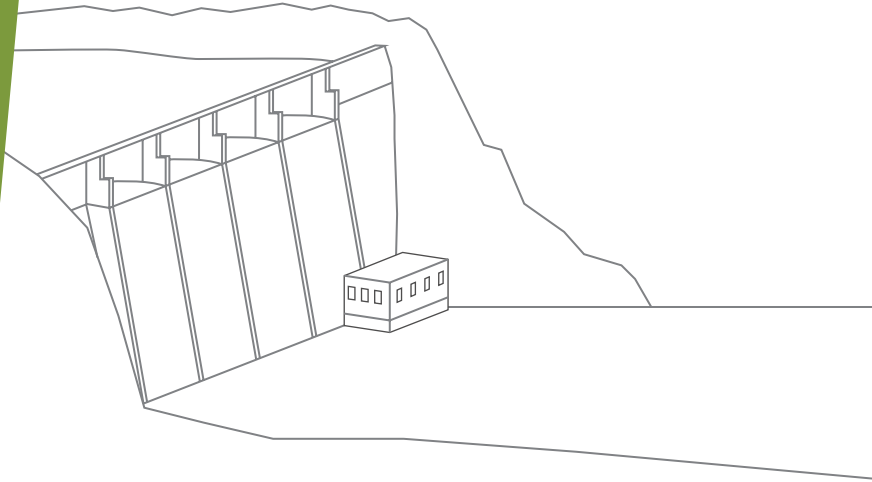
For many hydropower facilities, it is required by FERC to monitor dissolved oxygen levels in order to prevent the destruction and dispersal of aquatic habitats. This is usually done with three monitoring stations: one upstream (for background data), one within the impoundment (for risk analysis) and one downstream (at a location affected by the dam release).

To be effective, dissolved oxygen monitoring data should be provided in real time. The easiest and most efficient way to do this is with an integrated telemetry system. A data logger can support sensors at multiple depths, while logging measurements at pre-defined intervals. With telemetry, the system can then securely transmit the data to the Internet in real time for access from any computer.

Integrated data logging and telemetry stations are customizable based on FERC license requirements. They can house as many sensors as needed, and all equipment is powered via a central battery and recharging solar panel system. With multiple telemetry options to choose from, continuous real-time data are available from any computer. This ensures that the hydropower facility's operations continue smoothly, and any control measures can be implemented immediately if dissolved oxygen falls below a set minimum.

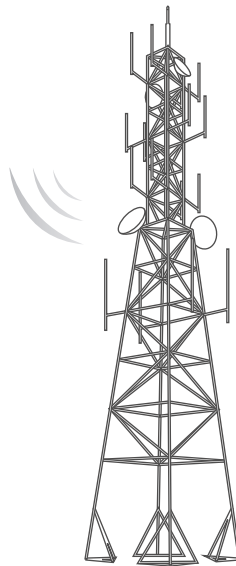
Hydroelectric Power Facility

While there are several types of hydroelectric power plants, hydropower dams are used to generate electricity through the potential energy of impounded water. The potential energy of the impoundment increases with depth, as does the potential for stratification. Water that is released from the impoundment flows through the dam, generating electricity as it spins a turbine.



Telemetry

Telemetry sends monitoring data to a central computer or web-based datacenter in real time. The wireless communication can be radio-to-shore, cellular or satellite based.



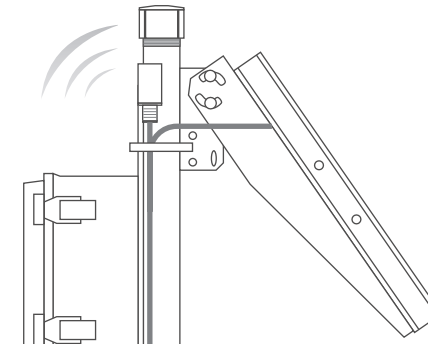
Live Data

Data can be made available 24/7 through an online datacenter. Dissolved oxygen measurements can be viewed in real time, or as a graph to see trends. Automated alerts can be sent via text or email in real time when dissolved oxygen falls below minimum standards.



Integrated Data Logging System

An integrated data logging system is a real-time monitoring station that houses the data logger, telemetry module, and power/charging supply. Since it is generally cost-prohibitive to run AC power to the monitoring location, integrated solar panels are used to continuously charge the 12VDC battery for autonomous operation.



Mounting Hardware

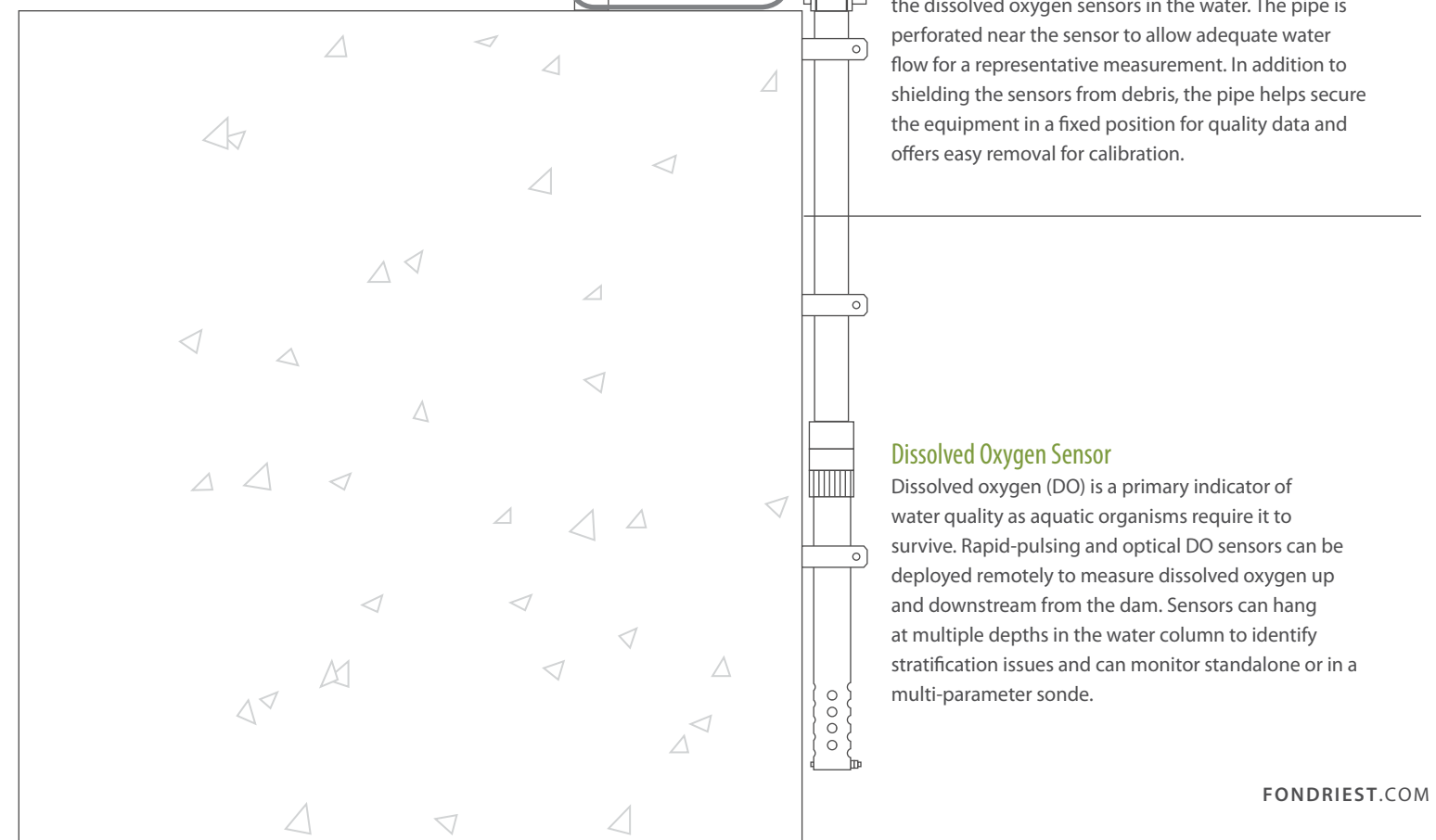
Data loggers can be mounted to a wall or pole based on location and reporting requirements. These systems can be installed on the dam or along bridges, piers or other structures in the river or along the bank.

Deployment Pipe

PVC or metal deployment pipes are installed to protect the dissolved oxygen sensors in the water. The pipe is perforated near the sensor to allow adequate water flow for a representative measurement. In addition to shielding the sensors from debris, the pipe helps secure the equipment in a fixed position for quality data and offers easy removal for calibration.

Dissolved Oxygen Sensor

Dissolved oxygen (DO) is a primary indicator of water quality as aquatic organisms require it to survive. Rapid-pulsing and optical DO sensors can be deployed remotely to measure dissolved oxygen up and downstream from the dam. Sensors can hang at multiple depths in the water column to identify stratification issues and can monitor standalone or in a multi-parameter sonde.



MONITORING STATIONS

The number and location of FERC mandated monitoring stations will largely depend on license requirements and the facility's structure. Common requirements for dissolved oxygen monitoring involves three stations. Each station should include a data logging telemetry system and as many sensors as are required. These stations can be buoy-based or mounted to a structure.



Selecting the Location

Required monitoring locations can be upstream, downstream, or within the impoundment. Upstream monitoring stations can be incorporated for background data if water quality standards are not dictated by the state. Impoundment stations can monitor multiple depths for stratification data, or simply monitor dissolved oxygen near the intake. Downstream stations can be found at the outlet, in the stilling basin or tailrace, following a weir, or further downstream of the facility.

Dissolved oxygen monitoring stations should be set at fixed locations for accurate data. Mounted systems can be placed on a structure on the shoreline or in the water, including on a pier, bridge, dam, or locks construction. Whether they are mounted to a wall or pole, the sensor should be suspended in a perforated PVC or metal pipe in the water. Structure-based telemetry systems are easy to set up wherever monitoring is needed.

If it is necessary to collect comprehensive water-column data, a buoy-based system may be more effective. Data buoys are often used within a reservoir for a complete water quality profile. Buoy-based systems provide a stable platform that can be setup anywhere in the waterway. These systems can support multiple sensors between the surface and the bottom of the water column, providing greater insight into stratification. Like structure-based systems, data buoys house a data logger, solar-powered battery pack, and telemetry for remote communication and long deployments. While data buoys come in several sizes based on sensor load and water conditions, buoys with 150 to 450 lb. net buoyancy are generally adequate for reservoir and river monitoring.

Upstream

Upstream monitoring stations can be structure or buoy based. These systems are usually required if state water quality standards are flexible or not applicable. A monitoring system upstream of the hydropower dam provides background data on expected dissolved oxygen levels, as this water has not yet been affected by the facility. These data can then be compared to measurements made downstream of the dam to see how much effect the power plant has on water quality.

Reservoir / Impoundment

Lake habitats are very different from river habitats. As the flow is slower, and the water column is deeper, many characteristics of the water will change. Data buoys are typically used to monitor water quality changes in reservoirs. Deep impoundments and reservoirs are much more likely to stratify, which creates two separate aquatic ecosystems, top and bottom, often with very different dissolved oxygen concentrations. As data buoys can be centered in the deepest part of the reservoir and support multiple sensors throughout the water column, they are ideal for these monitoring conditions.

Intake

Some FERC licenses require dissolved oxygen monitoring specifically at the dam's intake point. This is the point where water enters the facility for power generation. Intake monitoring is usually done by a mounted telemetry system, as the equipment can easily be attached to the dam structure with the sensor hanging fixed in the water. Deep hydro intakes are more likely to pull de-oxygenated water through the facility, and monitoring at the intake and outlet will provide data on how much that water will impact the river system.

Outlet/Tailrace

The hydropower outlet is the most important dissolved oxygen monitoring location. It is at this point that oxygen-depleted water is released into the river, affecting the rest of the aquatic system. Outlet-monitoring stations are typically mounted, though they can also be buoy based. Data from an outlet dissolved oxygen monitoring station will determine how much the released water will impact the environment, and if mitigation measures should be employed.

Stilling Basin

A stilling basin can be found directly below the dam. While most hydropower dam concerns revolve around too-low dissolved oxygen levels, the stilling basin can face the opposite issue, particularly if the outlet is further downstream. This basin is used to contain and slow down spillway water, which is often supersaturated with air. While the spillway water entrains oxygen for the fish below, super-saturation can cause gas bubble disease. Monitoring stations in a stilling basin often measure total dissolved gases in addition to dissolved oxygen to ensure quality DO levels while preventing supersaturated water.

Downstream

Downstream dissolved oxygen monitoring will provide data that show the actual effects of the de-oxygenated water on the river system. As opposed to relying on flow models based on intake/outlet data, downstream monitoring reveals the actual impacts of the hydropower facility. However, as they are further away, they will not allow for as quick of a mitigation response if levels are below the accepted minimum.



Pre-Deployment

To ensure accurate data, all sensors should be calibrated prior to installation and thereafter on a regular basis. If using a buoy-based system, the platforms should be fully assembled on shore prior to deployment. Regardless of the station setup and location, each complete dissolved oxygen monitoring system (sensors, data logger, telemetry, software) should be tested before deploying. While this process ensures that all equipment is functioning within specifications, it also gives everyone the chance to familiarize themselves with the system prior to deployment. Issues are always easier to deal with before installation than after.

Mounted Deployment

Mounted dissolved oxygen monitoring systems can be set up anywhere that there is a structure. Common deployment locations include pole or wall mounting on the dam, bridges, piers, docks, railroad trestles, and lock structures. The system can include a stainless steel enclosure to protect the data logger and telemetry modem from harsh weather and vandalism. The sensors hang from the station into the water within a perforated PVC or metal pipe. This pipe protects sensors from debris in the water while still permitting water flow for accurate measurements. The use of a deployment pipe also secures the sensors in a fixed position for quality data, while allowing easy removal from the water for recalibration.

Buoy-Based Deployment

In order to maintain a fixed position in the water, a buoy-based system must be moored to the bottom. When monitoring dissolved oxygen in a reservoir, a two-point mooring is recommended. A two-point setup keeps the water column below the data buoy open for sensors to hang, without risking entanglement with the anchor lines. It also offers greater stability if there are any currents or turbulence at the station. Mooring hardware usually includes two marker buoys, stainless steel mooring lines, bottom chains, and anchors. To provide the most comprehensive water quality profile, the buoy should be deployed in the deepest part of the water way. This allows for multiple measurement depths and will best reflect the characteristics of the impoundment as a whole.

DATA MANAGEMENT

A major part of FERC reporting is collecting and accessing the monitoring data. While it is possible to manually measure and record data on site, the use of a data logger and telemetry system is more cost effective. The ability to save, send and view measurement data in real time is efficient and convenient, particularly when frequent monitoring intervals are required to maintain compliance. Real-time data and alerts also allow for a faster response time when adverse conditions occur.



Data Logger

As the name implies, a data logger is an instrument that stores data. In environmental monitoring applications, data loggers can be used not only to collect data from sensors and sondes, but to control sampling rates and transmit data to a central location in real time.

While sondes often have the ability to log their own data, a separate, dedicated data logger can gather data from any and all attached sensors, while ensuring that no data are lost. If telemetry (wireless communication) is available, the logger can remotely control sensor sampling rates and transmit collected data to a central project computer. Data loggers with telemetry technology can provide real-time dissolved oxygen data and remote access via a cellular modem, radio transmission or satellite modem.

When housed in a data buoy, a data logger is charged by a marine battery and the buoy's solar power system. Most mounted DO monitoring systems also offer a rechargeable battery and charging solar panel to power the data logger. For dam-mounted systems near an AC power source, an AC converter can be used. Data loggers can be configured with a number of sensor ports for connection to industry-standard digital and analog interfaces, including RS-485, SDI-12 or 0-2.5 VDC. Dissolved oxygen sensors can connect to a logger directly or through a multi-parameter sonde. A data logger can also handle additional water quality sensors or temperature strings if they are required by the FERC license.

Telemetry

Telemetry, or wireless communication, is a useful tool for monitoring dissolved oxygen in real time. Common telemetry options are cellular and radio, though satellite telemetry can be used in more remote locations. The deciding factor when determining the most cost-effective telemetry option should be the local site conditions and proximity to a project computer. All three of these options permit real-time updates for water quality above and below the hydropower facility.

Radio telemetry is recommended when all equipment is in close proximity. If equipped with a license-free spread-spectrum radio, a data logger can communicate with a shore-side or dam-mounted radio base station. This range may vary depending on the logger and base station used. Spread-spectrum radio technology may allow a range as far as five miles (line-of-sight) or a few hundred feet (non-line-of-sight). The radio base station serves as a central hub for any compatible data logger in range, and offers the ability to send the collected data to a project computer.

Cellular telemetry offers more geographic flexibility than radio, though it does require a cellular data plan. This small, additional cost permits data transmissions from anywhere that receives a cellular signal. With cellular

telemetry, monitoring stations do not need to be in close proximity, nor is a base station required. If multiple monitoring stations are required, each data logger can send information individually to a central database. All the data can then be accessed wirelessly from any computer via the Internet. Data loggers may be equipped with cellular modems from different providers, including AT&T, Verizon and Sprint.

For remote applications where radio and cellular telemetry are not feasible, satellite telemetry can be used. The Iridium communications network maintains a dynamic, cross-linked constellation of Low Earth Orbiting (LEO) satellites, providing coverage all over the world. This means that data loggers with an Iridium satellite modem can transmit data in real time from anywhere on Earth. As with cellular networks, the data is sent to a central gateway, which then transfers the data over the Internet to any project computer or cell phone.

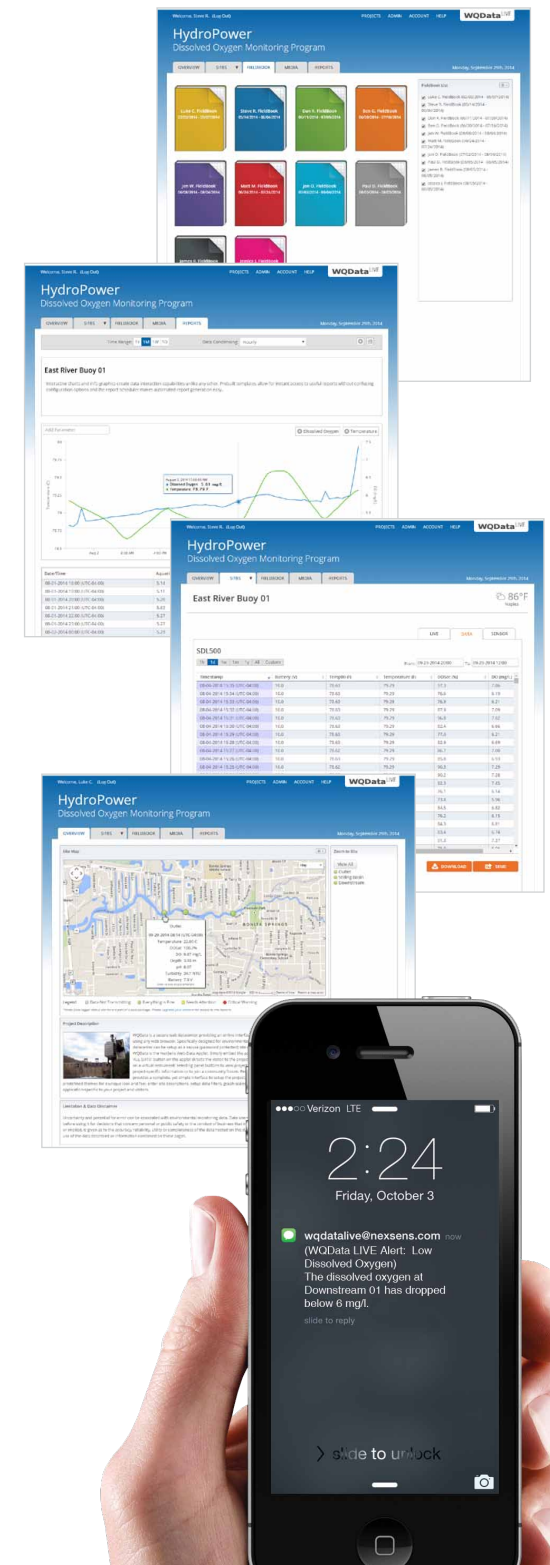
Real-Time Online Datacenter

The easiest way to share and view dissolved oxygen monitoring data is through a web-based datacenter. An online datacenter offers 24/7 instant access to project data via any web browser. DO monitoring and other data can be exported into the datacenter directly from the data logger, or through the project software.

This project management service can be password protected or public, and allows users access to the collected data in real time. In addition to any FERC-license information, the online interface can provide dynamic area maps, overlaid with weather information, recent and historical data, time series graphs and statistical summaries. Visitors can interact with the project maps and view real-time monitoring data or dissolved oxygen level trends over time.

But these cloud-based datacenters are more than just a pretty face. Many can be programmed to send out automated alarm notifications when DO levels fall below pre-defined limits. These limits are determined by collecting background data, usually from upstream of the hydropower facility. Once an allowable dissolved oxygen range has been set, the data are entered into the online database. If DO levels drop below the recommended range during dam operations, the datacenter will immediately issue an alert (text and/or email) to the appropriate dam manager or operator.

With the availability of real-time data and the datacenter's auto-alert system, dam operators can be notified immediately when dissolved oxygen levels fall. This means that timely control procedures can be implemented to improve DO levels through a dam release or other operation until the DO concentration rises above the minimum allowable limit. The online datacenter can also transmit this alert back to the data logger in order to respond to the fallen dissolved oxygen concentration. Automated responses may include taking more frequent readings during low DO periods, then resuming regular log intervals when levels return to normal.



QUALITY ASSURANCE

Accurate data will help a hydropower facility remain in compliance with FERC license regulations. In order to maintain the highest levels of accuracy, best practice recommends cleaning and calibrating the sensors at regular intervals. Cross-checking sensor data with a separate instrument is also recommended. This cross-check verifies that the data is accurate and within sensor specifications. It will also confirm whether or not the power plant is compliant with the license.



System Maintenance

While a FERC license may not explicitly require maintenance intervals for monitoring equipment, periodic upkeep and calibration is necessary in order to prevent sensor drift and ensure a longer instrument life. Sensor maintenance includes cleaning (especially if an instrument is not self-wiping) and replacing any deteriorating or missing O-rings to prevent water ingress. If a monitoring station is measuring additional parameters beyond dissolved oxygen (such as temperature or total dissolved gases), further field servicing may be required. Maintenance intervals are largely dependent on the sensor technology used, site conditions and variables such as the potential for bio-fouling. Dissolved oxygen sensors should be checked and calibrated every 2-4 weeks or as recommended by the manufacturer.

Dissolved oxygen sensors only require a single-point calibration, though a two-point calibration can be used to verify accuracy across the entire measurement range. A single-point calibration is typically done at 100% air saturation, while a two-point calibration includes a zero oxygen solution. The 100% air saturation calibration solution can be achieved with air-saturated water or water-saturated air. For long-term studies, it is recommended to calibrate with air-saturated water, though water-saturated air calibrations are easier to conduct in the field. If a two-point calibration is performed, the zero oxygen solution can be made or purchased.

When monitoring dissolved oxygen at a hydropower dam, it is useful to have a spare sensor or sonde available. Keeping a spare dissolved oxygen sensor on hand will reduce downtime due to unforeseen sensor failure, which could affect FERC reporting. If needed, the spare DO sensor can easily be field swapped during calibration or routine maintenance checks.

For greater details regarding maintenance requirements and sensor calibration, the manufacturer's user manual should be referenced.

Performance Verification

In addition to keeping the monitoring equipment calibrated, it's important to periodically verify that the dissolved oxygen sensors are providing accurate data. The best way to achieve this is by checking dissolved oxygen at the monitoring station using a separate, portable instrument. This is also known as spot sampling.

There are several portable dissolved oxygen measurement methods that can be used for spot sampling. The first method uses a sensor attached to a handheld display, also known as a dissolved oxygen meter. The sensor can be connected directly to the display or through a multi-parameter sonde. The spot sampling equipment can be lowered into the water column to a depth that matches the stationary sensors. While it is at that depth, a dissolved oxygen measurement can be taken and immediately displayed on the meter. The portable system data can then be compared to the stationary monitoring system and checked for discrepancies.

When used for spot sampling, a dissolved oxygen sensor can be optical, galvanic or polarographic. Optical DO sensors are recommended for their accuracy and comparability to deployed instruments (as most deployed DO sensors are optical). Galvanic and polarographic sensors are more economical and can take quicker readings than optical sensors, but they are flow dependent. This means that the sensors must be stirred if the waterway has low or no flow. Spot sampling sondes are recommended if the deployed instrument is also a sonde, so that all measured parameters can be checked using similar instrumentation.

The second portable verification method uses titration. The Winkler titration method requires taking a water sample, and then fixing and titrating it to determine the dissolved oxygen concentration. This can be done with a field kit or in the lab. However, as this method uses a sample instead of an in-situ measurement, it is more time-consuming to conduct and a water sample will need to be taken at each measurement depth.



RECOMMENDED EQUIPMENT

While there are a variety of dissolved oxygen monitoring instruments to choose from, some stand out above the rest. Fondriest Environmental has selected these products as the best in their field for their accuracy, dependability and value. Together, they provide an innovative and responsive real-time dissolved oxygen monitoring system. The In-Situ RDO PRO-X optical dissolved oxygen sensor combines advanced luminescent technology with the reliability of a smart sensor – including calibration storage and a digital output. The NexSens MAST data logging system arrives fully assembled, tested and operational with integrated solar power and a choice of real-time radio, cellular, and satellite communications. Alone, real-time data are good, but with remote data collection, 24/7 access from any computer, instant alarm notifications and trend tracking, the intuitive WQData LIVE takes real-time data to the next level.



In-Situ RDO PRO-X Optical DO Sensor

The In-Situ RDO PRO-X Optical Dissolved Oxygen Sensor is an extremely stable, accurate, low-maintenance optical dissolved oxygen sensor for long-term environmental monitoring. The RDO PRO-X sensor measures dissolved oxygen using the latest dynamic luminescence quenching technology that offers many advantages over Clark-type DO sensors, including stir-independence and insensitivity to interferences such as hydrogen sulfide, chloride, and ammonium. A user-replaceable sensor cap with pre-loaded calibration coefficients is replaced annually, eliminating the need for bi-monthly membrane replacements.

The In-Situ RDO PRO-X Optical Dissolved Oxygen Sensor includes a 10m cable terminating in bare wires for connection to data loggers and PLCs. For custom cable lengths, the sensor is available with a Twist-Lock cable connection. Using the Twist-Lock connection, sensor cables can easily be swapped or extended using a Twist-Lock cable extender, and custom lengths are available up to 4000 feet. The sensor is constructed with inert material and pressure-rated to 500 PSI, making it an ideal solution for highly saline or deep water environments. Common applications include dam discharge monitoring, multi-point dissolved oxygen profiling, and municipal process monitoring.

NexSens MAST Data Logging System

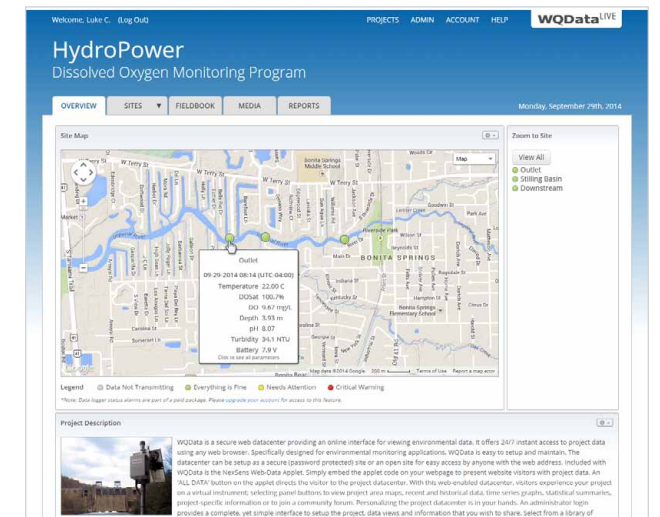


The iSIC-MAST system includes the data logger and solar panel pre-mounted to a 2" diameter pole to create a truly plug-and-play data collection and sensor interface platform. The system integrates a NexSens iSIC data logger and 20-watt solar power kit - all in a compact, pre-configured package. Simply thread the system to any 2" NPT male pipe thread, connect the solar panel & battery, wire the sensors, and setup a project using iChart software - it's that simple!

The iSIC data logger arrives ready for long-term deployment. All electronics are housed in a rugged, NEMA 4X enclosure constructed of heavy-duty fiberglass. The built-in 8.5 amp-hour sealed lead acid battery provides 12 volt power to the system, and the battery is continuously charged using solar power. Polymer-coated circuit boards, sealed connectors, corrosion-resistant stainless steel hardware and built-in lightning protection ensure reliable performance in the harshest conditions. All sensors are cabled through Sealcon gland fittings to ensure protection from the elements.

NexSens iChart Software is a Windows-based program for interfacing to an iSIC data logger or network of data loggers. The iChart Setup Device Wizard includes built-in drivers and a step-by-step interface for setting up and configuring remote monitoring sensors and systems. When connected, the user can quickly configure sample & log intervals, upload data, or troubleshoot communications.

NexSens WQData LIVE Web Datacenter



WQData LIVE is a web-based project management service that allows users 24/7 instant access to data collected from NexSens remote environmental data logging & telemetry systems. More than just an online database, WQData LIVE offers the ability to generate automated reports, configure alarms to notify project personnel when data values exceed threshold limits, create FieldBooks to store calibration forms, notes and media and much more. Projects are password protected with the ability to configure a public portal or presentation view to share data with the general public. Project Administrators have the ability to edit project descriptions and information, while users given Collaborator access are limited to data viewing and form entry.

The Google Maps view shows all project sites on a map with zoom, scroll and drag capability. Mousing over a site on the map displays the most recent data values, and clicking on the site navigates to a display showing the last reading or tabular data that can be downloaded to Excel and sent via email or FTP. FieldBooks can be created to store notes recorded during field visits, including forms to store calibration data, which can be submitted from the WQData LIVE mobile app. This eliminates the need for conventional fieldbooks while keeping critical project information in a single, easy-to-access location. Site photos can even be placed onto FieldBook pages or uploaded into the project's Media page.

The WQData LIVE report feature allows data to be shown both graphically and in a tabular format. Report templates can be saved so that specific information can quickly be referenced. Project alarms send email or text messages to project staff for immediate notification of critical conditions. With this unique set of features, WQData LIVE provides everything needed to effectively manage an environmental monitoring application.

PURCHASE OR RENT?

When managing a large monitoring project, purchasing several dissolved oxygen monitoring systems is often the most economical option. However, for short-term assessments or projects on a tight budget, it may not be practical to purchase the necessary DO monitoring equipment. In these situations, it is much more prudent to rent real-time monitoring systems. With several lease duration and extension options available, the flexibility of renting DO monitoring systems may still be cost effective for the larger compliance applications as well.

Dissolved oxygen monitoring equipment can be rented instrument by instrument, or as an entire system, calibrated and ready to deploy on arrival. Rental equipment can include sensors, sondes, handheld displays, data loggers, telemetry systems data buoys, and web-based datacenter access. Real-time telemetry via radio-to-shore, cellular and satellite can also be incorporated. A large rental pool also means that most dissolved oxygen monitoring equipment can be shipped same-day for quick deployment and emergency situations.

Just as with Fondriest purchases, rental projects have access to a knowledgeable support staff who will provide personalized service before, during and after the project.

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ABOUT FONDRIEST

Company

Located in the Lower Great Lakes and Ohio River Valley region, Fondriest Environmental is a leading distributor and integrator of equipment for natural resource professionals and outdoor enthusiasts. Our team of specialists can help customers understand the products they are buying and make the correct decisions out in the field. We seek to understand project needs, devise a comprehensive solution, provide the equipment and know-how to implement it and then offer long-term project support for whatever needs arise.

Capabilities

We work closely with NexSens Technology, a company that specializes in the design and manufacture of real-time environmental measurement systems. A variety of sensor, platform and telemetry options are available to fit the unique needs of each project. We can provide complete integrated solutions and support projects from conception to completion. An extensive fleet of rental equipment is also available for short-term project needs.

Certifications

Fondriest Environmental is a Certified Repair Center for YSI, NexSens & FishSens, offering quick turnaround, affordable labor rates and personalized service. Our knowledgeable technicians are available for phone, email and onsite support when the need arises.

Publications

We cover many customer projects in our Environmental Monitor magazine, which is updated daily online and printed quarterly. We also produce Lake Scientist, an interactive online resource providing research articles and news on lake ecology. Informational pages on environmental parameters and applications are available in the Measurement Sciences section of our website. And FishSens Magazine, available online, provides anglers, boaters and fisheries professionals with the latest fish science news.

Commitment

A commitment to integrity and longstanding customer relations are the standard, rather than the exception, at Fondriest Environmental. We support professionals, educators and researchers who continuously work to monitor and protect our global resources by providing them with the products and services needed to face today's environmental challenges. Our team of solution-driven experts has years of field experience and a keen eye for finding the best equipment for each application.

Contact Information

To reach an application specialist, please call (888) 426.2151 or email customer@fondriest.com



SYSTEM CONFIGURATION TOOL

Fondriest application specialists will assist with tailoring system configuration and equipment choices on a site-by-site basis to ensure reliability and proper data management. The questionnaire below can help you get started. Once completed, this form can be faxed to (937) 426.1125 or, if completed digitally, emailed to customercare@fondriest.com.

Contact Information

Name: _____
Organization: _____
Telephone: _____
Email: _____

Site Conditions

Describe the site conditions in a paragraph or two. Please include details regarding levels of wind, waves and boat traffic experienced in the area.

Site Location

The location of a monitoring system can affect what equipment platform best suits the conditions. Please select in what type of water body the system will reside.

Lake River Coastal Other Please Specify _____

Approximate Depth

With buoy-based systems, the mooring hardware and cable lengths used for a deployment depends on the distance to the sea floor. An application specialist can develop the best mooring plan to accommodate the approximate water depth.

< 5 ft. Between 5 and 25 ft. Between 25 and 50 ft. Between 50 and 100 ft. > 100 ft.

Water Column Measurements

Measuring dissolved oxygen at a single mid-level depth is often sufficient for FERC monitoring. In some cases, however, regulatory agencies may require readings at multiple depths.

Single Depth Multiple Depths Please Specify _____

Telemetry

License-free spread-spectrum radio telemetry allows communication with a shore-side NexSens radio base station as far as five miles line-of-sight from the monitoring site. Cellular telemetry allows greater geographic flexibility and is able to transmit from almost anywhere in the U.S., but it includes the cost of a cellular data plan. Satellite telemetry can be used nearly anywhere in the world, but it tends to have the highest data cost compared with cellular telemetry.

Cellular Radio Satellite None

Quality Assurance

A portable dissolved oxygen meter is an ideal way to verify the accuracy of a dissolved oxygen monitoring system. Select a cable length that will allow you to reach all measurement locations in the water column.

4m 10m 20m 30m >30m Please Specify _____

Project Length (Rental vs. Purchase)

Although it often makes sense to purchase systems outright, many short-term projects make it cost-prohibitive. Fondriest Environmental offers real-time dissolved oxygen monitoring systems with weekly and monthly rental rates to accommodate these operations. An application specialist can make recommendations on what choice is most cost-effective.

1-3 Months 3-6 Months 6-12 Months >1 Year Please Specify _____

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E customercare@fondriest.com



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demands
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CONTACT A FONDRIEST APPLICATION SPECIALIST
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