



dissolved oxygen

Case Studies & Solutions

for long-term water quality monitoring
with ROX™ optical DO sensor



ROX™ Luminescent Dissolved Oxygen Sensor

Optical sensing technology has replaced the stretched membrane on the ROX DO sensor

The ROX™ luminescent dissolved oxygen (DO) sensor was released in Spring 2006 for use in YSI's 6-Series V2 multiparameter sondes. In several significant ways, the ROX sensor differs from polarographic-style DO sensors, which have been the industry standard for DO measurement. The principal distinguishing factors relate to the durability of the sensing element and the stability of the signal, both of which have been significantly improved in the ROX sensor. These changes mark an important step forward in *in situ* monitoring applications.

In the past, polarographic DO sensors, with delicate Teflon® membranes and consumable electrolyte solutions, were often the limiting factors in deployment times of multiparameter monitoring equipment due to sensor drift or the impacts of biofouling. The introduction of the ROX sensor changes DO sensors from having the shortest deployment endurance to one of the longest. This has a practical implication to monitoring groups by extending maintenance intervals and reducing sensor maintenance, saving valuable time and money.

This report is a sampling of results which our customers have obtained using the ROX sensor since the product's launch. To say that ROX has revolutionized long-term monitoring may sound dramatic, but we believe this



is the case. We are now seeing maintenance intervals stretch from two weeks to six weeks or longer in heavy fouling environments.

No other company has the long-term monitoring features and application support that YSI offers. YSI's simple goal is to offer the most reliable water quality monitoring systems with the longest maintenance intervals possible. This is coupled with dedicated and knowledgeable technical support. Successfully realized, this goal lowers the cost of ownership for our customers and thus increases the number of monitoring systems deployed worldwide.

With reliable and accurate data from YSI instruments around the world, monitoring groups are able to continue the critical work of protecting our most important natural resource.

Happy Monitoring from your partners on the YSI Environmental Monitoring Team.

ROX™ Luminescent Dissolved Oxygen Sensor

The case studies and field trials in this report are organized as follows:

1-2 Lakes/Streams

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Customer Class Environmental Consultant
Environment Freshwater Reservoir
Location New York
Duration 27 days, hourly interval

This customer is an environmental consultant interested in maximizing the maintenance interval for long-term studies and minimizing the risk of sensor failure or other technical problems.

The customer conducted a 25-day side-by-side test with a ROX sensor and a DO sensor from an alternate sensor company that the customer had experience with and routinely provided deployment times of one week before maintenance was required. A gradual decrease in DO was observed over the course of the study. YSI's ROX exhibited excellent reliability and no drift over the course of the study.

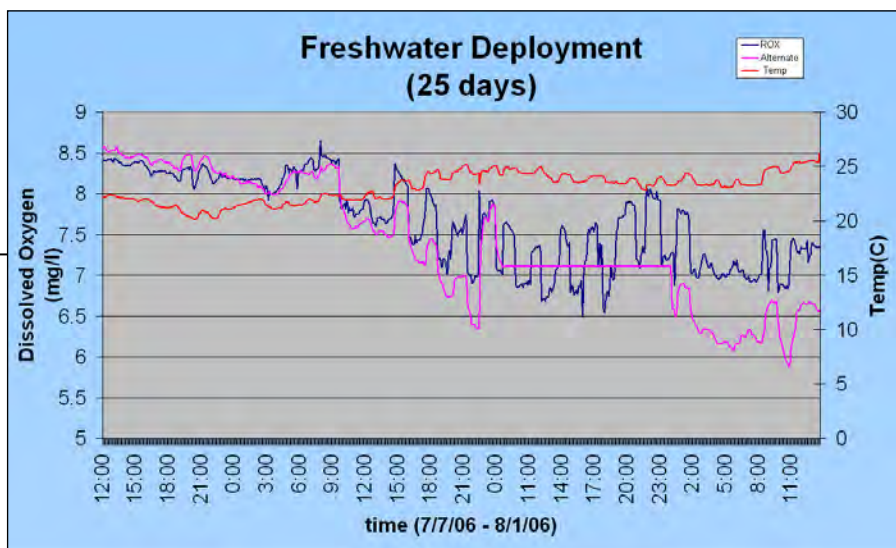
A post-deployment check of the ROX sensor resulted in a DO reading of 7.75 mg/l while a Winkler titration on the same sample of water resulted in a value of 7.718, indicating that there had been no drift in the ROX sensor.

While the ROX sensor remained stable, data from an alternate sensor show some of the typical problems with many in situ sensors: power failure and sensor drift



Simultaneous field trial of ROX sensor and DO sensor from alternate company

A number of problems were seen in the alternate sensor, with a failure occurring midway through the trial (7/21) that resulted in lost data for six days until the problem was found. The alternate sensor also demonstrated significant drift over the course of the four-week trial.



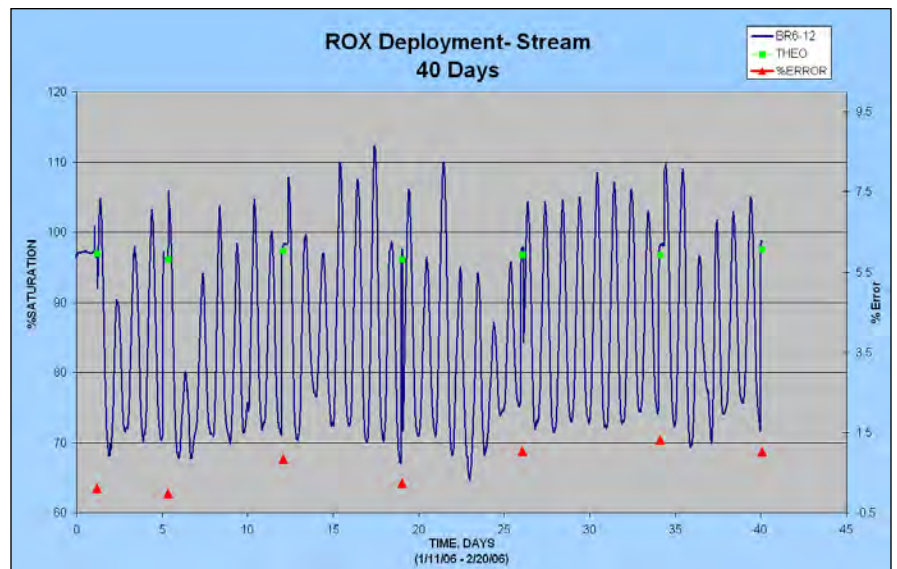
Customer Class YSI Field Testing
Environment Stream
Location Ohio
Duration 40 days, 15-minute interval

*Rural stream
 deployment site in
 southwest Ohio*

The data presented in this example was generated by YSI scientists in a stream near the company's headquarters in southwest Ohio. The technicians conducted regular quality control checks on the ROX sensor by taking a freshly calibrated handheld sensor into the field and collecting simultaneous readings with the ROX.



The QC points are indicated in green and the percent deviation from the QC and the ROX data point are plotted in red. Throughout the course of the 40-day study, the percent error never exceeded 1.5%, indicating that the ROX sensor did not drift and biofouling did not impact the readings.



For small municipalities such as the one located near this Ohio stream, time and resources are limited and the success of a long-term monitoring system relies on easy-to-use and reliable systems that do not require regular baby-sitting. This

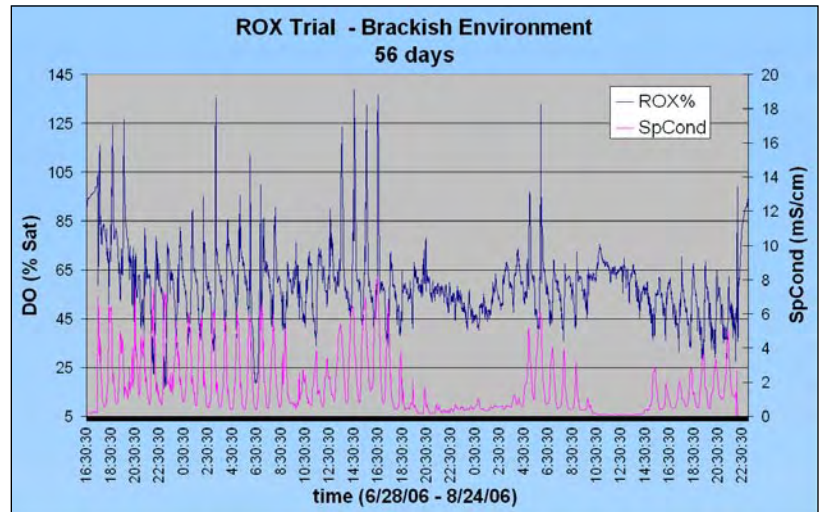
example highlights the effectiveness of a ROX sensor for continuous monitoring up to 40 days in a stream environment.

Customer Class Federal Monitoring Agency
Environment Brackish Creek
Location Southern USA
Duration 56 days, 30-minute interval

An extremely challenging site for testing in situ sensors, characterized by high concentrations of dissolved organics, high turbidity, high temperature, and the occasional hurricane

Product reliability and good customer support are critical decision-making factors for a large monitoring agency such as the U.S. Geological Survey (USGS). The data presented here is one example from trials conducted at a brackish water site in Louisiana to evaluate the ROX technology in order to determine if the agency should recommend switching from polarographic sensors for long-term deployment applications.

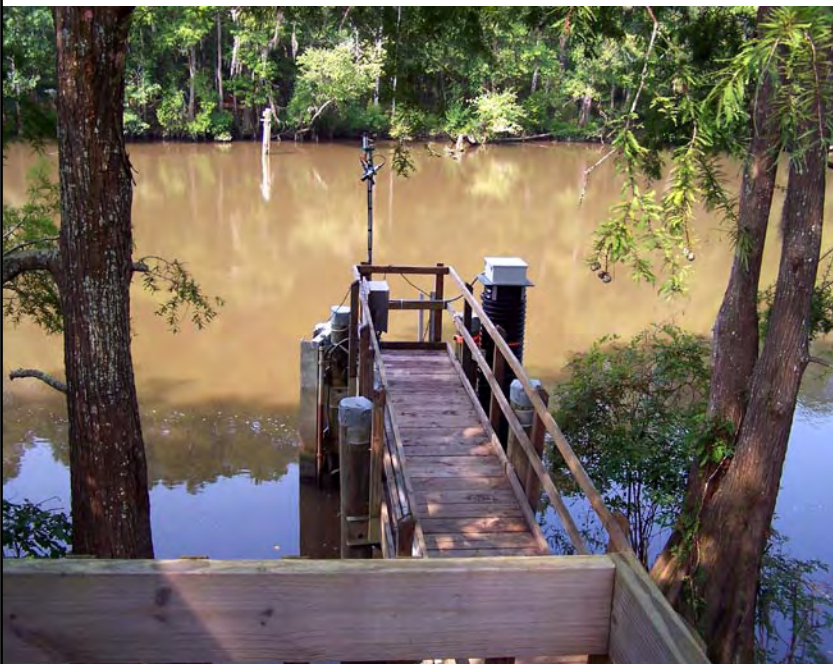
The most critical characteristics to this group are sensor stability, post-deployment accu-



racy, and the effectiveness of the anti-fouling system, all of which add up to improved system reliability and lower operating costs.

The last sample taken with the ROX in the field, after 56 days without maintenance, was 3.60 mg/l. The ROX was then thoroughly cleaned and a post-cleaning reading yielded a value of 3.62 mg/l. This indicated that impacts of biofouling had no effect on the ROX sensor. A Winkler titration was then taken on the same sample and yielded values ranging from 3.74 - 3.86. This is an excellent result with very little to no drift and no impacts of biofouling after many days in a high productivity and fouling environment.

YSI's power supply was also able to power the system for the duration of the study, a length of time that the competition will find difficult to match.

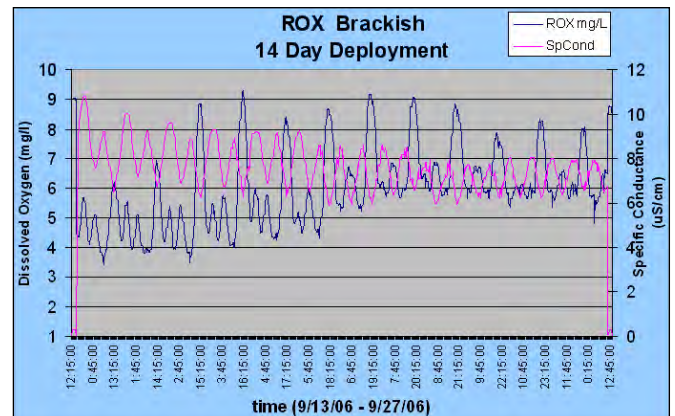


Customer Class National Monitoring Network
Environment Brackish
Location Mid-Atlantic USA
Duration 14 days, 15-minute interval

This customer group manages a National Estuarine Research Reserve (NERR) in Delaware. The data was collected in a mostly freshwater tributary that flows into Delaware Bay. The goal of the deployment was to compare the ROX sensor with the Rapid Pulse polarographic sensor in order to determine if switching to the ROX technology would result in a lower cost of ownership through extending deployment times (thus reducing the number of trips to the field) and reducing the time spent on calibration and maintenance.

The YSI sonde was deployed in warm (20-25 °C), shallow, productive waters. In addition, the relatively high turbidity (~20 to >100 NTU) presents physical challenges to polarographic membranes but pose no issues to the ROX membrane. The site displayed tidally driven wide swings in DO concentration.

The ROX QC data points are seen as several readings before and after deployment and are generated by placing the sonde in saturated DO environment, such as an aerated container, while allowing the sonde to continue to log data. The pre- and post-calibration readings were 98.3 and 99.1% saturation respectively, indicating no meaningful drift or biofouling effect during the two-week deployment.



Tidally influenced tributary of Delaware Bay is a challenging environment for in situ sensors: high productivity and turbidity along with wide swings in water quality on a daily basis

Customer Class Federal Monitoring Agency
Environment Estuary
Location Southeastern USA
Duration 30 days, 30-minute interval

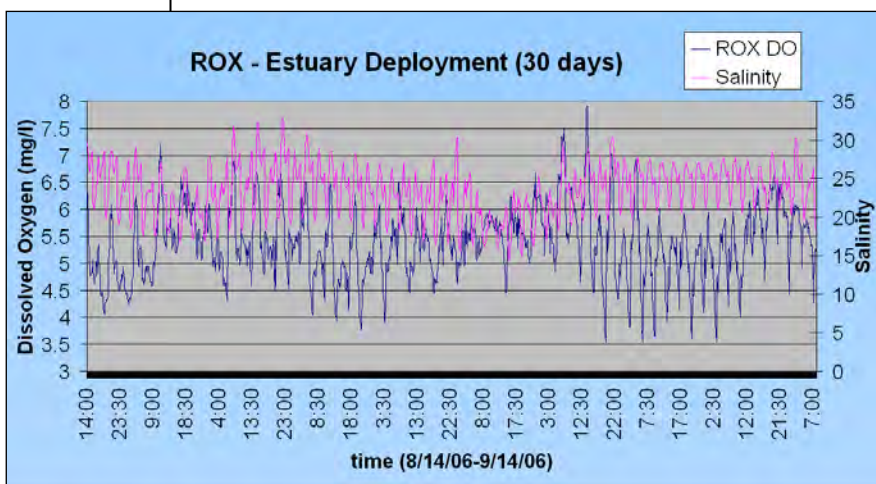
This customer is one of several sites throughout the United States that make up the National Park Service Vital Signs Monitoring Program. This long-term monitoring program has a goal of generating baseline data in order to accurately characterize the environment as well as to measure the impacts of changing land-use, storms, and pollution.

Continuous monitoring systems are required to obtain an accurate record of the rapid changes in water quality conditions in natural environments

Lower maintenance efforts and improved reliability is critical to this group, whose resources are stretched thin while being asked to increase the monitoring area. Biofouling of the sensors is of major concern in this warm and productive system. Inorganic fouling due to high sediment load is another problem. The ROX sensor with its dedicated anti-foul-



Over time, in situ sensors are often impacted by organic and inorganic fouling when deployed. The effectiveness of YSI's anti-fouling wipers, shown above, prevents sensor performance from becoming compromised

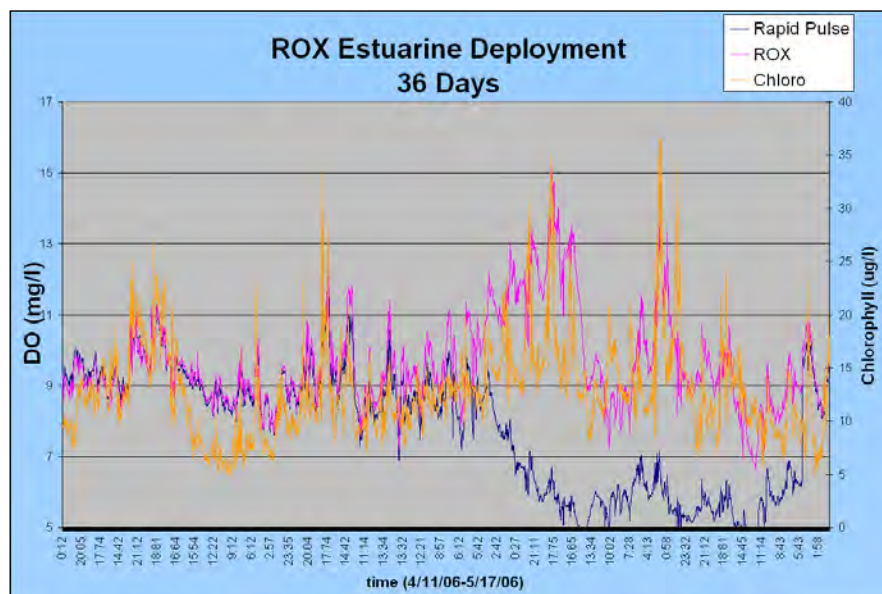


ing wiper was effective at keeping the sensor free of fouling material throughout the course of the study. The trial resulted in the ROX

sensor exhibiting excellent stability over the course of the 30 days with high fouling and large tidally driven fluctuations in salinity. The post-calibration check on the ROX sensor showed a difference of less than 2% from the pre-deployment check exhibiting no sensor drift or impacts of biofouling.

Customer Class State Monitoring Agency
Environment Estuary
Location Mid-Atlantic USA
Duration 36 days, 15-minute interval

These users manage an extensive real-time monitoring program in the Chesapeake Bay where deployment time, maintenance, and support is of critical importance. To add to the challenge, the waters in which they are tasked to monitor are very productive with harmful algal blooms, low oxygen episodes, and high turbidities all part of the normal course of events.



ROX sensor after 36 days in the field. Although there is fouling, as long as a portion of the ROX membrane is free from inorganic fouling, there is no impact on the DO signal

Due to the number of sampling stations (in many instances in remote locations), extending the sampling interval is of great interest.

The data show results from a 36-day trial with ROX and Rapid Pulse polarographic sensors reading simultaneously on the same sonde. Chlorophyll is also shown, to demonstrate how phytoplankton can control DO levels. In this test, the Rapid Pulse polarographic sensor was impacted by biofouling after approximately 21 days in the field. This is considered a good deployment length for a polarographic sensor in this type of environment and is only achieved through the wiper on the YSI 6600 EDS which slows the growth of biofouling organisms on the Rapid Pulse sensor.

As you can see, the ROX exhibits far superior longevity than even the best polarographic DO systems and exhibited no drift or impacts of biofouling after 36 days.

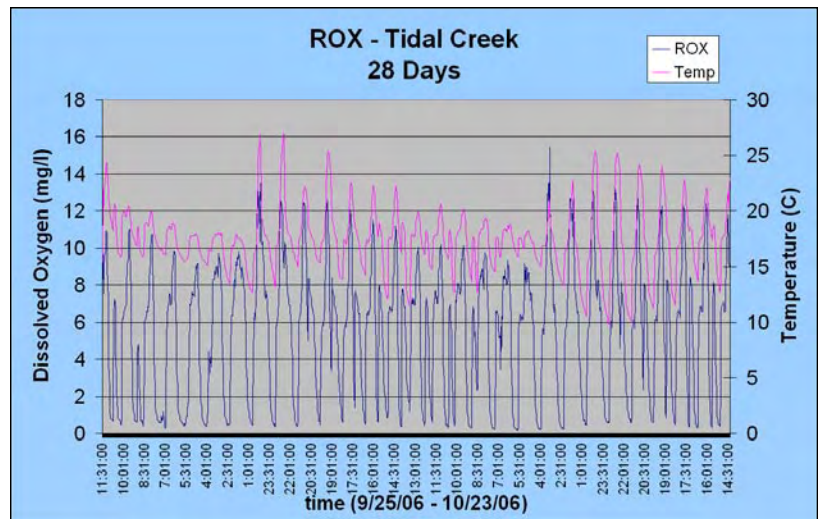
Customer Class National Monitoring Program, Coastal Research
Environment Tidal Salt Marsh
Location West Coast, USA
Duration 28 days, 30-minute interval

The group that generated this data is responsible for monitoring a dynamic coastal salt marsh area (part of NERRS) where large fluctuations in water quality are a daily or even hourly occurrence.

In the data set shown here, daily DO levels were dropping to dangerously low levels. A concern with monitoring anoxic environments such as this is the production of hydrogen sulfide from sulfur-fixing bacteria in the sediment. Hydrogen sulfide gas would quickly corrode polarographic sensors, causing accelerated drift. By design, the ROX sensor is insensitive to hydrogen sulfide and additionally has excellent accuracy ($\pm 1\%$) at low DO concentrations (0-20 mg/L).

Similar to the other long-term monitoring programs, the characteristics of greatest interest are accuracy of data and reduced operating costs through the extension of maintenance intervals.

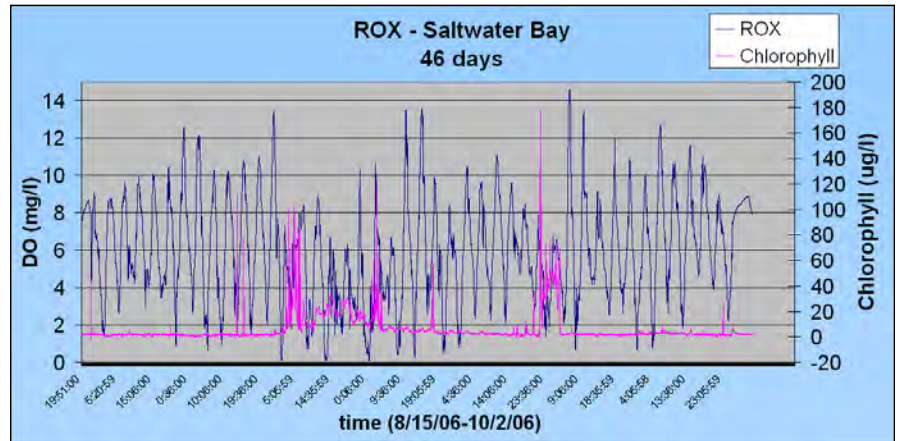
This data set shows a good example of what would be considered a very challenging environment for polarographic sensors yet is no problem for the ROX sensor.



Dramatic fluctuations in daily DO readings characterize the dynamic environment of this coastal salt marsh

Customer Class State Monitoring Agency
Environment Saltwater Bay
Location Southeastern USA
Duration 46 days, 10-minute interval

A state monitoring agency working in a shallow, warm water bay was interested in studying the impacts of dissolved oxygen on the health of sea grass beds.



The most important factors in sensor selection for this group were maximizing deployment times and accuracy of data, especially on the low end, since DO levels drop to very low or anoxic levels on a regular basis. The deployment sites are often extremely challenging with warm, shallow water, very high biofouling rates, and frequent storms.

The data shown here represent ROX and chlorophyll sensor results from a continuous 46-day trial. The data represent a dynamic system with DO levels often dropping into anoxic states. Due to the short duration and extreme nature of these low oxygen events, it is important to have a highly accurate and reliable DO sensor in the field. An additional benefit of the ROX for this group is the long maintenance interval for the complete system.

Due to the importance of sensor accuracy in low oxygen conditions the ROX sensor was tested in a sodium sulfite solution to check the accuracy in a anoxic sample. The ROX read the zero oxygen solution accurately (± 0.05 mg/l).

A YSI applications engineer and the customer at deployment site to check on sensor performance



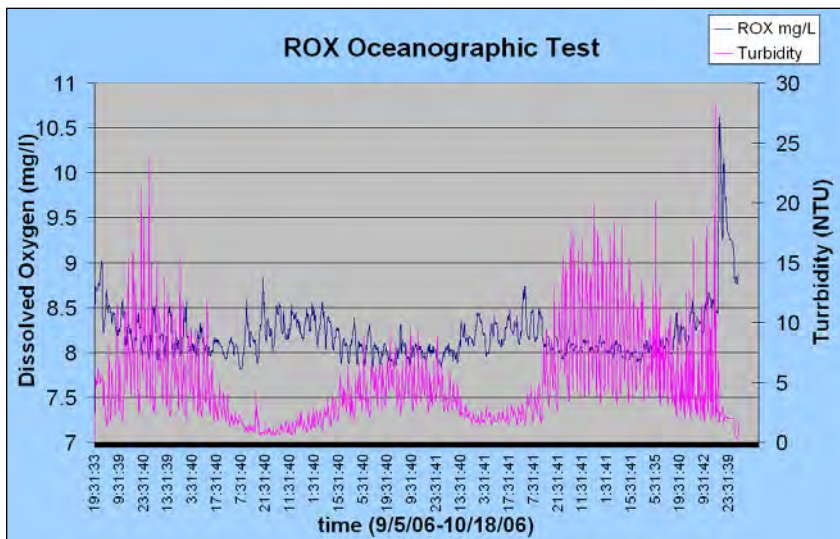
Customer Class Monitoring Agency
Environment Ocean
Location United Kingdom
Duration 43 days, 30-minute interval

The data presented is the result of an unattended field trial off the coast of England. Despite significant biofouling activity, the YSI optical wipers were effective at keeping the optical sensing area free of biofouling. In addition the ROX sensor is insensitive to water quality conditions such as turbidity and ambient light, thus providing accurate DO data in even the most challenging water quality conditions.

The data depicts levels of variation in DO and turbidity. There is a clear diurnal fluctuation in addition to a longer scale fluctuation, possibly due to the lunar cycle. Towards the end of the test a short-term, high DO event was detected, an event that would have most likely been missed by monitoring programs that rely on spot sampling.



As evident by the monitoring system (top) and close-up of the sensors (above) after deployment, this English coastal environment has significant amounts of biofouling

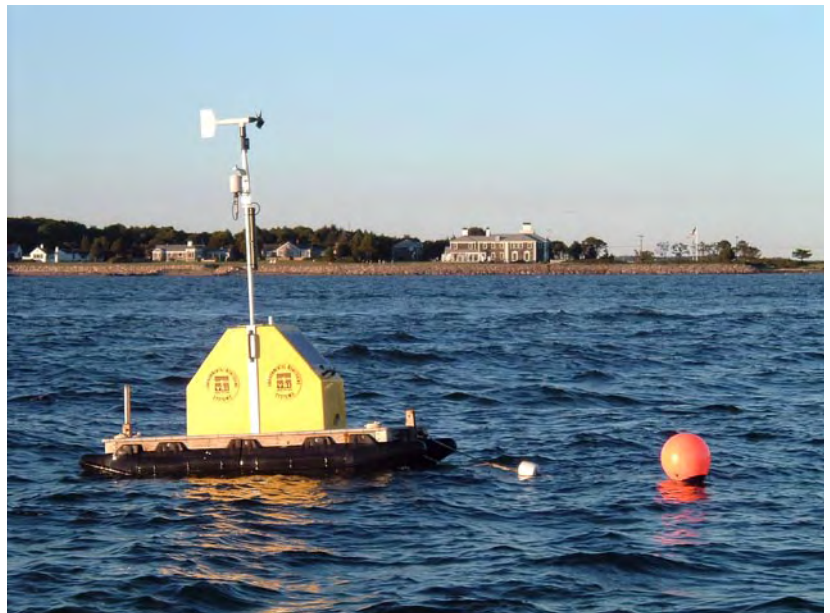
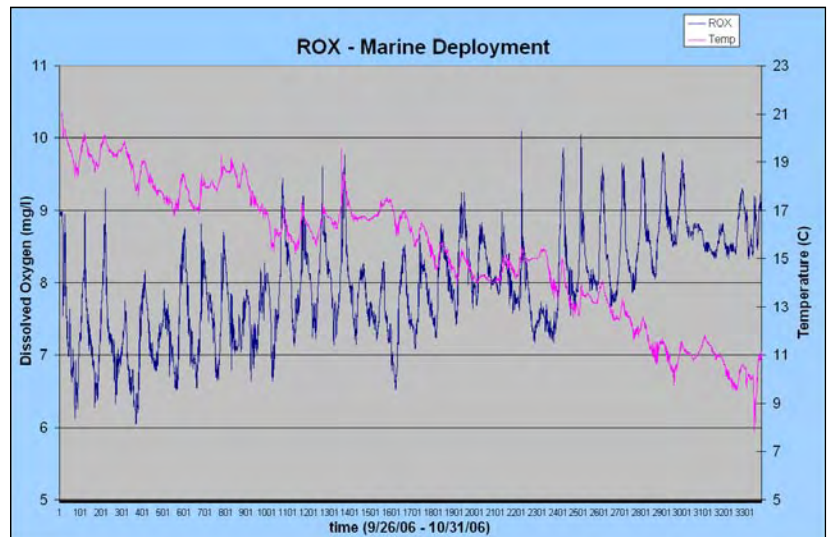


This test was part of a larger evaluation of the ROX technology to determine if a revision of DO regulations should be issued. The results were very impressive. No measurable drift was detected during the 43-day trial, a deployment length that would have been unlikely for polarographic sensors to achieve without drift.

Customer Class YSI Field Testing
Environment Ocean
Location Northeastern USA
Duration 35 days, 15-minute interval

This data set was generated from a permanent-instrument deployment managed by YSI off the coast of Massachusetts. The data was collected over two months in autumn and depicts the gradual drop in ocean temperature and the parallel change in DO. Decreasing daily DO swings are due to decreasing algal biomass and a slight increase in average DO concentration is due to the decreasing temperature.

The type of biofouling organisms change seasonally in marine environments, presenting a continuous challenge to long-term *in situ* instrumentation. During autumn the biofouling was dominated by soft, gelatinous organisms such as bryophytes. The YSI anti-fouling wipers were very effective in maintaining clean optical sensors during the 35-day study.

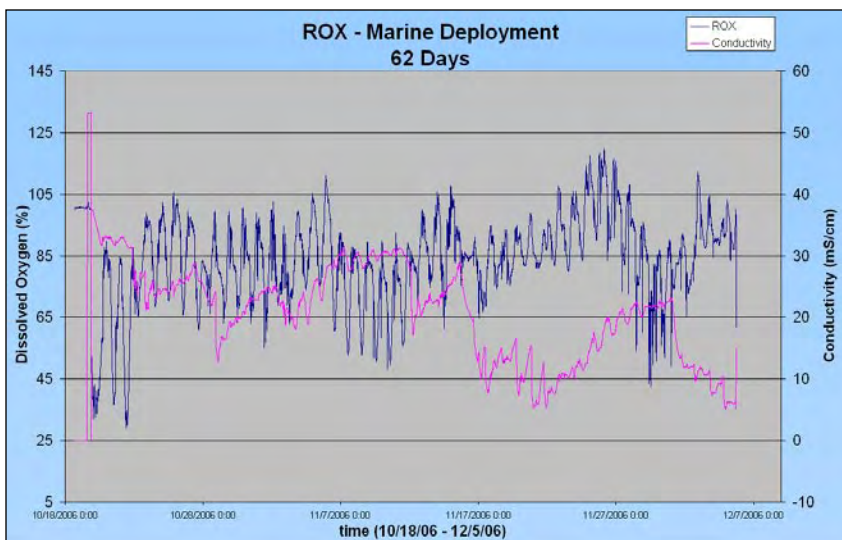


YSI's continuous monitoring test site at the mouth of Sippican Harbor in Buzzards Bay, MA. The site exposes sensors to a corrosive environment and heavy marine fouling conditions

Customer Class University Marine Research
Environment Coastal
Location Southern USA
Duration 62 days, 15-minute interval

The data shown below is from an extended study conducted in a highly turbid tributary to the Gulf of Mexico in Louisiana. The user is a coastal research group interested in continuous monitoring in the area of the Mississippi Delta, with particular interest in mapping the low oxygen and anoxic zones in this region. The low oxygen environment, coupled with high turbidities and high biofouling rates, add up to an extremely challenging environment for long-term *in situ* monitoring.

The data set indicates the types of deployment intervals that are now possible using the ROX sensor. There was no maintenance on the sensor during the 62 days of deployment. Not only did the ROX sensor exhibit excellent stability, the YSI 6600 sonde was able to supply power for the entire period with an aggressive 15-minute sampling interval.



High turbidity and rates of biofouling are not a problem for YSI's wiped sensors

In order to check the performance of the ROX sensor, a second sonde with a freshly calibrated ROX sensor was taken into the field at the end of the study and lowered to the same depth as the ROX sensor. The deployed ROX read 102.8% (7.73 mg/L) saturation while the QC ROX sensor read 101.5% (7.64 mg/L), indicating no significant drift, biofouling impacts, or loss of accuracy during this long and challenging deployment.

Economic Model for Dissolved Oxygen Monitoring

This model has been created to illustrate how the ROX technology can result in significant savings of the time and money required to maintain and deploy *in situ* sensors for long-term monitoring applications. The assumptions may not apply exactly to every situation; however, we have chosen conservative figures to create a general model that should be relevant to most monitoring programs.

For most monitoring groups, the most important factor in switching to this technology is the time saved, which can be used instead to expand a monitoring program without increasing headcount. YSI's ROX sensor is also far less susceptible to being damaged while in the field, further saving time by decreasing the number of unplanned trips to the field for sensor maintenance.

Rapid Pulse		Operating Cost/1 Probe	Operating Cost/5 Probes	Labor/1 Probe
Polarographic DO sensor		x1	x5	
Membrane kit		2/year	2/year	
Reconditioning kit		2/year	10/year	
Reconditioning labor per probe	20min./deployment	\$114	\$570	6 hours
Deployment length	2 weeks			
Deployment site visit cost (boat + labor)	\$552 – 1 site \$952 – 5 sites	\$9,936 (18 trips/season)	\$17,136 (18 trips/season)	72 hours
Total		\$10,050	\$17,706	78 hours
ROX		Operating Cost/1 Probe	Operating Cost/5 Probes	Labor/1 Probe
Optical DO sensor		x1	x5	
ROX membrane replacement		x1	x5	
Reconditioning labor per probe	5 min.	\$2	\$8	5 min
Deployment length	6 weeks			
Deployment site visit cost (boat + labor)	\$552 – 1 site \$952 – 5 sites	\$3,312 (6 trips/season)	\$5,712 (6 trips/season)	24 hours
Total		\$3,314	\$5,720	24.1
Savings per ROX		\$6,736	\$11,986	53.9 hours

Assumptions:

- Costs for individual sensors and membranes vary by region. On average, initial cost of ROX sensor is greater than Rapid Pulse sensor, while lifetime labor and replacement parts are greater for Rapid Pulse.
- 9-month (36-week) field season.
- Sonde with Rapid Pulse sensor requires membrane changes and maintenance every 2 weeks in a productive environment.
- Sonde with ROX sensor can be deployed for at least 6 weeks without maintenance in a productive environment.
- During field season, Rapid Pulse requires 18 site visits while ROX requires 6 site visits.
- Rapid Pulse requires 2 membrane kits and 2 reconditioning kits per season.
- ROX requires 1 membrane change per season.
- Trip to field includes 2 people and 1 small vessel:
 - 4 hours to visit one station, 8 hours to visit 5 stations.
 - Labor cost = \$19/hour, or \$152/site visit.
 - Vessel cost = \$100/hr, or \$400/site visit.
- Annual labor includes reconditioning and trips to field.



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(Yellow Springs facility)

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Third-Party Sensor Verification You Can Trust

YSI is the only company in its field to apply for and receive verification from the US EPA's Environmental Technology Verification Program. Independent tests on the following sensors demonstrated the accuracy of YSI sensor technology when compared to established standards in saltwater and freshwater:

6025 Chlorophyll
6560 Conductivity
6562 Dissolved Oxygen
6561 pH
6560 Temperature
6136 Turbidity

Sensors listed above were submitted to ETV program on YSI 6600EDS. Find information on performance characteristics of YSI water quality sensors at www.epa.gov/etv or call YSI at +1 937 767 7241 for ETV Verification Report. Use of the ETV name or logo does not imply approval or certification of this product nor does it make any explicit or implied warranties or guarantees as to product performance.