THE EVOLUTION
of Water Quality Monitoring

eBook

YSI Water Quality Monitoring Systems

E112

YSI

a xylem brand

Who's Minding the Planet?®

THE EVOLUTION of Water Quality Monitoring

DISCOVER

how YSI technology has evolved over time to meet our customers' monitoring needs.

EXPLORE

new sensor technology and how it's used to better understand our world's most precious resource.

LEARN

how YSI combines diverse sensing technologies into a single system, delivering your critical data when you need it.

Thank you for your interest in our eBook! We're excited to tell you about the ever-changing story of water quality monitoring, and how YSI fits into the world of environmental stewardship. And now, let's start our journey...

1954

Hardy Trolander, John Benedict and other Antioch College alumnus started looking for problems to solve through the application of good science and a desire to engineer solutions.

1981

J. Johnson and other researchers make continued improvements, building a range of instruments based on precision sensor technology.

2015

Now YSI stands on the shoulders of giants, improving and growing monitoring networks. These inform policies and empower the environmental stewards of tomorrow.

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THE EVOLUTION of SAMPLING

"I've seen young people working surrounded by mosquitoes and alligators, waiting for the tide to come in. They're not being paid a lot of money. But they've got passion. They want their job to have some meaning and purpose, to leave the world a better place."

Mike Lizotte, YSI Senior Applications Engineer

IN THE BEGINNING

Deep in our primal being, testing water quality has been central to the human experience – and human survival. Scan for predators, look for dead animals beside the watering hole, sniff the air, taste the water, see how other members of the clan fared after drinking there. When we shared the watering hole with mastodons and saber-toothed cats, understanding water quality was an immediate need (though it was addressed on a pretty broad-brush basis).

Our understanding of health and science has flowed from the need for clean water. From the Hippocratic sleeve for filtering water to the teeming droplet under van Leeuwenhoek's first microscope to the birth of modern epidemiology in 1854 at London's contaminated Broad Street pump, water quality and modern science have been constant partners.

Driven by technology, public health, science and environmental concern, the past few decades have been the most exciting yet for water quality monitoring. The capability to measure a wide range of water quality parameters has expanded from the laboratory bench to the field.

Water quality data collection has moved from written notes transcribed by a quivering analog needle to digital display readouts to sophisticated digital electronics with data telemetry options.

Sampling capacity has advanced from a few hand measurements a day, one parameter at a time, to constant streams of data transmitted by multiparameter instruments deployed for months at a time. And the resolution of data – temporally, spatially and in terms of accuracy – **has spiked**.

In this eBook, we'll reflect on the remarkable evolution of water quality monitoring. It's a tribute to the people at the design table, in the lab, on the manufacturing line and our customers in the field who bring their knowledge and passion to minding the planet.

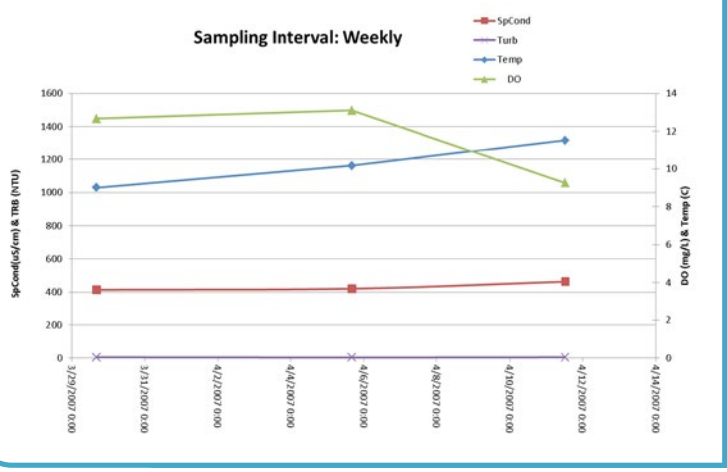
Water is the essential element for all life on earth.

The Hippocratic Sleeve, one of the earliest known methods of filtration.

The discovery of microorganisms marked a leap forward in public health.

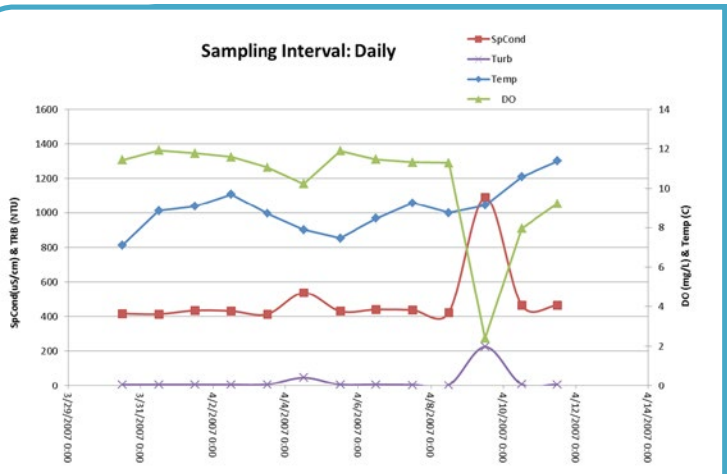
The Resolution Evolution

The evolution of water quality testing technology – and the lessons we can learn from it – is perfectly illustrated in these three charts. YSI calls the challenge of trying to make decisions – and assumptions – based on too little data the "**undersampling dilemma**." Our goal in constantly evolving our instruments is to allow YSI customers to have enough information to understand the systems they are measuring and make sound decisions based on the highest quality data.



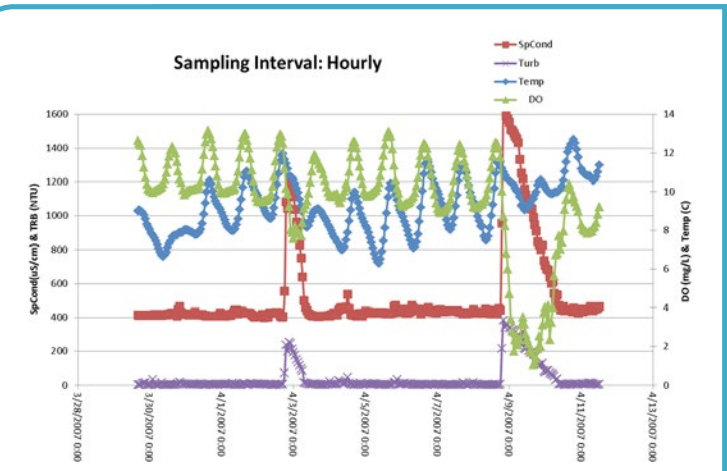
Sampling Weekly

Gathering data weekly for a two-week period yielded a simple, stable chart and the idea that dissolved oxygen fluctuates by about 3 mg/l at its most extreme and the average DO level is 11.66 mg/l.



Sampling Daily

Monitoring the river once a day yielded a dramatic look at the correlation among DO, temperature and specific conductance – in a huge drop of more than 10 mg/l that was not even detected in the weekly monitoring program.



Sampling Hourly

Increasing the monitoring frequency to hourly by deploying a multiparameter sonde at the site reveals more dips and spikes in specific conductance, DO, turbidity and temperature. Diurnal cycles become clear and a brief event at the end of the deployment was detected.

An Omniscient Eye

We can sum up the journey to today's water quality monitoring technology in one word: **more**.

More parameters. More flexibility. More time in the water. More depth. More data. More resolution. More connections among the things we observe and our understanding of the world's water.

From the lab bench to the riverbank to the deep, blue sea, our understanding of water quality – and our ability to make sound decisions based on our observations – draws together remarkable minds around the world.

The next step, of course, is giving those experts the tools to explore water quality at a level of detail beyond imagining just a few years ago. Water quality monitoring instruments have taken complex laboratory capabilities into the field. At every step, sampling equipment has gotten smarter, smaller and more rugged based on years of experience and the yearning to provide our customers with the best instruments. Many of the measurement technologies have moved from wet chemistry to optical sensors, and from electrochemical to optical based systems.

Ultimately, the most empowering technologies serve as an almost omniscient eye, constantly monitoring water and even reacting to measurements that could indicate a notable event, like a storm, higher flow, or an illegal discharge of pollutants.

Unattended monitoring is being able to get at high-resolution data. We don't miss events. That's how we get to understand water.

Real-time monitoring on the Thames river.

At YSI, we have built our product development program by constantly addressing the top challenges our customers report from the field:

- **Uncertain Future**
- **Repair and Maintenance Costs**
- **Incomplete or Inaccurate Data**
- **Budget Reduction**
- **Training Employees**

In this eBook, you'll see how continual improvement reduces each of those challenges.

Burning River: The Cuyahoga River on fire in 1952 Credit: Teaching Cleveland

GROWING AWARENESS

The driving forces behind much of today's water quality monitoring add up to roughly one part curiosity and two parts regulation.

Growing awareness of the importance of clean water has spurred water quality regulations worldwide. Americans grew wary of dye-colored rivers in New England and periodic fires on the oily surface of Ohio's Cuyahoga River.

With the potential for hazardous water quality events to strike at any time, like the pollution of the Animas River in 2015 from the accidental release of waste from the Gold King Mine, we must continue to be vigilant.

America's 1972 Clean Water Act

Following one such fire in 1969 – actually, the 13th fire recorded on the Cuyahoga in a century – the U.S. Congress gathered the political will and momentum to strengthen water quality regulations with sweeping legislation commonly called the Clean Water Act (CWA).

Effluent limitations were established, and wastewater treatment plants were funded nationwide. The CWA required pollution discharge permits with numerical criteria for point sources of pollution, for example from factories and wastewater treatment plants. It established a framework requiring states to monitor, report and improve where necessary, the chemical, physical and biological integrity of the waters of the state.

Subsequent amendments added urban nonpoint sources to the target lists and required water quality management plans from municipalities.

That was a clear call for data. Finely tuned, high-resolution data that is reliable enough to take action.

Pollution Budgets

As discharge permits failed to achieve water quality goals, the CWA required states to create total maximum daily load (TMDL) for watersheds on a wide scale. This included thousands of rivers, streams, lakes and bays. Quantitative assessment, planning and monitoring demanded data from countless miles of waterways.

At the heart of the pollution budget concept is measurement – measurement accurate enough to track loading from an array of sources.

The goal was constant measurement that could pick up the impact of a late-night point source discharge or the effect of runoff across the land following a storm. Measurement technologies that could pinpoint nutrients bubbling up from phosphate-rich streambed sediments, shining new light on pollution budgets that had been carefully drawn using only surface sources.

Nutrient reduction initiatives put phosphorus and nitrates into the spotlight, challenging technology companies to develop fast, accurate measurement instruments.

China:
Dawning Insight

With its massive economy, massive population and massive water management networks, China has huge needs for water quality data.

Bedeviled by devastating pollution and some of the worst floods in human history (including a 1939 deluge that reportedly killed 3.7 million people and a 2007 flood that ruined crops on nearly 30 million acres of farmland), China's infrastructure agencies and Ministry of Environmental Protection face epic challenges daily.

A historic lack of data hampered their efforts.

But when China's president and chairman of the Communist Party Hu Jintao called for greater scientific development on water quality issues – including drinking water safety, pollution prevention and water conservation – in 2007, China's water quality measurement efforts shifted into high gear.

Today, government officials and non-government organizations (NGOs) are building the nation's body of knowledge on China's water supplies.

In addition to flooding and pollution, algal blooms are chief amongst China's water quality concerns.

The European Union: Long Tradition

The European Union (EU) – as a multi-national community and as individual member countries – has a legacy of strict water pollution regulations that dates back more than three decades.

Notably, the EU Drinking Water Directive of 1998 established 48 microbiological, chemical and indicator parameters that must be monitored and tested regularly.

In 2000, the Union's Water Framework Directive required member states to characterize each of their river basin districts and review human impacts on water every six years. Again… **the vital tool is data.**

Profiling on the Thames river

Monitoring Nuclear Waste

EXO water quality monitoring sondes are being deployed in what is arguably one of the most hostile environments imaginable – nuclear waste legacy storage ponds at the Sellafield nuclear reprocessing site in Cumbria, UK.

Blog: Monitoring Nuclear Waste with EXO

Australia: Jungle to Desert

From the jungles of the north to the arid, red center and mountain streams of Tasmania, Australia spans some of the world's most diverse climates. So it's no surprise that the country's National Water Quality Management Strategy relies heavily on local insight – local regulations and local data.

With an emphasis on nutrients, chlorophyll and biological parameters, Australian regulations build on reference data gathered in relatively undisturbed systems as guides to developing water quality guidelines that lead to water quality objectives.

All along the way, from establishing the reference values to measuring success, data is at the heart of the system.

Challenges: Uncertain Future

Changing regulations and shifting parameters of interest require water quality monitoring programs to be nimble. YSI's **EXO** platform is a modular system, engineered to be easily customizable and reconfigurable with a simple swap of smart sensors, or integrated into more complex monitoring systems.

Surprising Sources

YSI multiparameter sondes and nutrient measurement technology were instrumental in helping stakeholders along Oregon's Tualatin River – a focus of one of America's first high-profile court cases demanding pollution budgeting and a total maximum daily load (TMDL) – understand the geochemical sources of phosphorus that were thwarting success in achieving goals for the river.

Blog: America's Early TMDL Case Study

EPILOGUE:
Shifting Landscape

Regulation has pushed water quality measurement into the spotlight around the world. Baselines, reference numbers, quantitative goals and a constant demand for compliance data have made accurate measurement absolutely vital at every level, from treatment plants to farm edges to mid-stream gauging and monitoring stations.

Growing engagement with a wide range of stakeholders inspire more people to measure water quality, making the need for reliable, user-friendly instruments more urgent.

And a spiraling supply of high-resolution data challenges researchers, consultants and engineers to interpret the findings and improve the quality of the world's most precious resource.

The great news: in most cases, **it's working**.

For example, five decades after scientists at Kent State University declared "Animal life does not exist.... This entire reach is grossly polluted," the Cuyahoga River is now home to 44 fish species.

The decommissioned US Coast Guard Station at the mouth of the Cuyahoga River in Cleveland, Ohio

THE EVOLUTION of SENSORS

"Sensors have evolved to produce higher accuracy data and repeatable measurements all while requiring less maintenance. The valuable sensor diagnostic information aides in determining if a sensor needs to be replaced or cleaned, all helping avoid surprises in the field."

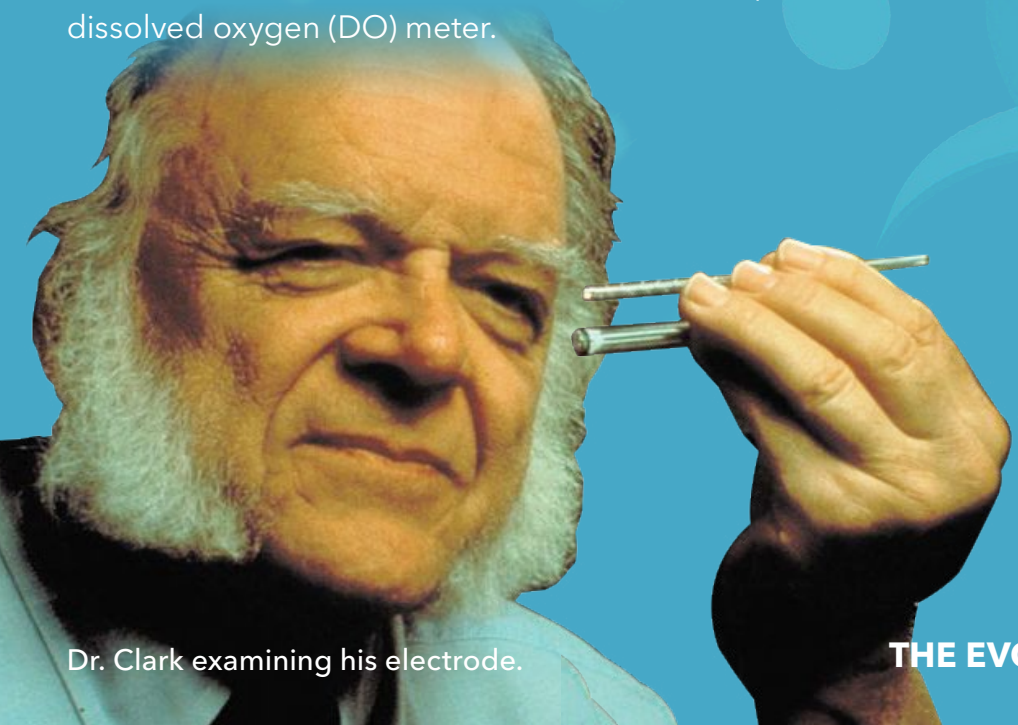
Laura St. Pierre, YSI Senior Product Manager, Water Quality Systems

THE FOUNDATION
Temperature & DO

The first break-through technology for YSI was the development of high-accuracy thermistors and the ability to reproduce on a production scale. This was key to developing water quality sensors since an accurate temperature measurement is required for all other parameters.

Measuring and incorporating temperature is important due to its effect on water's physical and chemical characteristics as well as its effect on the measurement characteristics of a sensor. For example, temperature affects water's ability to dissolve oxygen and instrumentation needs to compensate for this. Additionally, the temperature of the sample can affect sensor electronics, measurement response time and permeability of membrane-covered DO, for example.

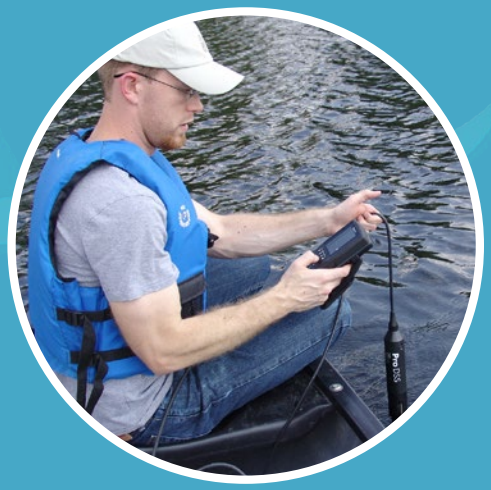
In 1956, Dr. Leland Clark and scientists at YSI developed the **Clark Polarographic Electrode**, a dissolved oxygen sensor that made open heart surgery possible by allowing technicians in the operating room to measure blood oxygen levels in real-time. Essentially, it allowed doctors to make **real-time decisions based on real-time data** – a theme that is still our mantra today. By 1962, YSI incorporated the Clark Electrode into the world's first commercialized, practical dissolved oxygen (DO) meter.



Dr. Clark examining his electrode.

The humble beginnings of YSI sensor manufacturing in 1951.

The YSI 52, one of the first portable dissolved oxygen field meters.



The ProDSS, the latest handheld multiparameter portable meter from YSI.

Evolution of the DO Sensor

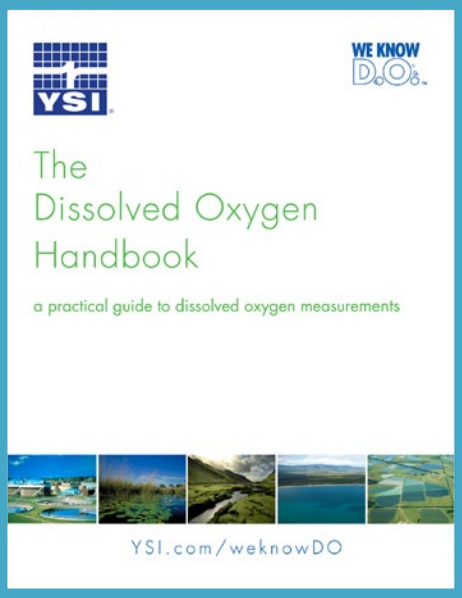
The value of this medical technology for measuring DO in other systems – such as water – was quickly evident, and YSI expanded into the environmental realm. Decades of refining laboratory instruments led us to design instruments for in-situ measurements: gathering data on-site rather than requiring people to bring samples back to the lab for analysis.

In 1993, YSI pioneered continuous, unattended DO measurement with the industry's first stirring independent dissolved oxygen sensor, the **Rapid Pulse DO** sensor, on our multiparameter 6-series sonde. This allowed for continuous, unattended data collection of dissolved oxygen measurements without the risk of collecting artificially low and inaccurate DO data due to inadequate flow.

Innovation continued when YSI replaced polytetrafluoroethylene membranes in the Clark Electrode with polyethylene in 2002, reducing the sensor's dependence on stirring and improving its response time. This made it easier than ever to get accurate dissolved oxygen measurements.

The original YSI 6562 Rapid Pulse DO sensor, which was used with a Legacy 6-Series sonde.

YSI utilized a patented pulsed design with minimal surface area to provide stirring-independent dissolved oxygen readings.



Don't forget to grab your copy of YSI's definitive and practical guide to DO measurements.

Get YSI's DO Handbook

Seeing the Benefits of Optical Sensors

Progress continued in 2006. That year, YSI's first optical-based DO sensor, the **ROX**, was released for use on 6-Series sondes. That was quickly followed by incorporating optical-based technology into the **ProODO**, a portable DO handheld. Our customers quickly realized the benefits of this new sensor technology.

With optical based sensors, no stirring is required for accurate measurements, ensuring consistent and easy data collection. Maintenance requirements went down, accuracy increased and calibrations held longer, resulting in an increased deployment time of unattended sondes. Now, instead of changing a membrane once per month and keeping electrodes polished, all that is required to maintain an optical DO sensor is changing the cap once every 12 to 18 months. Additionally, accuracy improved from +/-0.2 mg/L to +/-0.1 mg/L. Membrane covered sensors inherently drifted from calibration requiring weekly site visits to deployment locations for recalibration.

The Evolution of DO instruments:

YSI 50B

55 Handheld

ProODO

Time Goes By

The transition from membrane-covered electrochemical dissolved oxygen (DO) sensors to optical-based technology was a pivotal advance in enabling long-term deployment of water quality measurement instruments. Data from a membrane-covered DO electrode was reliable for three days to two weeks before values began to drift and recalibration was necessary; membranes needed to be changed monthly.

Optical DO probes hold their calibration for over six weeks, and sensor caps only need to be replaced every 12-18 months. This allows for accurate data collection over long periods of time.

The replaceable sensor cap for digital Optical Dissolved Oxygen measurements, without its guard in place.

ENTERING THE DIGITAL AGE

Silicon Valley has captured most of the headlines when it comes to the digital revolution, but in little Yellow Springs, Ohio, the water quality measurement industry's jump into digital technology was no less momentous.

YSI ProODO

Handheld meters entered the digital age with the **ProODO**, the most advanced handheld optical dissolved oxygen instrument on the market. It's combination of versatility, field-worthy durability, and data management are second to none. The built-in barometer makes calibration easier than ever, and the probe's digital signal allows readings up to 100 meters. Also, the user can log up to 5,000 data sets and transfer the data to their PC via USB.

Like it? **Win it!**

YSI ProODO

Dissolved Oxygen Meter

- No membranes
- No stirring
- No warm up time
- Less Maintenance

Enter to Win One

YSI
a xylem brand

The Digital Revolution

Early analog instrumentation measured tiny shifts in voltage or current through sensitive needles, displaying data on a scale arching across a meter. This view of live data is akin to the analog speedometers present in most cars; an electrical signal is sent from the sensing technology to the display, where it is then translated into a reading.

By the very nature of analog signals, there were a number of reasons engineers pressed forward to develop a more robust foundation for monitoring equipment, the chief of which was data quality.

Analog instruments are known for lower resolution and noisy data. Shifting to a digital output meant moving the smarts of a monitoring platform from the handheld to the sensors. With their own microprocessor and on-board memory, "smart sensors" were born. These self-contained devices could take a measurement and communicate it directly to a display. In comparison to analog devices, going digital removed any potential interferences with electrical noise, wet or dirty sensor connections, and signal degradation over longer cables.

Those advantages aside, transitioning to digital sensors had many other benefits including the ability to integrate on-board diagnostics and quality checks on each device, giving users confidence in the data collected.

Challenges: Training Employees

Calibrating and operating YSI sensors has never been easier, which makes training employees faster and cheaper while the quality of data coming back from the field continues to improve. Improving the user interface and employing digital sensors to improve signal strength and data quality, the YSI ProDSS represents a revolution in water quality sampling.

YSI Pro Plus

Handheld Sensors

In-situ monitoring began with handheld sensors – admittedly, instruments so bulky and heavy they required at least a couple of hands to hold. For example, some of you may remember the 3500 and 3800 instruments in the early 1990s were 15 to 20 pounds of cast aluminum, heavy cables, electronics, dials and LCD displays. Field technicians were limited to a few samples a day for pH, conductivity and DO.

Today, handhelds remain a mainstay of water quality monitoring fieldwork, allowing people to gather lab-quality measurements in the field. They have made water quality testing more efficient and more timely, and can capture measurements of parameters that may volatilize before they reach the laboratory.

Led by the **YSI's Professional Series** handhelds, sampling instruments have become lighter, faster and easier to use, opening up opportunities for water quality measurements to a wider world of users.

The **YSI Pro Plus** collects 5,000 data sets that can be assigned to any of 100 folders inside the system, allowing fast, efficient collection and management of measurements using one to four sensors, including a choice of DO, specific conductivity/salinity, pH, oxidation reduction potential (ORP), pH/ORP, ammonium, chloride or nitrate. In all, the Pro Plus provides accurate measurements of key water quality parameters – information that could help meet compliance requirements, frame out a long-term management plan or signal the need for targeted in-situ monitoring or grab sampling.

ProDSS:
Digital Sampling System

The ProDSS is a fully digital instrument that takes advantage of the clean, efficient signals from its digital smart sensors to allow cable lengths up to 100 meters. With the ability to measure up to **17 different parameters**, including turbidity and depth, the ProDSS offers advanced sensor technology in a portable and convenient platform.

Dissolved Oxygen (optical sensor) – Turbidity – pH – ORP – Conductivity – Specific Conductance – Salinity Total Dissolved Solids (TDS) – Resistivity – Seawater Density – Total Suspended Solids (TSS) – Depth Ammonium – Ammonia – Nitrate – Chloride - Temperature

In short, with nearly seven instruments in one, handheld instruments have evolved to make multiparameter field testing easier than ever - streamlining field sampling. With features that make it YSI's most user-friendly handheld system yet, the ProDSS is ***the ultimate in spot sampling and profiling.***

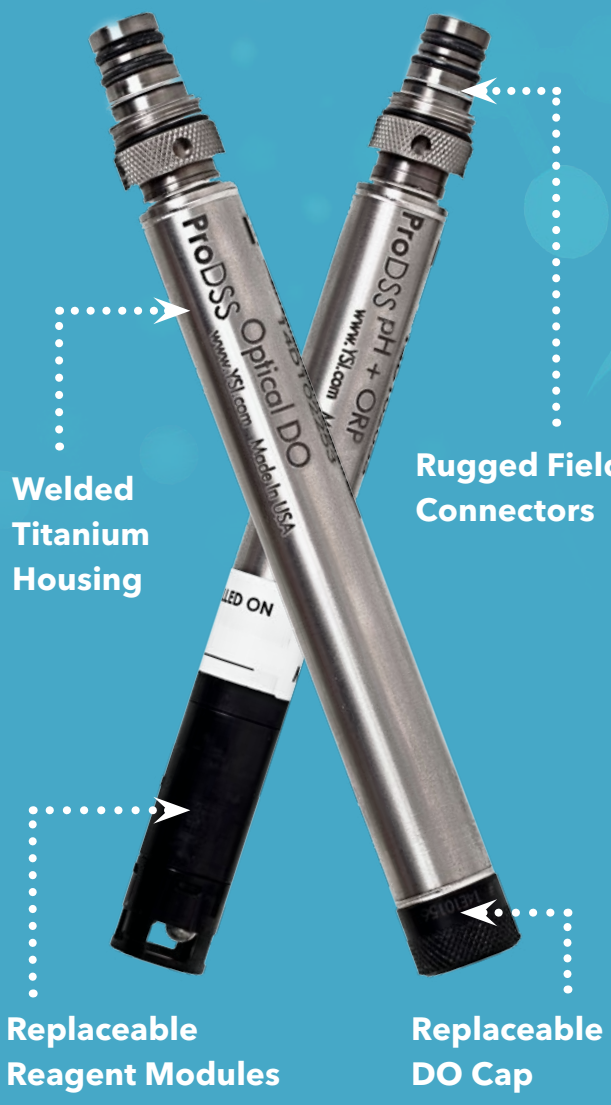
Discover the ProDSS

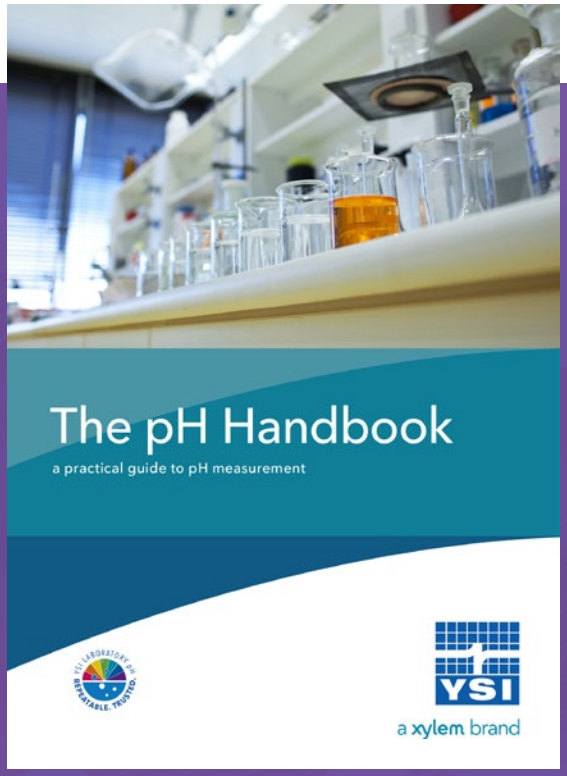
ProDSS:
Digital Sampling System

The single cable design of the ProDSS ensures users will not need to take multiple instruments or cables into the field, allowing for quick and easy data collection. Data management has never been easier, as the ProDSS features a large memory with extensive site list and Data ID tag capabilities. A built-in micro USB On-The-Go port allows for data transfer to KorDSS PC software (included) and quick data backup to USB stick. GPS (optional) coordinates can be logged and viewed on a map with KorDSS.

The ProDSS is a rugged and reliable instrument designed for true field work in even the harshest conditions. Titanium sensors, durable MS (Military Spec) cable connectors, rechargeable battery, and a waterproof (IP-67) rubber over-molded instrument casing ensure the ProDSS will provide the accurate data you need for years to come.

ProDSS Sensors





Want to learn more about pH?

The YSI pH Handbook is a practical guide to pH measurements in the lab and field. It is full of helpful tips and recommendations to ensure you take accurate and repeatable pH measurements.

Download the pH Handbook

Blog Spotlight:
Rugged, Field-Proven Meters

Blog: Field Proven, Three Examples

YSI - 1
Gravel Road - 0

The YSI Pro Plus was being used at an aquaculture facility to check the water quality of nearly 100 ponds, multiple times a day. The facility used ATV's (All-Terrain Vehicles) to get from pond to pond and on one particularly long afternoon, an employee, anxious to get home, sped off on his ATV after sampling the last pond. The Pro Plus meter bounced off the ATV onto the ground, while the cable remained firmly attached to a vehicle. Needless to say, the poor handheld dragged along a gravel road for more than half a mile before the driver noticed. He stopped, shook his head, and simply dusted it off. It was scratched up a bit but worked just fine.

YSI - 1
Aeration Basin - 0

A YSI wastewater customer knocked their sampling handheld into an aeration basin at their water resource recovery facility. Not the best of conditions to take a dip. Seemingly lost for good, he reluctantly moved on. One year later, yes, an entire year later, the tank was drained to complete some minor maintenance and there laid that rugged Pro Plus meter in the bottom of the tank. After a good bit of cleaning, they decided to try to turn it on. Not only did it work, but it's still being used at their facility today!

What's your survivor story?

Over the past few decades, YSI has collected stories of YSI instruments that have been to hell and back and we're always looking for more!

What's your survivor story?
Write us and let us know:
info@ysi.com

THE EVOLUTION of SONDES

"The next decade of water quality monitoring will combine data analytics, novel optical sensing technology, and innovative bio-fouling counter measures to reduce the cost per data point while driving up data quality."

Tim Finegan, YSI Director of Environmental Monitoring Systems

RISE OF THE SONDES

If a tree falls in a forest and no one is around to hear it, **does it make a sound?**

Of course! The same concept is true for any kind of water quality monitoring. Without monitoring 24/7, 365 days a year, we miss critical pieces of the puzzle and cannot ever fully understand an environment.

The advent of the sonde – French for "probe" – pushed in-situ water quality measurement to new heights, or at least to new depths. Protecting a variety of sensors in a ruggedized tube and channeling the data into onboard memory, sondes opened the door to long term unattended monitoring – the constant monitoring that allowed scientists to observe midnight activity and chart diurnal cycles.

That's how sondes – which gave us the ability to monitor remote locations constantly, for long periods, without the need for an operator on-site – revolutionized water quality monitoring.

Finally, we began to pick up the heartbeat of our waterways.

Sondes can be left out long-term to monitor key water quality interactions.

The EXO sonde design was streamlined to be ideal for continuous monitoring.

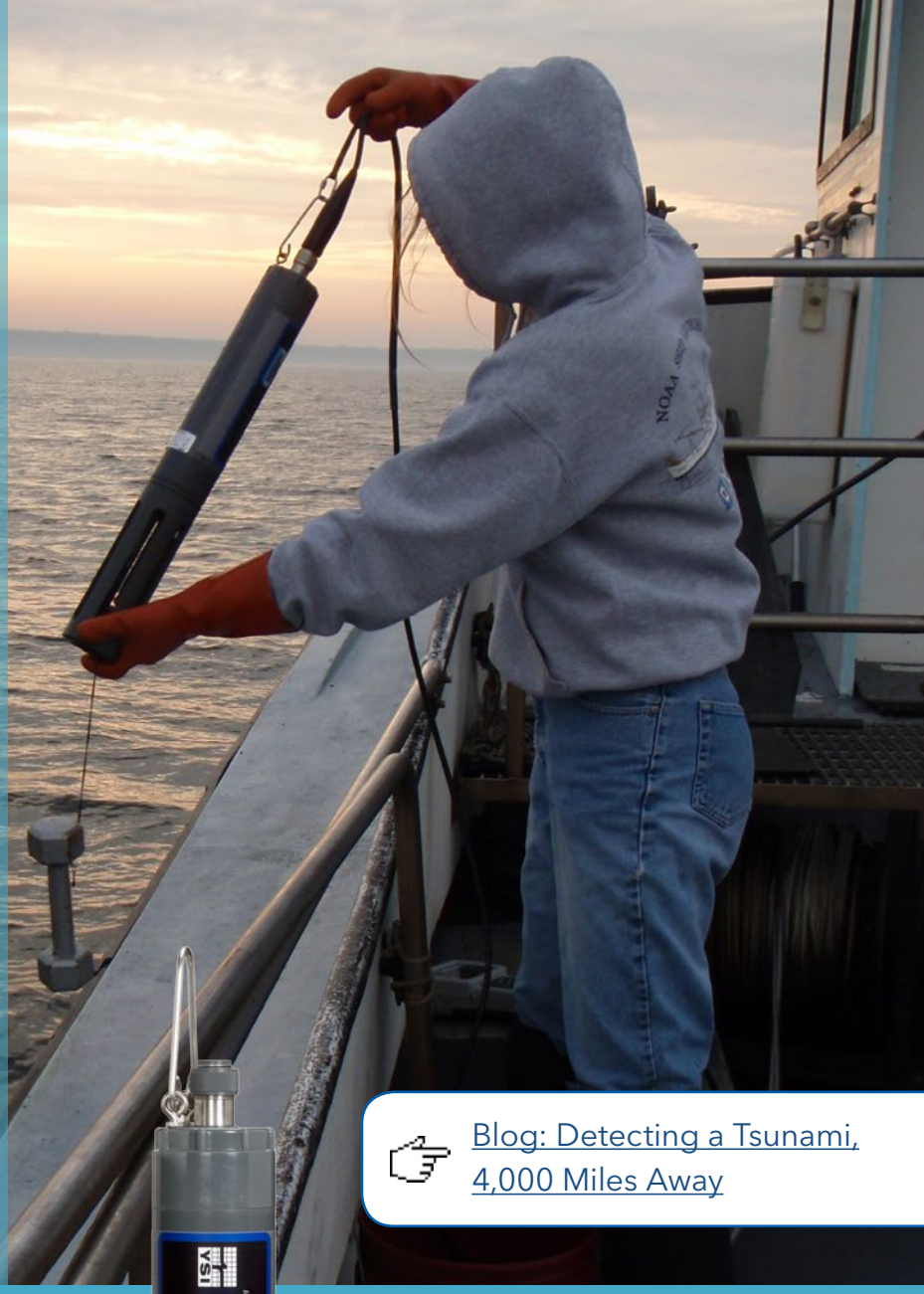
1995 | 6-Series Legacy Sondes

2012 | The EXO Platform

Leading the Way

YSI led the industry in the mid 1990s with the 6000 UPG, a 6.5-pound instrument with up to 120 days of battery life (or 45 days with DO and turbidity sensors, which require energy intensive stirring and wiping). The 6000 could be left in-situ to measure up to 15 water quality parameters, storing up to 150,000 readings in its 256-KB internal memory chip. From a few inches of depth to 500 feet in the sea, the first multiparameter sonde allowed scientists to witness events and connect relationships in new, exciting ways.

The 6600 and **6920** sonde series introduced chlorophyll and blue-green algae sensors to the mix and when the optical DO sensor was introduced it was backwards compatible with those platforms.



Blog: Detecting a Tsunami, 4,000 Miles Away

Continuous Movement Toward Continuous Monitoring

An **Aquatic Informatics** global industry study conducted in 2012 charts a steady march toward long-term continuous water quality monitoring among water quality professionals.

Currently, 44% of the respondents reported continuous monitoring in their primary area of coverage vs 30% discrete sampling or reading. Asked to predict the technologies they expect to be using in the future, participants described a significant drop in manual bottle sampling and a sharp rise in automatic sampling and unattended, multiparameter measurement by 2022.

Primary technologies by 2022

Manual Bottle Samples
2002 - 59%
2012 - 65%
2022 - 49%

Automatic Sampling
2002 - 19%
2012 - 37%
2022 - 43%

Multiparameter
2002 - 26%
2012 - 61%
2022 - 66%

Changing Training Priorities

Early in the development of sonde technology, training revolved around the technical nuances of coaxing a variety of sensors to talk to each other – and to the user.

"In the past, you had to have a lot of knowledge of the applications, and you almost had to be an electronics technician," recalls Mike Lizotte, YSI senior applications engineer, who started water quality monitoring in 1974. "**Now, training is not just getting the instrument ready, it's teaching the user how to choose a site, making the site robust enough to withstand a 100-year storm, and how to maintain it.**"

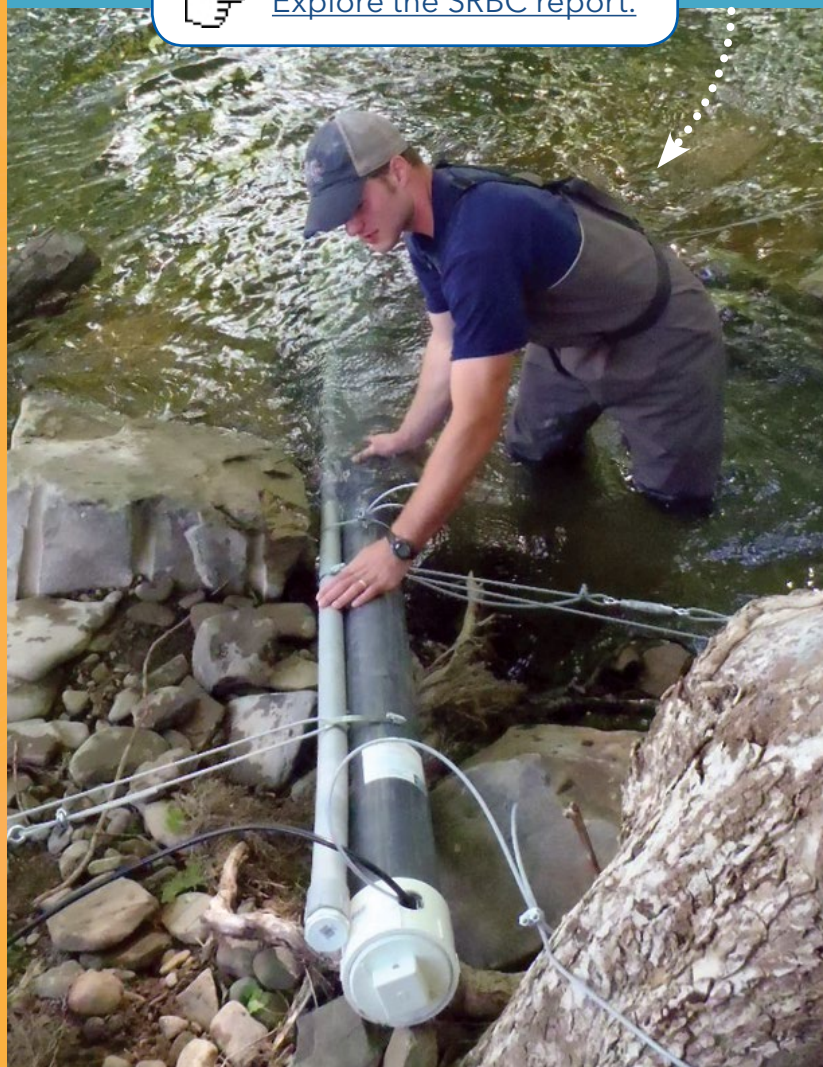
Frac Water Monitoring

To maintain a continuous watch on surface water quality and detect frac fluid spills in the Marcellus Shale gas fields, the Susquehanna River Basin Commission (SRBC) deployed a network of 50 YSI 6600 V2-4 multiparameter sondes in Pennsylvania and New York.

Drillers do not disclose the ingredients of their frac fluid, so SRBC focused its monitoring program on parameters that would indicate a spill of a saline solution or mineral-rich groundwater: temperature, conductivity, pH, DO and turbidity.

"The YSI sondes have been very reliable, with even less maintenance needs than expected," said the program leader after a year and 10 million readings. **"They are very versatile and durable for field deployment."**

Explore the SRBC report.



The **EXO** Platform

Fast-forward to today's **EXO1** and **EXO2**, which have redefined multiparameter sondes with new-generation technology. The EXO1 and EXO2 are reflections of decades of customer feedback, sondes that make long-term unattended monitoring longer and easier, and permit endless customization to meet the changing needs of today's monitoring, research and compliance teams. We call it "*breaking the sonde barrier*."

The EXO is not just a sonde, but a platform. Instead of probe-specific ports, these new sondes have uniform digital ports that accommodate any EXO sensor. Those smart sensors feature plug-and-play functionality – they identify themselves and carry their calibration specs in internal memory, so the sonde's microprocessor immediately knows what is plugged in and how the data will arrive.

Any sensor. Any port.

Video: Smart Ports, Smart Sensors.

Those smart sensors also allow technicians to do all calibrations in the lab – with as many as six of the same type of sensors at a time. It also allows staff to go out into the field with pre-calibrated sensors to plug into deployed sondes, rather than having to carry entire replacement instruments.

Learn more about the EXO Platform:

EXO1 EXO2

The places you'll go with **EXO**

Been somewhere exciting with EXO?

We'd love to hear about it - send us some pictures and we'll send you some swag.

What's your EXO story?
Write us and let us know: info@ysi.com

EXO™

Future-Proof

By offering **complete flexibility**, the EXO platform future-proofs instrument selection.

Instead of having to carefully choose among 28 sonde options, each with very specific combinations of ports that rigidly defined possible sensor payloads, the new generation is limitless. In the case of sondes, less is more – our line has distilled to two EXO sondes, as opposed to 28 versions of 6-series sondes.

In addition to making the initial purchase simpler, the EXO platform is easy to reconfigure as needs change. A user could equip an EXO1 or EXO2 with sensors for a study of nutrient enrichment in a lake – with ammonium, ORP, chlorophyll and DO, for instance – then reconfigure for a river deployment measuring dissolved oxygen, pH, fDOM, and temperature. Same sonde, same ports, same handheld datalogger – just a quick changeover of sensors and a speedy recalibration.

That flexibility will be especially vital as optical technology spreads even more widely. Previous generations of sondes were configured with a specific number of optical ports and specific numbers of ports for other types of sensors. That limited users to very particular combinations of parameters they could monitor. With EXO technology, users have no limits on which sensors they can combine.

Challenges: Budget Reduction

Longer deployments and more reliable instruments move quickly to the bottom line. The cost of sending a technician (or two) into the field to maintain or repair a sonde on a long-term, continuous monitoring project is substantial, and when trucks, boats or even helicopters are involved (as they are for some of our customers) the investment can be astronomical. Increasing deployment time by 25 percent and improving reliability can play a major role in keeping those costs in check. Fast, effective calibration with less reagent delivers significant cost savings quickly.

Tougher, Smarter and Friendlier

Incremental improvements to our sonde technology have led us to where YSI is today, and many improvements are delightfully simple. Uniform sensor dimensions allowed us to simplify wet-mate connectors, and the high-impact Xenoy and welded titanium housing for the EXO is our toughest and lightest yet.

Internal memory can store up to 1 million measurements, and Bluetooth communication simplifies data collection (though a USB output for direct connection to a PC, or wired output to dataloggers and telemetry systems are also available). The EXO2 can be easily integrated into daisy chain monitoring systems. And our online education system, including the extensive **EXO-University.com** module series, has revolutionized training.

YSI also designed the EXO to take ease, reliability and accuracy to the next level – or beyond. Our graphical KOR software walks users through calibration for reliable results and impeccable data. Red, yellow and green quality checks ensure good calibration, even by novice users.

EXO's SmartQC onboard monitoring systems continually scan for configuration errors and operation problems. If something goes wrong with a sensor, the microprocessor shuts down the problem port to prevent damage to the sonde and other sensors.

The Yellow Spring, Where YSI takes its name "Yellow Springs Instruments"

Fouling-Resistant

Copper-alloy sensor guards for our sensors chemically combat biofouling on long EXO deployments. So does our new, single-brush wiper system.

Instead of equipping each sensor with its own tiny wiper – which was a breakthrough years ago – our anti-fouling strategy has evolved. All our smart sensors for the EXO platform are exactly the same length so they may be cleaned by a single, central rotating brush.

The bigger brush is coarser, so it is not only more effective at removing biofilm, mollusks and aquatic plants, but it is also longer-lasting and easier to maintain than tiny individual-sensor pads. The single motor is more powerful than the multiple small ones it replaced, and also more energy-efficient and reliable.

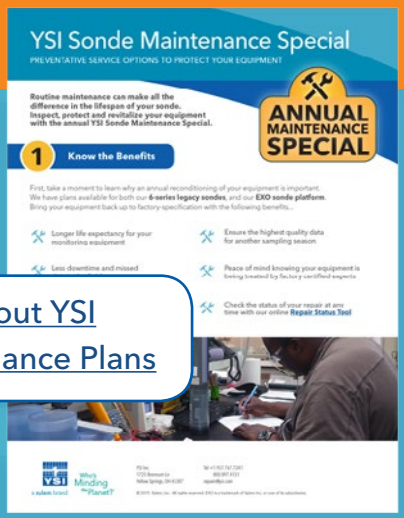
In all, our new single-wiper system has extended deployment time of EXO sondes by 25 percent over older sonde models.

"The ruggedness of the EXO is based on lessons we learned over the past 20 years. We took the top 15 potential improvements from the legacy sondes, and we made sure to address them all."

Tim Finegan, Director of Environmental Monitoring Products

Challenges: Repair and Maintenance Costs

The modular design and simple connectors of the EXO smart sensors make the new sonde quick and easy to repair and maintain, lowering the cost of ownership and minimizing the risks of stripping threads or breaking sensors during maintenance. Factory preventative service plans can help with budgetary planning over the course of a long-term project as well.



Learn More about YSI Sonde Maintenance Plans

Calibration and QC Breakthroughs

Calibration has long been an exacting, time-consuming, expensive process. Smart sensors introduced with the EXO platform have dramatically changed the calibration process. "Smart sensors have the potential to revolutionize the field maintenance process, by allowing the hot swapping of pre-calibrated sensors," says Tim Finegan, Environmental Monitoring Products Director.

Evolving Back to the Start of the Process

Smart sensors are built with on-board memory, allowing for all calibration information and sensor settings to be self-contained within the sensor (as opposed to the sonde). Because of this fundamental change in sensor design, a whole new host of quality assurance checks could be developed to help guide users through more complicated parts of equipment setup.

"The instrument – at least with YSI products – provides real-time feedback during the most critical process, calibration and preparation," says applications expert Mike Lizotte.

Backed by the KOR calibration software, a single staffer can quickly and efficiently calibrate all sensors in the lab, and less experienced technicians can confidently handle maintenance and sensor swaps in the field.

Our concurrent calibration feature allows technicians to calibrate multiple sensors of the same type at the same time, in the same cup of standard. That adds up to substantial cost savings. In fact, YSI calculated that improvements in calibration procedures for the EXO's smart sensors reduced the amount of standard needed to calibrate a fleet of ten sondes every six weeks by **$21,513** to **$62,113** per year, depending on the sensors and reagents used.

THE EVOLUTION of SYSTEMS

"It's like going from a dental x-ray to a high-res MRI. We have better tools, better ways of getting more high-resolution data, more parameters."

Kevin Simpson, YSI Director of Business Development

THE FEEDBACK LOOP

Data from water quality measurement instruments is being put to work immediately in process control systems, much as thermostats control the activity of your heating/cooling system at home.

Some of our systems have controls built in so they don't just report on water quality conditions – they do something about them. For instance, the **YSI 5500D** (ODO) optical DO monitoring and control instrument and **Aqua Manager®** software track DO levels, which aquaculture facility managers use to make quick adjustments to keep DO at optimum levels.

The 5500D monitor provides up-to-the-minute, detailed insight into fluctuations in dissolved oxygen levels driven by feeding events and stocking levels. But if oxygen concentrations drop below safe levels, the 5500D/Aqua Manager® package can trigger alarms, switch on oxygen pumps to save thousands, possibly millions of dollars worth of shrimp or fish from suffocation.

Similarly, the **YSI 5200A** and **Feed Smart** software can manage fish feeding equipment based on ammonia levels in raceway or pool water.

As our measurement and microprocessor technologies evolved, YSI also coded process control inside some of our instruments themselves. For instance, we programmed long-term unattended monitoring systems to recognize spikes in their measurements and increase their sampling rate – a strategy called **event-based sampling**. That way, the impact of a storm flushing sediment into a lake can be tracked. A precipitous drop in DO can be monitored so fisheries biologists know when it ended. A spill can be identified and followed.

Today, software that processes instruments' data can alert us to problems in the environment, much as they signal fish farmers of problems with their systems. As software continues to evolve, new opportunities will emerge not only to sound the alarm but to also address the problems.

Aquaculture process monitors keep track of critical parameters.

Blog: Automation Fine Tunes Aquaculture Production

Over time YSI systems have grown in scale and sophistication.

Our systems function as "autonomous labs" collecting a variety of water and weather data in real-time.

Super Power

The first step in developing instruments for in-situ water quality measurement was lowering the power demands of the sensors. Since then, product engineers have been on a constant quest to reduce power demands to make ever-more-complex systems more energy efficient. After all, better power management yields a longer deployment on a set of batteries.

The EXO reflects our latest advances in power management. Because the smart sensors are all designed to work together, they work in harmony with one another. That reduces the total power draw. So does wiping all six sensors with a single brush.

Microprocessors in the EXO put the sensors to sleep, waking them only when needed. Shortening the length of time required to warm up a sensor and reducing the period needed to take a measurement helps dramatically reduce energy consumption. So does an efficient division of labor within the sonde. Many sensors compute their readings into analytical values to make data more immediately useful.

Webinar: Real-Time Algae Monitoring

Complete integrated systems, like the one pictured here, are one of YSI's many fortes. By linking our instruments together, protected by secure housing, users can stream their water quality data directly to their computer. More time can be spent analyzing data, and less time spent in the field.

Fighting Fouling

As improvements in sensor technology and power management encouraged longer deployments, the limiting factors in sondes shifted. Initially, battery life was the biggest concern in equipping sondes for longer stays in the field. Longer deployments in a wider variety of environments – including many biologically rich ones – turned the focus to the fight against fouling.

Fouling is a constant challenge in water quality monitoring, causing data drift, malfunctions in the system or destruction of the instrument. From sensors plated with metals from their own electrochemical reactions to sea life making itself at home on sensor tips and sonde bodies, cleaning is a struggle.

Now instruments employ a wide variety of anti-fouling measures on our sondes, including a single sensor plane, copper-based anti-fouling materials, pump or flow-through systems, chemical injections, shutter systems and wipers.

The result is longer deployments. In fact, the new, robust single wiper system on the EXO platform has helped extend deployment time to **90 days** in certain applications.

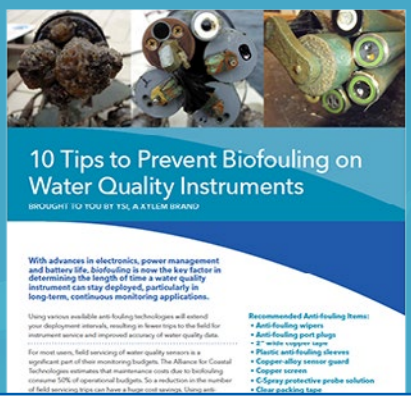
Predeployment

Postdeployment fouling

Clean EXO sensors

Have fouling concerns?

Be worried no more with our *10 Tips to Prevent Biofouling on Water Quality Instruments* eBook. Learn directly from our experts the best practices to protect your sondes from the threat of biofouling in productive environments.

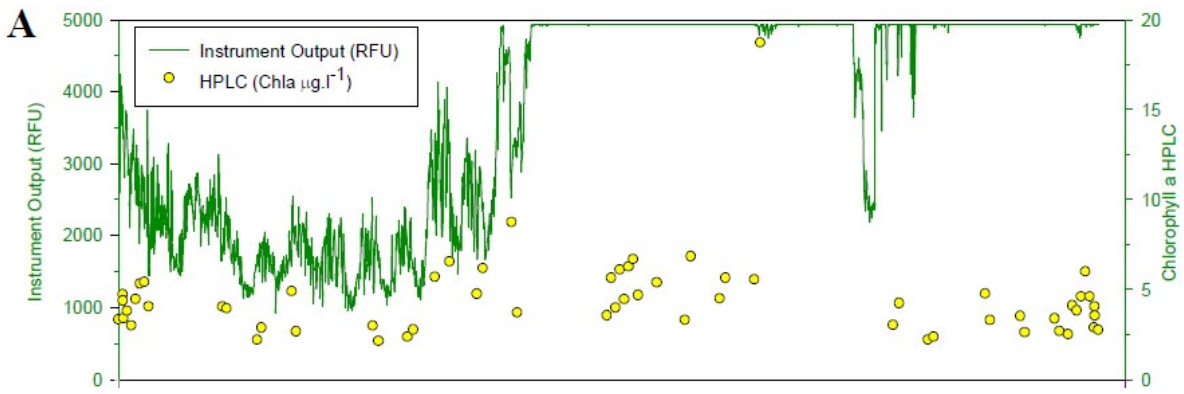


Download the Antifouling Tips eBook

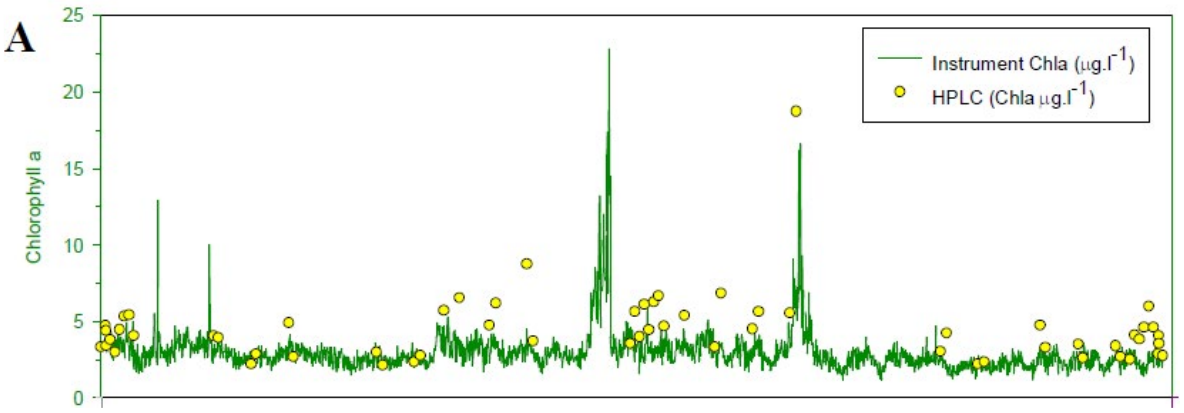
Why does fouling matter?

The result of a fouled sensor is useless data and wasted investment.

"High Accuracy" Product



YSI Sonde



● = Laboratory reading of water samples to verify sonde data.

Verify your data.

Sondes are reliable, to be sure, but even the most reliable system needs a sanity check from time-to-time. Utilizing a handheld, like **SonTek's CastAway CTD** is a great way to spot-check some of your sonde's readings for accuracy and longevity.

Deeper Understanding

With early field instruments, water quality monitoring was brought to the riverbank, or done off of bridges and boats. The advent of sondes opened up the possibility of long-term monitoring, but we hadn't even begun to imagine where these remarkable instruments would eventually be deployed.

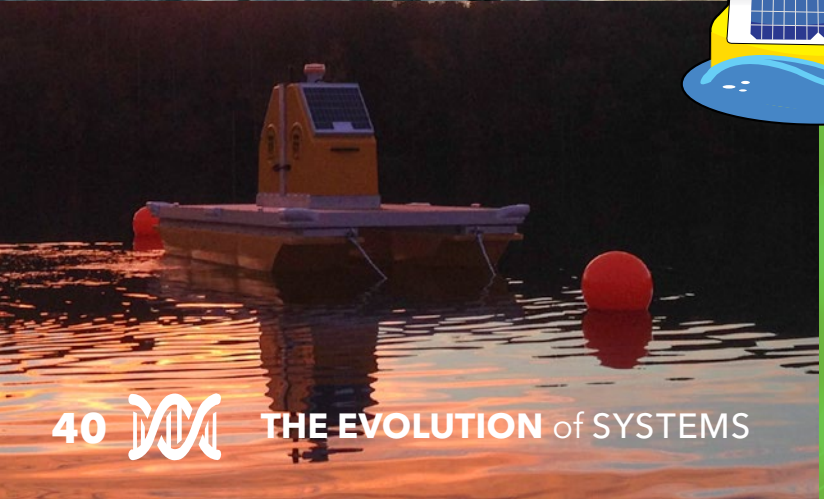
Water monitoring systems provide physical security for valuable instruments – protection from flood damage, debris, wildlife, theft and vandalism – as well as the assurance that the instrument gathers data in a fixed location.

Systems often integrate several instruments, including meteorological (MET) instruments, level or flow meters, automated samplers and telemetry systems.

Long-lasting power supplies, such as AC current from shore or battery packs recharged by solar panels, extends deployments in hard-to-access areas, though onboard energy efficiency helps deliver more data per AmpHour. At the heart of the system, of course, is a sonde with its own batteries, which can serve as backup power in case of an emergency.

Sturdy, reliable systems have allowed researchers to travel to remote mountaintops and far offshore. YSI also started looking deeper into water issues – as our technology became more sophisticated, we began to consider measurements well beneath the surface, giving our users a clear view of what is happening inside the water column.

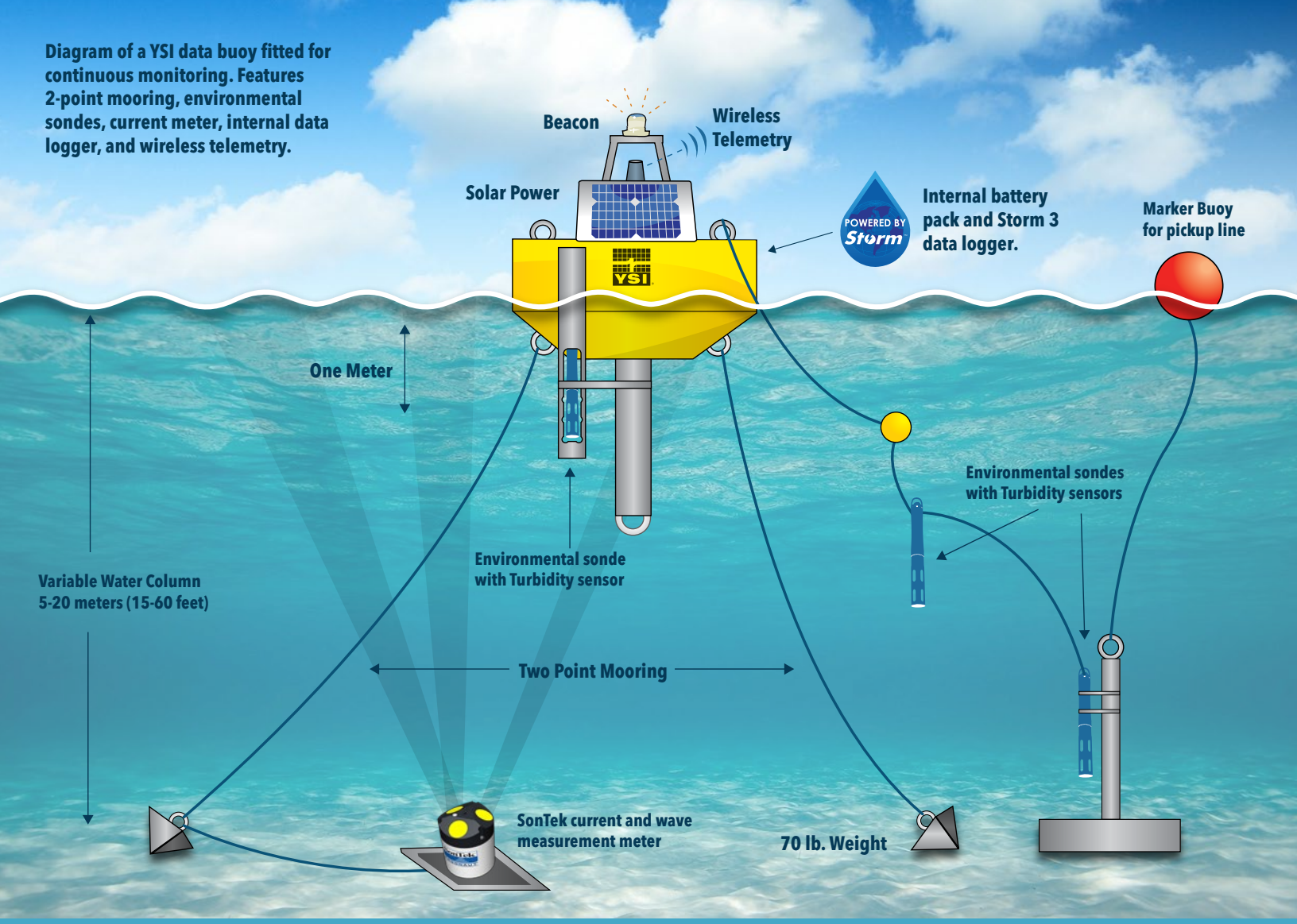
Go Anywhere



Let us do it for you!

YSI 's Integrated Systems and Services division provides installation and maintenance of systems such as these. Let them do the heavy lifting on your next monitoring project.

Visit ISS Online



Complete Systems for any Application

YSI Vertical Profilers, mounted on buoys or pontoons, also go deep to provide a look into the water column. Multiparameter sondes raised and lowered in the water record stratification, mixing, subsurface plumes of pollutants, zones of low oxygen content, floating algal blooms, and more.

In one dramatic example, a pair of buoy-mounted YSI Vertical Profilers in Taiwan's Shimen Reservoir trigger emergency protocols at the water treatment plant if high levels of sediment or algae are detected in the water column.

Sediment plumes are common phenomena at Shimen when storms cause rockslides along the reservoir's steep walls. Based on data from the sondes on the size, shape, depth and speed of a plume, treatment plant managers can draw from different intakes, accelerating the fill-up of an emergency storage pond, or switching to river water as a source.

Custom systems that combine YSI and SonTek technologies have been mounted on **nearly any platform**, from bridges to docks to ferry decks to a personal watercraft.

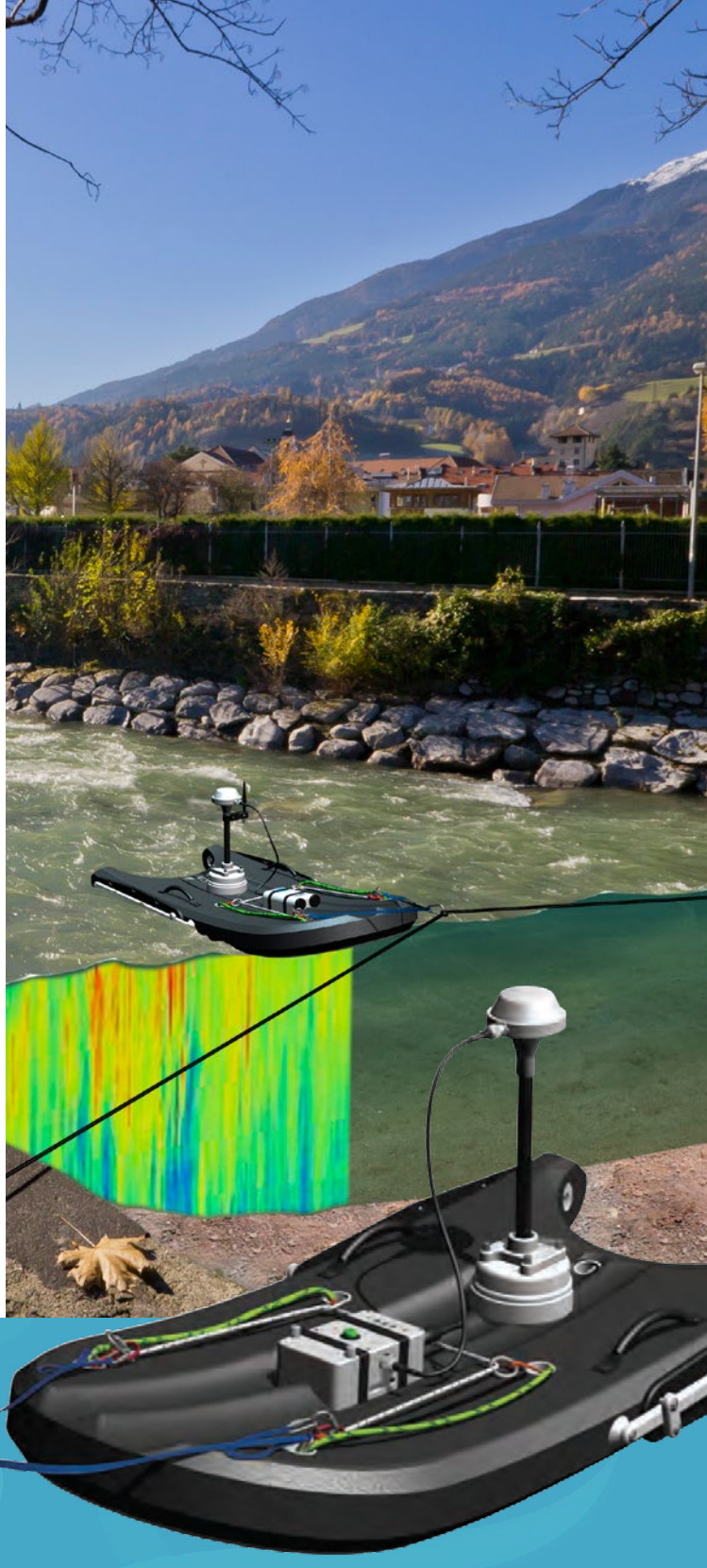
Blog: Safeguarding Shimen Reservoir's Water Treatment Plant.

Water Speed and Direction

The ability to integrate a variety of sensor technologies into a single monitoring system is a key element of what YSI is all about.

Sister company **SonTek** uses its acoustic Doppler technology – which measures the bounce of acoustic beams off particles in the water to measure the depth, speed and direction of flowing water – to provide vivid pictures of currents beneath the surface of rivers, lakes and even in pipes. The result is important data on river conditions (used by dispatchers to manage barges on the Mississippi, for instance) as well as discharge, a computed measure of how much water traveled past the instrument and how fast it was going.

SonTek's design team mounted a sophisticated acoustic Doppler profiler on a small floating platform to create the RiverSurveyor M9. Using the platform on a transect across the river, researchers can quickly download a color-coded, 3-D graphic depicting the velocity of water throughout the column and a meticulously measured channel cross section.



Huge River, Huge Challenge

The SonTek RiverSurveyor M9 helped hydrologists eager to measure the world's largest river discharge along the Amazon River. Such data is critical in deciding how to manage dams in the face of storms or heavy flows. Using its sophisticated design features – including RTK geolocation and the capability to switch acoustic frequencies based on water depth and conditions – the RiverSurveyor M9 efficiently profiled water movement across the vast channel to a depth of more than 50 meters.

Discover the SonTek RiverSurveyor M9

Read About Channel Profiling in the Amazon.

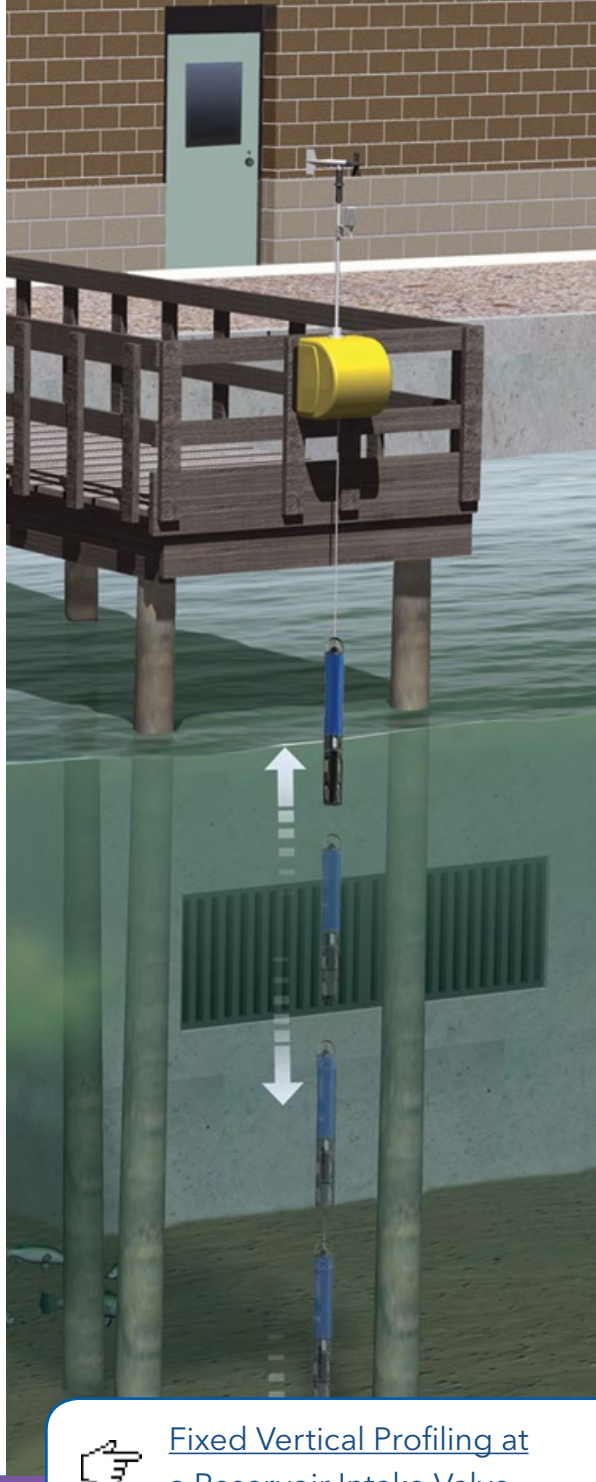
Logging Data

In the 1970s and early '80s, advanced instruments would log data on reels of 16mm motion picture film, marking one frame every 15 to 30 minutes. Film systems gave way to magnetic tape, then to digital storage. Over the past 20 years, sonde datalogging technology has grown from the terminal-based system underlying the 6000 UPG sonde of the '90s to the plug-and-play, user-friendly EXO. In a generation, we've paralleled the leap from HAM radio to cell phones.

The latest generation of water quality monitoring systems can store more than a million readings on-board. That may seem like quite a lot, but the hardware must keep pace with the demand for high resolution data from field professionals.

Beyond the instruments themselves are powerful software packages that help users organize, visualize, export and print all the information they have collected. These tools turn a massive stream of readings into highly visual depictions of measurements throughout a long-term deployment. This allows people to understand the dynamics of an environment with the click of a button.

But with all the tremendous advances in gathering and logging data, there's one computer that isn't being replaced – the human brain. "These are not diagnostic tools," notes Kevin Simpson, YSI's director of business development. "This is not artificial intelligence. Once we know, we still have to decide what to do."



Fixed Vertical Profiling at a Reservoir Intake Valve

Challenges: Incomplete or Inaccurate Data

Smart sensors process readings into analytical values and tag them with metadata. Because calibration meta data is automatically analyzed after calibrating, they can prevent users from deploying poorly calibrated instruments. During deployment, the EXO system can alert users to potential problems with their instrumentation.

"The implantation of advanced meta data generated by smart sensors can help troubleshoot systems, it plays a role in uncertainty determination, and presents an opportunity for new surrogate measurements that we are just beginning to explore."

Tim Finegan, Director of Environmental Monitoring Products

Understanding Ammonia

The accumulation of ammonia in aquaculture systems can result in toxic conditions that negatively impact livestock health. To ensure the best operational decisions are being made at a facility, it is important to monitor parameters that influence ammonia such as temperature, pH, and dissolved oxygen. YSI's spot sampling handheld water quality instruments allow for a quick check of water conditions, while our 5200A continuous multiparameter monitor can aid in process control for an entire facility.

☞ Blog: Understanding Ammonia in Aquaculture Ponds

Connecting Points: Integration and Communication

Connecting dataloggers, computers or other instruments to sondes and handhelds has undergone revolutionary change, too. Among the biggest challenges has been getting instruments to handshake and talk to each other.

Our aquaculture monitoring and control systems can serve as part of a network of up to 32 instruments, while the YSI **IQ SensorNet** enables a wastewater treatment plant to monitor every aspect of their process. A single IQ SensorNet module can link up to 20 sensors measuring different parameters.

A few decades ago, communications from sondes in the field in the U.S. required a license from the Federal Communications Commission (FCC). During that lengthy process, the government assigned researchers a frequency for broadcasting their data. Under most conditions, that VHF/UHF line-of-sight signal was limited to a distance of less than 10 miles.

The advent of other communications methods – Bluetooth or wifi for wireless broadcast of data to nearby tablets or laptops, or **WaterLOG** modems and satellite transmitters for long-range communications – blew past old restrictions like a HAM radio operator buying a new smartphone. Today, it takes just minutes to hook a sonde up for worldwide data streaming to the internet.

Cloud Cover

In fact, **WaterLOG**, a YSI brand, developed **Storm 3** dataloggers that feed via cellular modem or GOES satellite signal into Storm Central. That password-protected, cloud-hosted solution allows researchers to view and download data from their Storm 3 sites in real time, on any computer, tablet or smartphone. Powerful processing software alerts researchers about storms or pollution events, and the software delivers outstanding visualization and surprising customization of the data, connecting the numbers to maps and tables.

Storm Central allows water managers to achieve the goal we set as a company – to enable people to make real-time decisions based on real-time data.

Our data has also helped bring researchers together. As they have evolved, YSI instruments have increasingly integrated their data into models, meterological (MET) data sets and other data-crunching resources. Ease of handling data makes it easier for researchers to share numbers and insight.

Storm 3 our simple, reliable, and smallest data logger.

"**People are getting better at sharing,"** he says. **"Better decisions are being made based on that data – decisions on remediation and prevention. With better data, we can understand, collaborate, prevent and enforce."**
Kevin Simpson, Director of Business Development

Access your site data 24/7 with your laptop, phone or tablet.

Straight From The Gulf

Scientists in the Louisiana Universities Marine Consortium (LUMCON) use **WaterLOG Storm Central** to access data from the cloud – an easy feat because the system easily exports data that can be automatically folded into spreadsheets, graphic and visualization programs. That's vital to LUMCON's commitment to raising public awareness of the value of Louisiana's coastal and marine environment.

LUMCON Case Study

Evolving Relationships

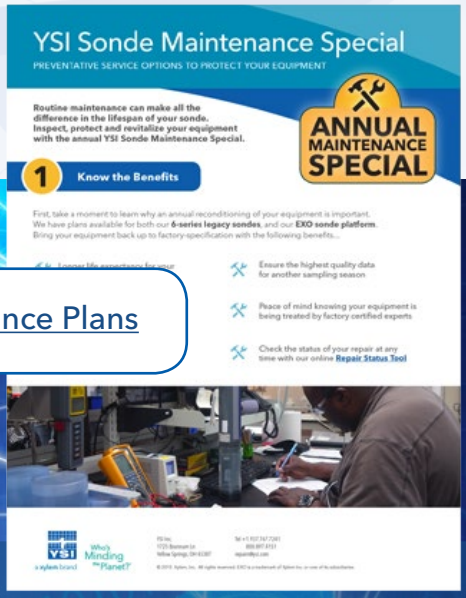
As technology has evolved, so has the relationship between YSI and its customers. Some of that evolution stems from the growing diversity of the customer base, broadening as more versatile, easier-to-use technology has made water quality measurement accessible to a wider array of people.

But another aspect of the change has been in the kinds of communication between YSI as a manufacturer and our customers.

YSI has gone worldwide, both through staff and with the help of a network of highly skilled and extremely dedicated representatives across the globe – reps with deep technical knowledge as well as an insider's understanding of their markets.

YSI has also evolved as a company to be more than just salespeople or even electronics advisors. Instead, much of our communication now revolves around how to best deploy our instruments, how to gather higher quality data, and what to do with the data once they have it.

YSI provides tools like **EXO-University.com**, a comprehensive online resource on the EXO platform and the industry's first online training series. YSI developed programs like our factory preventative service plans, which help keep our instruments in top working shape, reduce unplanned downtime, and help some customers include maintenance in their capital expense.



Video: I Use YSI

Maintenance Plans

"A successful company now has to be a partner in their customers' business. They have to be involved in the process, teach the customer precision. If the customer gets high-quality data, they will be your best salesperson."

Mike Lizotte,
YSI senior applications engineer,
Fall River, Mass.

THE FUTURE of MONITORING

"A big focus of manufacturers in the next 10 years will be all about data analytics – turning data points into actionable information automatically."

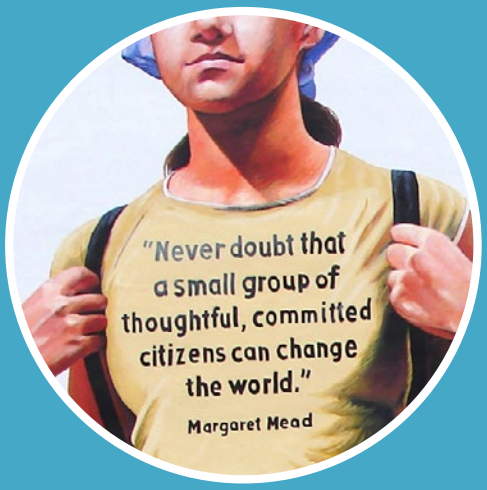
Tim Finegan, YSI Director of Environmental Monitoring Systems

LOOKING FORWARD

Looking back over six decades of evolution, one of the most exciting realizations is that evolution continues.

We have seen what committed water quality experts have done with more versatile, more accurate, more durable instruments – the doors that have opened since they got out of the lab and into the field, then increased the number of parameters they could measure, then increased the temporal resolution of their data.

Just imagine what will happen in the next few years...



YSI technology is used to better understand and improve the world.

The students of today are the environmental stewards of tomorrow.

YSI employees Aftab Barki and Melanie Poon.

Images from our company mural in Yellow Springs, Ohio.

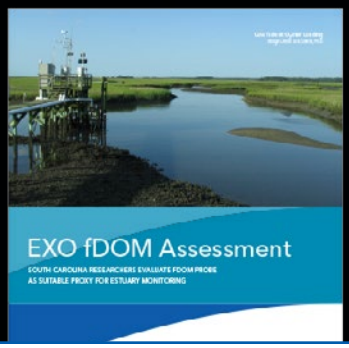
A **Bold** New World

Picture accurate, long-term unattended monitoring of nitrates and phosphorus, two nutrients with huge impact on water quality – and two nutrients that are firmly in the regulatory spotlight around the world. Picture rich troves of metadata, including geotags, bolstering the validity of massive data sets.

Scientists have now validated the use of fluorescent dissolved organic matter (fDOM) as a surrogate for methylmercury to eliminate the need for an expensive methyl mercury sensor in the field. Imagine finding surrogates for other challenging parameters like fecal coliform, using the tools we already have in our monitoring arsenal.

Researchers are already deploying torpedo-like autonomous underwater vehicles (AUVs) to troll transects in reservoirs and the ocean. They are already deploying vast numbers of oceanographic instruments to ground-truth measurements of the ocean surface by satellite.

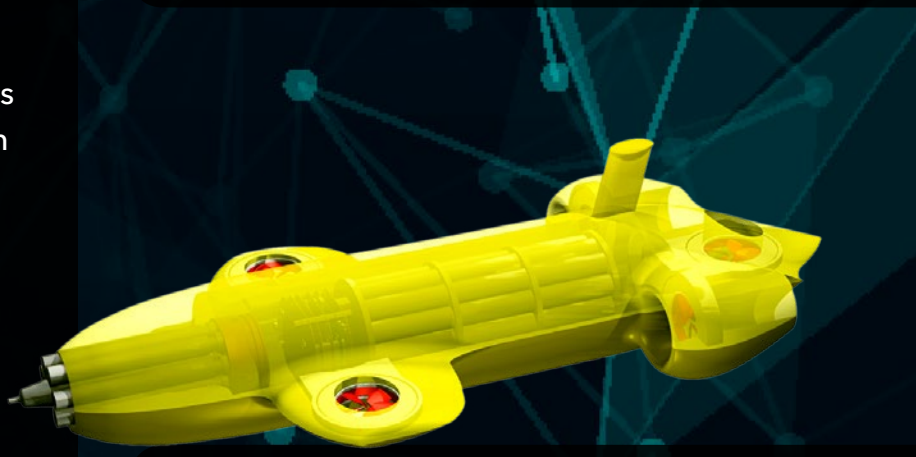
Stay tuned for robots and drones that can help deploy water quality testing instruments in challenging locations, extending our reach and allowing us to focus on making sense of the data flowing in.



Case Study: EXO fDOM Sensor for Surrogate Measurements

Autonomous underwater water quality mapping vehicles have been in use for the past 5 years, like the **YSI EcoMapper.**

Drone technology stands to change a lot more than package delivery.



AUV's like this one by **Hydromea** are already being deployed with YSI sensors onboard.

Imagine how much we can learn, how much deeper we can dive into the complex relationships that govern water quality.

And imagine how much more effectively and appropriately we can manage it – **making real-time decisions with real-time data**.

Now that's water quality monitoring evolved!

RESOURCES and CONTACTS

"A successful company now has to be a partner in their customers' business. They have to be involved in the process, teach the customer precision. If the customer gets high-quality data, they will be your best salesperson."

Mike Lizotte, YSI Senior Applications Engineer

Evolve Along with Us

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YSI.com/blog

Have a general question for us? Click the link below to get in touch with a knowledgeable YSI'er.

Ask us a question

Ready to start talking about your next project? Click the link below to speak with an applications specialist.

Email a specialist

ABOUT US

In closing, please allow us to introduce the team that made this eBook possible:

Brandon Smith

Product Manager

With a background in biology, and a passion for educating customers, Brandon represents the genesis of this eBook.

Lyndsey McDermand

Digital Marketing

YSI's email architecture and analytics expert, Lyndsey made it possible for this eBook to make it to your desktop.

Patrick Beatty

Marketing & Design

As a graphic designer and marketing specialist for YSI, Patrick ensured that not only is this eBook interesting, but it looks great too.

Patrick Higgins

Digital Marketing Manager

If you're on social media, read a blog, or ever use the internet, you probably found us because of Patrick. Before you talk to anyone else, you'll be connecting with Mr. Higgins.

Steve Werblow

Writer

Oregon-based writer and photographer.
Long-time collaborator with YSI.

What can Xylem do for you?

Xylem |'zīləm| 1) The tissue in plants that brings water upward from the roots; 2) a leading global water technology company. We're a global team unified in a common purpose: creating innovative solutions to meet our world's water needs. Developing new technologies that will improve the way water is used, conserved, and re-used in the future is central to our work. We move, treat, analyze, and return water to the environment, and we help people use water efficiently, in their homes, buildings, factories and farms. In more than 150 countries, we have strong, long-standing relationships with customers who know us for our powerful combination of leading product brands and applications expertise, backed by a legacy of innovation. For more information on how Xylem can help you, go to **www.xyleminc.com**

xylem
Let's Solve Water

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