Application Note

Sending Ferries to Uncover the Secrets of the Sea

Researchers tap "ships of opportunity" for automated, continuous water quality monitoring

Ferries crossing the Neuse River and Pamlico Sound on their regular routes have been equipped with a water quality monitoring system for continuously collecting water samples and water quality data as part of the FerryMon program, which began in 2000. Over the last seven years, FerryMon has uncovered water quality problems – such as toxic algal blooms, changes in water clarity and excessive nutrient loadings – that could not have been detected by standard water quality monitoring techniques.

"Ferries fill an important gap between traditional estuarine monitoring, where you go out once a week or once a month in small boats, and mooring-based offshore monitoring programs," explained Hans Paerl, Kenan Professor at the University of North Carolina at Chapel Hill, Institute of Marine Sciences (UNC-IMS). "Our nation's medium- to large-size water bodies are extremely important for fisheries, our economy, recreation and homeland defense, and yet, they are very challenging to monitor with traditional methods."

An automated, continuous water quality monitoring system is installed on three ferries that travel in the Pamlico Sound in North Carolina. This NC-DOT ferry, the Carteret, runs from Cedar Island to Ocracoke Island, where it crosses the southern Pamlico Sound and Ocracoke Inlet, a major exchange point with the Atlantic Ocean.

Before FerryMon, North Carolina did not have a routine monitoring program on Pamlico Sound, Paerl said. Because the Neuse River Estuary and Pamlico Sound are essential nurseries for a variety of important fish species, researchers need to be able to predict how this ecosystem will respond to water quality changes so that state agencies responsible for water quality and fisheries habitat can take quick action as necessary.

FerryMon – commissioned by the North Carolina Department of Environment and Natural Resources (NC-DENR) in conjunction with Duke University Marine Laboratory (DUML), UNC-IMS and the North Carolina Department of Transportation Ferry Division (NCDOT) – is based on Finland's ferry-monitoring Baltic Sea Algaline Project.

"We liked the Finnish setup, with monitoring equipment inside the sea chest of the vessel, out of sight to everyone except for the technicians and engineers," Paerl said.

FerryMon's water quality monitoring system, about the size of a washing machine, is installed on three NCDOT ferries: the *M/V Carteret, M/V Silver Lake* and *M/V Floyd J. Lupton*. The *Lupton* alone makes 40 crossings daily along the Neuse River between Cherry Branch and Minnesott Beach.

The heart of the monitoring system is the YSI 6200 Data Acquisition System – interfaced with the simple, small and durable YSI 6600 multiparameter monitoring sonde – customized for FerryMon.

YSI's sensors measure surface water temperature, salinity, dissolved oxygen, pH, turbidity and chlorophyll *a* fluorescence (algal biomass). Other underway monitoring systems often are created by wiring together stand-alone components, one sensor at a time, from different sources, and then integrating them with a data collection and telemetry system.

"YSI was certainly a pioneer in getting multi-probe sensors in a sonde that not only is sensitive but also compact," Paerl said.

Global Positioning System (GPS) time-stamped data collected by the sensors and stored in the 6200 system is sent nightly from the ferry by cell phone to the UNC-IMS laboratory. The data is then processed and made available to the NC-DENR, U.S. EPA, NOAA, local water quality and fisheries agencies, researchers and schools.

Unlike other underway monitoring systems, which often need researchers' ongoing attention and frequent maintenance, YSI's sonde operates self-sufficiently. Maintenance is performed every 10 to 14 days by a technician, who simply swaps out the sonde on each ferry with a newly calibrated sonde.

During the ferry's journey, the system also collects surface water samples, documenting where and when they were taken. A refrigerated automatic water sampler stores samples for later study in the lab. A technician travels on board the ferry once every few days to collect samples and program the sampling unit, Paerl said.

Seven years of strides

Since 2000, FerryMon has helped researchers like Paerl better understand daily environmental conditions in Pamlico Sound and the Neuse River Estuary.

1. Finding "patterns and patches"

FerryMon has documented variations in estuary and coastal waters and detected certain water quality issues that otherwise would not have been captured.

"Because marine organisms are seldom distributed homogenously, it's easy for monthly monitoring programs to miss patterns and patches in time and space," Paerl noted. "An algal bloom may only be a few hundred meters across, so we might not catch it with standard monitoring. This can affect regulatory actions and have important ramifications for management."

The ferries are "time and space intensive" over the track they monitor, Paerl said. In many cases, FerryMon has produced much improved

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temporal and spatial data on representative chlorophyll *a* levels and exceedances of Total Maximum Daily Loads (TMDLs).

"FerryMon has proven to be a very good sentinel or 'first alarm' system, telling us where a potential problem might exist," Paerl said.

In spring 2007, FerryMon helped reseachers identify a large dinoflagellate bloom, which can trigger low oxygen (hypoxia), fish kills and toxicity. "The ferries picked up this bloom and raised the red flag," he said.

He discovered that the bloom occurred in patches, exceeded the TMDL for chlorophyll *a* and was present on only one side of the estuary. A detailed water quality investigation found that the bloom was caused by a high freshwater discharge from the Neuse River.

2. Identifying toxic blooms, validating TMDLs

FerryMon caught another dinoflagellate bloom in September 2006 on the heels of tropical storm Ernesto, which produced significant rainfall and caused Pamlico Sound to be strongly stratified with freshwater and seawater and enriched with nutrients. "All this, plus the good weather after Ernesto, set up a *Karlodinium* bloom that turned out to be toxic," Paerl said.

More extensive sampling allowed researchers to delineate the extent of the bloom, which produced small fish kills in the Neuse River's tributaries. "For regulatory agencies, this provides more evidence that nutrient-input controls are important, and that the TMDLs in place are justifiable," he said.

A graduate student at UNC Institute of Marine Sciences, assists Hans Paerl (right) with the YSI 6600 multiparameter monitoring sonde, which continuously collects water quality data.

3. Recognizing trends, uncovering causes and effects

Researchers can review FerryMon data for trends and attempt to link blooms to nutrient-input events. By analyzing trends over multiple years, researchers can learn whether the frequency of blooms is increasing or decreasing, whether blooms are related to climate change and how the Pamlico Sound responds to hurricanes, tropical storms and droughts.

"You can start to see what water quality problems are triggered by natural events such as storms versus human-related activities such as nutrient discharges," Paerl said. "Ferry monitoring is proving to be an incredibly good tool for monitoring and assessing long-term decadal changes, or changes due to hurricanes, sea level rise and global warming."

4. Extrapolating chlorophyll values using remote sensing

FerryMon's chlorophyll *a* data is being used to calibrate remote sensing images of the Neuse River Estuary and Pamlico Sound. Researchers are developing algorithms that relate remote sensing images with ground truthing provided by FerryMon so that chlorophyll *a* estimates can be extrapolated for the entire area. Ultimately, the data can be used to detect algal blooms and turbidity events in areas were the ferries do not travel.

5. Learning about the effects of hurricanes

Paerl said FerryMon data has helped researchers learn how different storms affect water quality in Pamlico Sound, and how long these impacts last. Shortly after the first ferry was instrumented in November 2000, it documented the lingering effects of Hurricane Floyd, which struck the area in September 1999. "Elevated chlorophyll *a* levels and changes in species of algae were seen 18 months later," Paerl said.

Since then, several "wet" and "dry" storms have hit the North Carolina coast. Hurricane Isabel in September 2003 was a large, windy, "dry" storm that churned the waters but delivered little rainfall, and thus little runoff. "FerryMon saw elevated chlorophyll *a* and turbidity right after this hurricane, but the system recovered quickly," Paerl noted.

However, FerryMon found that tropical storm Ernesto, and other "wet" coastal storms that brought significant rainfall, produced longer-lasting effects. "We saw more freshwater and more nutrients carried downstream to the open sound system," he said.

Researchers used to make assumptions about the effects of hurricanes on water quality. "Now we can reliably document these effects for the state, which maintains a database for looking at issues such as climate change, long-term impacts and increased frequency of hurricanes," Paerl said.

6. Proving the ferry monitoring concept

FerryMon eliminates the need for monitoring groups to charter research vessels for expensive sampling cruises, and minimizes the need to set up numerous automatic monitoring stations on buoys, both of which can collect data only in limited areas. The last seven years have shown that an automated, continuous water quality monitoring program can be implemented on ships of opportunity for a relatively modest investment. FerryMon's initial equipment cost was just $75,000 per ferry, and its total operations cost $300,000 annually.

"If we had to use our own boats and pay for fuel and a crew, it would easily cost over a million dollars a year to run this program," Paerl said.

The future of ferry monitoring

Underway monitoring is capturing more attention from the scientific community as a reliable, inexpensive way to collect a wealth of water quality data that otherwise would be too impractical and expensive to collect at all. By installing these systems on ships of opportunity traveling on their regular routes, Paerl has been able to create accurate, high-resolution baseline datasets to observe how water quality, water conditions and ocean life change in the same area over long periods of time.

The state has continued to fund FerryMon. "Our legislators clearly see the value in this program, and our state agencies realize how important it is to keep your finger on the pulse of a system as important as Pamlico Sound," Paerl said.

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