Remote Environmental Monitoring: Applying Automated Sampling to Produce Real-Time Data for Long-Term Monitoring Cost Savings and Compliance Assurance - 14200

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ABSTRACT

Locations engaged in waste management and/or environmental restoration all have mandated or regulatory-driven environmental monitoring programs. These programs are expensive, labor intensive, and provide limited data. The nexus of field analytical sensors and probes to measure physical and environmental parameters along with the maturation of wireless communication technologies provides new opportunities to develop automated and real-time data acquisition and compliance reporting systems. These systems are capable of providing continuous data readings with benefits including greatly increased data volumes, self-validating data, and early warnings for selected environmental releases. Wireless communications systems transmit data to secure storage locations behind firewalls or in the internet cloud for user access and analytics. “Smart” systems also can be programmed to send instant alerts via phone, text, or email messaging if predefined contaminant thresholds are breached. The user interface incorporates data from traditional field sampling-fixed laboratory analysis to provide systems integration efficiency for multiple aspects of environmental monitoring and regulatory compliance. A case study application of real-time environmental monitoring systems at the Department of Energy’s National Energy Technology Laboratory is presented. The case study includes custom user interfaces, and systems integration applications for air, surface water, and groundwater applications. Also discussed are the sensor technology limits and the regulatory challenges in the deployment of remote environmental monitoring systems.

INTRODUCTION

Since the creation of the U.S. Department of Energy’s Office of Legacy Management (LM) in 2003, more than 75 sites have transitioned from the remedial activity stage into long-term, post-closure monitoring. Whether admission to the LM program occurred under CERCLA, RCRA, UMTRCA, FUSRAP, or other authority, LM sites all have mandated or regulatory-driven environmental monitoring programs, which require long-term supervision of environmental parameters of concern to ensure safety to human health and the environment. These monitoring programs are expensive, labor intensive, and provide limited, periodic data. The temporal gaps in information collection result in uncertainty for decision-making.

The long-term environmental monitoring mortgage for DOE increases each time a site transitions from remediation to post-closure status. A major challenge for DOE will be to manage the reduced federal funding levels with the increasing obligation of sampling and analysis costs for long-term monitoring. By leveraging the technological chain of sensors, communications, data storage, data security, and web interface platforms, substantial cost savings may be realized to mitigate the funding challenges. Simultaneously, these new technologies also bring increased data volumes so that more informed decisions can be made.

TRADITIONAL SAMPLING APPROACHES

The traditional approach to environmental monitoring for air and groundwater requires periodic field sampling at fixed locations. Sampling technicians are deployed to numerous locations on a quarterly, semi-annual, or annual basis to collect material from water wells or other media. The field samples are labeled, preserved, cooled, assigned chain of custody, and shipped to fixed laboratories to be analyzed according to EPA or other prescribed methods and protocols. Analytical results are verified and validated for items such as holding times, applicable quality assurance and quality control (QA/QC) protocols for the analytical method, various blank samples, and other items.

Each step in the field sampling and laboratory analytical data chain contributes cost. Sampling and analysis composes a large percentage of the cost of an environmental monitoring program. Moreover, if sample results are compromised or indicate potential concentrations outside established limits, resamples must be performed at additional costs and at an appropriately-delayed time interval to mitigate the correlated nature of groundwater concentrations. The chain of events required to collect sample data typically takes weeks or months to complete, with only a single, point-in-time sample result, the validity of which may be disputed. Thus, whereas contaminant concentrations in groundwater are known to fluctuate over time, budgets do not allow for more frequent sampling to settle data disputes. Consequently, the snapshot-in-time data collection approach often leaves lingering questions in the minds of regulators and stakeholders as to the true situation in the aquifer.

SAMPLING BY SENSOR

The industry-wide focus of miniaturizing computer and electronic components extends to the field of environmental data collection. Sensor and probe components are today smaller and more rugged than ever, making them capable of withstanding harsher environments. In addition, detection limits, sensitivity, and selectivity are advancing similarly. New generations of sensor technologies are emerging at an unprecedented rate, opening the door for automated sampling in long-term monitoring programs.

Automating the sampling process offers multiple advantages to the traditional approach. Sensors and probes can be deployed to provide round-the-clock information. These recurring data are stored in the sensor or a data logger and transmitted periodically via wireless communications to secure servers. The increase in available data for decision-making is exponential. Whereas traditional groundwater monitoring programs rely heavily on quarterly sampling, hourly readings by miniaturized sensors can provide up to 8,760 hourly data points per year. These additional data fill in the knowledge gaps left by current field sampling and laboratory analytical methods.

Remote environmental monitoring also addresses other issues associated with traditional sampling approaches. For example, resamples for upticks in contaminant concentrations become automatic procedures with the use of field sensors. If an actual uptick or release has occurred, the ongoing, real-time sensor data will provide “up-to-the-minute” reports on the state of the environment. If the uptick is a false positive due to field sampling or laboratory error, the automated sampling system’s subsequent measurements will confirm immediately that compliant levels are actually present in the aquifer. Thus, sensor data become essentially self-validating due to the large volume of data produced. Additionally, chain of custody and holding time issues are mitigated or eliminated. The sensor automatically gives each data point a time-date stamp and a sample location identification, without physically removing any sample subject to chain of custody. Because the measurements are taken in real-time, holding time issues are no longer relevant. Investigation-derived waste issues are also mitigated.

Despite significant opportunities, challenges remain in automated sampling. Sensor technologies are currently unable to measure all analytes in all media at acceptable detection limits. Nevertheless, many environmental parameters and contaminants may be measured today (even more via surrogate indicators) and market demand continues to drive sensor development by commercial firms. DOE continues extensive research into miniaturized sensors at national laboratories that offer promise for measuring radiological contamination. NETL has sponsored the research and development of a report on available sensors for hydrofracking applications (URS 2013) along with the remote environmental monitoring described herein.

WIRELESS COMMUNICATIONS, SECURITY, AND DATA STORAGE

Advances in wireless communications technologies offer increasingly advanced, cost-effective, and wide coverage options for transmitting sensor data from the field. Options include satellite, cellular, and radio frequency transmissions, with combinations of these technologies available to minimize costs. Multiple vendors offer wireless communications services and offer dual-mode options so that a single device can operate via either satellite or cellular method. With the growing demand for wireless data transmission and the growing competition among commercial vendors, costs continue to decrease.

The wide availability and easy access to wireless services make data security during transmission and storage of paramount importance. Both governmental and private approaches to security are available. Federal Information Processing Standard (FIPS) No. 197 promulgated and endorsed the Advanced Encryption Standard (AES) algorithm for protecting sensitive electronic data, which is also endorsed by the National Security Agency (NSA). Similarly, DOE Order 205.1B sets forth requirements and responsibilities for Cyber Security Programs (CSP) that protects information and information systems for the DOE. Using a Risk Management Approach (RMA), DOE meets the obligations of the Federal Information Security Management Act (FISMA). Additionally, Federal Information Processing Standards Publications (FIPS PUB) address security requirements for cryptographic modules. Data that are collected and transmitted wirelessly are stored on secure servers. Servers may be located behind secure firewall at the site being monitored or at secure internet cloud providers.

WEB SERVICES AND USER INTERFACE

Web services provide the communication and network portion of the automated sampling solution. Whereas the data collection, transmission, and storage chain is hidden from the user, the web interface is highly visible. The web services component is where the sensor data are managed, visualized, and displayed.

An efficient and dependable web services interface must have a well-designed architecture and should be able to host sensors and probes from any vendor. Design features should include a capacity for a large number of sensors, multiple simultaneous users, thin client support, firmware over the air (FOTA) support, automatic alerts, the ability to communicate to the sensor from a laptop or mobile device, and others. The architecture and design are critical because the web services platform must manage the database, internet connections, commands, alerts and alarms, as well as data analytics and reporting. It must also operate in multiple environments such as local and multiple servers, cloud instances, or any combination thereof. A web interface is more than just sending data from the sensor to the server.

DEVICE COMPONENT AND DOMAIN EXPERTISE

The field devices generate the actual monitoring data. Device composition extends beyond the sensors, probes, and wireless communications. Components include (1) the remote terminal unit, which provides the “brain” of the device; (2) the power supply, which must be designed with an appropriate power budget; (3) the sensors to generate and capture data; (4) communication links (satellite, cellular, etc.) to transmit data; and (5) packaging to enclose and protect the device from the elements.

Because the remote monitoring system is a chain of complex technologies, domain expertise is a crucial element for success. This includes sensor selection and platform interfacing, communications platform design and configuration, web interface customization, cyber security, packaging design and testing, and device maintenance. Experience in deploying, debugging, and maintaining devices contributes heavily to remote monitoring success.

NETL CASE STUDY

DOE's National Energy Technology Laboratory (NETL) has hosted a research application of automated sampling and remote environmental monitoring. The project monitors water quality related to unconventional oil and gas (UOG), particularly hydraulic fracturing (fracking), which is an active area of research at NETL. There is currently great demand from regulators and operators for pre-drilling baseline data, post-drilling and well completion data, and production period impacts to water quality. Previously, NETL sponsored a two-year program through Wilkes University, completed in 2012, to test the feasibility of deploying water sensors in areas where active fracking operations are ongoing. The results included in this report extend the research and represent 2013 activities using a more sophisticated user interface platform.

NETL owns three YSI 6600 multi-parameter sondes, each of which contains sensors capable of reporting data for seven water quality parameters: pH, turbidity, specific conductance, temperature, dissolved oxygen, chlorophyll, and blue-green algae (Figure 1). Changes in these water quality parameters are often indicators of impacted water quality.

Fig. 1: YSI 6600 Sonde

The NETL sondes were deployed to two field locations and one laboratory location for remote monitoring and testing. One of the sondes was deployed to Sutton Creek in northeastern Pennsylvania near Wilkes-Barre to monitor water quality in a stream subject to impacts from nearby fracking operations. A second sonde was deployed to West Run Creek near the NETL facility in Morgantown, West Virginia to monitor potential impacts of acid mine drainage. The final sonde was installed in a Morgantown NETL laboratory so it could be tested by challenging the sensors with fluids common to fracking operations (Figure 2).

Fig. 2: YSI Sonde Deployment in West Run Creek at the NETL Facility in Morgantown, WV

A key objective of the study was to demonstrate the feasibility of deploying sensors and capturing data using a web interface. The NETL remote environmental monitoring project sponsored the customization of a commercial off-the-shelf web interface to meet the needs of the NETL sensor study. Figure 3 shows the "dashboard" for the user interface. The dashboard contains iconic representations of the parameters being monitored along with summaries of the number of exceedance alerts for each parameter. Alerts are generated automatically if threshold levels for any of the measured parameters are breached. A geospatial map image shows the location of the field device, with the sensor located a few feet away in the stream. Zoom features allow the user to create a larger map area that displays all sensor locations for the project. A time series graph displays daily average contaminant trends over a seven-day period for each water quality parameter. Links to other areas of the website are also available so the user can perform data analytics and generate reports. Data being reported from each of the sondes is accessible from the dashboard.

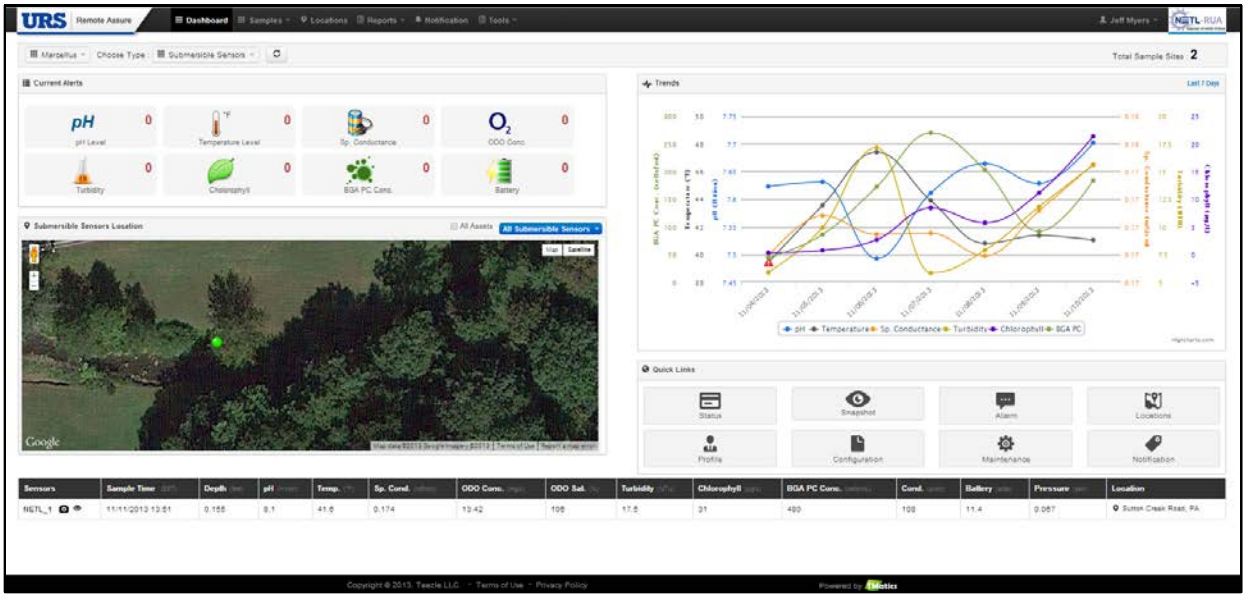

Fig. 3: Dashboard for the NETL Remote Environmental Monitoring System

Figure 4 shows the Sutton Creek sonde in place in the stream under approximately 12 inches of water. Water levels vary in the stream depending upon rainfall. A steel rebar stake can be seen on the right side of the photo, which tethers the sonde's connecting cable and minimizes movement of the sonde. The sonde location in the creek bed was excavated to ensure a sufficient water cover at all times, which is especially important during winter months when freezing can occur and potentially damage the sonde.

Fig. 4: Sonde under 12 Inches of Water

Figure 5 shows the satellite communications and solar panel equipment, which is located approximately 50 feet from the creek. The solar panel is positioned to receive maximum sunlight. Satellite communication was selected after a check of GPS coordinates against coverage strengths from several cellular service providers indicated undependable cellular communications at the relatively remote location. Data are transmitted once per day to an internet cloud instance. Threshold alerts are sent instantaneously via voice message, text message, and email if breaches occur. Low temperature alerts were sent multiple time per day during winter months.

Fig. 5: Satellite Communications Equipment and Solar Panel - Northeast Pennsylvania

Figure 6 is a 24-hour graph of hourly water quality parameter data. Most variables exhibit largely random behavior; however, water temperature displays a daily warming and cooling cycle. The 24 data points for each parameter are averaged to produce the daily average value presented on the dashboard weekly summary (Figure 3).

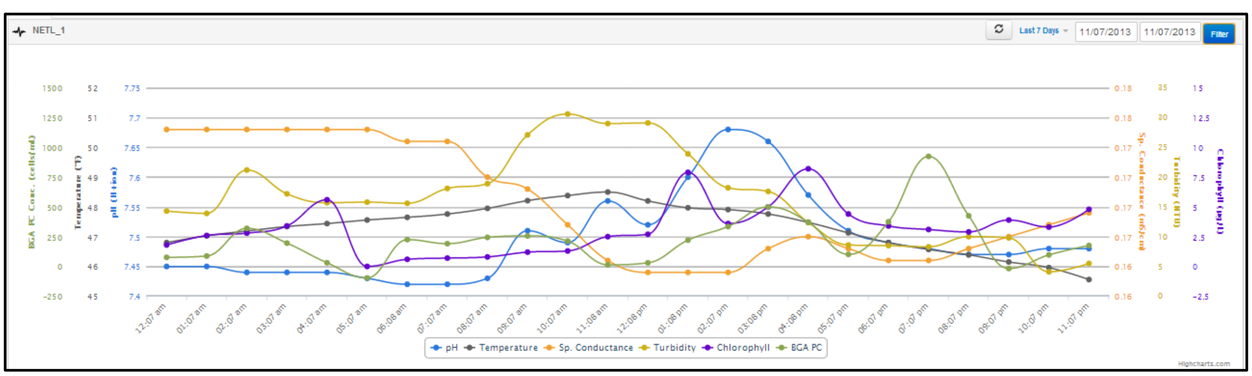

Fig. 6: Graph of Hourly Water Quality Parameters

CONCLUSIONS

Automated sampling offers opportunities to modernize sampling and monitoring procedures at DOE and other sites where long-term environmental obligations exist. A chain of complex modern technologies can be assembled using off-the-shelf components to create viable remote monitoring systems. The initial phase of the NETL automated sampling project has demonstrated feasibility for deploying sensors, transmitting and storing data securely, and customizing user interfaces to report results and perform data analysis. Thousands of data for each of the seven parameters being measured have been collected and analyzed.

REFERENCES

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