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A Strategy and Case Study Example for Designing and Implementing Environmental Long-Term Monitoring at Legacy Management Sites

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Introduction

Environmental monitoring objectives of site owners, regulators, consultants, and scientists typically share the common elements of (1) cost management, (2) risk management, and (3) information management (Figure 1). Many site owners focus on minimizing monitoring costs while regulators typically focus on risk and regulatory compliance. Scientists and consultants typically provide information management in the form of spreadsheets with extracted information provided in reports to other users. This common piecemeal approach upon individual focus on elements of the monitoring objectives, rather than the common objective of minimizing cost and risk using site information, results in missed opportunities for cost savings, environmental protection, and improved understanding of site performance.

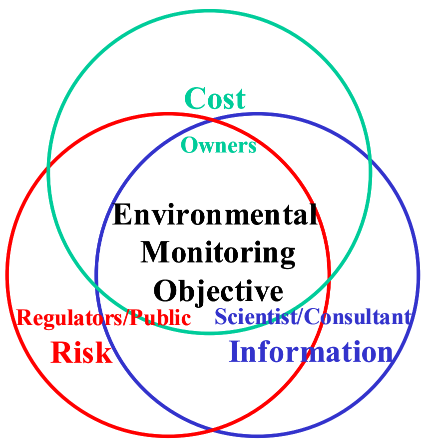

Figure 1. Three elements of environmental monitoring objectives.

Observation of the current monitoring systems within the DOE complex and in private industry, suggest a number of inadequacies.

(1) Information is often poorly managed. Old data and reports are often difficult to locate even in paper form. Old data is often not used in updated reports to regulators or clients and is unavailable to researchers. Excessive time is spent tracking down data and information useful for risk management. At most sites, site relevant data cannot be obtained from a single location. Weather data, GIS and monitoring data, and construction as-builts are commonly stored separately. Continuation of sub-optimal or excessive sampling caused by poor information management results in increased environmental risk and/or monitoring costs.

(2) Overall a vast amount of time is wasted processing the data rather than analyzing data. Data is often processed by junior staff with superior technical skills (e.g., knowledge of a specific numerical model), but with limited experience. Experienced senior staff in regulatory agencies,

funding agencies, or employed by the site owners often never see or do not have access to raw data. Senior staff also often lack the specific skills required by a given model needed for data manipulation. Junior staff gain in technical experience is limited by the significant efforts spent on data management tasks rather than data analysis.

(3) Impediments to sharing of data and information results in poor teamwork. More complex environmental sites collect a variety of hydrological, geochemical, geophysical, and biological monitoring data with no effective mechanism to share data even among researchers with good intentions. Fundamentally, we need a system with the ability to share the dots before we can expect interdisciplinary teams to effectively connect the dots.

*In response to these observations, researchers at INEEL have built and are using an environmental monitoring system designed to manage information and risk in the most cost-effective fashion possible***.** This approach saves money while providing the desired information to the regulators, site owners, consultants, and scientists. Productivity gains come in from automated management of raw data, from automated and improved extraction of information from data, from putting powerful but hard-to-use numerical tools at the disposal of experienced professionals with limited knowledge of a particular numerical code. The largest productivity gain is likely to come from ready access to data and numerical tools of other disciplines and the ability to explicitly track the data filtering and analyses of others from raw data to report or publication grade figure. These features allow the users to obtain the desired information in a customized automated format and in a cost effective manner.

The INEEL Monitoring System

Monitoring systems are often built incorrectly by installing sensors in the field without sufficient effort on ensuring that the monitoring system objectives are achieved. Although the monitoring system design illustrated in Figure 2 indicates that the sensor is the beginning element in a monitoring system strategy, the design of the monitoring system actually begins with an analysis of the desired monitoring objectives. The actual monitoring system is then constructed using the objectives as the starting point and choosing the sensor last that will provide adequate monitoring data to allow for basis of action.

Environmental site owners and regulators do not want data; they want information to make a decision. As a result, a monitoring system must be more than just a series of sensors whose data is collected and stored in Excel spreadsheets, and transferred to the owners and regulators as tables and simple figures. The monitoring system must include the data but must also include analysis of the data to provide information to make a decision. To this end, a monitoring system must be strategically designed in a basic organized fashion and then tailored to meet the individual site-specific situation. The generic monitoring system design includes four main components: 1) the System Analysis, 2) Information, 3) Decisions, and 4) Actions. System Analysis contains much of the nuts and bolts of the monitoring system including the selection and placement of sensors, the interpretation of these sensors, the storage of the monitoring data and the organization and use of this data in predictive models. Information is what the client (owner, regulator, or the scientist) is most interested in. This information is most often provided as modeling results or as spatial or temporal maps of the monitoring data. The information is next used to make a decision on the monitoring data. This decision may be no action, to a revisit of the existing conceptual model on that was used to design the monitoring system. Final, the decision must lead to Actions, where the value of this decision is evaluated.

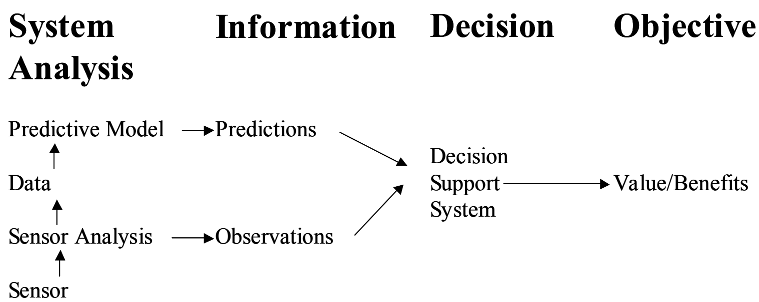

Figure 2. A conceptual illustration of an environmental monitoring system.

Monitoring systems should be designed as simple as possible but as complex as necessary. Some monitoring systems are based on monitoring for single processes such as subsurface water flux, or on multiple processes if the conceptual model has couple-processes. Water flux through a landfill cover is an example of a relatively simple monitoring system often used to evaluate the performance of the surface cover (Figure 3). In this example, a series of tensiometer could be installed in the surface cover and monitored on a daily basis. However, the electronics of a tensiometer is typically a pressure transducer that outputs a voltage reading to a data logger. This voltage value is converted to the data the desired information (i.e. the soil matric potential) through a calibration equation. From the matric potential we can both calculate the total energy gradient (i) driving the water flux and obtain an estimate of the unsaturated hydraulic conductivity ($K(\psi)$) to calculate the magnitude and direction of the water flux. The measured flux value can be compared to the performance-based value to automatically determine an action. If the measured flux is less than the performance-based flux, no action is necessary. Values greater than the performance-based standard could signal an auto generated e-mail notifying the users.

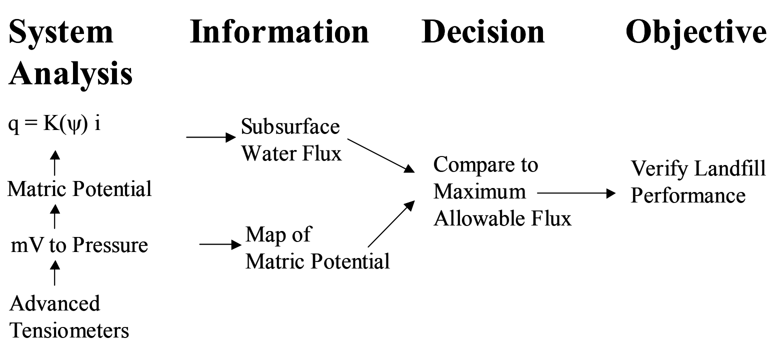

Figure 3. Example of a landfill cover performance monitoring system

Researchers at INEEL have developed a tool that incorporates all the relevant aspects of operating a long-term monitoring system (see Table 1). The tool is designed to provide information for the users rather than simply data. Information is tailored to the individual needs, moving from the "what you see is what you get" to "what you see is what you want". The data file management system uses relational databases rather than Excel files. The system allows "repeatable results" since all calibration equations, data filtering algorithms, and data analysis routines are documented. Additional analysis routines can be easily added to the system and since the system is automated, normal operational costs are low.

Monitoring – current efforts	Monitoring – future systems
Data centric	Information centric
Fixed product – wysiwyg	User controllable output
Non-existent or primitive data management (excel files)	Use of relational database for data and operations on data
No intrinsic QA/QC	Intrinsic QA/QC
Limited functionality	Extendable functionality
High yearly O&M cost due to manual efforts	Low O&M costs due to automation

Table 1. Comparison of typical existing long-term monitoring systems with those need to meet the DOE long-term monitoring objectives.

Gilt Edge Example

A prototype of the INEEL monitoring system has been installed at the Gilt Edge Superfund site located southeast of the town of Lead in the Northern Black Hills, Lawrence County, South Dakota. At this site, underground mining operations for gold, copper and tungsten had been conducted intermittently by several owners and operators since 1876. Presently, much of the site is a waste rock landfill and is currently generating acid mine drainage at an average rate of 60 gpm. A decision was made to minimize acid production from this dump by reducing the availability of oxygen to the waste rock and reducing the water flux through the rock materials, by emplacement of a geomembrane cover over 70 acres of this site coupled with a diversion system for surface water.

Early in the system design EPA and its subcontractor the Bureau of Reclamation recognized the need for information on the cover system and the underlying waste rock. Objectives of the monitoring system was to include the following:

- Information on the integrity of the cap and diversion system
- Information on the system hydrological and geochemical behavior, such that rational decisions can be made for the operation of this cover and liner system
- Easily accessible information for stakeholders (public, SDENR, EPA) on the system performance
- Information which could be used to enhance future cap designs

Working from this desired set of objectives, a monitoring system was designed that included near real time data access, standardized data analysis routines, sufficient data storage capabilities, and a set of sensors to provide the necessary data. The sensor components of this system consist of a 522 electrodes resistivity monitoring system consisting of 462 surface electrodes and 60 borehole electrodes (in 4 wells with 15 electrodes each). The surface electrodes are installed on 9 benches (under the liner) and along two diversion ditches. In addition the system contains an outflow meter at the toe of the dump, an autonomous, remotely accessible weather station and four wells (average depths of 250 feet) with thermocouples, pressure transducers, tensiometers and sampling ports for water and air in the waste rock.

The monitoring system was designed as an integrated whole, to function completely autonomously. Thus, data that is collected by the sensors is transferred to a central server, parsed into a database and processed without any user intervention. Data becomes available through a standard web browser within one hour of being collected. User access to information is password controlled, with a CMS (content management system) allowing customization of information level and format. Examples of the output for the Gilt Edge mine are illustrated in Figures 4 and 5 and can also be seen at **http://geophysics.inel.gov**.

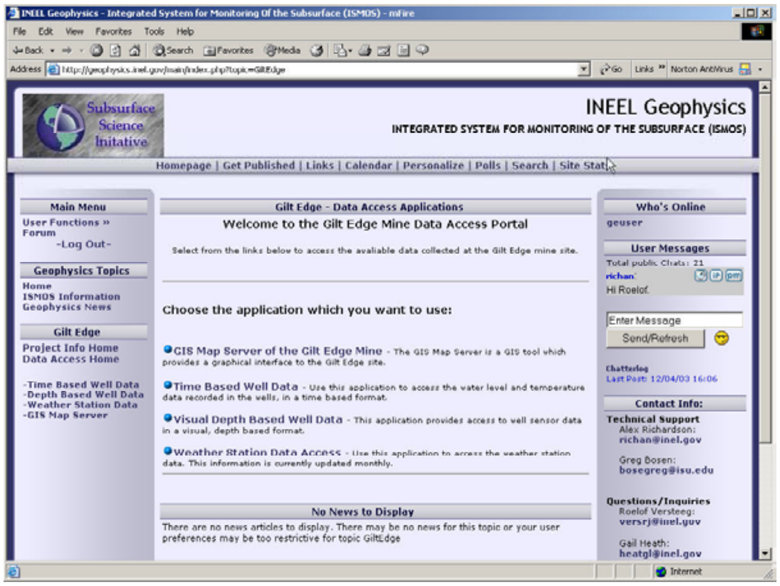

Figure 4. Home page on Gilt Edge long-term monitoring system.

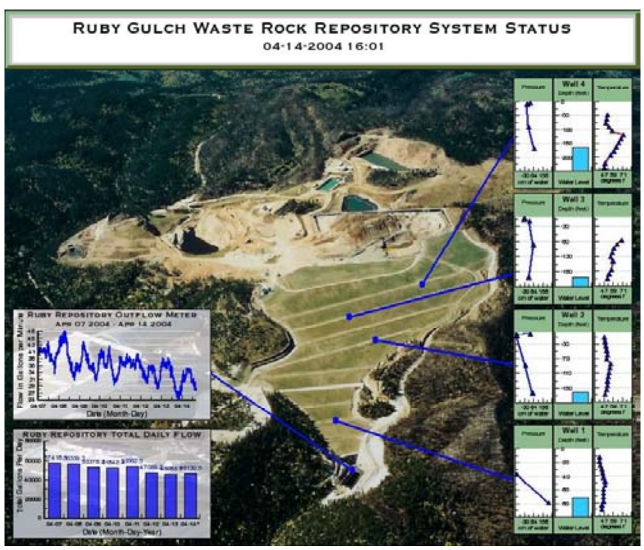

Figure 5. Example of the real time data observations at the Gilt Edge mine site.

Additional information on the hydrology can be viewed as to the viewers' preference. For the Gilt Edge example, groundwater well information can be viewed as a standard water level as a function of time hydrographs or in included with the tensiometer data as time series movies of the matric potential as a function of depth (Figure 6) to more easily evaluate water flux through the landfill.

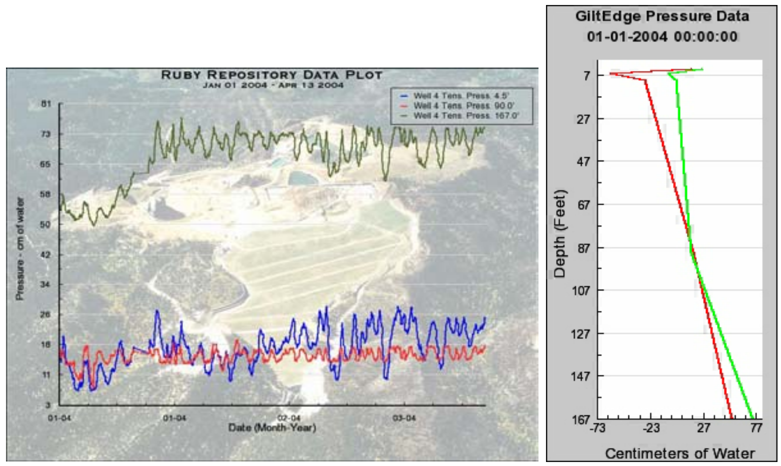

Figure 6. Examples of the Gilt Edge water levels in the wells and a vertical profile of the matric potential using a nest of tensiometers.

More complex automated inversion of monitoring data from the INEEL system is used to evaluate the effectiveness of the Gilt Edge landfill cover. Figure 7 illustrates results of electrical resistivity data that was collected along Bench 8, and the results of the inversion of resistivity data. All aspects of the data analysis including preprocessing (e.g. filtering of the data to preset standards, and elimination of data with poor reciprocity fits) and running of the actual inversion are done automatically. These results can be interpreted to identify zones of potential changes in flow pathways and changes in chemistry of the waste rock when coupled with other monitoring information.

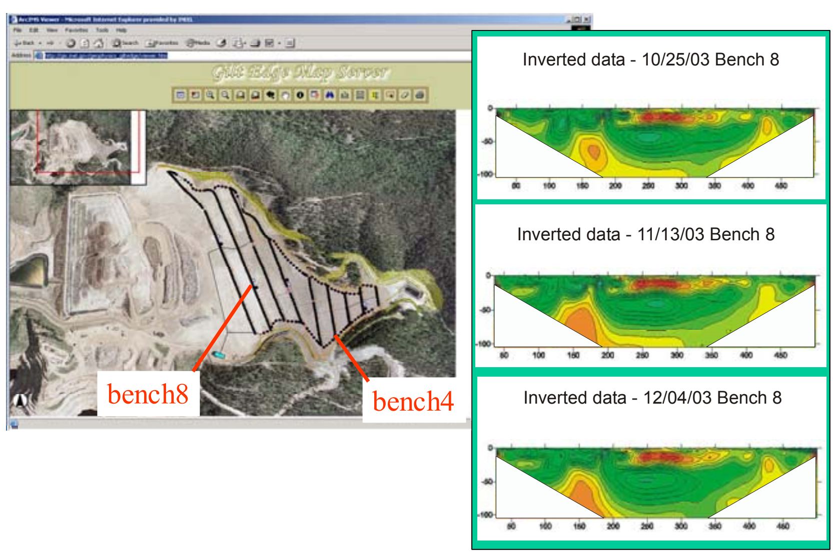

Figure 7. Example of the automated analysis of the Gilt Edge resistivity data sets.

Summary

Information on subsurface processes is required to ensure the remedial solutions to environmental problems are performing as expected. To a large extent, this information can be obtained from automated monitoring systems. However, simple data collection and processing do not comprise a complete monitoring system. There is a need to translate raw and processed data to useable information allowing the stakeholders to make informed decisions. This process must be accomplished in a cost effective and scientifically defendable manner.

The structured data management system described in this paper allows the stakeholders to meet their long term monitoring objectives. Clear monitoring objectives are the keystone of the success of the system. A fully designed holistic approach from the sensor selection, data collection, data processing and information distribution is advocated. The system must provide sufficient information to allow for reproducibility and transparency of the monitoring results. To accomplish such tasks, the monitoring system must have an efficient data and information management system. Finally, a well-structured information distribution and use system allowing the stakeholders to obtain the information that they need is critical for the ultimate success of the system.

As an example of the state of long-term monitoring, this paper illustrated a system has been installed by INEEL at the Gilt Edge superfund site. The EPA and the Bureau of Reclamation established monitoring objectives on the integrity of the landfill cover and diversion system, and desired information on the hydrological and geochemical behavior within the landfill. With these objectives, an automated system was designed and installed in 2003. Although the web based monitoring data system is still under construction, easy access the monitoring information and resistivity interpretation in near real time is currently available at http://geophysics.inel.gov allowing the EPA to evaluate the Gilt Edge cover monitoring information.

The integrated monitoring approach described in this paper allows all the users; owners, regulators, and scientists the opportunity to easily share performance monitoring information between each group. The monitoring approach minimizes the cost of obtaining this information as well as providing a consistent approach to store and maintain the monitoring data. The web-based system allows easy integration of different streams of monitoring data, and allows automated analysis of the monitoring data. The Gilt Edge monitoring system is still under construction. Future improvements to the system will include additional analysis tools and automated e-mail alarms of deviation from performance criteria.