THE USE OF MODERN DATA MANAGEMENT SYSTEMS IN THE CEMEX UK AGGREGATE BUSINESS

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Abstract

The aggregates industry faces increasing requirements and costs to monitor activities and manage its environmental impact, similar with many other industries in the UK. Controls on limiting impact are often incorporated into environmental permits through the establishment of regulated limits. Monitoring is therefore necessary for both managing the regulated activities and demonstrating legal compliance with permits and conditions.

Activities requiring control may include water abstraction and discharge, and in sensitive situations limits may be applied to groundwater and surface water elevations[1] to protect ecological and archaeological sites. In addition to compliance monitoring, it can become advantageous for operators to collect information, through supporting research, for planning and permit applications. The rate of data generation today and the increasing importance of managing data in real time are driving companies to invest in efficient integrated data management systems. Without efficient systems the burden of monitoring and reporting large data volumes can be unnecessarily costly.

CEMEX has embraced the need for efficient monitoring over the past 15 years through the acquisition and implementation of a sophisticated data management system known as EQuIS™ which is produced by Earthsoft Inc. It is an integrated suite of applications utilising a common database and associated modules. Modules implemented by CEMEX enable all monitoring to be planned and scheduled into the future and for technicians to capture field monitoring information on tablet devices in the field and report electronically direct to the database. In addition, loggers monitoring flow and groundwater/leachate elevation return data using telemetry. The data collected are synchronised with the EQuIS™ database enabling virtually real time management and control.

This paper outlines the systems established by CEMEX as a case study and describes some of the benefits.

Wilson, K.S. 2015. The use of modern data management systems in the CEMEX UK aggregate business.
Pp. 76-85 in Hunger, E. and Brown, T. J. (Eds.)
Proceedings of the 18th Extractive Industry Geology Conference 2014 and technical meeting 2015,
EIG Conferences Ltd, 250pp.
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Introduction

Major industry in the UK is required by regulators to monitor its impact on the environment, for example to measure its use of resources such as water, by way of conditions in environmental permits. The Environment Agency (EA) is facing reductions in government funding and moving towards operator self-regulation. The aggregates industry has operations that can impact on the environment and it too faces pressure for self-regulation. This necessarily requires attention to environmental monitoring and the retention of evidence to demonstrate compliance.

In some organisations, monitoring of its activities and reporting on permit compliance are carried out at a site level. This leads to individual systems being adopted by different site managers with consequential inconsistencies and increased costs throughout the organisation. In addition to the poor coordination, organisations lose an understanding of cost and performance. Moreover, data can be stored in a variety of formats and types from paper-based records residing in filing cabinets or remote archive facilities, to spreadsheets and local databases. Such disparate systems have resulted in an inability to monitor change and to compare information between sites within an organisation. Ultimately this has meant that data collected have not been available to be used as a management tool. In effect the cost of the data collection exercise has been wasted. The implementation of a robust data management system has the dual advantages of maximising efficiency, thereby minimising costs, and converting what would otherwise be a straight operational cost into an investment in an information asset that can be used as a management tool.

In the early to mid-1990s CEMEX UK Operations Ltd. (CEMEX) tested two database products. The first was good at handling chemistry data but poor in other

[1] The term 'elevation' is used here to mean the level of groundwater above Ordnance Datum (sea level).

respects. It was effective for the period it was used but the increasing range of expectations meant it was out grown quite quickly. A second product was tested and support provided to the developers to enhance its capabilities. However, development was slow and the final product when it did arrive was disappointing. As a result CEMEX then acquired the EQuIS™ software from EarthSoft in 1999 because of its greatly enhanced level of sophistication and future proofing. It offered the potential to manage extensive monitoring work as efficiently as possible at that time but has since grown in capability. The process of working with the two previous products and the developers provided knowledge and experience that was invaluable in ultimately selecting the EQuIS™ product. Key considerations for selection were the database structure, the user interface and the minimisation of user interaction with the data. An example of a feature of great importance was units. Earlier products at that time required the use of consistent units, e.g. chemical results had to be entered in mg/l. This meant that results arriving in µg/l had to be converted to mg/l before entry. Such calculations before data entry would have been a weakness where those entering data could make an error that would be impossible to identify and trace. EQuIS™ had the ability to accept data in any units and provided the ability to convert to consistent units on reporting. Small features such as this play an important role in giving confidence to the data.

Through EQuIS™ CEMEX created a centralised database, robustly controlled reference values and an Excel field data workbook tool completed by its field technicians at each monitoring event. CEMEX provided a workflow for submitting the workbooks to the centralised database. Subsequently, CEMEX implemented new EQuIS™ modules for planning samples and activities, field data collection, logger data and the automatic generation of reports and schedules, for a more fully integrated data management system.

This paper is a case study describing the data management system in use by CEMEX in the UK to manage the majority of its environmental monitoring. The focus is on the work done for the aggregate business but the system is also used to support the ready mixed concrete business as well as its legacy landfill portfolio.

What Are Monitoring Data?

Monitoring data consist of the results of measurements and analyses used to characterise the condition of the environment but may also include measurements for process control and compliance. The data come from a range of sources including field measurements, laboratory analyses, data loggers and PLC (Programmable Logic Controller) devices. All provide information on different aspects of operations and their impact.

Monitoring involves the taking of samples and undertaking analyses and measurements on a range of matrices, including groundwater, surface water, process water, abstractions and discharges, and obtaining many results. Results alone though are only a small part of the monitoring data collection required to understand and interpret the information. In addition to a result, information is required on context, quality and instrumentation.

Monitoring data are relied upon for regulatory purposes and in business decision making. It is crucial that these data are reliable and of the highest quality possible. Not only is it necessary to store a good quality result but also to store what are referred to as metadata. Metadata are information about the data. As an example we can consider the situation where an analytical result has been recorded as 10.2. A value of 10.2 alone is of little value unless associated information is also known including when, where and by whom the sample was taken, how the sample was collected, what type of sample it was, its matrix, colour and odour, the analyte, the units of the result, what test method was used to obtain the result, which laboratory undertook the test and what the detection, quantitation and reporting limits were. All of this information is metadata relating to that single result and all of it is required if a meaningful interpretation of the result is to be carried out, not just at the time the result was originally received but also in the future, when it could be required for a purpose that was unplanned or unexpected at the time of monitoring. This same principle is applied to all types of monitoring information. Data quality and metadata are further described in Stagg et al., 1999.

The extent of the metadata required means that it can be challenging to collect, manage and store and this challenge has been a component leading to the development of systems like the one described in this paper.

The Data Warehouse Concept

A data warehouse is more traditionally thought of as a large building with extensive racking systems housing archive boxes of paper records. Indeed this is an all too frequent reality for some large organisations. While this may be a necessity for some paper-based documents such as reports, correspondence etc. where no electronic document management systems are in place, the storage of monitoring data in paper-based archive systems creates significant difficulties in the longer term unless they are converted in to digital format. The value of a paper archive is only as good as the quality of its index and the consequence of a poor index is that it can be very difficult to determine what the archive holds. In an age of 'instant results', a paper archive can also be more time consuming to access and is therefore less likely to be used. At best this should be a temporary situation until resources are made available to extract the information and convert it into an electronic format. Data stored in paper form are not only generally unavailable for day to day use, but also vulnerable to damage and loss (Weaver and Gray, 2003).

An electronic data warehouse is generally formed from a relational database, with many data tables enabling complex information to be stored in a well-structured and organised way. The aim is to store each piece of information only once, and to link it to other data using key fields in each data table. In its most basic form, data storage is its only function. Information is extracted using database queries to produce reports in a form required for each specific purpose. CEMEX uses the desktop EQuIS Professional and its online counterpart EQuIS Enterprise as a way to interrogate the database and produce reports customised for internal and regulatory needs.

An important part of the data warehouse functionality is the protection of data through control of user permissions and system back-up. The strength of the data warehouse is its ability to not just store the information but to bring together information from different sources, in different formats and from different applications into a single repository with a common structure. Having data in a centralised facility hosted on a central server makes the data available to multiple users for assessment, analysis and interpretation. Each user may use the information for different purposes, at different times and on different projects. An additional concern is the security of the database itself. It is imperative that any online system has adequate security.

Wherever people have a role in data management and/or manipulation there arises the potential for the introduction of errors. Minimisation of people's access to data where there is the ability to change it becomes a vital design consideration in the establishment of a data flow system. The means by which data are collected and submitted to a database can be just as important as controlling the quality of the measurements and results themselves.

The EQuIS™ database has been found to be a comprehensive and versatile data warehouse incorporating the ability to manage all of the data and metadata required of it by CEMEX to date. More recently implemented modules provide the additional management and interrogation tools required. The data requirements and additional modules used are described further below.

CEMEX MONITORING REQUIREMENTS

This paper focuses on the monitoring required within the CEMEX aggregate business in the UK. The monitoring is required to provide information for the following purposes:

- Greenfield sites with potential for development: Information is collected to support environmental impact assessments, planning and environmental permit applications and hydrogeological risk assessments.
- Surveillance monitoring: Surveys to assess any impacts of operations on for example hydrogeology, ecology and archaeology.
- Compliance monitoring: Monitoring undertaken to confirm and demonstrate compliance with regulatory permit conditions and other agreements.

The range of different types of quarry and plant means that a variety of monitoring is required. In broadest terms the operations are quarrying and material processing, but the need for permits for restoration of quarries means that waste related monitoring is also required. In the context of aggregate operations in CEMEX the parameters monitored include those shown in Table 1. Measurements can include gas flow and temperature, weather conditions etc.

The combination of the number of operational units, the range of parameters required and the associated metadata mean that large amounts of information have to be collected. While the majority of monitoring is still required to be undertaken by field technicians, a growing amount of surveillance is being achieved using remote logging devices with telemetry. These provide near real-time high frequency data for process control and compliance purposes. The EA in England has agreed that 15-minute frequency measurements can be a substitute for instantaneous flow measurements and so most loggers associated with environmental permits collect data at 15-minute intervals. These devices in turn generate large volumes of data.

Table 2 shows the approximate number of data records collected annually by CEMEX and imported to the EQuIS™ database. It can be seen that large volumes of data can be associated with environmental and process control monitoring. Modern data management tools are essential if data collection on a significant scale is to be controlled.

Matrix	Chemistry	Elevation/ Head	Flow	Volume/ Weight	Measurements
Groundwater	✓	✓			
Surface Water	✓	✓	✓		
Water Abstraction	✓	✓	✓		
Water Discharge	✓		✓		
Weather					✓
Solid Waste	✓			✓	
Sub-surface gas	✓		✓		✓

Table 1. *The range of monitoring undertaken by the CEMEX Aggregate business in the UK.*

Data Type/Activity	Number of Records
Sites monitored e.g. quarry, landfill, concrete plant (actively monitored)	>220
Monitoring locations used e.g. a borehole (actively monitored)	4,500
Samples collected and analysed (e.g. of water, leachate, gas, waste, etc.)	12,000
Water level measurements – manual	24,000
Monitoring location condition observations e.g. accessible, locked, labelled	250,000
Analytical results from all samples	225,000
Sub-surface gas concentration measurements	250,000
Logged data (flow, water level, meteorological)	50,000,000

Table 2. *Approximate number of data records collected annually by CEMEX in the UK.*

The CEMEX Data Management System

Collecting representative field samples and measurements and receiving good analytical results is not enough. If mistakes are to be avoided it is essential that the data collection system integrates all aspects of the work. In CEMEX a comprehensive suite of EarthSoft modules has been adopted and implemented. This involves:

- The EQuIS™ Database as a data warehouse.
- EQuIS Professional for technical and data quality management plus general reporting in a desktop environment.
- Sample Planning Module (SPM) to enable planning and then scheduling of all monitoring required.
- EQuIS Data Gathering Engine (EDGE) for combined instruction of the field technician and recording scheduled monitoring events. It is used on tablet devices in the field by monitoring contractors.
- EQuIS Enterprise for automated electronic processing of data deliverables from field contractors, laboratory and PLC devices; automated reporting of submissions, errors and compliance exceedances; web-based data presentation through customised dashboards and widgets.
- EQuIS Live for synchronisation of EQuIS™ with third party databases managing logged data.

These components are described further below.

SPM: Sample planning and scheduling

SPM enables all future monitoring requirements to be set up and planned for any future period. The locations to be visited, the sampling, measurement requirements and observations are established along with the frequency of the tasks. Analytical suites are also set up against each planned task. During the month preceding the monitoring month, all monitoring at all sites for the forthcoming month is scheduled using a single utility. The scheduling action creates unique tasks, allocates dates in accordance with the rules established in the plan and creates sample codes, analyses and activities. Once scheduled, a single report is produced for each of the following:

- Pre-registration file of all analytical requirements during the following months. This enables the laboratory contractor to register the work on the Laboratory Information Management System (LIMS) and to prepare and despatch all bottles required to pre-arranged addresses.
- A schedule of work required by the field contractor with scheduled dates enabling the contractor to allocate appropriate resources and set up visits in their calendar.
- A set of Field Electronic Data Deliverables (Field EDDs). Each file contains the specification of all observations, measurements and sampling required for a site visit. This file is opened in the EarthSoft EDGE software on a tablet device in the field and provides a combined schedule of work and form to complete thereby recording the details of the activities undertaken, such as monitoring location condition reports, date and time of measurements/samples, field observations, field results etc.

The creation of the scheduled tasks and associated samples and activities within the database provides detailed information on what is required, reported as above, and then what is expected to be returned from each of the respective contractors. A comparison of what is scheduled against results that are returned enables an assessment of the completeness of each task to be made.

Field work

The use of Field EDDs on a tablet in the field ensures that the field technicians have a full picture of what is required and can check that everything is complete. All sample bottles are provided to the technician by the laboratory and are supplied with site name, location code and sample code already pre-printed on each bottle. It remains then for the technician to check that the correct bottle is filled with the correct sample from the correct location. The field measurements and sample detail are entered into the Field EDD to complete the record of the work undertaken.

The provision of a visual completeness checker in the field through EDGE enables the technicians to see that all required work has been completed. A SIM card is fitted to each tablet device and the completed Field EDDs are sent by email, or uploaded to a File Transfer Protocol (FTP) facility before leaving the site.

In addition to the submission of the data file back to CEMEX, the technician is able to automatically generate an electronic chain of custody form using the information collected during the field visit. These are printed on a mobile wireless printer and accompany the samples to the laboratory. Samples are identified by sample codes generated by the SPM at the time of scheduling and provided to the laboratory to print on the bottle labels. The codes are present in the EDGE files and are entered on the chain of custody form along with information relating to the date and time of sampling. Chain of custody forms are also sent by email to the laboratory reception so that they know what samples have been despatched. The sample codes then tie up with the pre-registered codes in the laboratory LIMS so the analysts know exactly what has to be completed for each sample. All results are then reported against those sample codes. The whole process ensures that samples have a unique code from the time they are created to the time the results are reported, thereby minimising the opportunity for error.

Data submission and processing

As described above, EDGE Field EDD data files are submitted from the field by the technicians as soon as their work on site is finished, often before the samples have been collected by couriers for transportation to the laboratory. The laboratory sends an EDD when the samples have been received at their sample reception and further EDDs once the analytical work is complete. These EDDs include receipt, test and result information and documents containing the signed laboratory certificates.

All EDD files are sent either as attachments to emails to the CEMEX EQuIS™ database, or posted to an FTP site. The EQuIS™ Enterprise software operates an automated Electronic Data Processor (EDP) that retrieves email attachments or files from the FTP site. The information provided in the EDDs is checked and validated. Data meeting CEMEX validation criteria are imported to the database automatically. Where data files contain data errors or otherwise fail to meet the required criteria, an email containing the submitted file and an error report is sent back to the data provider requesting correction and re-submittal. These emails are also copied to CEMEX data coordinators. Each month between 500 and 600 data files are received and processed automatically of which between about 3% and 8% get rejected as a result of errors. These are resolved by the data submitters and/or CEMEX staff.

The use of EQuIS™ EDP not only hastens the transmission and processing of data to the database but also enables CEMEX staff to focus on the data management process and data quality issues rather than basic administration. This has resulted in fewer staff being required to manage the process. Automated systems have enabled a large increase in monitoring to be accommodated using existing employees.

Logged data management

Recent advances in the technology of telemetered data systems have enabled more devices to be connected to central database systems, with data returned at near real time frequency with greater ease and efficiency. CEMEX has adopted a standard for permitted discharges and licenced abstractions in its quarries utilising MagFlow flow meters and telemetry to monitor compliance with its permit flow rate and volume conditions.

In addition to flow meters, CEMEX operates a number of level sensors and meteorological stations around the UK and data from these devices are also logged and telemetered. In total, CEMEX currently operates about 150 loggers with telemetry around the UK, a number with multiple devices attached. Large volumes of data are generated (as before, logged flow meter data are recorded at 15-minute intervals as a substitute for instantaneous flow rates) and these are returned to a central database at regular intervals. The frequency and transmission periods are customisable to meet local conditions, as site specific conditions and requirements can vary. The central database in use at the time of writing for the majority of loggers is Flowview, a proprietary system operated by RS Hydro Ltd. and incorporating the use of the addVANTAGE Pro database system from Adcon Telemetry GmbH. All logger set-up, management and communication is carried out through this interface. Other logger systems in use include one from OTT Hydromet GmbH.

CEMEX has adopted the EQuIS Live module as a method for integrating logged data into EQuIS™. EQuIS Live contains data agents that communicate with third party software to retrieve logged data at customisable intervals. Synchronisation ensures that CEMEX has all the required information to hand to meet reporting and compliance obligations in its EQuIS™ data management environment. The primary benefit to CEMEX of storing its logged data in EQuIS™ is the integration of all data from all sources into a common environment, so that consistent reporting and analytical tools can be used across all data types and from all devices. This enables such features as direct charting of manual and logged results for the same parameter and a comparison of one data type against another for the same location, all in the standard EQuIS™ environment.

A powerful tool within EQuIS Live that is of value to CEMEX is the Derived Data Agent. This creates what are called Derived Data Series (DDS). These are new data series created through the application of a formula to a raw logged dataset, or indeed any other DDS. These automatically continue to update as new raw data arrive so that all DDS are kept up to date.

CEMEX uses these DDS for the calculation and reporting of flow totals, addition of flow meter totals for comparison against permit conditions where multiple meters are used on a single discharge, the derivation of elevations to Ordnance Datum and totalised rainfall at required frequencies.

The volume of data collected makes assessment without the use of electronic tools challenging where limitless resources are not available. EQuIS Enterprise as a web interface to the database also enables the presentation of data graphically as described below.

Process flow for field monitoring

The use of all of the database modules is integrated into the process of monitoring management, enabling the work to be undertaken in a cost-effective and efficient way. The CEMEX field monitoring process starts with the following, during the month prior to the work being undertaken:

- CEMEX runs a single report in SPM to schedule all planned work for the next monitoring period.
- CEMEX runs the laboratory pre-registration report for all analysis required in the next monitoring period and sends to the laboratory.
- Laboratory send required containers to the field contractor/technicians.
- CEMEX runs a field monitoring summary report for the monitoring period and sends to the field contractor.
- The field contractor schedules and assigns the required work to individual technicians.
- CEMEX runs EDGE reports from the database to generate a single zip file, containing EDGE files for each site to be visited during the monitoring period and sends to the field contractor for distribution to individual technicians.

When the time comes for the work to be done, the following takes place:

- Field technicians visit the site on the required date and open the EDGE file on their tablet device. They follow instructions in the EDGE file on monitoring required and record details of the event as necessary.
- On completion of monitoring at the site EDGE is used to generate and print a Chain of Custody form to accompany the samples to the laboratory.

- Samples are collected by a courier for delivery to the laboratory.
- The technician electronically signs their EDGE file and sends by email or FTP to CEMEX.
- The CEMEX EQuIS Enterprise EDP extracts the data from the email and/or FTP and automatically processes the information, applying a series of checks and validations before importing to the database.
- Once the samples arrive at the laboratory, they are processed and an electronic receipt sent to CEMEX for automated entry to the database.

At this stage, the field element of the work is complete. Once all the analyses are complete, the laboratory sends the information by email to the CEMEX EQuIS Enterprise EDP for validation and importation to the database.

Field data collected by loggers are collected directly by EQuIS Live without the need for field technician involvement.

This monitoring process is summarised in the schematic diagram shown in Figure 1. At the time of writing the CEMEX field contractor is Enitial and the CEMEX contract laboratory is ALS. The Enitial and ALS logos are shown in Figure 1 to represent the respective function.

When field or laboratory data are delivered to and processed by EQuIS EDP, EQuIS Enterprise runs automated reports to notify data specialists that the information has arrived, and where necessary of any non-compliant results. In this way any actions required are initiated as soon as the data arrives in the database. Reporting is described further below.

Data Reporting And Visualisation

The pressure to monitor the environment in the vicinity of operations to demonstrate compliance is resulting in large amounts of data being generated. With this comes the need to not only manage the data but also to check data quality and generate reports and assessments. The reporting and visualisation functionality are integral parts of the data management system as it is these that enable the data to be used. Conversely, without good reporting tools it is likely that effects would be missed. CEMEX uses the reporting and visualisation functionality as described below.

Reporting of non-compliances

Once data have been validated and accepted into the database through EQuIS Enterprise EDP, automated CEMEX reports run to check for compliance with permit conditions. Any exceedances of warning level or action level values generate an automated email report to designated recipients alerting them to the exceedance. The recipients are data coordinators and technical specialists who can assess the exceedance and where required initiate follow-up investigations and complete formal notifications to the regulator.

Permits often require notification of non-compliances to the regulator within 24 hours. Submission of data as soon as the field visit is complete enables the assessment of any non-compliant field results immediately. Similarly the assessment of laboratory results against assessment criteria synchronously with the data arriving in the database means that appropriate regulatory reporting can be undertaken within the prescribed period.

Regulatory reporting

Various conditions in permits frequently require regular reports of the latest monitoring results to the respective regulator. EQuIS Professional provides a database interface for users where reports can be created and run to provide the necessary data for submittal in compliance with reporting conditions. Reports are created as tables, cross tabs and graphs as required.

EQuIS™ enables the creation of custom reports and CEMEX has created a number of reports that meet its reporting obligations. These can be run from templates and so regular reporting is both quick and efficient. An example is shown in Figure 2.

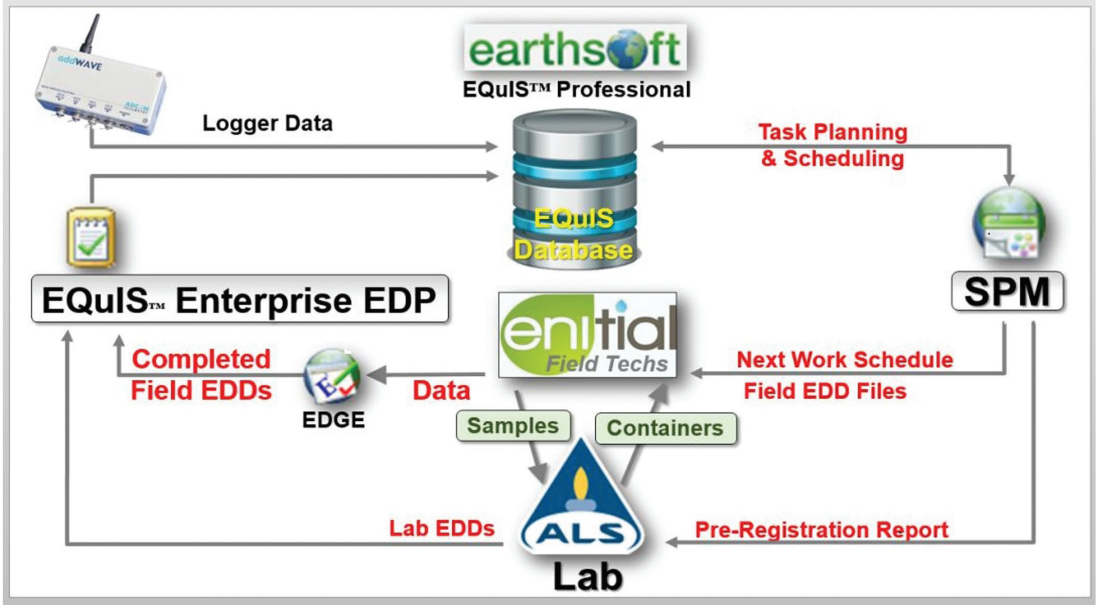

Figure 1. *Schematic of the data flow process for field monitoring and submission to the database.*

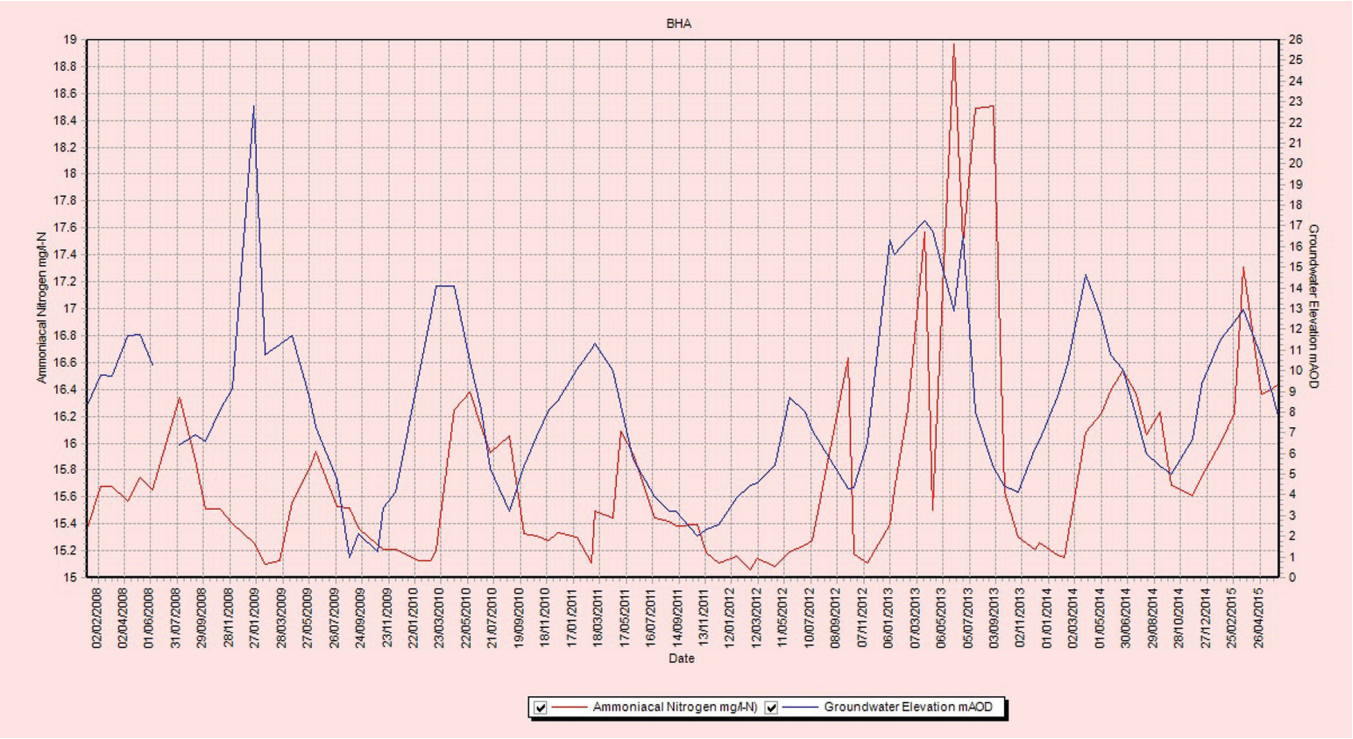

Figure 2. *Illustration of a customised report charting ammoniacal nitrogen from laboratory analysis and manually measured groundwater elevation.*

EQuIS Enterprise

In addition to the workflow automation described above, EQuIS Enterprise is a web-based interface to the database. Although there are administrative tools for system managers, the primary benefit of Enterprise is the ability to view data in a series of user defined web pages, or dashboards.

Each dashboard is customised to display tabular data or charts/graphical representations, plus interactive maps. Charts can display a mixture of data types, obtained in different ways (see Figure 3) and from different sites. Various chart types are available including time series line charts, histograms and traffic light displays. The data displayed on dashboards are always up to date, making it easy for users to visually assess the latest information as soon as they sign in.

At CEMEX, site related monitoring data are now being made available to site and area managers in addition to the technical specialists through this interface. With logger data displayed on dashboards, managers have a near real-time interaction with the activities for which they are responsible, for example flow meters on discharges. This gives them an insight that they have not previously had and from their desk in the office. Alarms set to alert on exceeding a permit limit help to maintain compliance but alarms on no flow can aid in quickly warning of breakdowns at remote locations.

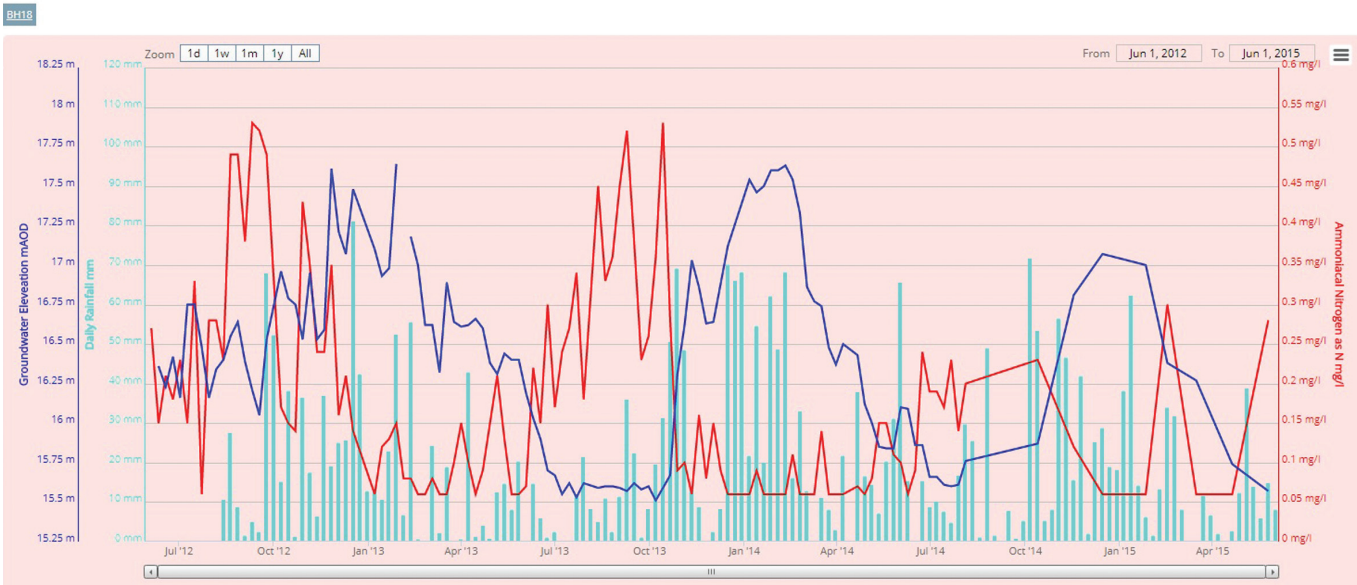

Figure 3. *EQuIS Enterprise widget illustrating the ability to chart data from different sources. Here, ammoniacal nitrogen results from laboratory analysis, manually recorded water level data and logged rainfall data are shown together.*

Benefits And Costs To CEMEX Of Modern Data Management Tools

While the use of modules such as SPM, EDGE and EQuIS Live has brought more recent improvements to data management, arguably the most valuable overall benefit to CEMEX was the immediate one that followed implementation of EQuIS™: that being the automation of data flow from the field and from the laboratory. This now routine process created immediate and long lasting benefits in time saving on what is effectively administration and great improvement to metadata collection and data quality. The comprehensive data validation incorporated into EQuIS™ from the start effectively eliminated sample identification errors while additionally providing the majority of metadata required for the function. The early use of EQuIS™ established the data validation and associated quality benefits, and these have become increasingly valuable as the requirement to monitor has grown many times while the human resources available have remained unchanged. More recent modules have further improved efficiency and reliability whilst providing controls on completeness.

The use of modern data management tools such as EQuIS™ and its associated modules has enabled what are often individually complex monitoring requirements at each site to be consolidated into a single management application. In doing this and in establishing the required frequency controls, the complexity is managed by the software and the opportunity for omission and error has been greatly diminished. Consolidation using SPM has also resulted in savings in time in the management of container and analysis ordering at the laboratory and in the instruction of field contractors.

An additional benefit from the use of SPM has been the ability to manage completeness. All the required monitoring work is scheduled in SPM and then the software compares what was scheduled with what arrived. In so doing, completeness reports enable the identification of any information that is missing or of the wrong kind. While software is not the only way to achieve this, any manual method would require substantially greater human resources. CEMEX manages all the monitoring described above using EQuIS™ with two dedicated full time employees. The consequence is substantial savings in the cost of human resources required to manage the function.

As described above, site specific monitoring requirements can be complicated. The use of the EDGE software by the CEMEX field technician contractors has led to more efficient and informative direct instruction in the field, to an improved quality of work in the field and has increased the range of field information provided. An example of increased range is the undertaking of a concise monitoring point condition inspection on each visit, tied in to automated reporting of condition failures as soon as the data are returned to the database. In this way CEMEX is alerted to problems immediately and can take action to rectify faults as soon as possible. This enables CEMEX to maintain its monitoring points efficiently and keep them fit for purpose.

The large amounts of information being collected means that it can be time consuming to check all new results and measurements against permit compliance limits. EQuIS Enterprise runs automated reports for CEMEX when new data are received by the database and automatically alerts technical specialists to non-compliant results. The rapid notification of non-compliances enables CEMEX to notify the EA and other regulators within the prevailing reporting deadlines. Large data volumes also make it challenging to assimilate the data and to rapidly assess changes and implications. EQuIS Enterprise provides the ability to create charts from data derived from any source, to be displayed on a web-based dashboard that is always current when opened. Such visualisation tools provide a means to rapidly assess large volumes of data without having to run reports. This tool is increasingly providing CEMEX with significant time savings and added value, and to a wider range of people within the business than previously possible.

Over the last five years CEMEX has been increasing the numbers of logging devices fitted with telemetry. Large volumes of data are collected from these sources. The ability to store all logger data in EQuIS™ has meant that information from all sources such as laboratory, field measurement and logging devices is now visualised and reported on in a single application, greatly reducing time spent on compilation and integration in intermediary software such as Excel. The benefits are minimisation of data compilation errors and time saving for technical specialists whose time is valuable. Additionally once in the database the information is immediately available for any future use as sites develop and evolve.

The use of a sophisticated data management software provides the opportunity to collect and manage large volumes of data using a small number of people. This has significant benefits in terms of cost saving. It is difficult to quantify the savings to CEMEX because larger numbers of staff were not employed prior to the acquisition of the database. Looking at other companies with large environmental monitoring commitments but without the benefit of a similar data management system it would appear that they employ perhaps 3 to 5 times the number that CEMEX do for the equivalent work. The annual maintenance costs of the software amount to less than the cost of one employee and so the software is considered to represent significant cost savings. Another way to assess the cost of a database is to consider the data as an asset with a value. It is estimated that the annual maintenance cost of the database is less than 0.25% of the value of the data within it based on the cost of collection at today's prices. As it is never possible to go back and get the data the information is irreplaceable and so acquires an additional value that is not quantifiable.

Less tangible benefits arise from the accessibility of the data and ease of manipulation for reporting. This represents time savings for company specialists analysing the data or for consultants employed to use or report it. A significant proportion of consultant time can be spent on compiling and presenting data in tables or charts, almost all of which is unnecessary when using EQuIS™ because reports are set up to produce the output required. It is difficult to quantify the saving to CEMEX but it is estimated that between 25% and 30% of project time can be saved in compiling and manipulating data. Whether reports are produced internally or through external consultants, significant time and cost savings result where large numbers of reports are produced. Hidden cost benefits can be associated with being able to

use or manipulate data for purposes that were not the original intention of the monitoring. Examples can include assessing complaints from neighbours, or in defence of a claim from a regulator. Where the data are available, and in an easy to access form considerable additional effort/cost would be required to address such issues.

CEMEX converted all its historical monitoring data to electronic format soon after implementing the database. At this time the archive was relatively small but the exercise still involved more than one man year of effort. Where historical data have not previously been put in a database and there is a large set of records, the digitisation process can be an expensive one. However, in addition to the benefits described above the presence of the information in a database can produce savings such as the elimination of work duplication. The Ohio Department of Transport estimated that more than 1.2 million paper-based files were stored in warehouses; examples of the data types are provided in Beach (2007). It calculated that by transferring its historical data to a GIS-based database, it could reduce duplication of past field-based projects by 10% to 20%, leading to annual savings of between 12 and 24 million US dollars. EQuIS™ was selected as the data warehouse to help realise these savings (GIM International, 2009).

One advantage of EQuIS™ is that it is not an 'out of the box' piece of software; that is it is customisable to meet a particular user's data needs. As a result specific or possibly unusual data types can be accommodated, however it does bring with it the need for IT professionals to set it up and maintain it. Also, environmental professionals without a database background may have a steep learning curve to become familiar with the concepts and operation. Such customisable software enables the applications to be quite varied. In Kaeli (2014) the software is being used to support an extensive environmental epidemiological study in Costa Rica. Stantec Inc (Canadian company consulting in the design and engineering sectors) use the system in monitoring the Marcellus shale in North America (Bolakas et al, 2014) and Barrick Gold use the system to record automated air monitoring data in the Dominican Republic (Digweed, 2011). This clear versatility has been very useful for CEMEX, enabling the software to accommodate all the data types so far required.

In common with all good databases there is a need to maintain tables holding reference values of various kinds, and to ensure that all references remain valid. Referential integrity is a vital part of the strength of a database. Without this robust control of the system even a comprehensive data management package can be undermined and the value of its information reduced. There can also be errors and unexpected problems in operating the database that require specialist assessment. As a result there is a need for a higher level management role, albeit with a lower time input, to undertake such duties. This role requires a scientific professional who understands the technical aspects of each of the environmental monitoring tasks employed, as well as a deep understanding of the database philosophy, structure and operation. Companies without such skills internally do need to employ an appropriately experienced consultancy for this support. CEMEX have such skills in house but still choose to employ Earthsoft and an external consultancy to provide support for occasional custom utilities and more complex reports.

The robustness of database systems requires a degree of rigidity in how data are loaded to the system. This can offer a level of complexity that users new to databases can find challenging. Many regulators around the world, particularly in the United States of America are requiring data submittal to them from permit holders and laboratories in a fixed format using their Electronic Data Deliverables (EDDs). An example is the New Jersey Department of Environmental Protection's (NJDEP) Private Well Testing Act Program where the reporting requirements are given in an associated manual (New Jersey Department of Environmental Protection, 2008). This provides an example of the kind of documentary support required for data transmittal formats. The United States Environmental Protection Agency (USEPA) use a similar approach, stipulating the required EDD format (USEPA, 2015). CEMEX was the first company to use EQuIS™ in Europe and so created its own format for a range of EDDs. Although these required a lot of thought and associated work initially, once they were set up and implemented little further work was required. Potential new users of database systems utilising EDDs can find the prospect daunting but there are many EDDs now established that can be adopted.

The database and associated modules do not have everything required by all users and inevitably the system continues to evolve. One of the areas identified by CEMEX requiring enhancement was the storage of associated documents within the database. For example an Environmental Permit is a legal document required for management of a particular activity. Having a pdf version of it stored in the database provides better long term completeness, thereby keeping all information together in one place. CEMEX worked with Earthsoft to increase the document management capabilities of the software and this continues to evolve. The background to this and the development are further described in Wilson (2015).

Conclusions

A centralised approach to environmental monitoring has been adopted by CEMEX utilising the EarthSoft EQuIS™ suite of data management software. This has brought about significant benefits. These management systems incorporate the use of the EQuIS™ database and associated modules for planning and scheduling monitoring as well as manual field data collection and telemetered logged data. The scale of monitoring required by CEMEX has meant that data management has become an essential tool in dealing efficiently with the monitoring required of a modern business with its variety of complex data and using available human resources.

Benefits to CEMEX arising from the data management system include:

- Minimisation of errors through automated schedule management and controlled data flow.
- Efficient collection and storage of essential metadata.
- Minimisation of the cost of the overall monitoring function.

- Cost savings from data automation to field and laboratory contractors, resulting in reduced contract costs.
- Integration of monitoring point condition management.
- Technical reporting is achieved using standardised reports as well as saved customised settings.
- Always current web pages provide data presentation tools; delivering a time saving in data visualisation and assessment.

Future planned enhancements to the EQuIS™ suite of software are expected to further extend the functionality and provide greater efficiency to the CEMEX monitoring function.

Acknowledgements

The author would like to thank CEMEX UK Operations Ltd. for permission to publish this paper, and Joanna Tidmarsh, Mitch Beard, Russell Atkins and the EIG editors and reviewer for their helpful reviews that improved the manuscript. The opinions expressed are those of the author alone and do not necessarily represent the views of CEMEX.

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