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Data Management and 3-Dimensional Conceptual Site Models as a Best Management Practice for Optimizing Site Management

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ABSTRACT: Incomplete conceptual site model(s) [CSM(s)] are often a result of a combination of inadequate data density, poor data management, and/or a failure to visualize and evaluate complex 3-dimensional (3D) data sets. Decisions based on these incomplete CSMs often lead to repeated site characterization events, failed remedy implementtations, and poor communication of site conditions to stakeholders. Developing an accurate CSM that leverages data stored in a relational database integrated into 3D visualization and volumetric analysis is a best management practice (BMP) that provides the ability to evaluate complex data sets. A comprehensive environmental data management system (EDMS) and visual CSM was completed for an industrial site in São Paulo, Brazil, and is presented as a case study for optimizing remedy implementation and long-term monitoring strategies. Creation of the two dimensional/3D (2D/3D) CSM ultimately assisted in the identification of an additional source area, defined residual contaminated mass, refined the groundwater plume architecture, provided intimate visual depiction of contaminant distribution over time, identified and closed data gaps, and provided for targeted site investigation and remediation strategies. The 2D/3D CSM also provides a valuable mechanism to evaluate offsite property management issues, identify cost saving opportunities and better tactical risk management strategies and provides a visual data set that can be routinely updated during a site's lifecycle.

INTRODUCTION

Traditional data processing and management techniques fail to provide the data integrity, security, quality control, and access to data sets necessary for development of an accurate conceptual site model (CSM). A comprehensive EDMS and visual CSM development was completed for an industrial site in São Paulo, Brazil, as a BMP for optimizing site management. This comprehensive 2D/3D CSM was developed utilizing the historical site data to enhance site information, enhance data evaluation and validation to identify potential data gaps, determine the need for additional site assessment and/or remedial actions based upon site conditions and provide insight for the development of more targeted assessment and remedial design strategies.

Site Description. The Site is located in an industrial area west of São Paulo, Brazil. The site initiated its activities in 1976 as a specialty chemical manufacturing company. Between 1981 to 2000 the site operated as a manufacturer of adhesives. Today the site is used only for storage of final specialty-chemical products and for commercial distribution associated activities. Historical site investigations identified the primary contaminants of concern (COCs) as chlorinated volatile organic compounds (CVOCs), more specifically the two primary COCs are carbon-tetrachloride and chloroform which are observed in two distinct plumes, North Plume and South Plume. For this paper, chloroform results will be presented.

EDMS AND CSM DEVELOPMENT

The EDMS was utilized to organize data collected over a twelve year period into a relational database (EarthSoft's EQuIS™). Data was migrated by both hand entering and digital transfer that included over 100,000 records (location data, water levels, geologic information, well records, analytical data, etc.). Existing data were primarily provided as Microsoft® Excel® spreadsheets (Excel), AutoCAD® (CAD) drawings, and report Adobe® Acrobat® (pdf) files. A secure ftp data transfer site was created to facilitate the upload of historic and existing data for integration into the database. Data were then prioritized and categorized for translation into EQuIS electronic data deliverable formats (EDDs). Location data were entered into an EQuIS GEOEZ EDD format. A priority ranking was established to cross-reference location data integrity based on how the coordinates were obtained: (1) coordinates obtained from boring/well logs, (2) coordinates provided in Excel tables, (3) coordinates determined from Geo-referenced CAD figures, (4) coordinates determined from rectified CAD figures, and (5) coordinates determined from rectified pdf figures. Well completion, boring log, and water level data were processed in a custom access database to format the provided Excel spreadsheet information into EQuIS EDD GEOEZ format. The processed EDD was then compared to boring logs provided as pdf and supplemented by hand entering any data not included in the Excel worksheet (USCS classification, PID readings, sample intervals, and well completion details).

Groundwater analytical data (>68,000 records) were provided in an Excel worksheet or an electronic data deliverable (EDD). This table was imported into a custom access database for reconfiguration into EQuIS EFWEDD format which included translation of compounds to English, assignment of a Chemical Abstract (CAS) number, assignment of an analytical method, and assignment of a unique sample ID. The created EDD was then checked in the EQuIS Electronic Data Processor (EDP) prior to loading to the database. Soil analytical data was not provided in electronic format and required hand entering into an EQuIS historic data EDD primarily from box-plot CAD figures.

Concurrent with loading of the project data into the EQuIS database, a geo-referenced site basemap was created in ESRI® ArcGIS®. The Site basemap was generated by rectifying existing CAD maps and pdf report maps and exporting site features as ArcGIS® shapefiles. Features included: roads, facility details, streams, buildings, property boundaries, surface contours, boring locations, remediation system designs, etc. as shown on Figure 1. This geo-referenced basemap became the basis for evaluating 2-dimensional spatial relationships for the CSM.

Once the database design and data transfer were completed, data were queried and exported for evaluation which included: two-dimensional analysis of data sets in ArcGIS, statistical trend analysis using Excel, and 3D analysis using Mining Visualization System (MVS) software by C Tech Development Corporation. Generation of an initial geologic CSM was initially attempted using Unified Soil Classification System (USCS)

FIGURE 1. Georeferenced Site basemap created from existing CAD and pdf files.

designations reported on individual boring logs. During the processing of this data, it was determined that these designations were overly complicated and could not be correlated across the Site. As a result, a coherent Site geologic hierarchy could not be created, therefore, other data sources were evaluated to simplify the geologic interpretations. This included evaluation of seismic refraction data (12 transects) acquired by Alta Resolução Geologia e Geofisica in 2005. Based on the seismic data, a geologic hierarchy was developed that consisted of three distinct units: an unconsolidated unit, a moderately consolidated unit, and a consolidated unit (Tubarão Formation). In order to generate a 3D CSM based upon the seismic data it was necessary to convert the geophysical interpreted data sets into MVS formatted data sets. Fortunately, the geophysics report provided tabulated data with interpreted geologic picks for each geophone location. In addition, a CAD file was provided with the geophone locations along the seismic transects. These data results were imported into ArcGIS, rectified, and exported to MVS geo file format. Additional site boring log data and well completion data were also evaluated in context of the seismic interpretation and were then added to the raw MVS geologic data set. This combined data set was then kriged using MVS's geologic kriging algorithm. Figure 2 illustrates the working geologic CSM with raw geologic data points used in the kriging process.

Once the initial geologic CSM was created, analytical data from 2006-2011 groundwater data sets were exported from EQuIS as MVS interval data files for six individual sampling events. The six sampling event data sets were initially kriged using the MVS 3D-kriging algorithm. Based upon these initial kriging intervals, it was determined that the well sampling network was influencing the kriging results (i.e., reduced sampling networks resulted in more uncertainty, which influenced plume shape). In order to correct this finding, trend analysis for each well at the Site was completed for carbon tetrachloride and chloroform groundwater concentrations and was used to assess the preferred monitoring well network. An example of the trend analysis is provided for one nested well set in Figure 3.

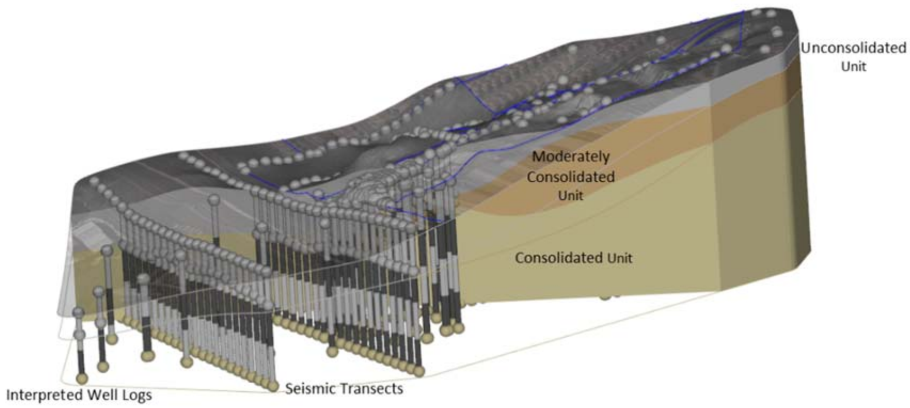

FIGURE 2. Geologic CSM developed from seismic refraction data, well completion logs and interpreted boring logs (vertical exaggeration = 3x)

Based upon the trend analysis, a historic (pre-remediation) data set was created for the 2006 sampling event data, and a CSM data set was created for the 2011 sampling event (CSM baseline data set). Data were appended to these data sets if trends were consistent through time or at least for recent sampling events (e.g., wells with non-detects that had not been sampled for a number of years were assigned non-detect results). These interpreted data sets were then kriged in MVS. The kriged results were then cut by the water table in order to remove any results within the vadose zone. These kriged results became the basis for the analytical CSM for carbon tetrachloride and chloroform and are illustrated in Figure 4.

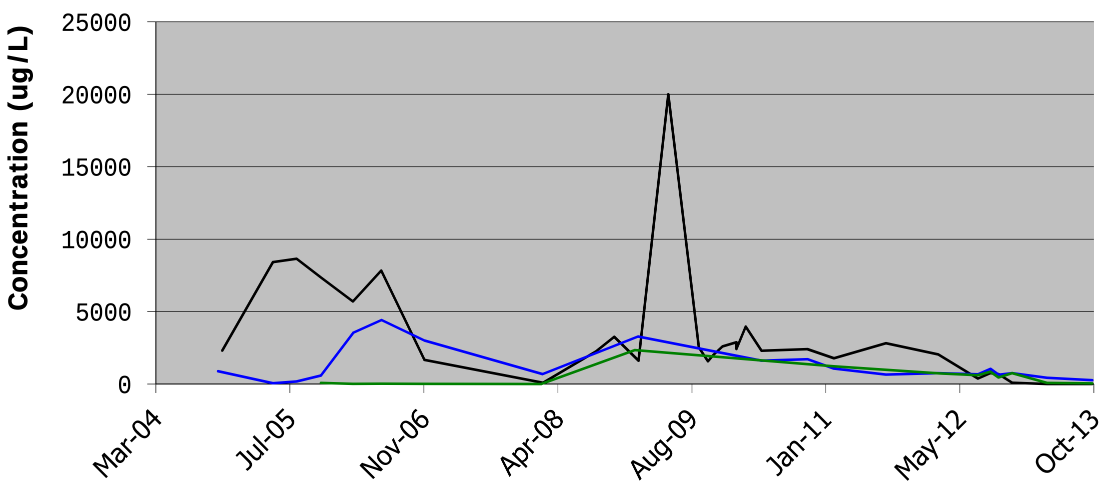

FIGURE 3. Example of time series trend analysis for a nested well set near the South Plume source area.

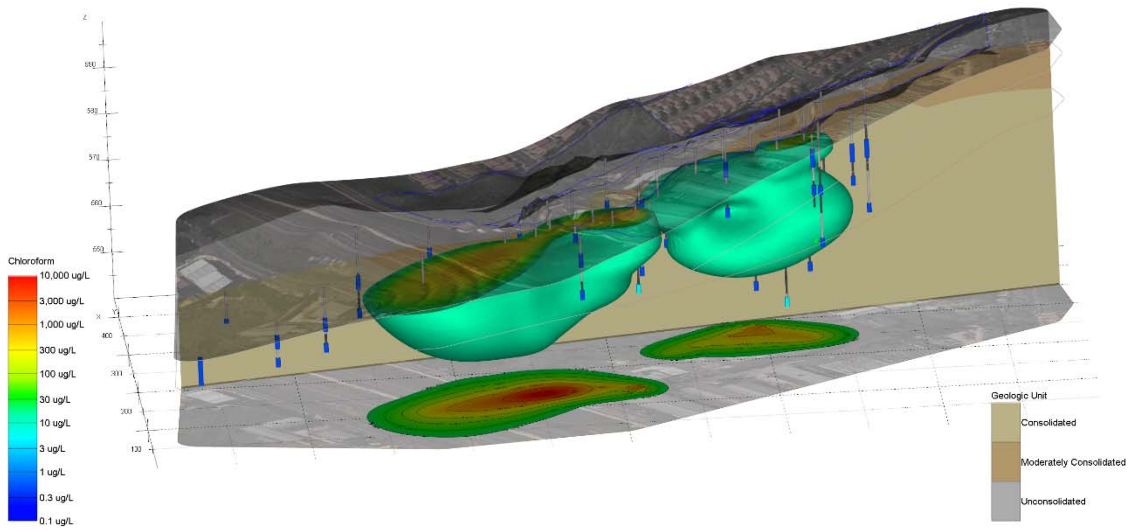

FIGURE 4. Chloroform CSM with 3D groundwater plume and 2D maximum extent groundwater plume (set to bottom of model) with chloroform concentrations greater than 10 ug/L (Vertical Exaggeration = 3x).

RESULTS AND DISCUSSION

After the CSM was developed, it was used to evaluate historical investigation and remediation performance, current conditions, identify data and information gaps, and ultimately used to develop a long-term site closure strategy. As a result of the CSM, it was determined that operations at a former waste water treatment (WWT) facility had contributed to chloroform impacts in groundwater and significant contaminant mass still resided in two previously identified source areas. In order to address this newly identified source area, a decommissioning plan for the WWT facility was developed and implemented. In addition, five additional monitoring wells were installed (2 nested well pairs and an intermediate well) to finalize delineation of the groundwater plume in the northern plume. A permeable reactive barrier (PRB) was designed and constructed along the northern site boundary downgradient of the former WWT facility and 40 in-situ soil mixing borings were advanced and approximately 19,000kg of EHC® at varying percent solids slurry was delivered at the remaining two source areas and an off-site property. Additional source excavation was also completed adjacent to a former Hot-Melt Sump. Figure 5 illustrates the remedial measure implemented following evaluation of the site using the 3D CSM, and includes the PRB, Hot Melt excavation, soil mixing borings and fence diagrams of the geology and dissolved chloroform groundwater plume.

In conjunction with the evaluation and implementation of remedial measures, the 3D CSM was also used to statically evaluate the monitoring well network. This was completed by utilizing the MVS well decommissioning module, which evaluates the statistical significance of individual monitoring wells on the kriging results. Based upon these results, select wells were removed from the CSM data set and the model recalibrated to validate the well decommissioning influence on the groundwater plumes. This process was initially used to evaluate and determine a more targeted well network for remediation compliance monitoring, which resulted in a 20% decrease in the well network.

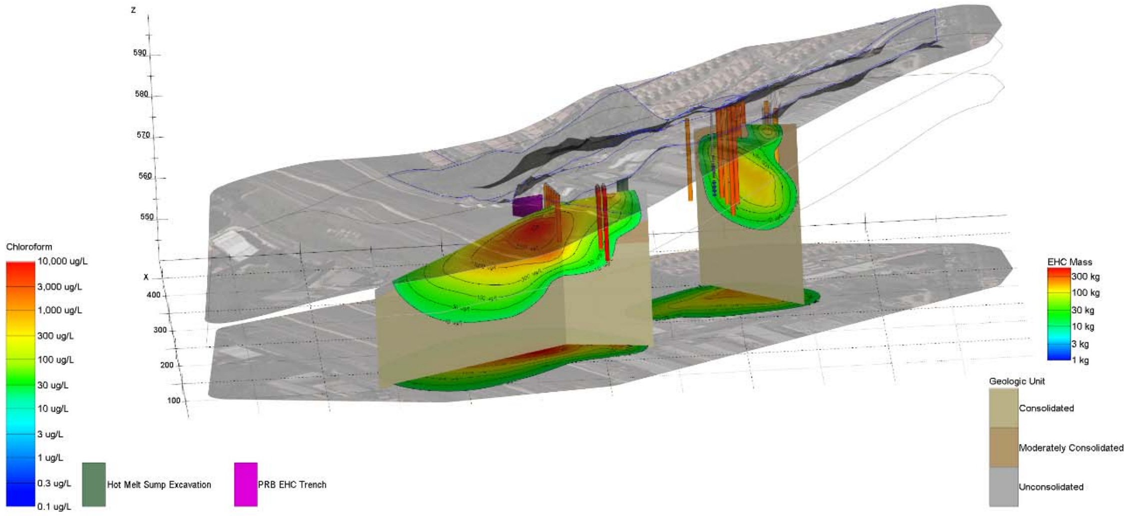

FIGURE 5. Source excavation, PRB EHC trench and soil mixing EHC borings implemented following CSM development (Vertical Exaggeration = 3x).

This optimized monitoring well network has been sampled semi-annual starting in March 2012. Data from these monitoring events plus all remedial action implementation data collected have been loaded to the EDMS and continually incorporated into the 3D CSM.

Groundwater monitoring data collected following the implementation of the above remedial measures has shown significant decreases in the dissolved CVOC groundwater plumes total mass, average concentrations and maximum concentrations as shown in Figure 6. Figure 7 illustrates current conditions at the site as of September 2013. Based upon first-order decay rates calculated from the 3D CSM, a total lifecycle of approximately 6 years has been predicted assuming that the decay rates calculated are sustained over the projected time frame.

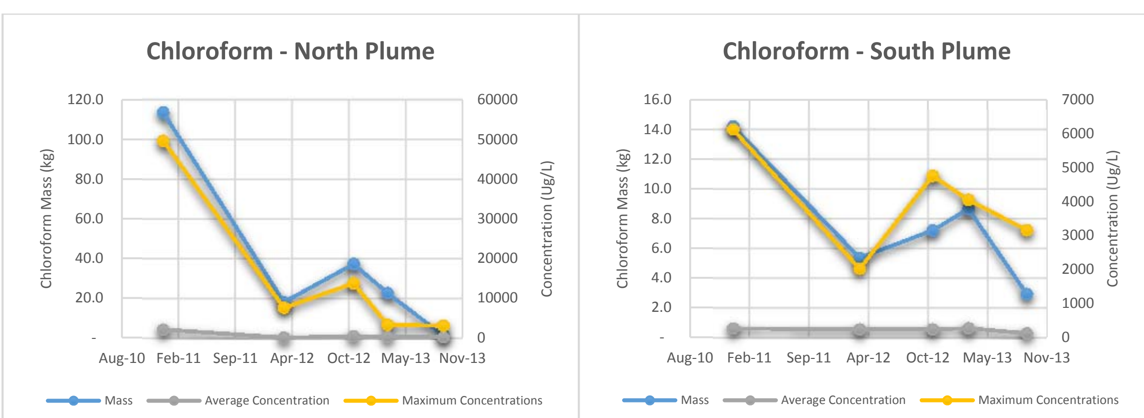

FIGURE 6. Calculated mass, average concentration and maximum concentrations for dissolved chloroform in groundwater for the North and South Plumes.

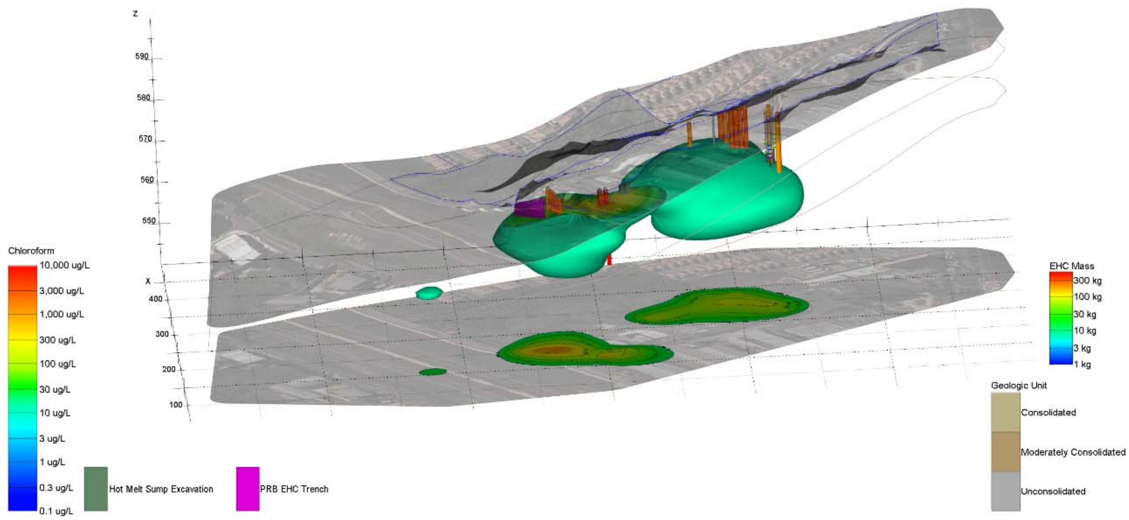

FIGURE 7. Current chloroform (September 2013) CSM with 3D groundwater plume and 2D maximum extent groundwater plume (set to bottom of model) with chloroform concentrations greater than 10 ug/L (Vertical Exaggeration = 3x).

CONCLUSIONS

The migration of all existing site data into a comprehensive EDMS in conjunction with development of a 3D CSM, has provided a BMP solution that:

- Provides a structured platform for continual data import, evaluation and validation
- Identifies data and information gaps
- Can be used to validate monitoring well networks
- Can be used in association with engineering pilot tests and full scale designs for remediation construction and an in-situ applications
- A cost-effective approach to environmental liability management that reduces lifecycles.