

Integration Of 3D Geographic Information System (GIS) For Effective Waste Management Practice

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ABSTRACT

Soil remediation in response to the presence of residual radioactivity resulting from past MED/AEC activities is currently in progress under the Formerly Utilized Sites Remedial Action Program near the St. Louis, MO airport. During GY05, approximately 92,000 cubic meters (120,000 cubic yards) of radioactive soil was excavated, packaged and transported via rail for disposal at U.S. Ecology or Envirocare of Utah, LLC. To facilitate the management of excavation/transportation/disposal activities, a 3D GIS was developed for the site that was used to estimate the in-situ radionuclide activities, activities in excavation block areas, and shipping activities using a sum-of-ratio (SOR) method for combining various radionuclide compounds into applicable transportation and disposal SOR values. The 3D GIS was developed starting with the SOR values for the approximately 900 samples from 90 borings. These values were processed into a three-dimensional (3D) point grid using kriging with nominal grid spacing of 1.5 by 1.5 meter horizontal by 0.3 meter vertical. The final grid, clipped to the area and soil interval above the planned base of excavation, consisted of 210,000 individual points. Standard GIS volumetric and spatial join procedures were used to calculate the volume of soil represented by each grid point, the base of excavation, depth below ground surface, elevation, surface elevation and SOR values for each point in the final grid. To create the maps needed for management, the point grid results were spatially joined to each excavation area in 0.9 meter (3 foot) depth intervals and the average SOR and total volumes were calculations. The final maps were color-coded for easy identification of areas above the specific transportation or disposal criteria.

INTRODUCTION

Soil remediation by excavation of soils is ongoing at four work areas within the St. Louis Airport Site (SLAPS), an unincorporated St. Louis County property, located approximately 17 miles northwest of downtown St. Louis, Missouri. From 1946 to 1966 the SLAPS was used to store Manhattan Engineer District (MED)/Atomic Energy Commission (AEC) residues generated by uranium separation processes at the Mallinckrodt Chemical Works. The process residues included solids from the neutralization and filtration of ore raffinate and barium-cake residues

stored in piles on the ground, radium-bearing residues stored in drums, used dolomite liners and recycled magnesium fluoride liners, tailings from a process to recover uranium from magnesium fluoride slag, empty drums, radioactively contaminated metal scrap, drums containing miscellaneous residues, uranium-containing sand, and radioactive scrap materials. Some of these materials were buried in earthen pits on site. In 1966, the U.S. Government sold the uranium-bearing residues to the Continental Mining and Milling Company that were moved by Continental Mining and Milling from the SLAPS to Hazelwood, Missouri for shipment to Canon City, Colorado. Structures in existence at the SLAPS were razed and buried on site including 60 truckloads of scrap metal and a radioactively contaminated vehicle. One to three feet of approved borrow material was spread over the entire site to reduce radiation exposure rate to levels in compliance with standards at that time. In 1973, the U.S. Government and the City of St. Louis agreed to transfer ownership of the SLAPS via quitclaim deed from the AEC to the St. Louis Airport Authority (1).

Remedial investigations at the site from 1982 through 1995 established that radiological contamination extended as deep as 5.5 meters below ground surface consisting primarily of Ra-226, Th-230, Th-232, and U-238 (2, 3, 4, 5, 6). The remedial action for the site was excavation of soils to reduce MED/AEC contaminants and backfill with clean soils. Excavated soil at the site is transported by rail to U.S. Ecology or Envirocare of Utah, LLC for disposal.

During the course of the excavation, in-situ soil concentrations encountered were variable and not always within the expected range based just on point values from the site-characterization data. Since the selection of the waste disposal facility was situational—based on radioactivity concentrations relative to the disposal facility waste acceptance criteria, project costs for sequencing excavation to achieve the desired waste concentration, and costs associated with post-excavation blending to achieve the desired waste concentration—a more robust method was needed to refine the estimates of the concentrations that would be present in the final waste material following normal blending that occurs during excavation and handling. The goal was to provide a simple, real-time and readily understandable presentation of expected soil concentrations for use in excavation analysis. Two basic objectives were established: (1) develop an interpolated three-dimensional (3D) grid of values for various parameters across the site and (2) use these results to prepare maps and tables for engineering and logistical excavation evaluations.

GIS PROCEDURES

A GIS (geographical information system) was used to meet the two objectives through a four-step procedure. Software used for this effort included EVS (7) was used for the 3D gridding, ArcScene (8) for 3D GIS visualization, and ArcMap (8) for all GIS data processing and preparation of the two-dimensional (2D) maps. Three-dimensional GIS procedures were selected over traditional CAD-based 2D excavation evaluation methods because of the flexibility, speed, and efficiency provided by the GIS. By processing all of the data within the framework of a GIS, it is easy to evaluate the volumes and concentrations over pre-defined or over arbitrary excavation areas. The general steps were:

- Step 1 evaluated the 3D visual and geostatistical spatial distribution of observed results from approximately 900 samples collected across the 30,000 square-meter (7 acre) site.
- Step 2 developed 3D point-value grids for the key excavation criteria. Grids were developed for two radionuclide sum-of-ratios (SOR) waste criteria—one for

transportation and one for disposal criteria. Ordinary kriging with spherical variogram was used as the interpolation method with each grid containing approximately one million points.

- Step 3 developed a spatial volumetric grid with grid attributes of the two SOR criteria, soil volume, associated ground surface, depth, and excavation bottom for each grid point.
- Step 4 was the production of the desired output for use during the excavation.

The details of each step are presented below. While each step involved several non-traditional procedures, all methods can be performed with by combining and 3D gridding program with common GIS procedures to produce the desired results. The new technology presented herein is that combination of GIS processed to create the final 3D volume-concentration results.

Step 1—Sample Point Analysis

The sum of ratios (SOR) values for each sample location were calculated using the formula

$$SOR_x = \sum_{i=1}^n \frac{\text{Compound activity}_i}{\text{Disposal or Transportation Threshold Limit}_i} \quad (\text{Eq. 1})$$

where

SOR = Sum or ratio for transportation or disposal

i = compound;

n = number of compounds included in the SOR (varies)

Threshold Limit = applicable regulatory activity for compound;

By using the SOR approach, it is possible to easily determine whether a given sample result is greater or less than the applicable regulatory limits. SOR values equal to or greater than 1 indicate values above the limits while values less than 1 indicate values below the limits. For this analysis, it was possible to use the SOR values to determine 3D locations above or below the limits and combine all of the data in a given excavation area to estimate the average values and the relationship to the regulatory limits for that specific area.

To determine the site-wide horizontal and depth sample distribution for each SOR value, the sample locations were visualized in 3D using ArcScene (the 3D data visualization program in ArcGIS). The top and bottom of each sample interval were used to create the vertical extent of each sample with each sample represented by a 3D disk. This analysis was performed for both SOR values. Each sample location was displayed based on whether the SOR value at a given location was greater or less than 1 (Fig. 1.).

With this representation, it was possible to visually evaluate the distribution of samples with elevated SOR values and their relationship to the other samples. In addition, the statistical functions of the GIS were used to quantify and locate the number of samples with SOR values greater than 1. This initial screening effort allowed for a rapid 3D definition of elevated SOR areas before the gridding process was initiated.

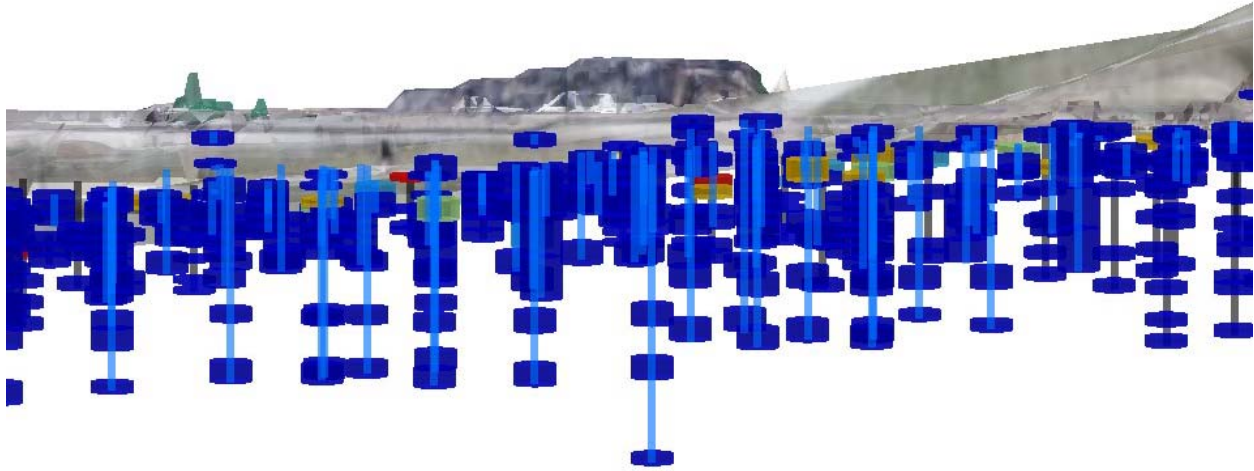


Fig. 1. Example of boring and sample locations. Blue disks have SOR values less than 1, green SOR range 1-2 SOR, orange SOR range 2-4, and red disks SOR range 4-20.

Step 2—Creation of Point Grid

Once the data were screened using the point analysis, a spatial point grid file was created for each SOR to characterize the entire horizontal and vertical extent of the sampled area of the SLAPS. The grids were developed using the 3D kriging function in EVS (7) using spherical variograms for both SOR values. The following parameters were used in the gridding process:

- Grid spacing— nominal 1.5 meter (5-foot) horizontal spacing and 0.3-meter (1 foot) vertical spacing;
- Grid extent—the entire volume (area and depth) of the site where soil was sampled
- Output results—transportation and disposal SOR values and data confidence grids in X, Y, Z, value to an ASCII text file format
- To facilitate data management, the two SOR grids were combined into a single GIS database file. The separate SOR value/data confidence grid data were joined to the coordinate grid using simple database join procedures.
- Once the combined database file had been developed, a 3D GIS point feature class was created in a personal geodatabase using the grid X, Y, Z values to define the spatial coordinates (Fig. 2.).

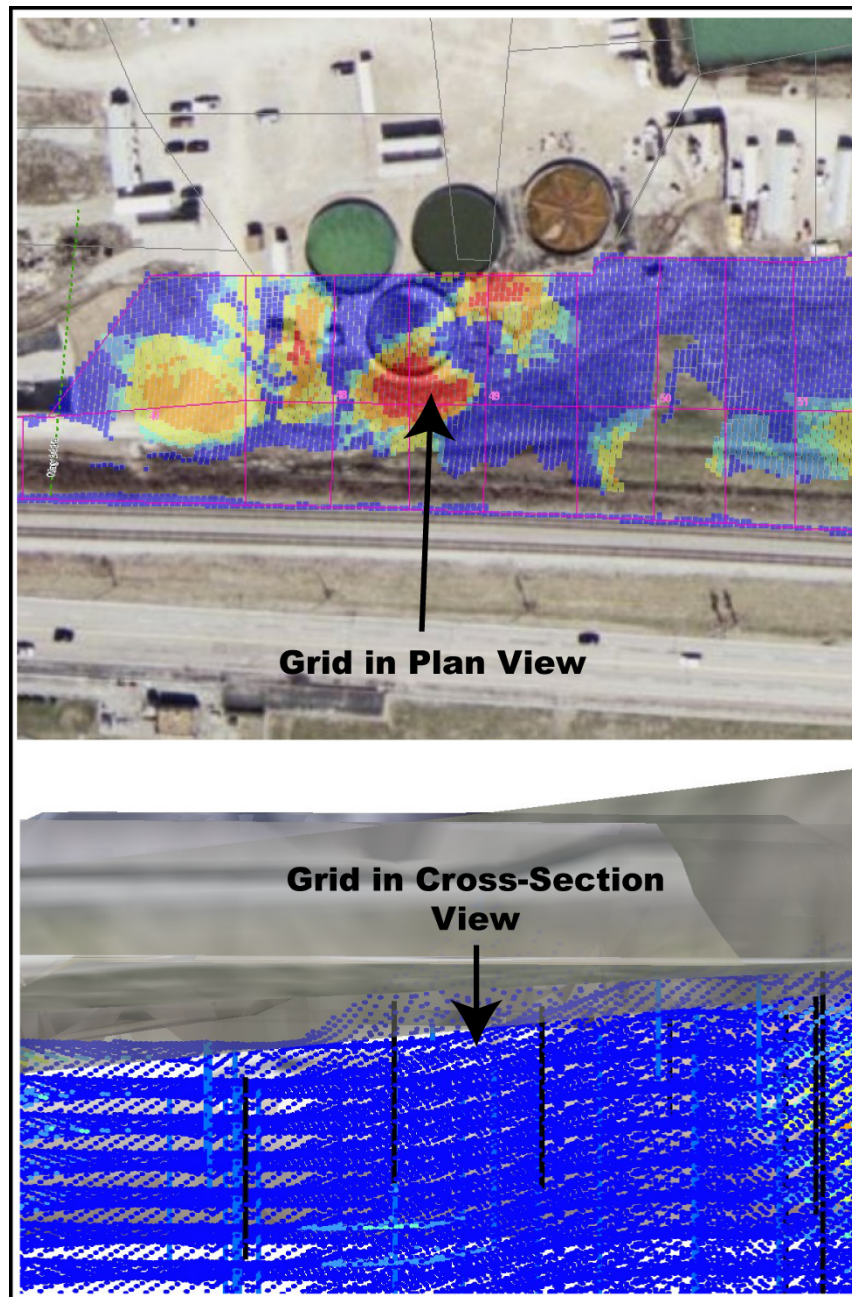


Fig. 2. Plan and cross-section views of 3D grid.

Step 3—Development of Volumetric Grid

This step was conducted by calculating the individual soil volume for each grid point by multiplying the Thiessen polygon area around each point by the 0.3048-meter (one foot) vertical grid spacing. Each final grid element nominally represented 0.4 cubic meters (0.5 cubic yards) of soil. Development of the final grid included the 3D spatial intersection of all grid elements with the base of excavation and ground elevations. Points above the base were retained for subsequent analysis while those below were excluded. After this step was completed, approximately 250,000 grid elements remained representing only the affected soil volume to be excavated.

For the combined SOR grid, for each grid point, the soil volume, depth below ground surface, and elevation of the base of excavation were determined using the following steps:

- The first layer (depth =0) of the 3D point feature class grid was extracted into a separate GIS feature class file. This was a point grid file with a thickness of one foot across then entire area containing approximately 35,000 points.
- The ground surface and base of excavation elevations for each grid point in the extracted layer were determined using a spatial join of grid points to the land surface and base of excavation contours, which were in CADD files.
The available contours were converted from CADD contours into GIS format. These contours were used to create TIN (triangulated irregular network) GIS elevation feature classes representing land surface and base of excavation. These TINs were recontoured using a 0.3-meter (1-foot) contour interval. By using TINs, all of the characteristics of the CADD contours were preserved while allowing for a more precise (but not more accurate) spatial join of the grid points to the contours.
The layer grid points were spatially joined to the contours. Each individual grid point was assigned the elevation value of the closest land surface or base of excavation contour.
- This one-layer grid was next used to create Thiessen polygons representing the areas around each grid point. Thiessen (Voronoi) polygons are created by mathematically creating polygons by joining the by the perpendicular bisectors of the lines between adjacent points across the grid.
- The volume of soil in cubic yards represented by each Thiessen polygon was calculated by multiplying the area of the polygon in square feet by the thickness (in this case one foot) and dividing by 27 (conversion factor for cubic feet to cubic yards).
- After this step, each Thiessen polygon had attributes defining the soil volume and land surface and base of excavation elevations at 1.5 meter (5-foot) horizontal spacing across the site. This Thiessen polygon feature class could be used for each layer of the SOR grid because the horizontal and vertical grid spacings were the same for all layers.
- These Thiessen polygons were spatially joined to the entire 3D grid so that each grid point had attributes of location, disposal SOR, transportation SOR, soil volume, ground surface elevation, and water table elevation. Because the personal geodatabase feature class has slow geoprocessing speed compared a shapefile, the geodatabase grid feature class was first converted to a shapefile before the spatial join. This performance issue can also be addressed using an ArcSDE geodatabase.

Initially, the grid feature class contained approximately 1 million points in a rectangular “cube” representing the maximum horizontal and vertical extent of the input samples. The next step was to refine the grid to a volume represented by the SLAPS site and above the base of excavation. This was done using the following GIS procedure:

- Select the generic grid points inside of the SLAPS boundary

- Create a polygon feature class representing the SLAPS area.
- Using a spatial join, select the grid points that are within the SLAPS boundary with a buffer value of 1.5 meters (5 feet).
- The selected grid points are exported to a new feature class in the geodatabase.
- From this grid, select grid points that have an elevation greater than or equal to the base of excavation. This is a simple attribute selection by comparing the elevation of a given point to the base of excavation elevations determined when the spatial join with the Thiessen polygons was done.
- These selected grid points are exported to a feature class in the geodatabase.

Step 4—Development of Output

To be consistent with the existing excavation plans, the grid was processed to generate the volumes and average concentrations for each existing excavation sub-unit. Each sub-unit represented areas of approximately 1,000 square meters and excavation lift of one meter (three feet). Site-wide, sub-unit, color-coded maps categorized by excavation lift interval were created. By combining the volumes and concentrations from various sub-units, field engineers can readily determine the best excavation sequence to meet the transportation and disposal criteria. Additional output included the 3D visualization of the excavation volumes and an interactive GIS where arbitrary excavation areas and lifts can be processed to determine volumes and average concentrations for any of the parameters included in the final grid. Because the GIS processes soil volumes as individual 0.4 cubic meter grid elements, a wide range of excavation scenarios and configurations can readily be analyzed to meet the requirements of the project.

Various 3D figures and 2D maps were created in the GIS to determine the horizontal and vertical extent of impacted soil at SLAPS.

3D Visualization of Sample and Grid Results

To visually assess the volumetric extent of each SOR, the combined grid was visualized in 3D using ArcScene. In these visualizations, the observed sample disks created in Step 1 were visualized along with the SOR values greater than a value of 1. This visualization was used to quickly assess the areas where the soil contamination was greater than a transportation or disposal SOR values greater than 1 (Fig. 3.).

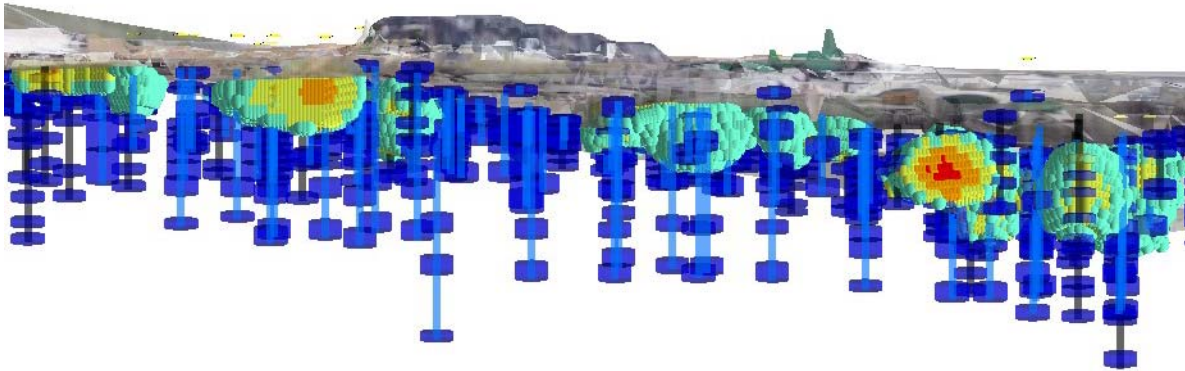


Fig. 3. 3D visualization of sample points and resulting SOR grid values where $SOR > 0.75$ are displayed.

2D Map Presentation of Volumes and Average SOR Values

For each SOR, predicted values were mapped at various depth intervals above base of excavation: 0-.9 meters, 0.9-1.8 meters, 1.8-2.7 meters, 2.7-3.7 meters, 3.7-4.6, and 4.6-8.6 meters (0-3 feet, 3-6 feet, 6-9 feet, 9-12 feet, 12-15 and 15-28 feet). The point grid values for each depth interval (Fig. 4. top) were spatially joined to nominally rectangular polygons representing planned excavation areas. Using the spatial join statistics of the GIS, the total volume of soil and average SOR value was calculated for each depth-interval polygon (Fig. 4. bottom). The results for each SOR were then overlaid the site base map using the transparency features in the GIS and the applicable volumes and average SOR values were posted on the maps. Separate maps were created for each SOR for each depth interval across the site. Tabular values of the necessary parameters were also created for each excavation area.

CONCLUSIONS

By using 3D GIS to evaluate soil concentration data at a site with radionuclide, it has been possible to develop a very robust and flexible method to determine remediation volumes and average concentrations over project-defined areas. The key advance in technology has been to develop procedures for creating a 3D point grid that can readily be processed within a GIS. Once the grid point feature class has been developed, a wide variety of attribute values can be assigned to each grid point. For the SLAPS site, the ground surface, excavation bottom and two SOR criteria have been determined for each grid point. The technology developed has a wide range of application to environmental soil, sediment, and groundwater remediation problems. The specific data assigned to the grid points can be used to assess nature and extent of multiple compounds at a site, either individually or in combination as was done for SLAPS, calculate remediation volumes, determine horizontal and vertical extent of contamination, and be readily used for a wide-range or remedial option planning and approaches. The technology has been implemented at other sites with up to 17 individual compounds being used to address remedial planning issues.

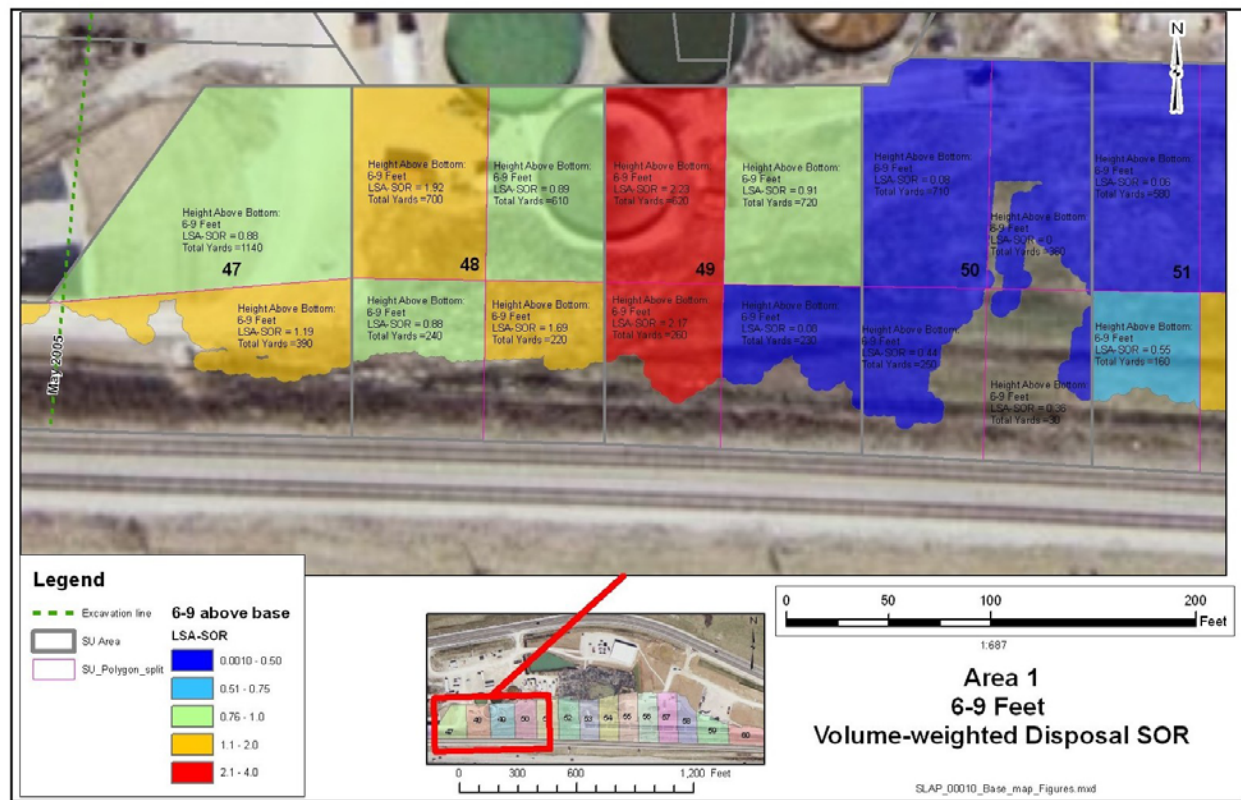
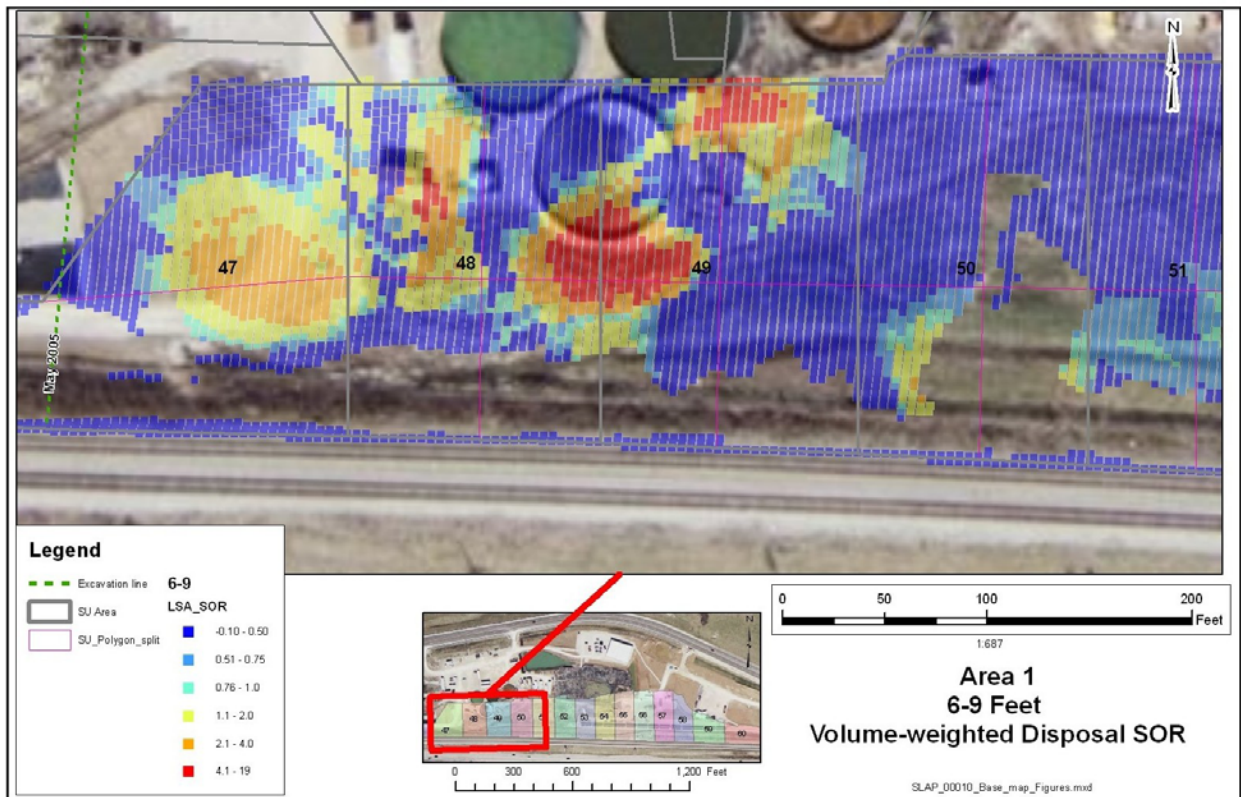


Fig. 4. Examples of the point grid values (top) and the summary polygon map output (bottom) for the depth interval 1.8-2.7 meters (6-9 feet) above base of excavation.

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