THREE-DIMENSIONAL ANALYTICAL TECHNIQUES FOR ASSESSING OVERBURDEN TOXICITY AS A DECISION-MAKING TOOL FOR RECLAIMABILITY DETERMINATIONS

L. A. Parsons, K. Kirk, and A. Wilhelm

United States Department of the Interior
Office of Surface Mining, Reclamation and Enforcement
Western Support Center
1020 15th Street
Denver, Colorado 80202

ABSTRACT

The rationale behind the development of overburden and regraded spoil analytical databases, and the application of multi-dimensional spatial analysis techniques, is discussed in relation to the requirement that reclaimability findings be made for lands disturbed by surface coal mining operations in the Southwestern United States.

Recent advancements in computer hardware and software now allow real time graphic visualization, manipulation and volumetric calculation of three-dimensional (3d) data. True 3d analytical techniques are being used by the Office of Surface Mining Reclamation and Enforcement (OSM) to determine the locations and the volumes of both unsuitable (potentially acid- and toxic-forming) and suitable (non-toxic or non-acid-forming) materials in overburden and regraded spoils at surface coal mines in the Southwest. These methods have greatly increased OSM's accuracy and efficiency by quantifying true three dimensional data for making and supporting regulatory decisions pursuant to the Surface Mining Control and Reclamation Act of 1977 (SMCRA).

In the future, these techniques will be used in the development and verification of special handling plans for topsoil substitutes and supplements, and the selective isolation of acid- and toxic-forming materials. Concurrent with the development of these 3d analytical techniques, overburden sampling and Quality Assurance and Quality Control (QA/QC) programs have been developed to assure data reliability prior to applying these techniques in regulatory decision making.

INTRODUCTION

The Office of Surface Mining, Reclamation and Enforcement (OSM) requires re-establishment of adequate vegetative cover as a key element of the reclamation process following the surface extraction of coal. This requires the identification and analyses of potentially acid- and toxic-forming materials in the overburden so that these materials are not placed in the root zones of reconstructed the mine soil.

The large amount of baseline overburden and regraded spoil analytical data, submitted to OSM in permit application packages and annual reports, frequently results in extended times to conduct technical reviews of these documents. Actual material quality and associated volumetric analyses determined from large amounts of baseline information, using traditional methods, not only can be time consuming, but also may be subject to errors by technical reviewers. Traditional methods, including paper analysis of bore hole sample data and two-dimensional (2) geologic modeling, have often been performed <u>once</u> during the permit review period due to time constraints placed on the review, and the time consuming nature of these methods. This situation has led to disagreements among permit technical reviewers, between OSM and the mining industry, and between OSM and the public concerning final findings of mine reclaimability and proposed mitigative measures of acid- and toxic-forming materials. True 3d methods, that include real time 3d analysis and volumetric calculations, allow the examination of multiple operational scenarios; and, therefore, are significantly more flexible in assessing remediation plans and associated monitoring programs. Since these graphically intensive methods produce graphical outputs that honor scattered data, the output leads to a better understanding of existing site conditions and supports regulatory decisions on proposed reclamation plans.

In an effort to support technical and regulatory findings for permit approval and mine reclaimability, OSM has developed overburden and regraded spoil databases and associated 3d analytical tools for two mining operations in the Southwest. These graphical displays are being used to identify and calculate volumes of acid- and toxic-forming materials in situ and suitable topsoil substitutes and supplements to mitigate these unsuitable materials when they are found in regraded spoils.

This paper describes 3d methodologies developed by OSM to rapidly asses the large quantities of spacial data for mines in the Southwestern United States. OSM programs, initiated to support the use of 3d techniques for regulatory decision making at Federally regulated surface coal mines, are also discussed.

REGULATORY REQUIREMENTS

Public Law 95-87, The Surface Mining Control and Reclamation Act of 1977 (SMCRA), requires that surface coal mine operators identify potentially acid- and toxic-forming materials in geologic strata and in the reclaimed landscape. Once identified, the operator is required to cover or treat these materials to mitigate adverse environmental impacts. Specific regulations outlining procedures to meet these requirements include:

30 CFR 780.22 (a)(2):

"Each application shall include geologic information in sufficient detail to assist in determining all potentially acid- and toxic-forming strata down to and including the stratum immediately below the lowest coal seam to be mined;"

30 CFR 816.22 (b):

"Substitutes and Supplements. Selected overburden materials may be substituted for, or used as a supplement to

Table 1. OSM Root Zone Suitability Guidelines.

RECLAIMED ROOT ZONE MATERIAL SUITABILITY CRITERIA* FOR THE SOUTHWESTERN UNITED STATES

Parameter	Material Quality: Good	Marginal	Unsuitable
pH	6.0-8.6	5.5-6.0 8.0-9.0	< 5.5 > 9.0
EC mmhos/cm (1)	< 8.0	8.0-12.0	12.0-16.0
SAR (2)			
sl and coarser	< 12.0	12.0-20.0	20.0-25.0
l and cl	< 10.0	10.0-16.0	16.0-20.0
40% clay	< 8.0	8.0-14.0	14.0-18.0
Texture (3)	ls, sl, l, sil, with 35% c	s, lcs, cl, sicl with 45% c	45% c
Saturation%	25-85	20-90	20-95
Coarse Fragments (4)			
< 3 inch %	15	15-35	35
< 3 inch %	3-10	10	
Erosion Factor (5)	.37	.37	
Acid-base potential	+ 5 T CaCO3 equiv/1OOOT	0 T CaCo3 equiv/1OOOT	-5 T CaCO3 equiv/1OOOT
Boron	5 ppm	5-10 ppm	> 10 ppm
Selenium (Total)		< 0.8 ppm	> 0.8 ppm
Selenium (Extractable)		< 0.15 ppm	> 0.15 ppm

* All suitability criteria may be modified if sufficient data is submitted to support the modifications and the data technically represents the site specific nature of the modification.

1. When EC is less than 2.0, then SAR's can not be > 25.
2. SAR values can be modified if adequate data is submitted to support the modifications.
3. ls= loamy sand; lcs= loamy coarse sand; sl= sandy loam; l= loam, sil= silt loam; scl= sandy clay loam; s= sand; cl= clay loam; sicl= silty clay loam; cl= clay.
4. For topsoil substitutes/supplements, percentage can be increased if it is shown that the higher percentage will increase slope stability and/or vegetation establishment. Suitabilities will be determined on a site specific basis.
5. For each material proposed to reclaim slopes 25% (4h lv), a K factor must be determined from the results of appropriate physical and chemical analyses, as outlined in the National Soils Handbook (SCS, 1983). Material suitability will be determined using the Revised Universal Soil Loss Equation (Renard, 1990).

display in numerous ways to better understand internal relationships contained within the model. The model can be rotated to any combination of user-specified azimuth and inclination or "grabbed" with the mouse and dragged to any desired orientation. The model can be sliced along the X, Y, and/or Z axes at specified intervals or interactively by "clicking" the mouse at the specific location where a slice is to be made. This results in producing color filled sections on any or all three sides of the block model.

While slicing and rotating the user can also select a particular range of iso-values surfaces to be displayed (or not displayed). This is referred to as "peeling" the block model at the selected iso-values. The user may jump graphically between multiple property models which gives the effect of superimposing the models. For example, 3d block models for selenium and SAR could be examined together to spatially determine where the combined effects on reclaimability of these two parameters is greatest.

Another valuable feature of IVM is the ability to display real or interpolated drill hole information graphically within the 3d block model. The user may "click" the mouse on the desired sample locations and thereby query the 3d data set for that location. This allows the user to rapidly compare the laboratory overburden quality raw data against the value of the 3d block model to determine model accuracy. Determination of model accuracy can also be accomplished by jumping between the 3d property model and 3d residual grid for a given parameter.

Without analytical procedures to quantify the block model, the display capabilities produce no more than so many very colorful, pretty pictures. IVM allows the user to perform a full compliment of analyses that include interactive grid manipulation, 3d grid operations and volumetrics. True three dimensional techniques actually perform analysis on four-dimensional data (X,Y,Z,Value). These 3d methods allow the rapid analysis of multiple "what-if" scenarios, graphic manipulations, graphic displays and volumetric calculations.

topsoil if the operator demonstrates to the regulatory authority that the resulting soil medium is equal to, or more suitable for sustaining vegetation than, the existing topsoil, and the resulting soil medium is the best available in the permit are to support revegetation."

30 CFR 816.102 (f):

"Exposed coal seams, acid- and toxic-forming materials, and combustible materials exposed, used, or produced during mining shall be adequately covered with nontoxic and non-combustible material, or treated, to control the impact on surface and ground water in accordance with 816.41, to prevent sustained combustion, and to minimize adverse effects on plant growth and the approved postmining land use."

Specific analytical parameters and prescribed limits define potentially acid- and toxic-forming materials in the Southwest. The chemical parameters used by OSM to determine material toxicity for mining operations in this region are pH, SAR, EC, acid-base potential, selenium, and boron. Material texture, saturation percentage and erosion factors are the physical parameters used to determine material toxicity and suitability. Operators are required to sample and analyze overburden and regraded spoil materials for these parameters and from the analytical results, identify all acid- and toxic-forming materials in the overburden and regraded spoils, and develop mitigation plans pursuant to SMCRA. Submission of all sampling and analytical data is required for identification of acid- and toxic-materials and plans for their mitigation; and ultimately to support permit application approval or denial by OSM. OSM completes spatial data analyses and material verification by using true 3d analytical procedures.

In the Southwest, mitigation operations include covering acid- and toxic-forming spoil with an adequate depth of nontoxic material, usually four feet. Suitable materials available for mitigation are usually identified in the overburden strata by comparing the results of core sample geochemical analyses to the suitability limits shown in Table 1. If determined suitable, these overburden materials can be placed over toxic-spoil to mitigate potentially adverse environmental effects. Once redistributed, these mitigative materials become the rooting medium of the reconstructed mine soils. Therefore, all mitigative materials are considered to be topsoil supplements and must be suitable according to OSM's root zone suitability guidelines.

At all OSM regulated mines in the Southwest, operators sample regraded spoils on 330' centers to a depth of four feet. Each one-foot increment sample is analyzed for suitability/toxicity and acid generation potential (Table 1). If any or all sampled increments are determined to be toxic-forming, then the operator redistributes suitable materials over the toxic material to achieve a prescribed depth, usually of four feet.

Approval of reclamation techniques at one Southwestern mine, was contingent upon the identification of suitable materials in the overburden prior to mining disturbance. In active mining areas, the operator was required to submit analytical results from the highwall sampling program that was initiated by the operator to identify suitable mitigative materials. Results from the regraded spoil and highwall sampling, and mitigation programs are submitted to OSM on an annual basis for review.

PROCEDURES

Overburden core and regraded spoil sampling data for this mine were input into a data base management system (DBMS), utilizing Borland's Reflex software. Input information for each core hole included x,y location (State Plane coordinates), collar elevation, depth of sample and sample analytical results. DBMS filters were then developed in Reflex to identify unsuitable and suitable samples pursuant to the suitability guidelines approved in the mine permit (Table 1).

Standard non-spatial statistical analysis was then performed on these data. Mean analytical parameter concentrations, suitable parameter concentration percentages, and unsuitable parameter concentration percentages were determined for a preliminary data review. From the filtered databases, reports and files were developed so these data could be transferred to both the Interactive Surface Modeling program (ISM), a 2d grided surface analytical tool, and the Interactive Volume Modeling program (IVM) a true 3d analysis tool, both by Dynamic Graphics Inc., Alemeda, California. The ISM and IVM software are currently running on a Silicon Graphics Inc. Iris 4D/380 super minicomputer at the TIPS National Computer Center in Denver, Colorado. This combination of software and hardware allows users to rotate, zoom into, pan around, slice through and peel layers of the 3d block model. Rapid real time interactive abilities to view the model are vitally important, because no single view of the block model can adequately reveal the complex geometric relationships contained within the model. The 3d block models are created using true 3d minimum tension gridding or true 3d trend gridding. For the model developed from the DBMS, minimum tension gridding was used. Other block models may be created externally from IVM using 3d krigging.

Within IVM, the block model can be calculated in one of three ways. The first method calculates the true 3d grid throughout the volume defined by the input data distribution or by the user. The second method restricts the calculation of the grid laterally to the area defined within a predefined polygon (i.e. limits X and Y but not Z). These methods are most applicable in accessing overburden quality for those parameters or chemical species, related to overburden quality, that are primarily due to secondary deposition such as many of the trace metals, selenium, sodium, calcium and magnesium. The third method allows the user to use previously calculated, faulted or unfaulted 2d, surfaces created in ISM, as hard boundaries which limit the 3d modeling process in the X, Y and Z planes. These stratigraphically controlled and spatially limited planes create 3d block models that can then be stacked together to form one large block model. Stacking the blocks enables the scientist to develop a model of overburden quality and perform volumetric calculations for overburden quality values that are stratigraphically specific while not allowing the model to be influenced by measured overburden quality values in overlying or underlying layers. Limiting the 3d model is particularly useful in examining the true 3d distribution of chemical parameters that are most commonly associated with the original paleodepositional environment such as pyritic sulfur distribution within a specific strata at the site. These procedures are absolutely necessary when limiting the block model of overburden quality between the surface topography and deepest zone sampled to prevent trending beyond the limits of available data. Therefore, 3d block model stacking provides a more realistic model of chemical property variation within a vertically limited zone.

Once the 3d block model is created, a 3d display file is created from the 3d block model. This display file is the 3d equivalent of a 2d contour or iso-value map. The file contains 3d iso-value surfaces throughout the model. These surfaces are graphically displayed as smooth, color-filled, Gouraurd-shaded 3d bodies. Once built, the user can manipulate the

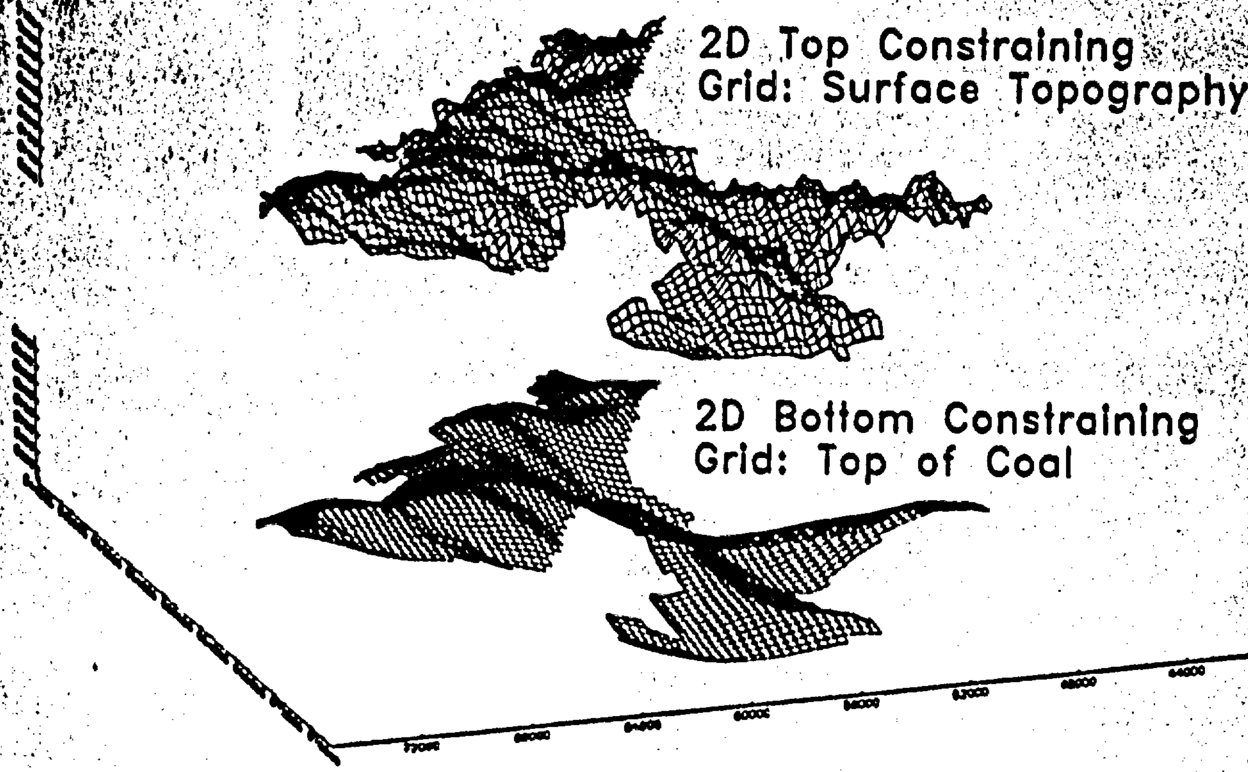


Figure 1 Two dimensional grids used to restrict block model.

ISM was used to develop 2d grids of surface topography from either digitized topographic maps, USGS Digital Elevation Models (DEMs) or in a general sense from bore hole collar elevations, along with a 2d structural surface representing the bottom of the core holes. These 2d grids were later used to "clip" or constrain the 3d block models of critical parameters created by the IVM software. These techniques were completed to facilitate 3d analysis and associated volumetrics of the critical parameters only within the zone of interest and to preclude 3d grid or block model trending beyond the limits of the actual data in the vertical direction. (Figure 1).

The critical parameter database was then used to create three dimensional scattered data sets that included 3d sample location coordinates (X,Y, and elevation, msl), and the suitability parameters outlined in Table 1. The scattered data were introduced into IVM and used for 3d grid generation, volumetric calculations and real time 3d graphical analysis. Residuals (differences between 3d model values and scattered data values at a given point) were examined and the data regridded until residuals were minimized and the 3d model accurately honored the 3d scattered data. Real time 3d graphical analysis was then performed with IVM to determine the 3d spatial distribution of the potentially acid- and toxic-forming material along with the 3d spatial extent of suitable topsoil substitutes. Calculation of volumes within specific iso-value ranges was also performed at this time. The volumetric analyses were used to determine if there was an adequate volume of suitable material to cover the potentially acid- and toxic-forming material to mitigate potential adverse effects on successful revegetation at the site (Figure 2).

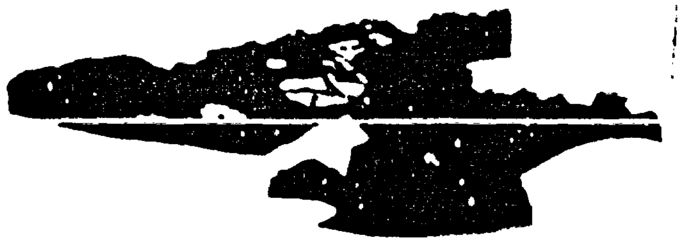
The estimated volumes needed to mitigate the 5,022 acres, illustrated in Figures 2 and 3, with four feet of non-toxic\suitable material is approximately 32,408,640 cubic yards. Volumes of suitable materials available in the overburden, to the top of the first minable coal seam, is approximately 163,805,120 cubic yards. Suitable materials available to thirty feet, that can easily be handled for mitigation, is approximately 41,936,344 cubic yards (Figure 4). Therefore, adequate volumes of suitable materials, that can be special handled economically, exist in these mining areas to mitigate identified toxic spoils as required.

CONCLUSIONS

From the results of this project, technical findings were made to support OSM's decision to approve the topsoil substitution and supplementation plans for the mine. Use of true 3d analytical tools, with real time 3d graphical and volumetric analysis, have greatly improved the efficiency of making regulatory decisions associated with potentially acid- and toxic-forming materials associated with surface coal mining reclamation in the Southwest. Three-dimensional analysis will further be used for verification of permit compliance, suitable substitute and supplement usage, and approved mitigation operations of acid- and toxic-forming materials identified in the regraded landscape as the mine progresses. These techniques will also be used to determine and support technical and reclamability finding for other pending mine permits.

To further support the accuracy of submitted overburden and regraded spoil analytical data for use in 3d graphical analyses, OSM has developed overburden and regraded spoil sampling and quality assurance and quality control programs. Submission of overburden and regraded spoil data, in digital form, for use in both the ISM and IVM software is being strongly recommended by these programs. These programs are now being utilized in the review of Federally regulated mining operations in the Southwest. By requiring specific sampling and analytical methodologies and control procedures, OSM and the coal mining industry can more accurately describe premining landscapes, mitigate adverse environmental effects and better plan for a successfully reclaimed environment.

Three Dimensional Spatial Distribution of Potentially Toxic and Non-Toxic Forming Materials View 1



Three dimensional distribution of both Toxic and Non-Toxic overburden materials from top of coal to surface topography.

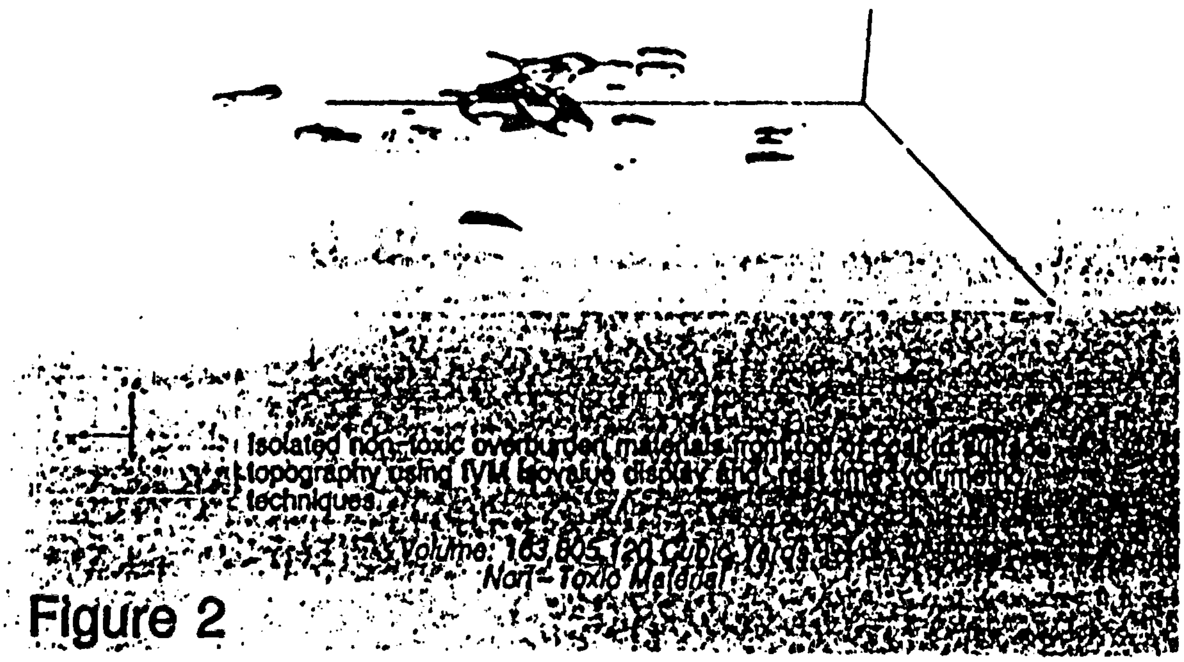
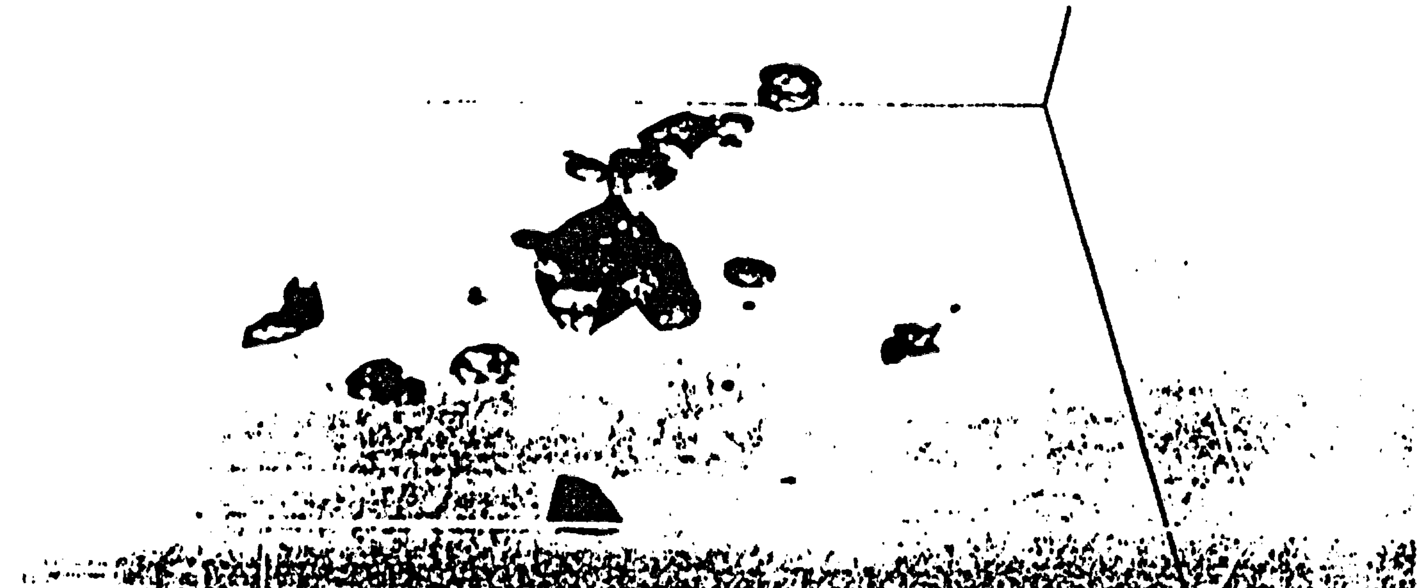


Figure 2

Three Dimensional Spatial Distribution of Potentially Toxic and Non-Toxic Forming Materials
View 2

Three dimensional distribution of both Toxic and Non-Toxic overburden materials from top of coal to surface topography. Vue using increased vertical inclination.



Isolated non-toxic overburden materials from top of coal to surface topography using IVM isovalue display and real time volumetric techniques. View using increase vertical inclination.

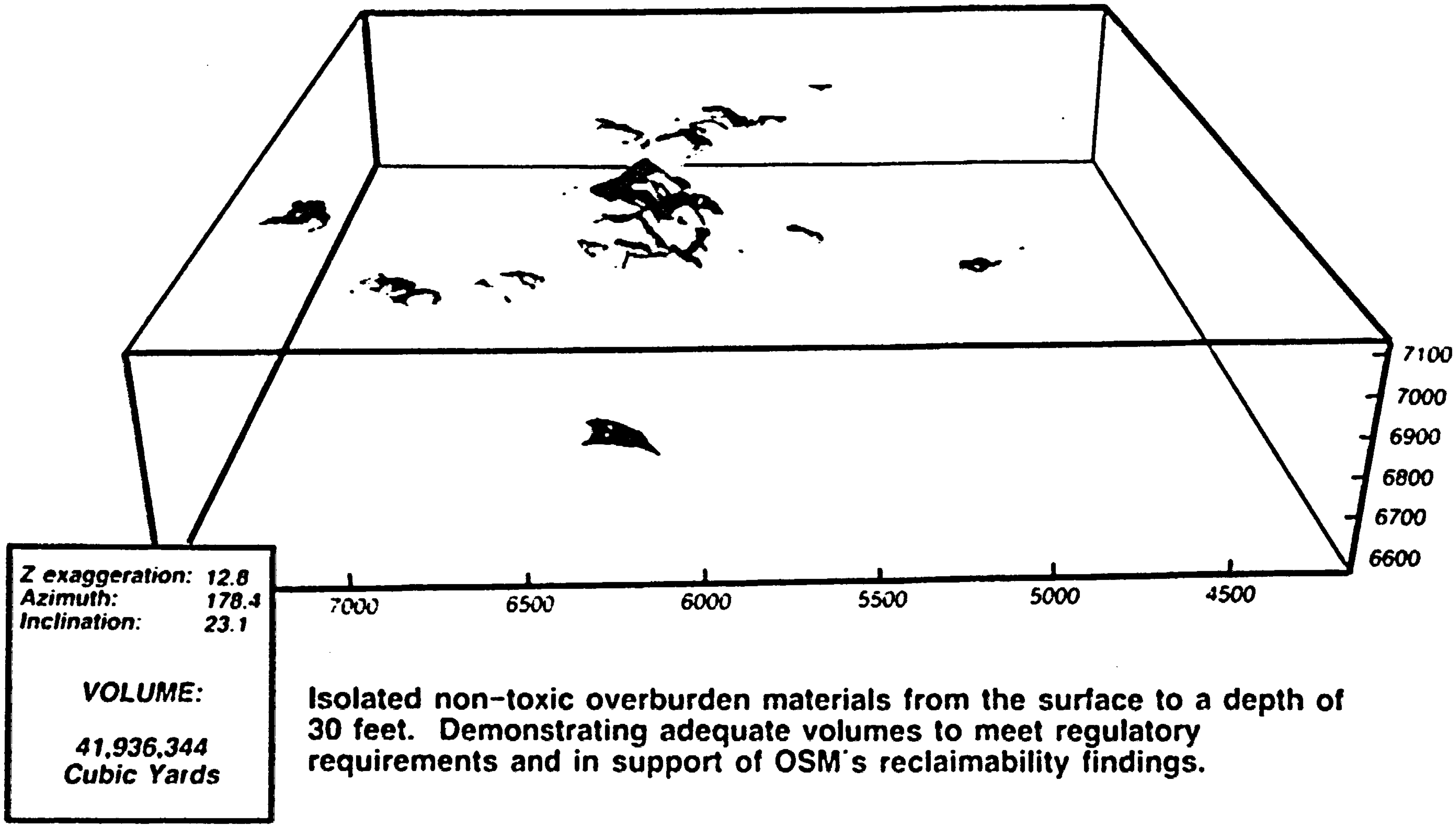
Volume: 163,805,180 Cubic Yards

Non-Toxic Material

Figure 3

Figure 4

Non-Toxic Forming / Suitable Material Available for Mitigation to a Depth of 30 Feet



Isolated non-toxic overburden materials from the surface to a depth of 30 feet. Demonstrating adequate volumes to meet regulatory requirements and in support of OSM's reclaimability findings.