USING GEOSPATIAL TECHNOLOGY TO DESIGN AND MANAGE RECLAMATION OF THE MABEL NEW-SUPERIOR MINE[1]

Jon E. Brandt[2]

Abstract. The Mabel New-Superior mine is a pre-law open-pit uranium mining site located in the Texas Western Rio Grande Plain. Mining operations ceased sometime in 1963 and the site was abandoned. Even though the pit highwalls were relatively low, ranging from 1.5 to 10.7 meters (5 to 35 feet), their vertical surfaces and length (approximately 3,456 meters/11,340 linear feet) posed a clear-cut safety hazard. Additionally, the overburden and protore adjacent to the pits presented a radiation hazard – both from ingestion of the radioactive dust and continued erosion and deposition of radioactive materials in the adjacent watersheds. The Texas Abandoned Mine Land (AML) Program had limited time to collect baseline data and to design, bid, and manage the reclamation work. The timeline from data collection to earthwork completion spanned 18 months. Project earthwork covered 34.5 hectares (85.2 acres), involved approximately 252,318 cubic meters (330,000 cubic yards), and cost $ 2.1 million. Each project phase utilized data collected with or displayed by Global Positioning System (GPS) equipment. It took 12 days, over a 2-month period, to collect over 3,000 gamma radiation data points for the radiation survey. The radiation survey, plus additional collected field data, were compiled and analyzed with Geographic Information System (GIS) software. The baseline radiation levels were estimated, using sub-surface radiation data and a geostatistics GIS software module. GIS software also facilitated bid document preparation, by delineating the areas containing highly radioactive materials and quantifying the volumes of protore and overburden for excavation and burial. Once the earthwork began, GPS and mobile GIS software were tools we used in the field to keep track of the targeted radioactive materials and verify cleanup of areas. Work payments were facilitated as a result of routinely compiled and analyzed GPS field data using GIS. A small AML staff (1 to 3 people) accomplished all of the preceding tasks (except the actual earthwork) quickly and accurately, using geospatial technology at every stage of the reclamation project. Two other GIS tools, involving image analysis and water erosion prediction, are briefly discussed because of their utility in evaluating vegetative cover and assessing soil erosion.

Additional Key Words: Texas, uranium, radiation, pre-law, management, survey, mobile computing, hardware, and software.

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[2]Jon E. Brandt, P.G., is a Soil Scientist with the Abandoned Mine Land Program at the Railroad Commission of Texas, Austin, TX 78701.

Introduction

This paper will describe some of the geospatial tools and procedures we used while reclaiming an abandoned uranium mine in south Texas. In early 2005, we were evaluating the potential work in 2006 for our abandoned mine land (AML) program. We had a couple of eligible pre-law uranium sites (the Texas AML program was non-coal certified in 1992) that had similar reclamation priorities, but each posed different problems. One of the sites had a pit holding millions of gallons of water which would have to be discharged. For that site, we had the entire baseline site data collected and had already developed a basic reclamation design. The other site, the Mabel New-Superior mine, did not have any appreciable water in the pits but we did not have very much site data, except for 0.6-meter (2-foot) topographic contour lines and a preliminary gamma radiation survey from 1999.

Even though we did not have much site data or a preliminary reclamation design, we selected the site that did not have pit water because of many unresolved issues with the other site's water (water-handling options and permits). We usually collect site data several years before we initiate a project. In this case, we would have to collect the data, analyze it, develop a reclamation plan, and issue an invitation to bid in less than 6 months. We had to implement this accelerated project design and bidding timeline because all clearing and grubbing of vegetation at the site had to be completed by February 28, 2006. The U.S. Fish and Wildlife Service requires that vegetation removal activities cease between March 1st and August 31st each year to avoid disturbing nesting birds. We believed this shortened timeline was feasible because we would be able to quickly collect and analyze the site data with our GPS/GIS resources.

I will discuss several of the geospatial methods/procedures we used for three distinct phases of the AML reclamation project: mapping as part of the site assessment; project design; and project management. I will cover only a couple of the more relevant tasks employing GPS equipment and GIS software at each phase[3]. A brief discussion of other helpful GPS/mobile GIS tools will also be included in this paper.

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[3] Mention of trade names does not constitute an endorsement by the Railroad Commission of Texas.

Mine Site Description

The Mabel New-Superior mine is a pre-law open-pit uranium mining site located in Live Oak County (Figure 1a), within the Texas Western Rio Grande Plain major land resource area (USDA-NRCS, 2006). Mining operations ceased sometime in 1963 (Eargle et al., 1975) and the site was abandoned. Since most of the uranium ore bodies were irregularly shaped and relatively shallow, there were several pits of varying size instead of one large pit. The pit highwalls were relatively low, ranging from 1.5 to 10.7 meters (5 to 35 feet), but their vertical surfaces and cumulative lengths (approximately 3,456 meters/11,340 linear feet) posed a clear-cut safety hazard. A radiation hazard also existed from overburden and mine waste/protore that was adjacent to the pits (through ingestion of radioactive dust and erosion and deposition of radioactive materials in the adjacent watersheds).

Much of the native vegetation is characteristic of a semi-arid open grassland with scattered trees and brush (ie., live oak and mesquite). However, most of the land that was cleared in 1961 for mining and the subsequent spoil piles had since been densely vegetated with thorny brush species such as guayacan, spiny hackberry, guajillo, blackbrush (USDA-NRCS, 2006), and mesquite. Recent NAIP (National Agriculture Imagery Program) aerial photographs show the mine pits and the different vegetation patterns of the adjacent landscape (Figure 1b).

Mapping: Mine Site Data Collection

As mentioned earlier, we already had detailed topographic contour data for the mine site, which had been obtained through a contracted aerial photogrammetric survey completed in 2003. We also collected site information related to access roads and utilities that might be impacted. The depths of radioactive materials overlying native ground were measured at twenty-seven locations in order to approximate the pre-mine ground surface elevations. Two other important data sets needed for project design were obtained from radiation surveys that were collected with our GPS equipment. The GPS equipment used and the kind of data collected before and during the reclamation project are summarized in Table 1.

Table 1. GPS units used for data collection and project management at Mabel New-Superior.

GPS Equipment	Software	Type of GPS Features Collected	Differential Corrections
Trimble® GeoExplorer II™	Pathfinder Office 2.90	Point: Micro-R survey Polyline: Pit highwalls	Post-Processing with Base Station Data
Trimble® ProXRS™ Backpack GPS receiver with attached data collector	Asset Surveyor 5.27 & Pathfinder Office 2.90	Point: Micro-R survey Point: Subsurface radiation profiles Polyline: Roads Polyline: Pit highwalls	OmniSTAR Satellite Corrections ~$900/year
Trimble GeoXT Hand-held unit	ArcPad 6 & ArcMap 8.3	Point: Micro-R survey Point: Subsurface radiation profiles Polyline: Roads Polygon: Clean up areas Polygon: Spoil piles	WAAS (Wide Area Augmentation System)

Gamma Radiation Survey

We used gamma radiation surveys to assess the extent of contamination from radioactive materials left on the surface. We collect gamma radiation data when characterizing abandoned uranium mines because uranium's decay products, particularly radium, produce much of the gamma radiation that is detected at a site. Radium is the source of radon, a serious health risk (U.S. EPA, 2006). Site-specific background radiation levels are established by measuring the natural, non-anthropogenically-affected gamma radiation of the surrounding landscape. This radiation background, with its associated radium concentrations, is used to establish the degree of cleanup that will be required at a site. We usually attempt to leave materials in the top two to four feet that contain a maximum of 5 pCi radium-226 over background levels. I surveyed the entire mined area with a hand-held sodium iodide scintillator (Ludlum® MicroR meter, used for low-level gamma surveys). The gamma radiation observations were taken at a 1-meter height and at varying distances from each other, depending on the relative changes in radiation levels.

More measurements were made around the outer perimeter of the spoil piles, where gamma radiation levels began to decrease, in an effort to differentiate between land influenced by the mining and the surrounding unaffected areas.

The preliminary radiation readings from 1999 were recorded with a Trimble® GeoExplorer II™ and the GPS positions were post-processed to increase accuracy. I recorded the remainder of the radiation data with a Trimble® TSC1 data collector (attached to a Trimble® ProXRS™ GPS receiver using real-time OmniStar satellite corrections). I held the MicroR meter in one hand and the TSC1 data collector in the other (Figure 2). This proved to be ergonomically preferable and helped speed up data acquisition. Data entry was accomplished with the same hand holding the data collector (using that hand's thumb). Over 3,000 radiation observations were collected in eleven days with the ProXRS/TSC1 GPS equipment. Between four and twenty-seven GPS positions were taken for each radiation observation, with an average of six GPS positions per data point – roughly equivalent to 5-1/2 hours standing still in one spot while collecting GPS positions. In contrast, if the GeoExplorer II had been used for all the data collection, the time spent waiting for GPS positions would have been twenty-five to forty-two hours. Another benefit offered by the ProXRS GPS backpack was protection from the thorny brush. I found that I could easily traverse the thorny brush by first walking backwards for a couple of steps, using the backpack as a shield, and then gradually pivoting to a forward position.

Subsurface Radiation Profiles

Many shallow holes were bored throughout the mine site to allow collection of subsurface radiation data. We have found downhole gamma radiation is usually linearly correlated with Ra-226 contents (also in Beahm, 1989), so we have used microR meter observations to identify radioactive materials that need to be cleaned up . Even though varying amounts of clean cover can attenuate gamma radiation from buried radioactive materials, localized radon flux can still occur and pose a health hazard (Dolan et al., 2003). A cylindrical gamma scintillator (5.1 X 18.5 cm) was lowered into each hole and gamma radiation measurements were taken at selected intervals. An example of the resulting data plotted with Statgraphics™ is shown in Figure 3.

At the beginning of the survey, all of the subsurface radiation data were recorded in a field book. Our AML program was fortunate to receive a Trimble® GeoXT™ handheld GPS from the Office of Surface Mining (OSM) halfway through the survey. I was able to field test the unit and found that it greatly facilitated the recording of the subsurface radiation data. The GeoXT™ was WAAS (wide area augmentation system)-enabled and provided sub-meter accuracy for the borehole locations (Figure 4). Also, since the GeoXT™ runs Microsoft (MS) Windows Mobile, I was able to enter all of the data directly into a MS Excel™ spreadsheet in the field. This provided significant time savings because I did not have to repetitively record the depths for each measurement in a field book. Instead, I could cut and paste depth values for each borehole. Data entry was accomplished with a stylus, using Windows Mobile handwriting recognition and the screen's numeric block space. Another advantage of digital data entry is that I did not have to spend time in the office transcribing the field book information. In turn, I was able to cut and paste the Excel™ data into Statgraphics™ (a statistical software program) for data analysis and plotting of the radiation profiles.

I compared the functionality of the GeoXT™ to the ProXRS™ for a couple of days during the mapping. I found that there were many advantages provided by the GeoXT™: less weight (0.7 kg versus 6.7 kg for the ProXRS™ with 2 camcorder batteries); no cables (the ProXRS™ has three - with one regularly getting snagged by vegetation); color display, more memory; longer battery life; and more data collection options (can create shapefiles on-the-fly with ESRI's (Environmental Systems Research Institute) ArcPad 6™, while the ProXRS™ is relatively limited to the uploaded data dictionaries and generic features). I collected 228 pairs of points, using each GPS unit to collect a point for the same feature in the field. Subsequent analysis of the data points in ESRI ArcMap 9.1™ showed that the GeoXT points were offset to the northwest 95% of the time. The distance between the points ranged from 0.14 to 4.7 m (median was 1.2 m). The differences in location were probably caused by variation in GPS placement and height (the ProXRS antenna is located above a person's head which reduces signal blocking) and the different reference frames that provide the differential GPS corrections to each unit.

Reclamation Project Design

We used the mapping information we collected in the field, along with the topographic data, aerial imagery, and data from the Texas Natural Resources Information System (TNRIS) to design the reclamation project. The project engineer used Autodesk® AutoCAD with Carlson® SurvCADD™ to design the earthwork and prepare most of the bid documents. I compiled, evaluated, and interpreted all of the different site datasets using ArcMap 9.1™ and several of its extensions. For this paper, I will only discuss a limited number of the datasets that directly involved the use of ArcMap 9.1™ in designing the reclamation project.

Estimating Pre-Mine/Background Gamma Radiation Levels

Highly radioactive spoil materials were widely distributed throughout the site during mining. The gamma radiation readings at a 1-meter height ranged from 10 to 2,100 micro-Roentgens/hour (μR/hr or micro-R/hr) within the mined area and adjacent landscape. A reclamation project boundary ("disturbance area") was established soon after the surface radiation survey was completed. The boundary was based on the 1-m height gamma radiation data and included adjacent land where eroded radioactive materials had been deposited. Because of the shortened project timeline, this boundary was necessary early in the project approval process, before we were able to complete many of the boreholes for subsurface surveys.

We found that the gamma radiation levels within 50-100 meters of the more radioactive spoil piles were exaggerated because of the shine (radiation emanating from a distant object) generated by the spoil (Colorado–CDPHE, 2008). Consequently, I used downhole gamma radiation measurements to get a rough estimate of pre-mine/background radiation levels, since the detector would be relatively shielded from the radioactive spoil. I examined the radiation profiles from all the boreholes and picked those that did not appear to be influenced by overlying radioactive spoil or surrounding, above-ground radiation levels. I first ran several trials, using different interpolation methods from the Geostatistical Wizard (Geostatistical Analyst extension, ESRI® ArcMap™ 9.1) on radiation data at different depths. One of the trials involved co-kriging two datasets: the downhole 1-ft radiation for twenty-two boreholes and selected 1-m height gamma radiation data that seemed to be correlated with native ground and were not

noticeably influenced by adjacent radioactive materials. The resulting gamma radiation prediction map exhibited very linear features uncharacteristic of natural systems. After several trial runs with the Geostatistical Wizard, we opted to use simple kriging to estimate the baseline/pre-mine radiation levels because it did not require many decisions and provided a measure of prediction error. The input data for the estimate consisted of the 30-cm depth data from seventeen boreholes within the project disturbance area. I simplified the prediction map (Figure 5) by consolidating some of the prediction surface ranks and clipping the areas outside the disturbance boundary (Figure 6).

Quantification of Radioactive Materials

The locations and volumes of radioactive materials were determined by using a combination of datasets that were collected in the field. The areas encompassing radioactive materials were classified according to the range of radioactivity (Figure 7) then multiplied by spoil depth measurements to obtain estimated volumes of radioactive spoil requiring clean up. The spoil depths were obtained using three methods: direct measurements of the shallower materials boreholes, measurement of spoil pile heights with a tape measure, and spoil height estimates from the aerial photogrammetry. This level of detail was adequate for the bid document.

The clean up areas were prioritized with the mean gamma radiation levels that each of them exhibited. A range of gamma radiation levels was listed along with the estimated volumes (Table 2). Our plan was to have the contractor follow a backfill sequence that would sequentially place spoil having the highest radiation levels in the pits first, followed by the medium level spoil materials, and then ending with the low level radiation materials. This work progression would reverse the spoil placement that occurred during mining, resulting in the last materials used in the backfill likely being the first ones that had been removed by mining. Since we would be completely backfilling the pits, we had a finite volume (252,318 cubic meters [330,000 cubic yards] covering 34.5 hectares [85.2 acres]) that we used to establish the total quantity for earthwork.

We bid the project in May2005, but had to revise the bid document and re-bid the project because the lowest bidder submitted a non-compliant bid and the next highest bidder greatly

exceeded our estimated cost. In the process of re-bidding the project, the Radiation Control Program (Texas Department of State Health Services or TX-DSHS) was consulted about the relatively high radiation levels within a small portion of the project area. Radiation Control

Table 2. Clean up priorities and associated spoil volumes.

Gamma Radiation Range	Area Priority for Clean Up Efforts	Estimated Area	Proportion of Non-Pit Area	Estimated Volume
(micro-R/hr)		(m^2) (acres)	(%)	(m^3) (cubic yds)
>= 2001	Very High	45 0.01	0.015	44 57
>=901 and <2001	High	795 0.19	0.29	711 930
>=351 and <901	Medium	36,164 8.94	13.8	37,233 48,696
>=151 and <351	Low	93,397 23.07	35.6	82,139 107,428
<151 to >Baseline	Very Low	103,422 25.54	39.4	13,529 17,694
<= Baseline (Variable)	At Estimated Baseline or Below	28,692 7.09	10.9	N/A
	Total	282,515 64.84	100.0	133,656 174,805

Program staff considered the radiation levels high enough to require the monitoring of personnel exposure to radiation, so we added bid specifications for radiation monitoring. The amended specifications required that the contractor hire a health physics consultant to provide the following for contractor staff working at the site: pre- and post-project urinalyses; whole body dosimetry; and personal air sampler monitoring (air sampler filters were analyzed for gross alpha and beta gamma in the field, then sent to a laboratory for determination of uranium and radium).

The TX-DSHS provided a pre-construction radiation safety course at no cost to the contractor's employees and AML program personnel.

Project Management

We depended heavily on GPS equipment during all phases of the reclamation project. Elevation control during earthwork employed a Leica Geosystems SR530 RTK DGPS (real-time kinematic, differential GPS). I uploaded all of the reclamation project shapefiles, along with baseline radiation data, to the Trimble GeoXT™. ArcPad™ software (ESRI) was used in the field to document progress of the reclamation efforts. This GPS/mobile GIS tool allowed us to easily establish vantage points for site photographs, keep track of the targeted radioactive materials, verify cleanup of areas, estimate spoil volumes in the field, and determine work payment quantities for the contractor. All of the following examples involved the GeoXT™ running ArcPad™ version 6.

Progress of Reclamation Efforts

Field observations were collected with the GeoXT™ to document reclamation progress. These observations were regularly uploaded to ArcMap 9.1™ in the office. These interim project status maps were saved as separate MXD files, exported to PDF (Adobe™ portable document format) files, and output to a color laser printer for our project field books (Figure 8).

Vantage Point Photographs

We picked eleven locations within and around the project boundary where we believed we would be able to photographically record the progress of the reclamation project. Each vantage point location was recorded with the GPS along with compass bearing of the direction we were facing. All of the pre-reclamation photographs were printed on a single page, along with the compass bearings, which was included in our project field book (photograph, Figure 9). That way, we were able to reference the landmarks within each image while we were framing subsequent photographs in the field. This worked well and provided enhanced project documentation (Figure 10).

Verification of Radioactive Material Cleanup

I created a GIS point feature to record radiation measurements during the reclamation project. I would survey areas where the contractor had picked up radioactive spoil materials and record the resulting gamma radiation levels. These clean up radiation levels were plotted on the estimated baseline gamma radiation levels (Figure 11). It is evident that the post-reclamation 1-m gamma radiation measurements were lower than the estimated pre-reclamation gamma radiation in approximately 70% of the project area. Much of this difference was due to the bias caused by radioactive ground shine. In contrast, there were small areas under some of the spoil piles where the natural radiation levels were significantly higher than estimated. Overall, we were satisfied that our reclamation mitigated the technologically enhanced naturally-occurring radioactive materials (TENORM) left behind by the mining (Figure 12).

Field Estimates of Radioactive Spoil Volumes

Fortunately, we were able to use the contrasting colors of the spoil and underlying native soil to roughly gauge the degree of clean-up attained. The perimeters of any areas containing radiation levels that exceeded our estimated baseline gamma radiation thresholds were staked and flagged. A polygon GPS feature was contemporaneously recorded with the GeoXT™ during flagging and its area (obtained by viewing that shapefile's Geography tab in ArcPad™) was multiplied by the spoil depth to provide an estimated volume. This volume was then converted to a dump truck load count so we could calculate the approximate time it would take to complete the work and any of our staff would be able to track clean up progress. Any areas requiring additional clean up would be subsequently surveyed to document and ensure that gamma radiation levels were below the targeted level.

Work Payment Quantities

Reclamation project earthwork consisted of radioactive material cleanup and general contour grading, which was paid by the completed acre. The contract specifications required that the contractor both achieve the design contours and clean up radiation levels before they were paid for any earthwork. Consequently, the contractor decided to split the entire project area into quarters instead of taking the approach we had envisioned – which involved sequentially

backfilling the decreasing levels of radioactive material over the entire area. This alternative reclamation sequence radically increased the need to track clean up volumes and ensure pit volumes and depths were sufficient to receive remaining radioactive materials. The GeoXT™ gave us the capability to calculate real-time clean up areas and provide field documentation of completed contract quantities. The areas where general contour grading (earthwork) had been completed were documented with the GeoXT™ and billed by the contractor in five separate invoices. Total project cost was $2.1 million, which included $77,417.48 for radiation monitoring.

Other GIS-Related Tools

I also would like to mention a few other raster and vector analysis tools that we have used at the Mabel New-Superior site. ERDAS Imagine®, Spatial Analyst™, and GeoWEPP have been particularly valuable for our ongoing collaborative work with Dr. Philippe Tissot, a nuclear physicist on the faculty of Texas A&M University–Corpus Christi, and some of his students who have been evaluating the erosion, transport, and off-site deposition of TENORM from pre-law uranium mines in south Texas.

ERDAS Imagine® and Spatial Analyst™

ERDAS Imagine® (version 8.6) is an image analysis program that we routinely use to rectify/georeference raster files, enhance imagery, and mosaic and/or classify aerial photography. Spatial Analyst™ is an ArcGIS™ extension that allows spatial modeling and analysis. At the Mabel New-Superior site, I used ERDAS Imagine® to evaluate NAIP imagery in the process of finding an easier way to access a stock pond near the mine. I performed an unsupervised classification of a black-and-white aerial photograph, grouping the different kinds of vegetation into five classes (this analysis can also be accomplished with Image Analysis for ArcGIS). The classified image was brought into ArcMap™, where Spatial Analyst™ was used to convert the raster classifications into polygon features for area calculations. We were able to find several paths through the brush that would require less clearing (Figure 13). The five paths were uploaded to the GeoXT™ so we could use it to locate the chosen route and navigate to the pond.

GeoWEPP

GeoWEPP (Renschler, 2007) is a Windows program that provides an interface for WEPP (Water Erosion Prediction Project) and ArcMap™. GeoWEPP utilizes geospatial information from ArcMap™ that is associated with hillslopes or small watersheds (digital elevation models, soil or spoil data, vegetation, etc.) and models the data in a continuous simulation, providing assessments of soil conservation options. Dr. Tissot and Felischa Cullins, one of his graduate students, are comparing the GeoWEPP sediment transport and deposition predictions to actual soil/spoil sediments collected at different locations in the watersheds associated with the Mabel New-Superior mine. See Figure 14 for an example of a hillslope erosion analysis performed at another mine site.

Summary and Conclusions

The GPS and GIS tools available to the Texas Abandoned Mine Land (AML) Program made it possible to collect baseline data and to design, bid, and manage reclamation work in a limited amount of time. Much of the work would not have been possible or would have taken much longer to complete if these GPS and GIS tools had not been available.

The timeline from the beginning of baseline data collection to completion of the earthwork spanned 18 months. Every phase of the project utilized data collected with or displayed by GPS equipment. Mobile GIS and desktop GIS were used to analyze, interpret, and display the GPS data. A small AML staff (1 to 3 people) accomplished all of the preceding tasks (except the actual earthwork) quickly and accurately, using geospatial technology at every stage of the reclamation project.

We received indirect confirmation of the accuracy provided by our geospatial tools when we found an aerial photograph taken of the mine site in 1964. Unfortunately, this photograph was found six months after the reclamation project was completed. The photograph would have been an invaluable asset during data collection and reclamation planning, since it showed the mine site less than a year after mining had ended and before volunteer brush and trees covered the spoil piles. We georeferenced the aerial photograph and overlaid pre-reclamation gamma radiation

survey data on the photograph to see how they were related to the post-mine landscape. We were very pleased to see that the radiation survey data correlated well with the mine features (Figure 15).

Acknowledgements

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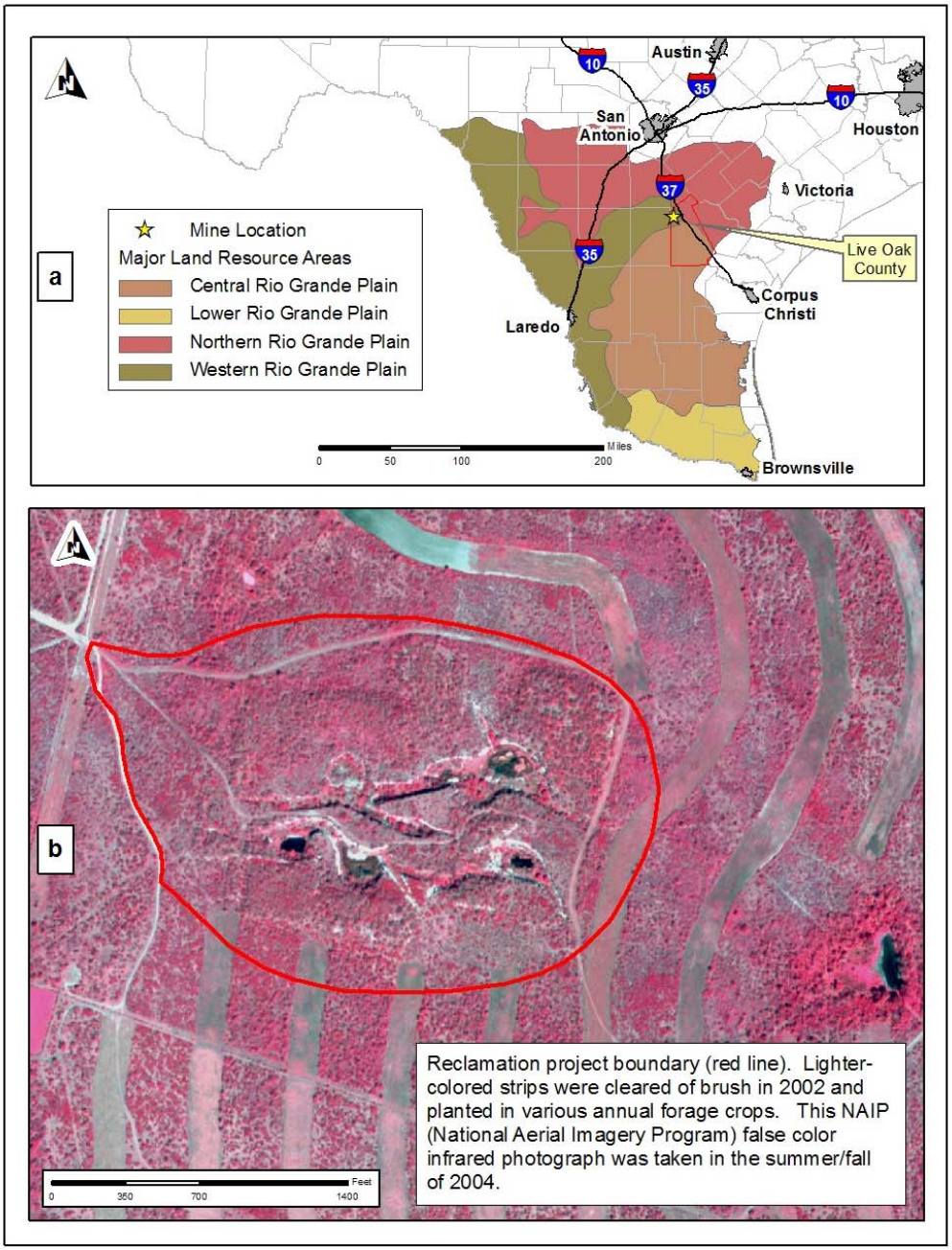

Figure 1a. Location of mine site; 1b. Mine site and adjacent landscape.

Figure 2. ProXRS backpack GPS with TSC1 data collector in right hand and MicroR meter in left hand.

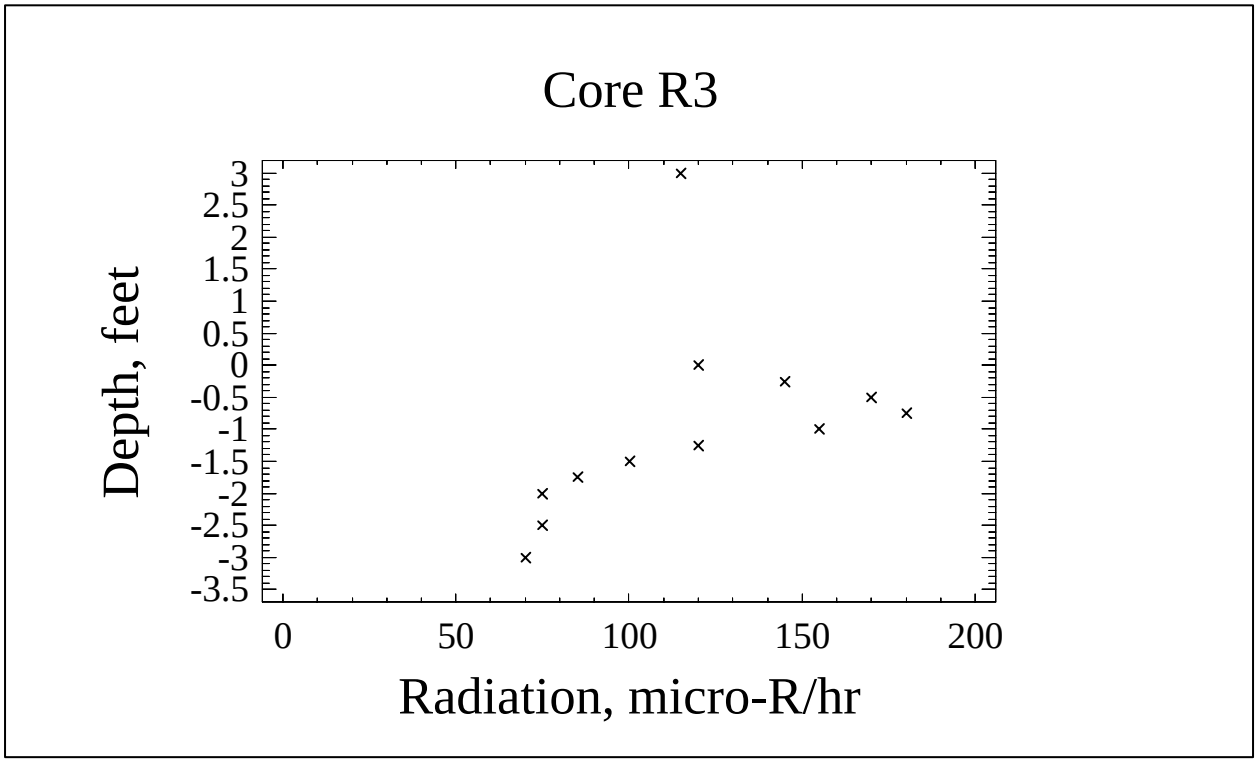

Figure 3. Example of the subsurface radiation profiles obtained from the boreholes.

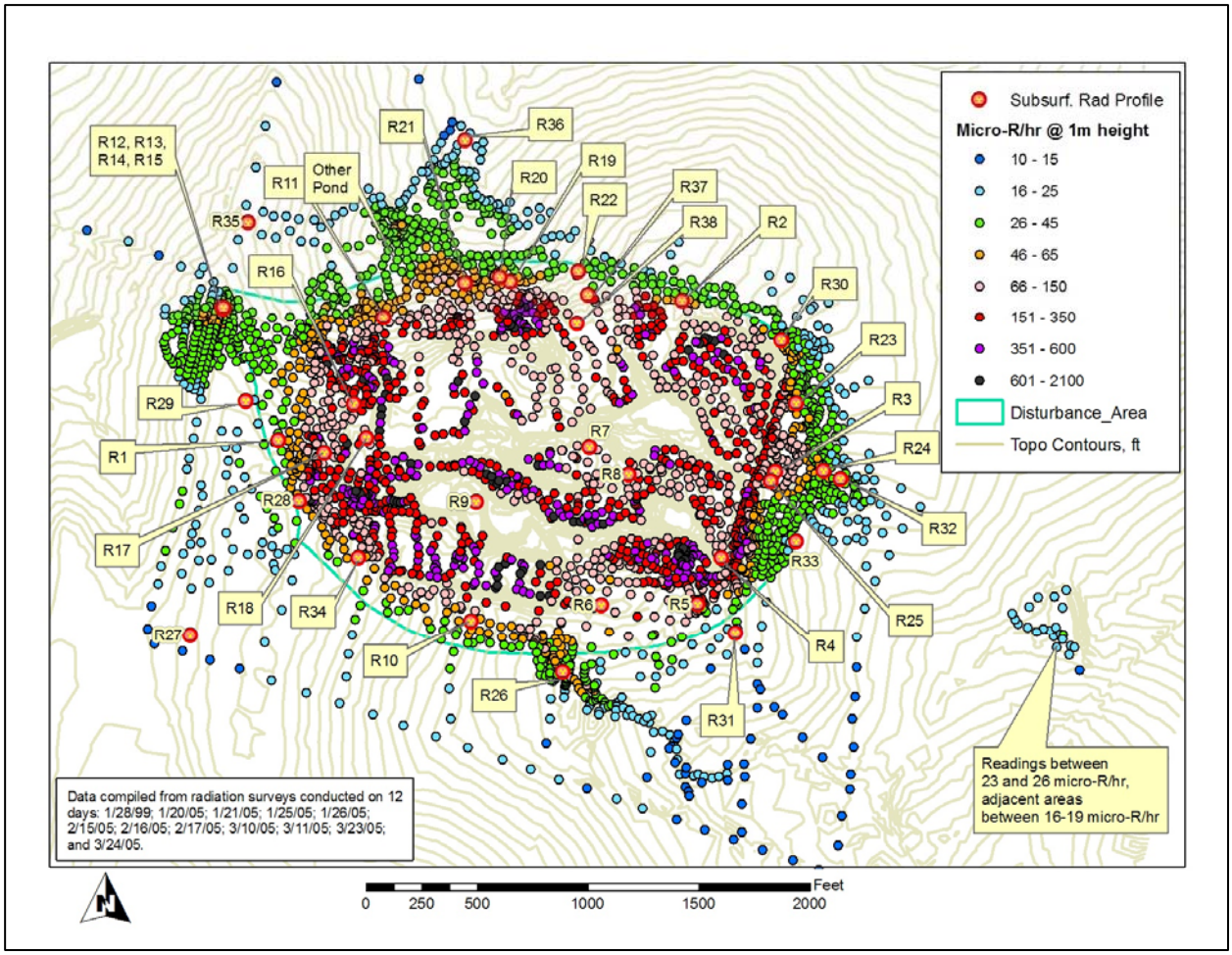

Figure 4. Subsurface radiation profile locations (boreholes) along with radiation survey data.

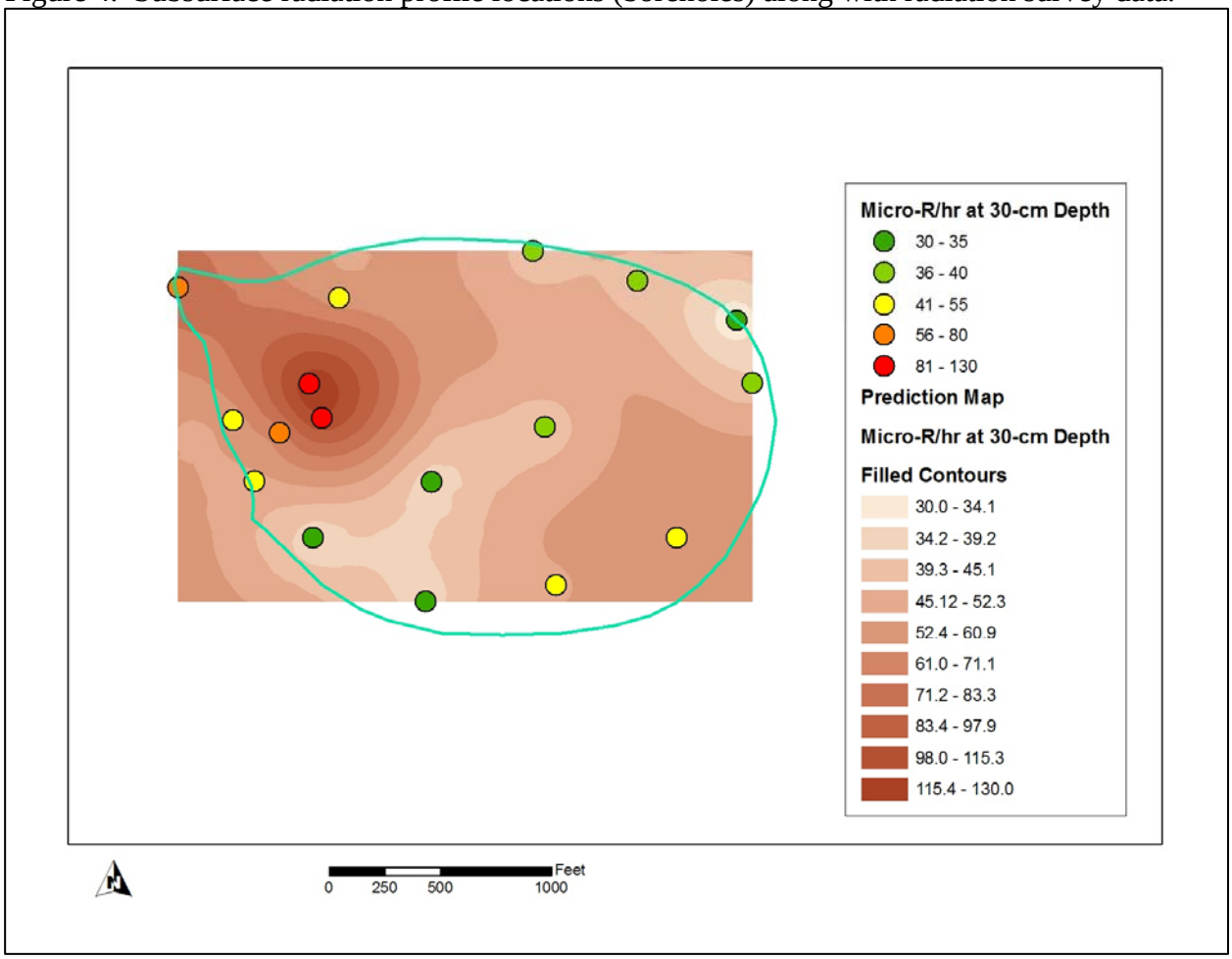

Figure 5. Surface produced by kriging selected subsurface gamma radiation readings.

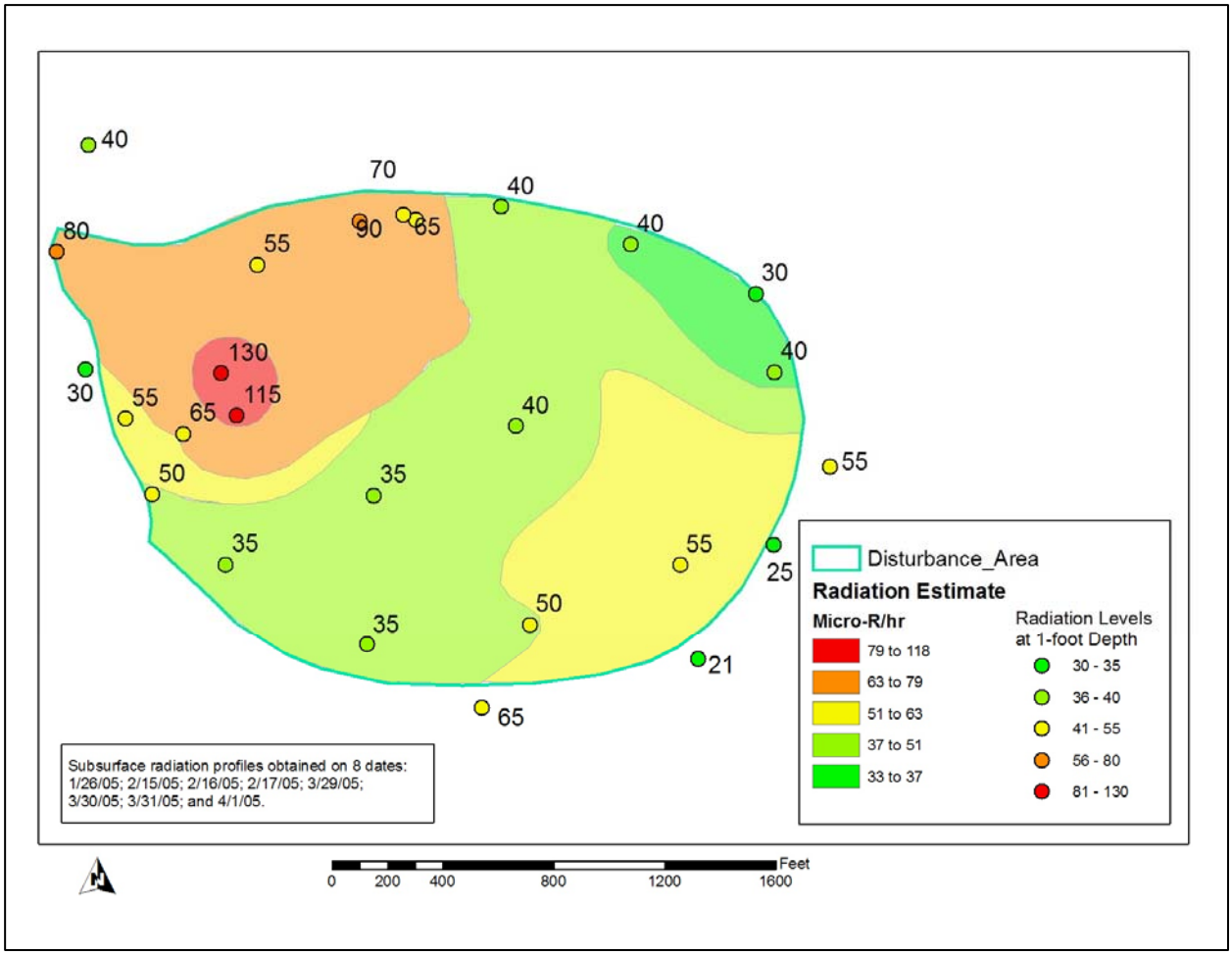

Figure 6. Estimate of pre-mine radiation levels used to establish clean up targets.

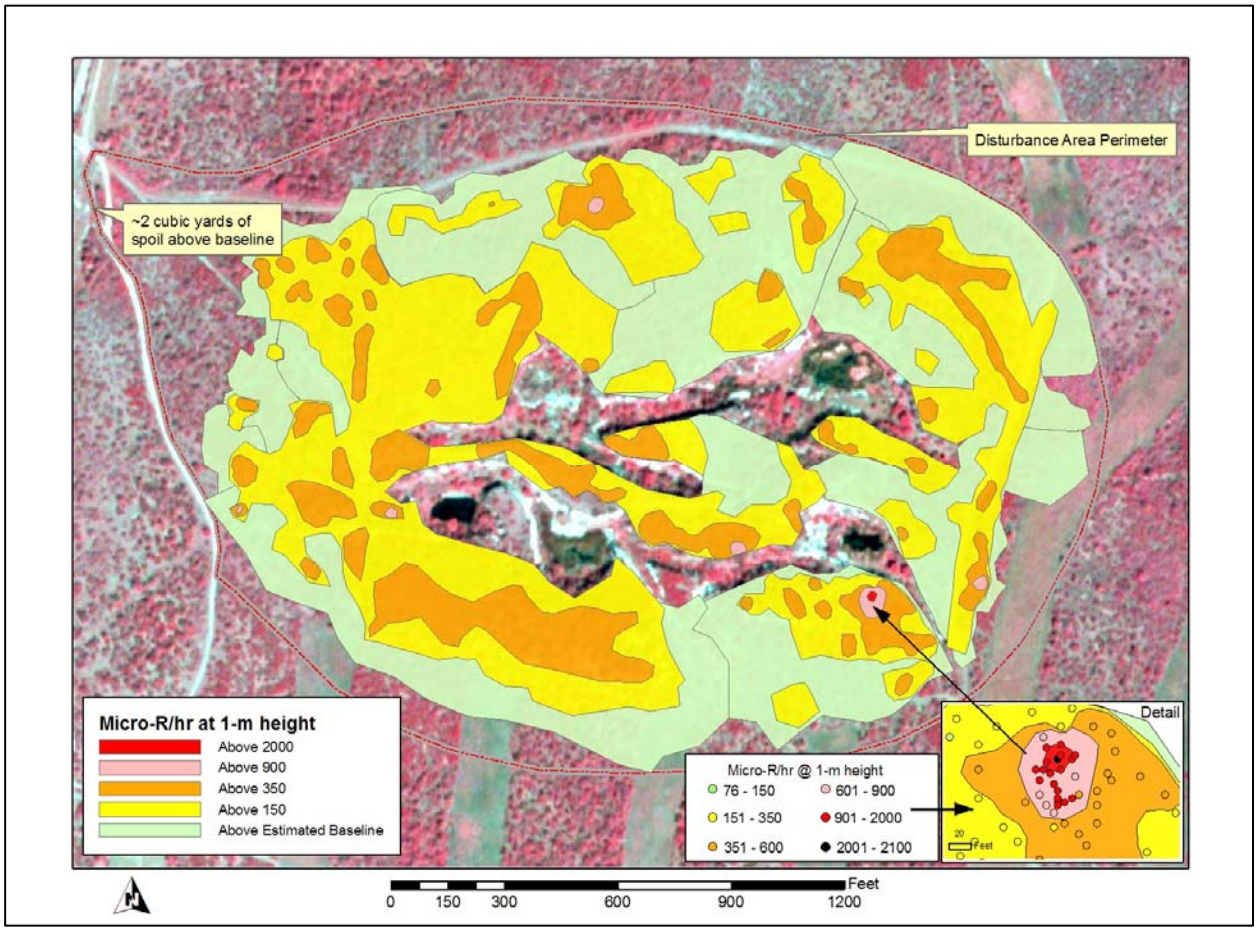

Figure 7. Areas requiring clean up, classified by radiation level.

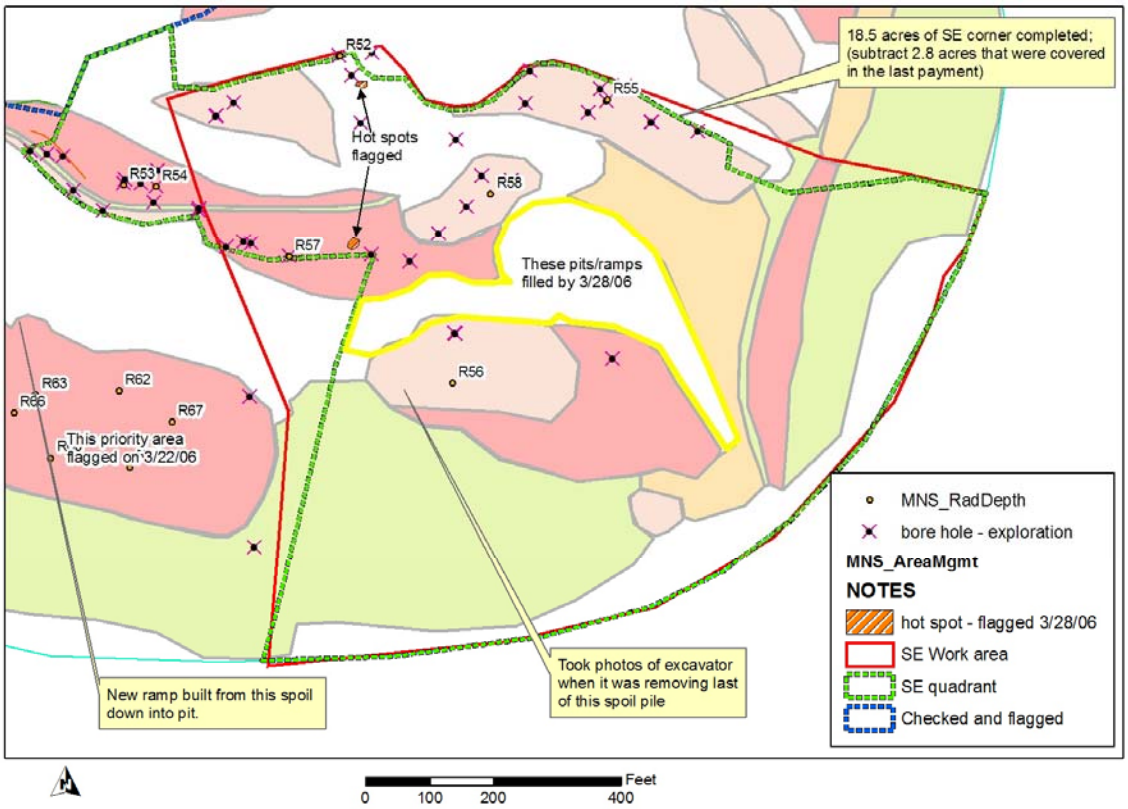

Figure 8. Example of interim project status maps used in the field.

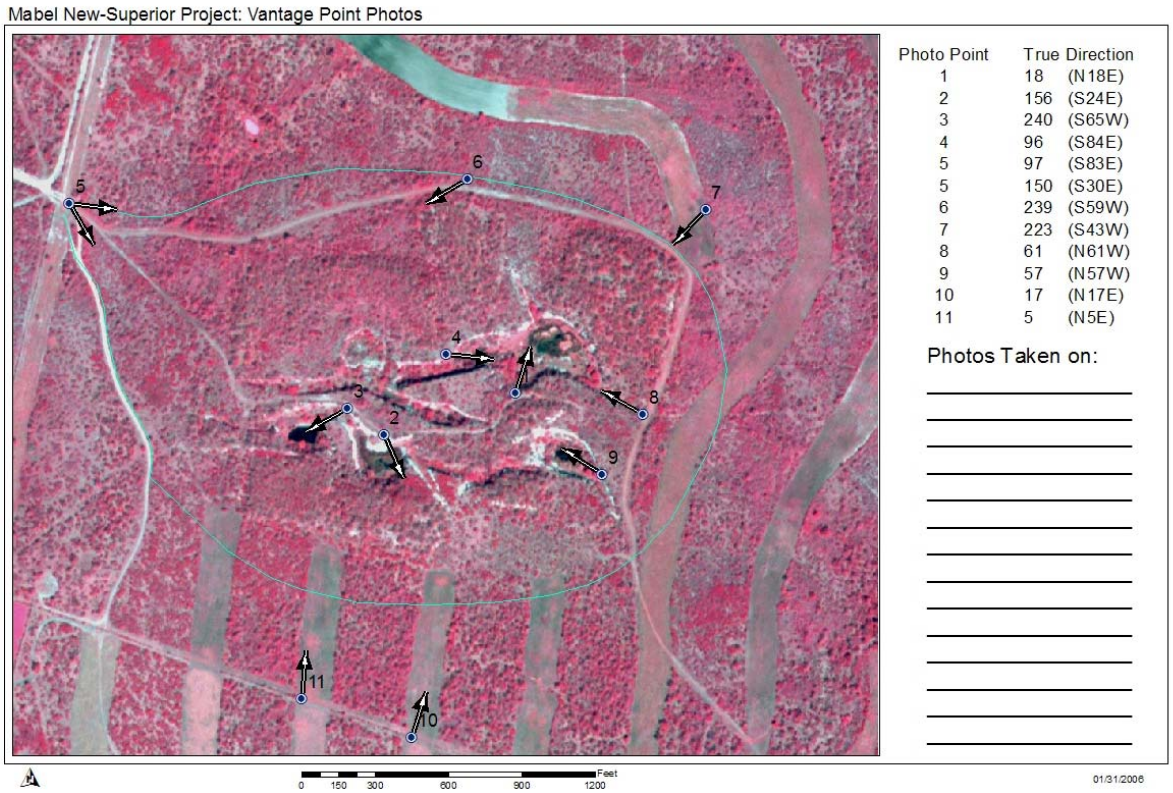

Figure 9. Locations and camera directions for vantage point photographs (which were taken to document progress of the reclamation project).

01/25/2006

02/09/2006

03/22/2006

Figure 10. Progress of earthwork associated with Ramp #3 over a two-month period, as documented from the same photo vantage point.

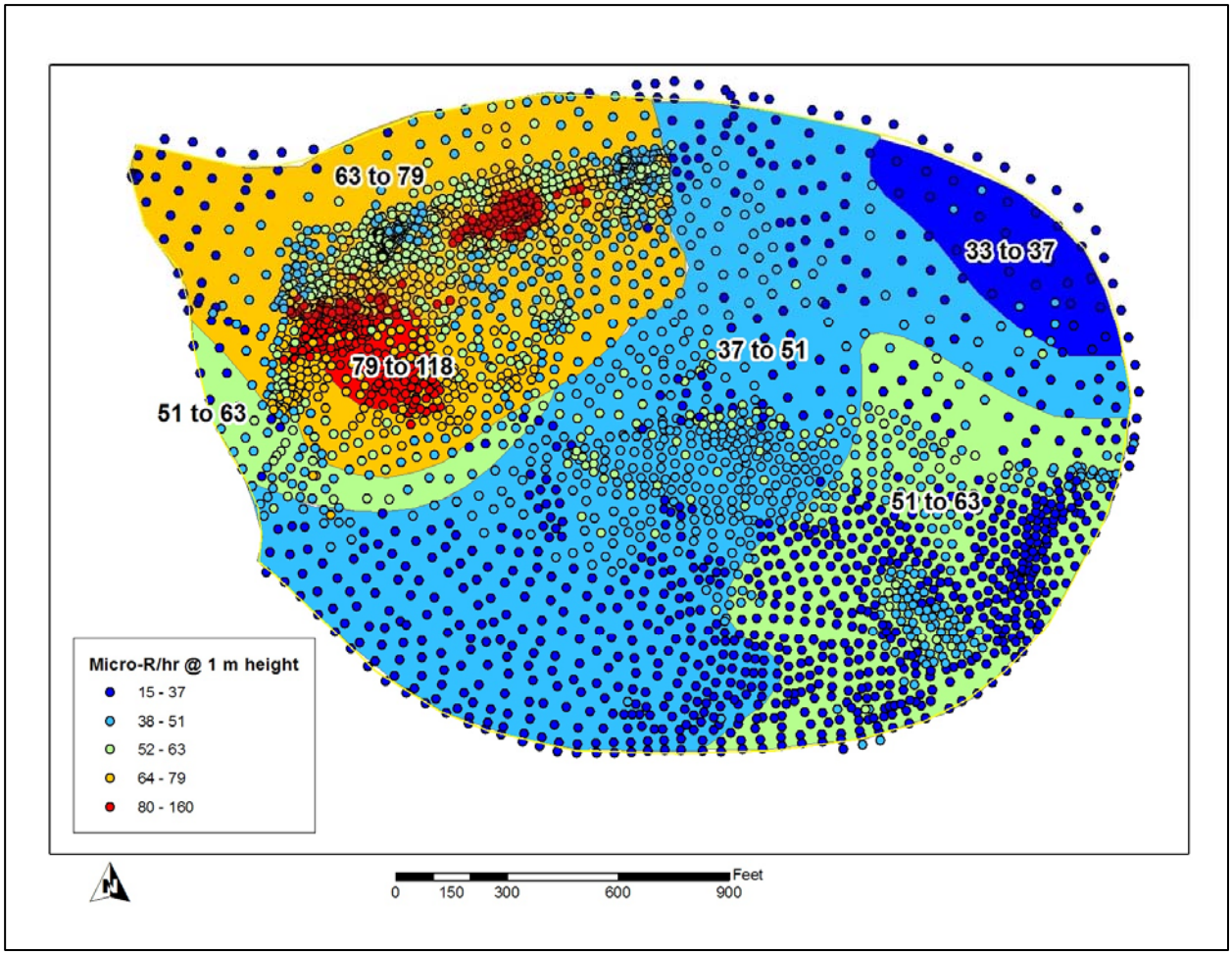

Figure 11. Comparison of post-reclamation gamma radiation data points to estimated pre-mining radiation levels.

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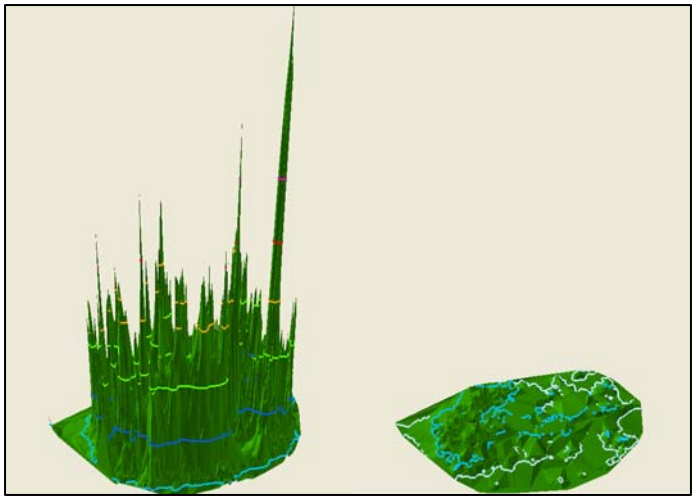

Figure 12. Relative gamma radiation levels before (left) and after (right) reclamation. Plots produced with ESRI 3D Analyst™ and ArcScene™.

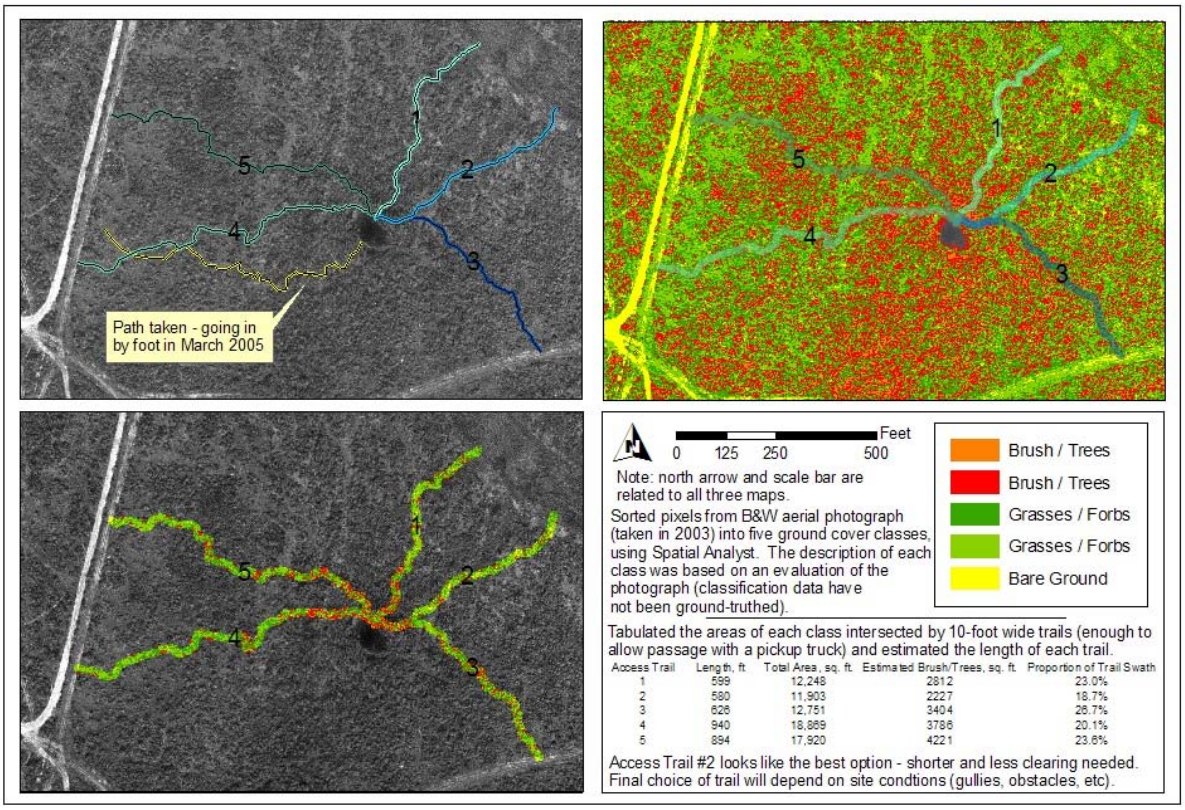

Figure 13. Use of image and spatial analysis to plot alternative paths to a sampling site, with estimates of the amount of brush and tree clearing associated with each path.

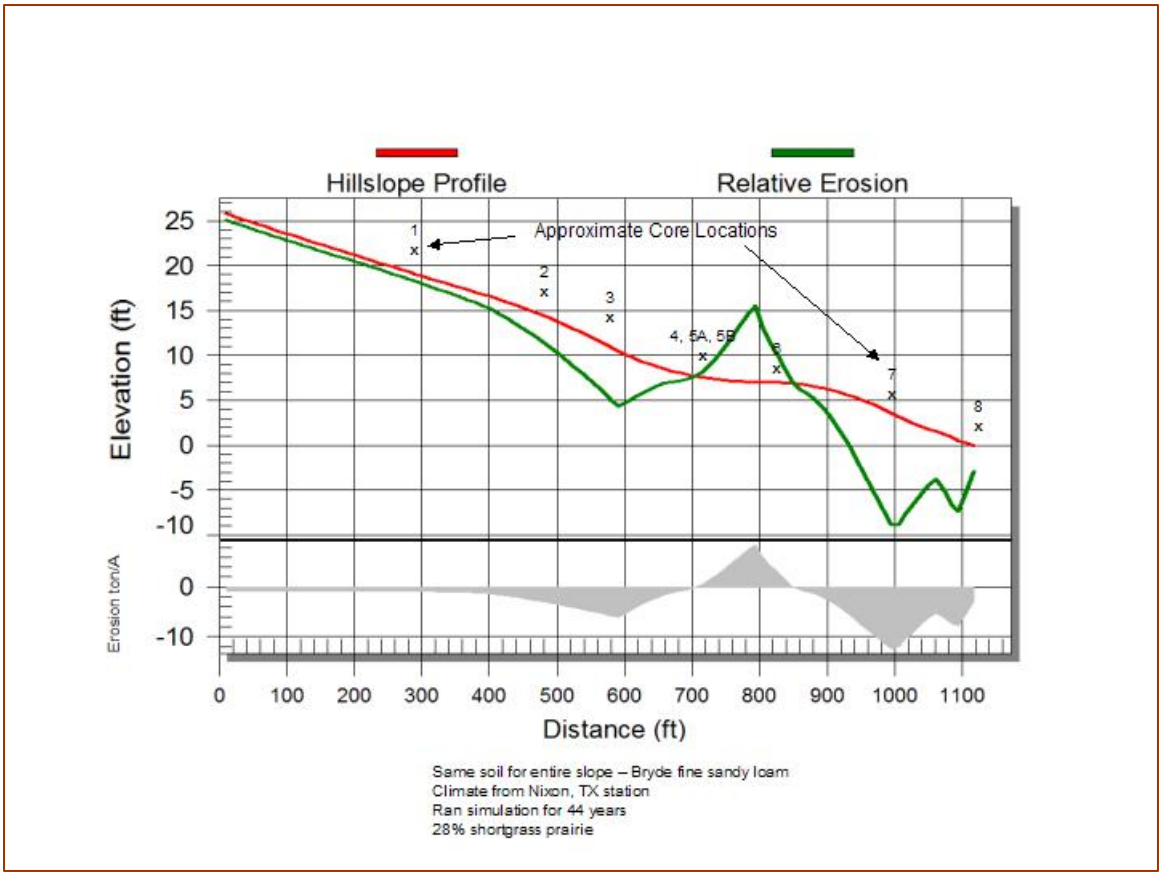

Figure 14. Example of hillslope erosion analysis provided by GeoWEPP. Note: the approximate sample core locations were added with a separate graphics program.

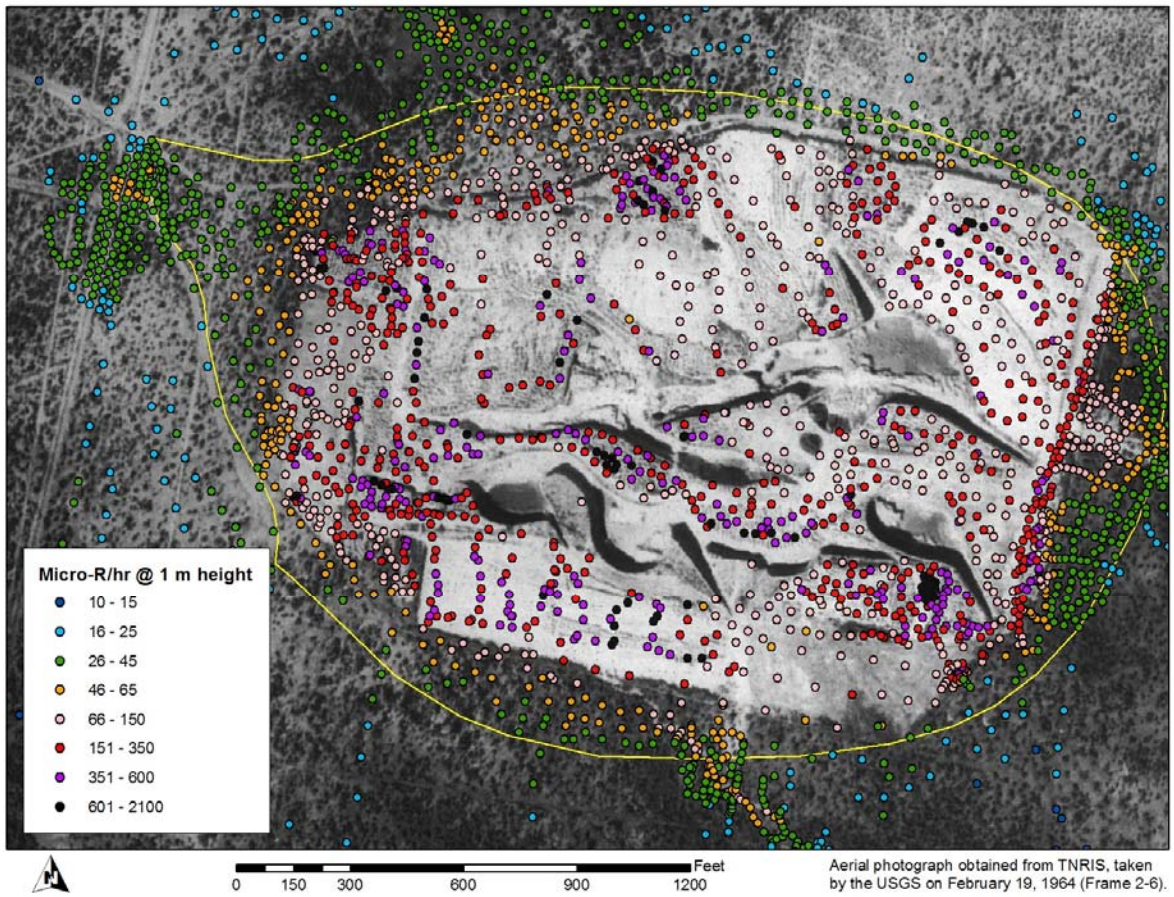

Figure 15. Pre-reclamation gamma survey data from 1999 and 2005, plotted on georeferenced aerial photograph taken in 1964 (less than a year after mining was completed).