PRIORITIZING ABANDONED URANIUM MINE LAND RECLAMATION USING A GIS MODEL[1]

Linda S. DeLay[2], Susan A. LucasKamat, and James R. Smith

Abstract: Abandoned uranium mines left a legacy of probable contamination in New Mexico. The New Mexico Mining and Minerals Division is collaborating with state, federal and tribal agencies to inventory and prioritize the reclamation of abandoned uranium mines. As a pilot project, the New Mexico Abandoned Mine Land Program sampled data from 38 abandoned uranium mine disturbances. Mine attributes, including radiation readings, mine disturbance areas, waste pile volumes, shaft and adit dimensions, cultural features and mine access roads, were collected using Trimble Pro XRS and XH GPS units utilizing a Pathfinder data dictionary. Radiation measurements were collected using Ludlum Model 14-C and Model 19 survey meters. Data of the various mine attributes were integrated into a personal geodatabase.

ESRI ArcGIS Spatial Analyst was used to build a model to prioritize the 38 abandoned uranium mines for remedial action. Mines were ranked by potential risk exposure to populations. Model inputs included the mine locations and proximity to dwellings, domestic wells and watercourses, density of mine openings and presence of high radiation readings. Thirty-five percent of the sites were less than 1.2 kilometers (0.7 miles) from a domestic well and less than 16 meters (52.5 feet) from watercourses. Sixteen percent were within 8 kilometers (5 miles) of a densely populated area; two sites were surrounded by dwellings.

ESRI ArcGIS Spatial Analyst was used to reanalyze the model with additional data for 108 abandoned uranium mine disturbances. Changes in priority ranking of mine sites are examined and discussed.

Additional Key Words: geodatabase, ArcGIS, Spatial Analyst, model

---

[1] Poster was presented at the 2009 National Meeting of the American Society of Mining and Reclamation, Billings, MT, ***Revitalizing the Environment: Proven Solutions and Innovative Approaches*** May 30 – June 5, 2009. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2] Linda S. DeLay is a GIS Analyst Specialist, Coal Mine Reclamation Program, New Mexico Mining and Minerals Division, 1220 S. St. Francis Dr., Santa Fe, NM 87505, Susan A. LucasKamat is a Geologist, Mine Registration Program, New Mexico Mining and Minerals Division, James R. Smith is a Reclamation Designer, Abandoned Mine Land Program, New Mexico Mining and Minerals Division.

Proceedings America Society of Mining and Reclamation, 2009 pp 302-330
DOI: 10.21000/JASMR09010302
http://dx.doi.org/10.21000/JASMR09010302

Introduction

Over 333 million pounds of uranium yellow cake (U_3O_8) was mined in New Mexico on private, state, federal, and Indian lands from 1940 to 2002 (McLemore, 2007a; Mine Registration Program, 1989-2002). Most of the production was from the Grants uranium (U) district in McKinley and Cibola (formerly Valencia) counties. These two counties produced more U than any other district in the United States during the period of 1951 to 1980 (McLemore, 2007a). Mines ranged in size from small dog holes and surface mines, with one to three workers, to large underground operations, employing hundreds of miners. Uranium ore was last mined in New Mexico in January 1990; U production continued via mine water recovery and ion exchange processing until December 2002 (Mine Registration Program, 1989-2008).

The abandoned U mines left a legacy of radiological contamination throughout New Mexico. Mining activities, such as the discharge of mine water, the use of unlined containment ponds, and the crushing and transportation of ore, dispersed contamination. With the recent renewed interest in U exploration and mining in New Mexico, there has been a push from the public to clean up the legacy of past U mining practices. A systematic analysis of the former U mining sites is required to prioritize the abandoned U mines by potential or existing environmental harm. Abandoned U mines include all U mines that have been deserted and are no longer maintained, or are inactive.

Purpose

The New Mexico Mining and Minerals Division (MMD) is collaborating with state, federal, and tribal agencies to survey, prioritize, and clean up the abandoned U sites. The purpose of the New Mexico Abandoned Uranium Mine (AUM) Inventory Project is to ascertain the extent and magnitude of the occurrence of abandoned U mines in New Mexico, especially those mines that have not been previously addressed by a tribal, federal, or state entity. The AUM inventory is a database of information on mine location, reclamation status, mining history, physical and radiological hazards, and production history. A goal of the inventory is to determine the appropriate means and remedy for rendering these sites safe to humans and returning the sites to beneficial use, including, but not limited to, a self sustaining ecosystem. The AUM inventory project was initiated in December 2006.

The AUM Prioritization Model is an attempt to create a spatial analysis model that represents and quantifies possible impacts of abandoned U mines for decision-makers to use in the reclamation and remediation planning process. The analytical and visual capabilities of geographic information systems (GIS) can be a useful tool in qualifying and quantifying spatial relationships for determining the priorities in addressing which abandoned U mines should be reclaimed first. The model described in this paper is a pilot project and is in the test phase. The model will not be finalized without further analysis and review, including consultation with appropriate agencies and tribal governments.

Methodology

Abandoned Uranium Mine Inventory Geodatabase

The Mining and Minerals Division created the abandoned U mine inventory as a collection of tabular data of geographic locations (latitude and longitude, UTM, and Public Land Survey System), mining methods, mining features, mining history, surface and mineral ownership, production statistics, approximate disturbance areas, reclamation activities, radiological hazards, post-mining land use, and regulatory/jurisdictional agencies. The first step in creating the database was to define a U mine. The definition of U mine has two extremes: 1.) a property with verifiable U production, or 2.) any prospect, exploration project or a property that was developed to produce U. Verifiable U production at mines created extensive surface disturbances that increased potential exposure and risk to human health. Development projects and prospect properties did not create extensive surface disturbances. Therefore, only mines that have verifiable U production are included in the AUM inventory.

To create the AUM inventory, MMD started with the two New Mexico Bureau of Geology and Mineral Resources publications: "Database of the U mines, prospects, occurrences, and mills in New Mexico" (McLemore, 2007b; McLemore, et. al., 2002) and "Uranium mines and deposits in the Grants district" (McLemore and Chenoweth, 1992). This database was created for use in U resource analysis on a section and quarter-section basis. According to McLemore (2007b), there are 1,534 occurrences, prospects, deposits, and mines in New Mexico that have U mineralization, exploration or production associated with them. Of those 1,534 records, approximately 330 occurrences have verifiable U production and 466 disturbances have no verifiable production. The database records were analyzed and combined to create one abandoned U mine per shaft/pit complex. The Mining and Minerals Division identified 259 AUMs (Fig. 1) with verifiable production.

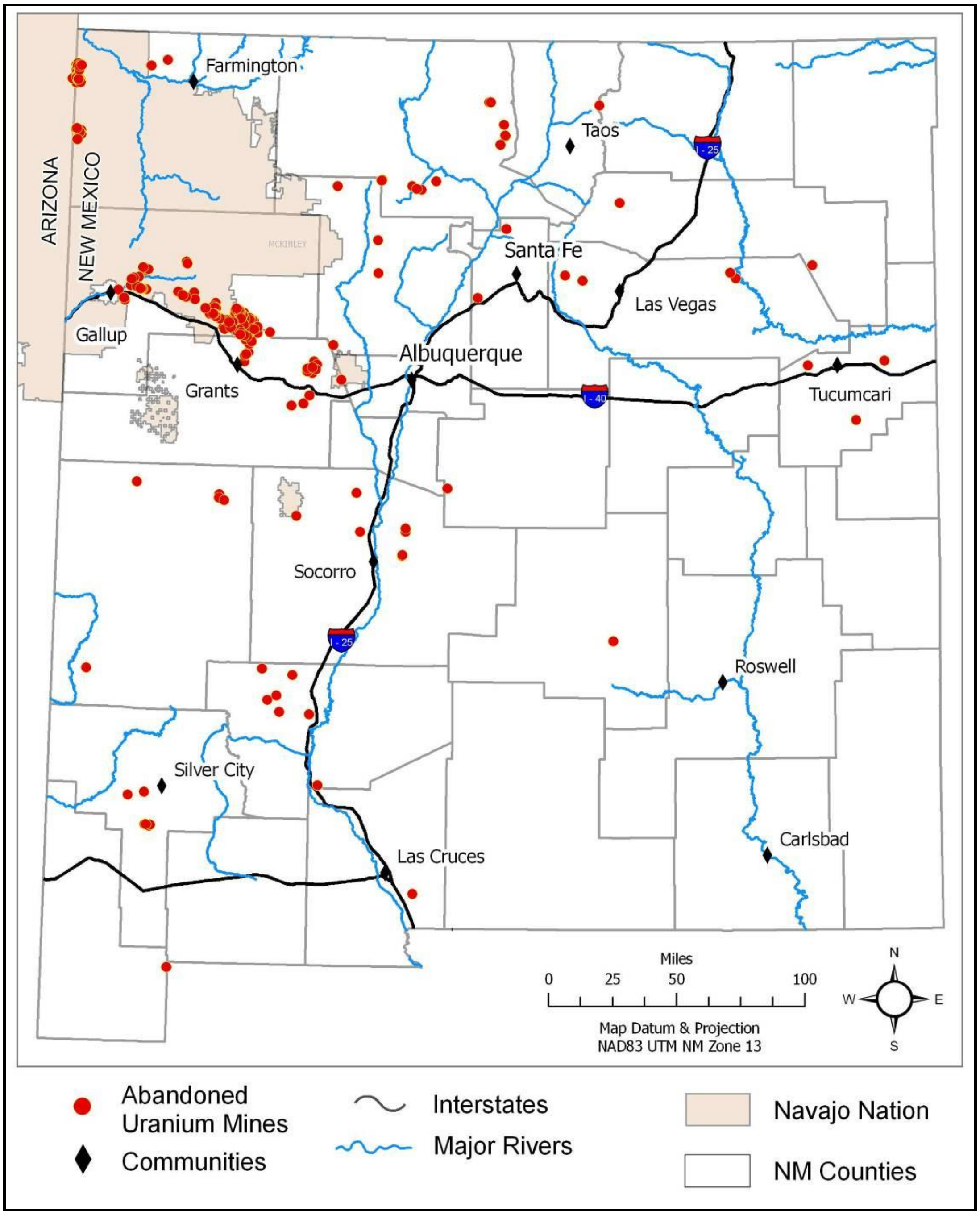

Figure 1. Distribution of abandoned uranium mines in New Mexico.

The tabular records were supplemented with details from mining company registrations and field investigation reports. The New Mexico State Mine Inspector has mining company registrations for U mines that operated from the 1950's to 1980's (State Mine Inspector, 1954-1980). The primary source for field data is the 1981 AUM survey (Anderson, 1981). The Bureau of Land Management (BLM) completed field investigations of selected U mines on federal lands in the 1980's and 2000's (Schuster, 1985; BLM, 1987; BLM, 2002). Cultural resources reports and project files from past New Mexico Abandoned Mine Land Program construction projects were also used as references (Fuller, 1989; Drake and Fuller, 1990; Abandoned Mine Land Program, 1981-2008a).

Starting in July 2007, mine feature attributes were collected during field visits to the abandoned mine sites by both MMD staff and contractors (Abandoned Mine Land Program, 1981-2008b; Souder, Miller & Associates, 2008). Mine feature attributes (Fig. 2), including radiation readings, mine disturbance areas, waste pile volumes, shaft and adit dimensions, roads, and cultural features, were collected using Trimble Pro XRS and GeoExplorer XH GPS units utilizing Pathfinder data dictionaries (Fig. 3). Radiation measurements were collected at both ground contact and at 1 meter height using Ludlum Model 14-C and Model 19 survey meters and recorded using the GPS units.

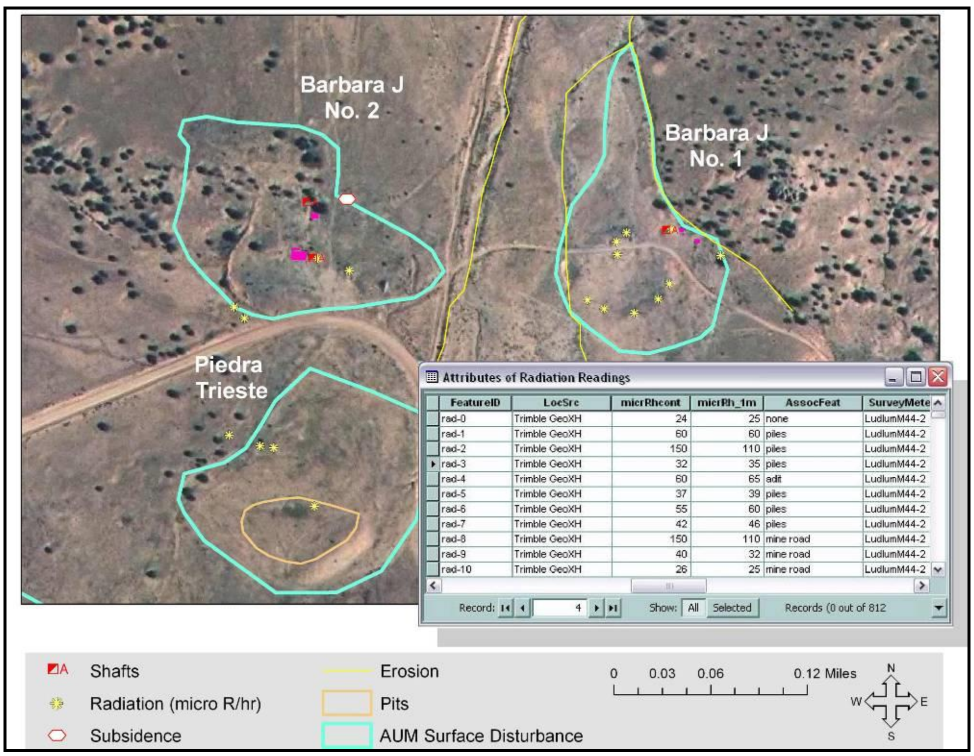

Figure 2. Example of field data collected for each AUM disturbance.

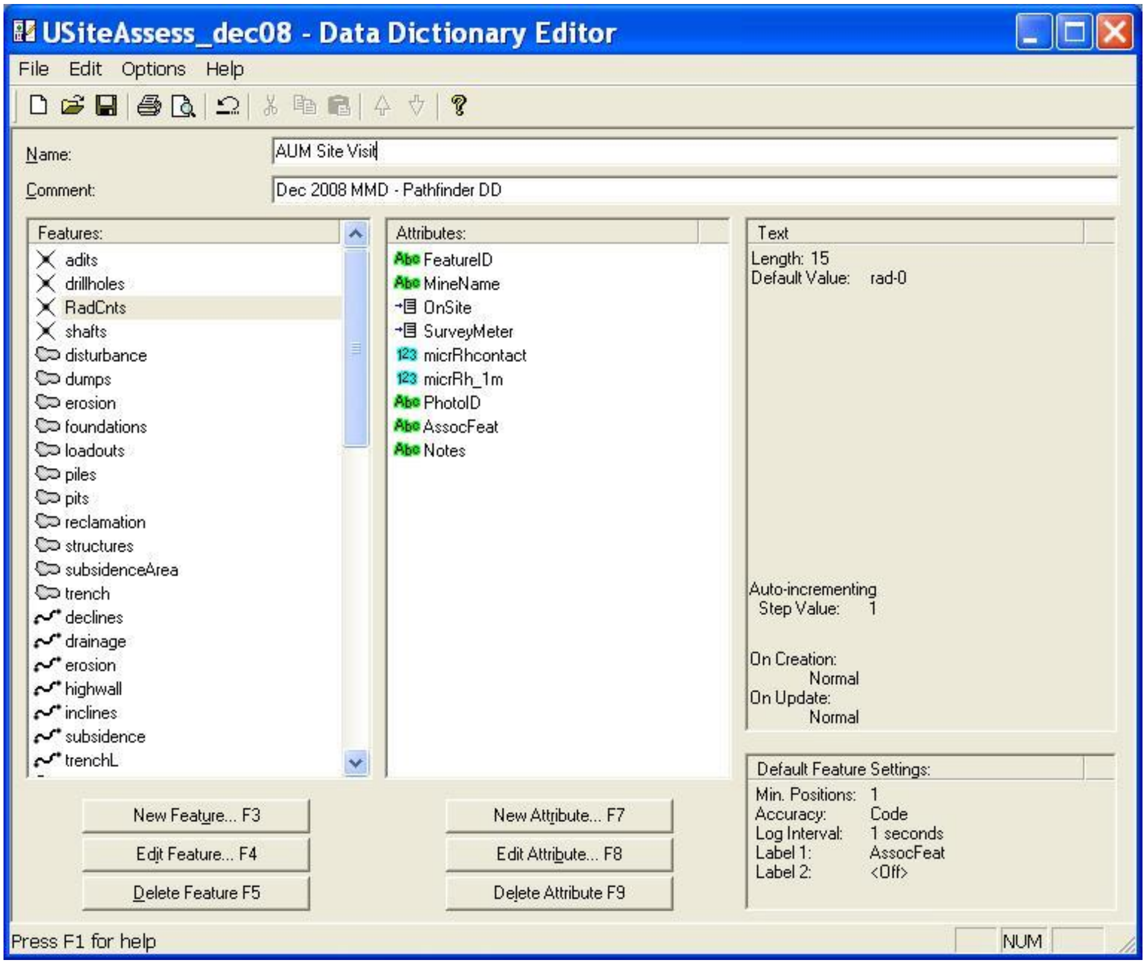

Figure 3. Data dictionary used to standardize data collection between contractors and MMD staff. The highlighted feature above, RadCnts was used to collect radiation readings. Attributes collected for each location included a feature identification number (FeatureID), the mine name (MineName), a yes/no pull-down to identify if the point was within the mine disturbance (OnSite), a pull-down list of survey meters (SurveyMeter), the radiation reading at ground contact (micrRhcontact), the radiation reading at 1 meter (micrR_1m), corresponding photo identification number (PhotoID), the names of any associated features (AssocFeat), and other notes (Notes).

Mine disturbance areas were delineated from 1-meter resolution 2005-2006 digital orthorectified quarter quad (DOQQ) aerial photography in ArcView 9.2 and 9.3. The extent of GPS-collected features, site information, historic reports, and color and texture contrasts visible in the DOQQs all contributed to the decision of where to locate the mine perimeters. The mine perimeters may not match the underground extent of the mines. Due to sparse vegetation cover of the area, many roads and vehicle tracks could also be identified, useful in navigation to and from sites during field assessments. Many roads served as haul roads to transport ore between the U mines and mills. The road data provides additional information on the possible extent of mine disturbances and possible contamination pathways.

The GPS data (features and feature attributes) collected over a period of several months were converted into feature classes within an ESRI personal geodatabase. Digitized information, supplementary field note data, and hyperlinks to digital photos were standardized and integrated using ESRI ArcInfo 9.2 and 9.3 software. Shapefiles were converted to feature classes within an ESRI geodatabase. The geodatabase offers many advantages over shapefiles by providing better organization, attribute management, geometry editing and analysis capabilities.

Prioritization Model

The goal was to prioritize AUM sites based on several variables that could represent possible impacts to human and ecological health through exposure to U waste. Field survey data from 38 AUM disturbances (Fig. 4) were analyzed as a ranking pilot project to study how the AUMs could be prioritized. Because AUMs are distributed throughout the state, the analysis and priority model were run on the state as a whole and on specific watersheds.

After the initial pilot analysis, we reanalyzed the GIS priority model with an additional 70 AUM sites (Fig. 5). We were interested in discovering which AUM sites would be classified as high and low priorities. At this time, there are no radiation measurements available for the additional 70 mines; therefore, the second model was run on the superset disturbances (n=108) without the radiation reading variable. The analyses involved 90 watershed sub-basins (HUC 12-digit).

Each mine was scored according to measurements of five separate variables: the number of open / unsafeguarded mine hazards, radiation readings (μR/hour) at 1 meter distance from the ground, the distance to nearest well, the distance to and spatial clustering of the nearest drainage, and the proximity, number and spatial clustering of dwellings within a 5-mile radius of each mine site (Fig. 6). The scores from the five variables were combined for each mine. Priority was based on the ranking of the scores for each mine site. The largest score was ranked the highest in priority and given a ranking of one. The second largest score was given a rank of two; the third, three. Ranks were assigned to all scores so that the lowest score had the highest rank. Ranks were assigned to a priority based on natural breaks in the scores. Priorities were classified into 4 groups: high (1), medium (2), medium-low (3) and low (4). Spatial Analyst in ArcInfo 9.2 and 9.3 was used to calculate statistics and metrics.

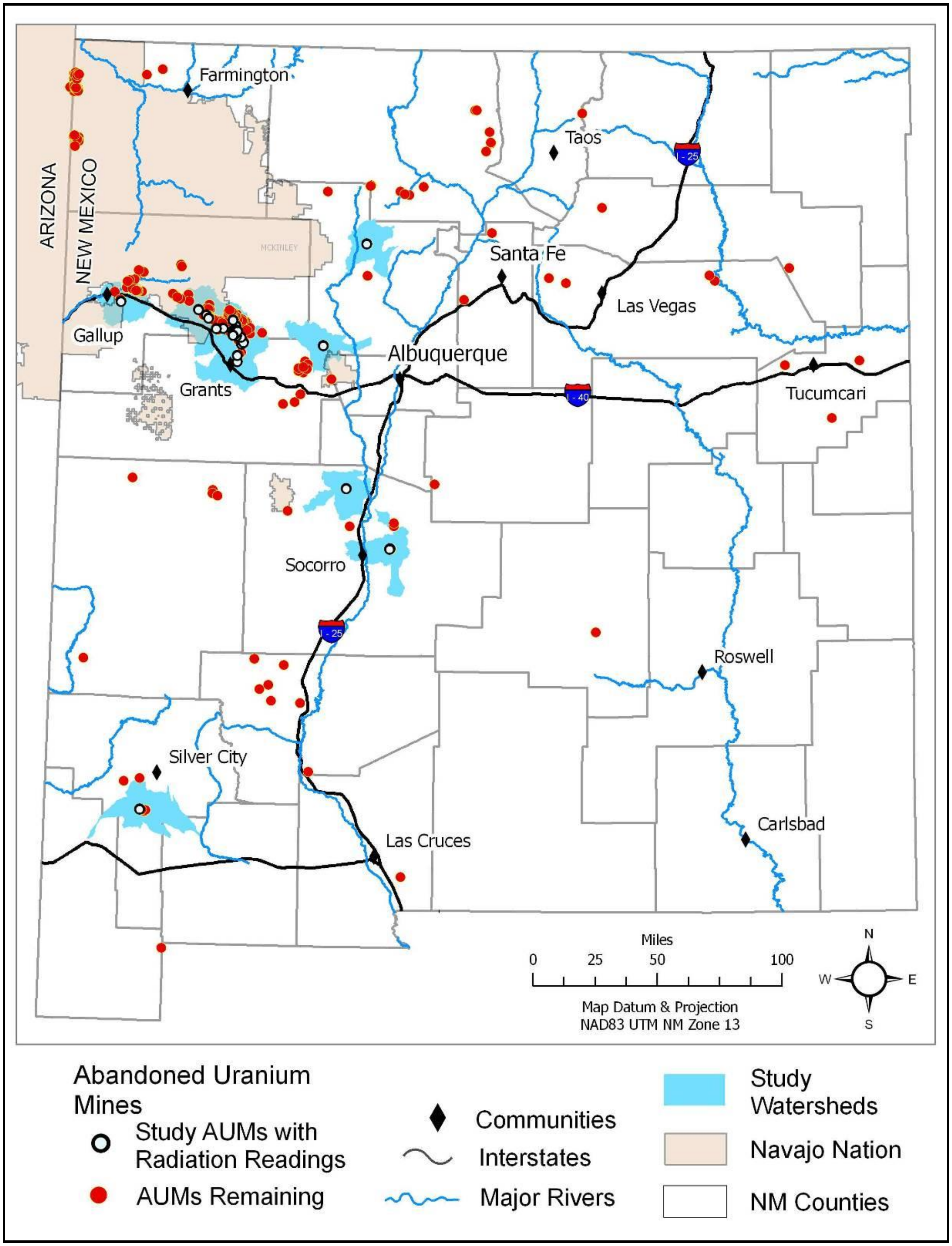

Figure 4. Thirty-eight abandoned uranium mines in New Mexico with radiation readings included in the ranking pilot study.

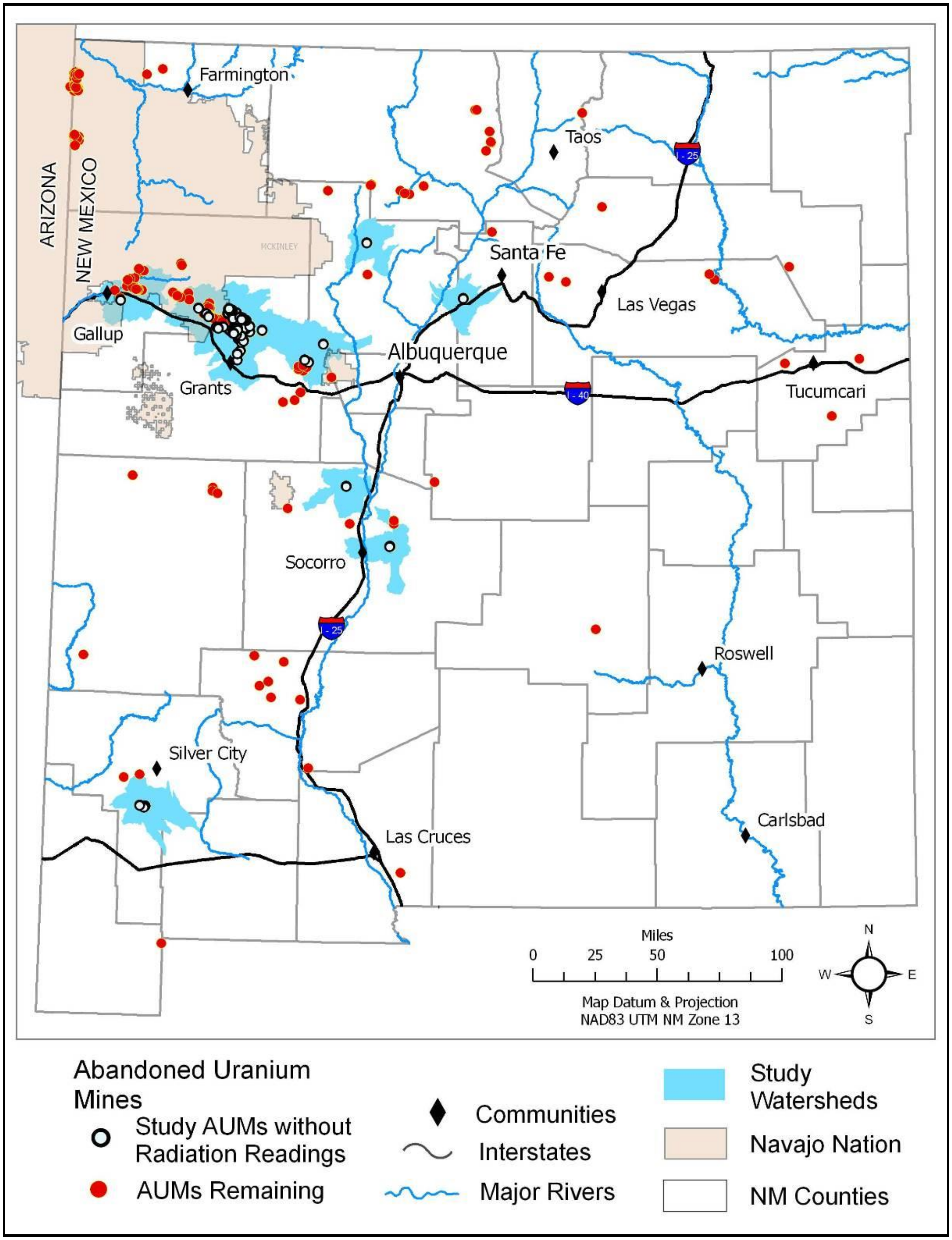

Figure 5. One hundred eight abandoned uranium mines in New Mexico in the expanded data set. Radiation readings were not included in the superset analysis.

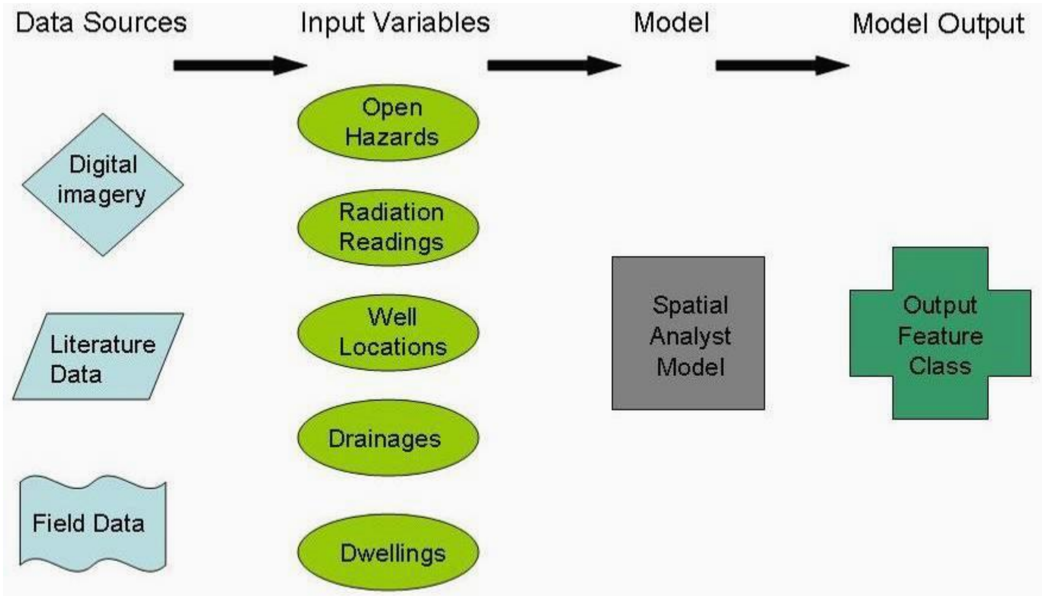

Figure 6: Abandoned uranium mine prioritization model schematic.

Open hazards. Open hazards at the mine sites include adits, shafts, inclines, pits, and trenches that are open and may present a physical hazard to people passing through the sites. The scores are based on the total number of open unsafeguarded hazards at each site; ten points were assigned per unsafeguarded feature (Fig. 7). The number of open hazards was based on observations of open features found during survey work and features that were recorded in project files and past survey reports. The cultural resources reports (Fuller, 1989; Drake and Fuller, 1990), Anderson (1981), and Abandoned Mine Land Program project files were used to locate features that had been reclaimed, that were still visible or that required safeguarding at a future date.

Radiation readings. Radiation readings within the mine boundaries were selected using the ArcInfo Intersect tool. This prevented background readings of off-site areas from being weighted in the analysis. ArcInfo's spatial analyst tool for descriptive statistics supplied a table of statistics. Preliminary sampling of general mine disturbances, waste piles, mine openings (shafts, adits, holes and wells), and mine access roads at AUM sites in the San Mateo Creek watershed (n=15) shows a wide range of radiation values at ground contact (Table 1). The average background radiation reading was 18.8 μR/hr (n = 5).

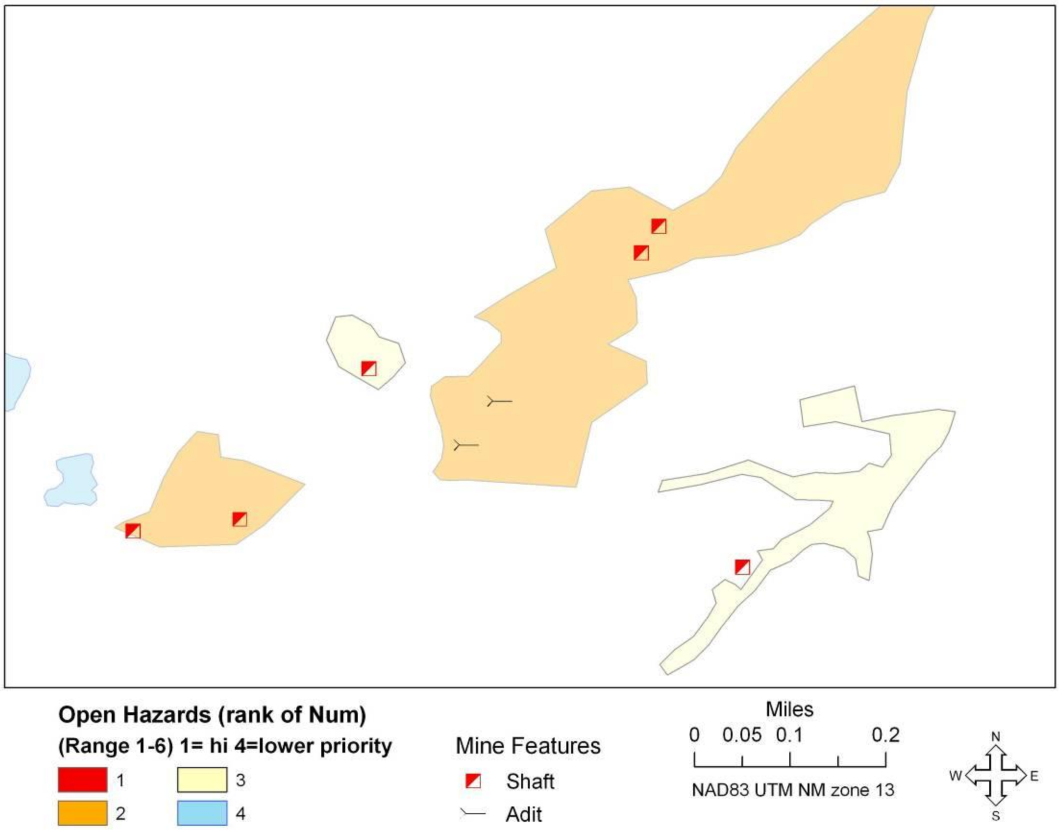

Figure 7. Method used to calculate open hazard priority. The rank of open hazards range between 1 and 6. Natural breaks in the data were used to classify these values into 4 priority groups.

Table 1. Radiation readings at ground contact (μR/h) at 15 mine sites.

Feature	General Mine Disturbance	Waste Piles	Shaft, Adit or Well	Mine Road
Sample size (n)	5	47	10	9
Average (μR/h)	297.8	387.7	197.0	159.5
Range (μR/h)	17 to 457	32 to 2857	21 to 486	26 to 400

The preliminary sampling ranges were used to set scoring ranges for radiation readings (Fig. 8 and Table 2). Scores were applied to sites based on the maximum radiation value. Readings above 450 μR/hr were labeled “hotspots” and given an added weighted value. The radiation scores were an attempt to classify the AUMs for the purposes of the priority model. They are not an established or cited standard by regulatory agencies.

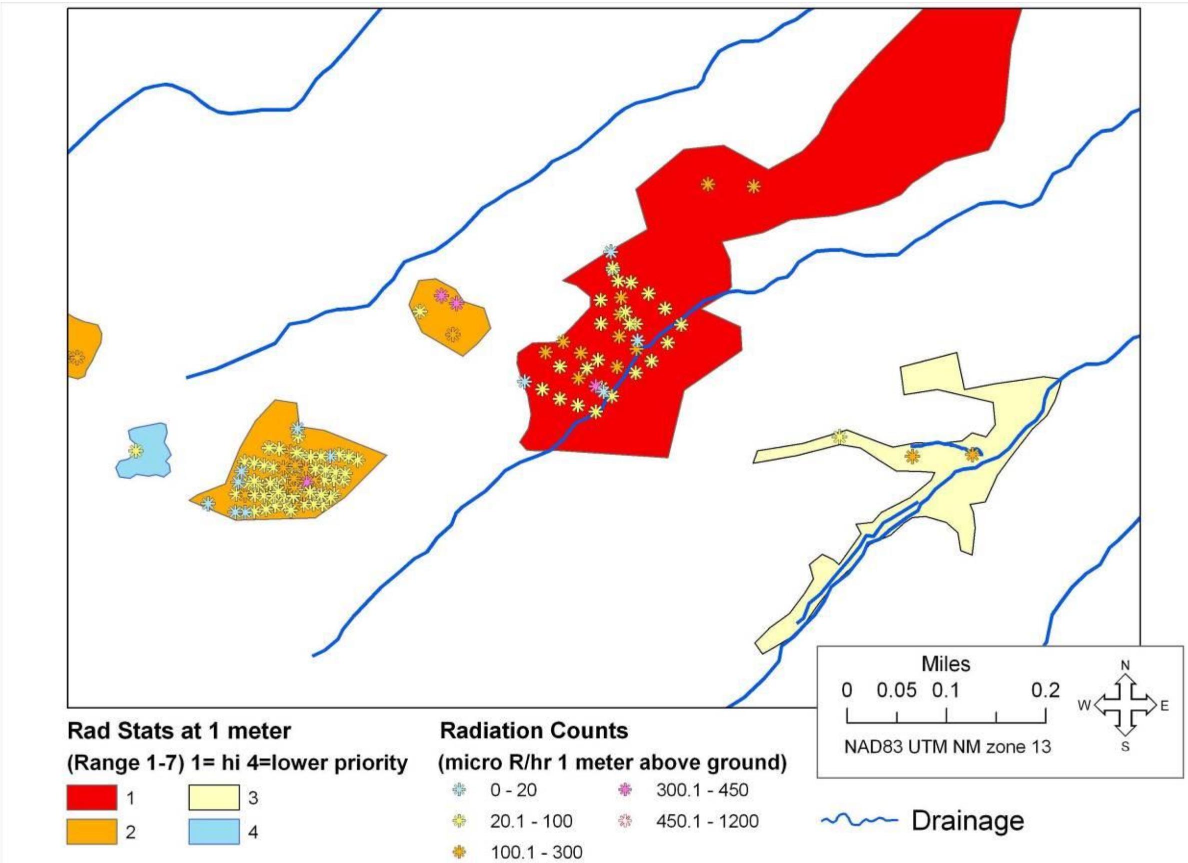

Figure 8. Method used to calculate radiation reading priority. The rank of radiation readings ranged between 1 and 7. Geometric intervals in the data were used to classify these values into 4 priority groups.

Table 2. Scores applied to radiation readings.

Radiation reading (μR/hr)	Description	Score
< 15	Background	0
15 – 20	Background to Low	10
20 – 100	Low to Moderate	20
100 – 300	Moderate	30
300 – 450	Moderate to High	40
> 450	High	Additional weight

Well locations. Proximity of each AUM to wells is a possible contamination pathway and represents a possible risk to drinking water. Well locations were queried from the New Mexico Office of the State Engineer's database (iWaters database, 2008). Depth to water is not available for all wells. Wells are classified in the iWaters database by their end-use. Examples of those classifications include, but are not limited to, public utility, domestic, multi-residence, mining/milling, industrial, livestock, irrigation, sanitation, and recreation. The Spatial Analyst

Near tool was used to calculate the perpendicular distance from the centroid of the mine boundary to the nearest well location (Fig. 9). Physical distances between mines were compared. Based on the distance, a score of 40, 30, 20, or 10 was assigned to each mine, where near distances were given the larger score.

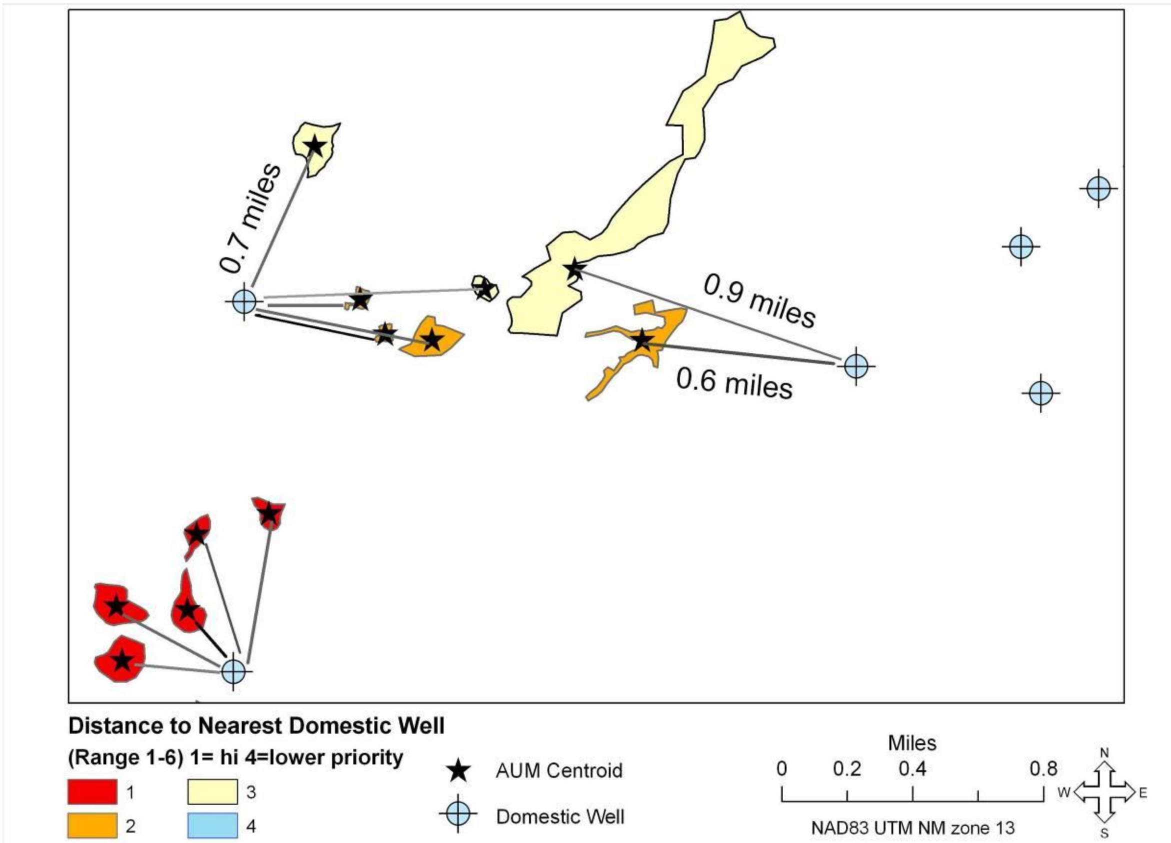

Figure 9: Method used to calculate proximity to wells priority. The rank of distance to nearest ranged between 1 and 6. Natural breaks in the data were used to classify these values into 4 priority groups.

For the first ranking pilot study of the 38 disturbances only domestic wells were queried from the iWaters database and used in the first pilot study analysis. The second analysis of the 108 AUM disturbances in the data superset used a larger set of wells that included multi-residence, community system, agricultural, and livestock related water wells.

Drainages. Proximity of each AUM site to the nearest drainage (streams, arroyos, or erosion features) also could represent a possible contamination pathway for drinking water supplies. The National Hydrographic Dataset (United States Geologic Survey) was used to locate streams and rivers in New Mexico. The layer was supplemented by digitizing additional drainages (predominantly arroyos) observed in the 1-meter resolution aerial photography. Erosion features collected with GPS were merged with the polylines from the hydrographic dataset and digitized drainages. The distance between the mine disturbance polygons and the drainage polylines cannot be measured with ArcGIS 9.2 calculation tools, therefore we created points along the polygon perimeter from which to measure proximity. Xtools was used to create a point shapefile of the mine perimeter polygon: every 30 meters along the mine disturbance perimeter a point was created. These points were used in the proximity calculations using the ArcGIS Near tool. The resulting values were analyzed with the Statistical Summary tool. Scores of 10, 20, 30, or 40 were assigned to each AUM based on the calculated minimum distance of the mine boundary perimeter points to the nearest drainage polyline.

Preliminary sampling of 15 AUM mine disturbances in the Ambrosia Lake region shows that 5 of the sites are within 8.5 to 68 meters (27.9 to and 223.1 feet) of a major drainage and all are within 471 meters (0.3 miles) of a drainage (Figure 10). Since one or more drainages can surround a mine, a separate field was created to hold scores indicating the measure of spatial clustering. This field adds additional points to a site's score. A mine gets a higher score, indicating a higher probability of possible contamination risk, if it is close to multiple drainages and / or surrounded by a drainage. Spatial clustering of drainage around a mine disturbance was measured by creating a pie feature with eight slices. The pie shapefile center was placed on the mine polygon center. The pie has a 1.5-miles radius to reflect average distances to nearest drainages. Each pie slice that intersected a drainage was assigned an additional 5-point score. A spatial clustering score of forty meant that the mine was completely surrounded by drainage (Fig. 11).

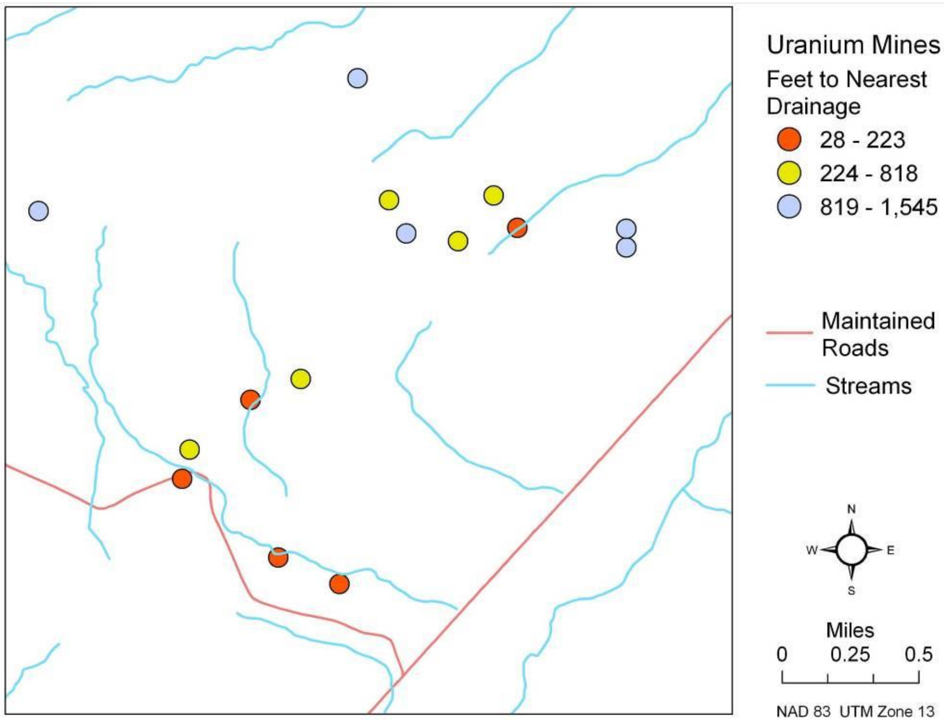

Figure 10. Method used to calculate proximity to the nearest drainage priority. Preliminary sampling (n=15) of distance of abandoned uranium mine to the nearest major stream.

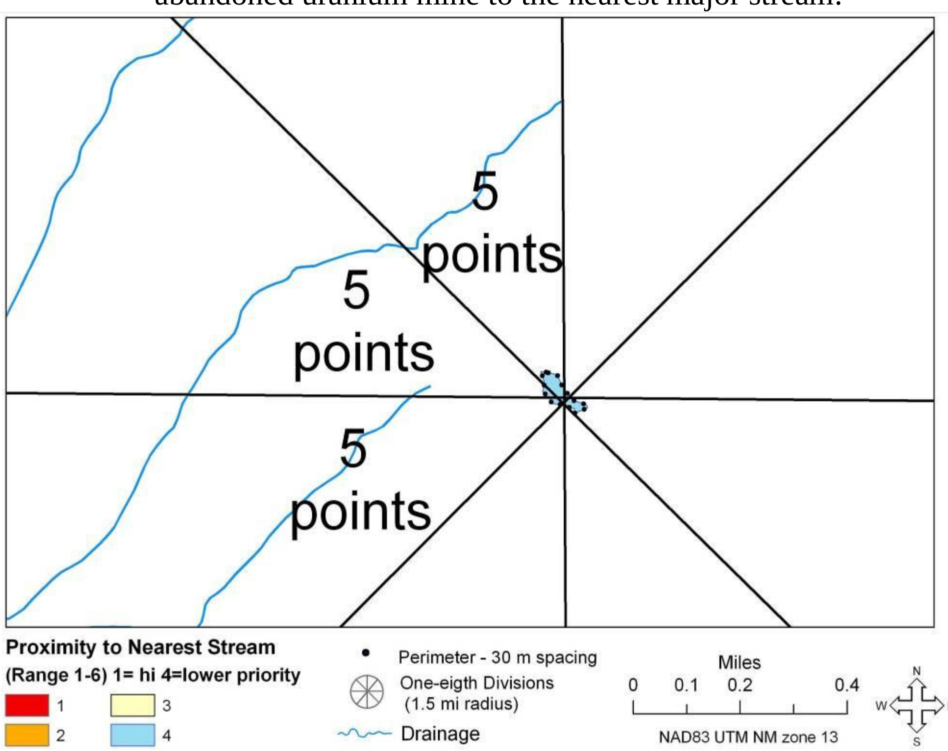

Figure 11: Method used to calculate spatial clustering of the nearest drainage priority. Drainages occur in three pie slices around the mine. The rank of spatial clustering ranged between 1 and 6. Natural breaks in the data were used to classify these values into 4 priority groups.

Dwellings. Proximity of abandoned U mines to dwellings and populated areas may increase the probability that people may visit or travel through the sites and be exposed to mine site waste products and contamination. Wind-blown materials from the sites are also likely to affect populations in close proximity. The 2005-2006 DOQQ aerial photos were used to detect dwellings and more densely populated areas within a 5-mile radius of each mine disturbance. A feature class was created based on the 5-mile buffered distance from the mine site centers. This was the search extent for image interpretation of dwellings. A feature class was created of all the single dwellings (houses, hogans, trailer homes, and general buildings) and a polygon file was created of groups of dwellings (any cluster of approximately 10 or more dwellings). One point represented any cluster of buildings related to a ranch complex. Points were assigned for each dwelling/populated area that fell within the 5-mile buffer (Fig. 12). The count of single dwellings was summed for each AUM with the use of the Spatial Join Analysis Tool.

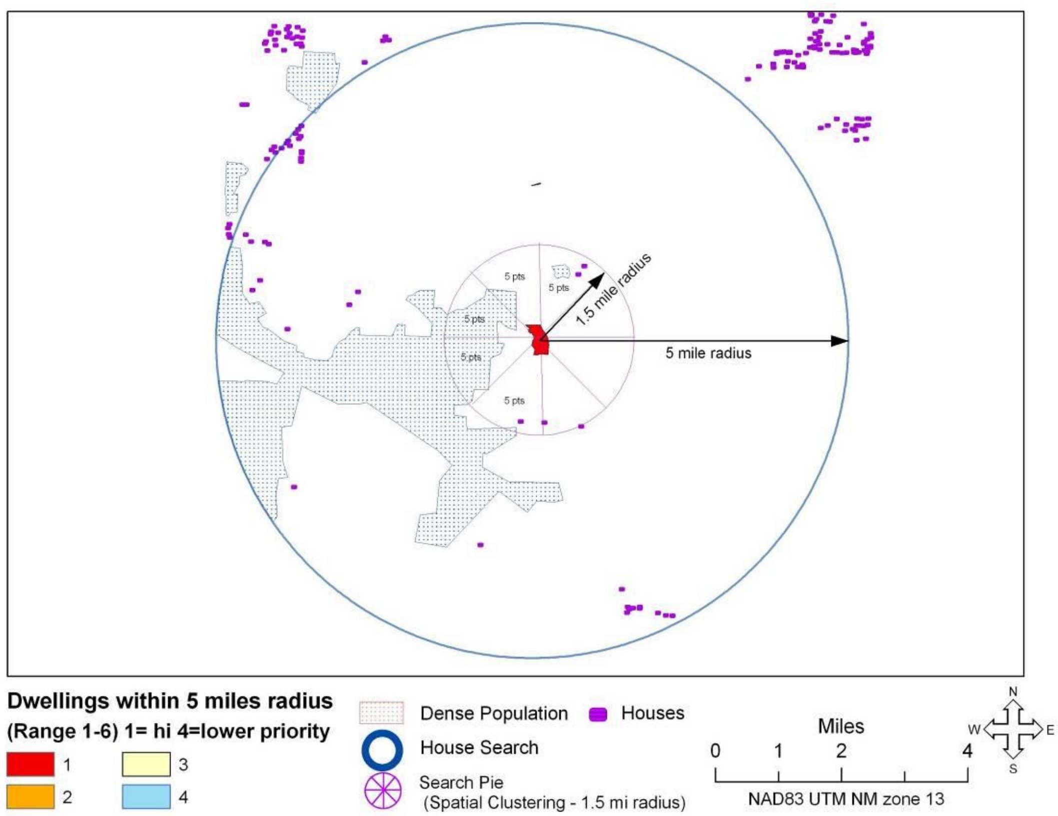

Figure 12: Method used to calculate the proximity, number and spatial clustering of dwellings priority. The 5-mile buffer is used to score proximity and density of population. The 1.5-mile radius buffer is used to score spatial clustering. The rank of dwellings measurements ranged between 1 and 6. Natural breaks in the data were used to classify these values into 4 priority groups.

The distance from each AUM center to densely populated areas and the percent of the search area that those populated areas covered was also calculated and included in the scoring. A separate field was created to hold scores that indicate the measure of spatial clustering of dwellings around each mine site. Again, the 1.5-mile radius 8-piece pie was used to measure the spatial clustering.

Final priority. Each variable's table was joined (tabular join) to the mine boundary shapefile for classification and for map layout display. The Calculator tool in the ArcInfo was used to combine the scores. Ranks for the combined scores were assigned and added to the mine boundary shapefile. Priority was assigned based on a range of values. Priority ranges were based on Jenks natural breaks or geometric intervals in the continuous data, with some subjective score assignments based on high or low end values. Data distributions were viewed in ArcInfo and used in the scoring decisions. Ties were also used in scoring. The priority values were appended to the mine boundary feature class so that maps of the resulting priority for each of the five variables and final score could be created.

Results and Conclusions

Of the 38 pilot study AUMs, thirty-five percent of the sites were less than 1.2 kilometers (0.7 miles) from a domestic well and less than 16 meters (52.5 feet) from watercourses. Sixteen percent were within 8 kilometers (5.0 miles) of a densely populated area; and 2 sites were surrounded by dwellings. Seventeen of the 38 AUMS in the pilot project are located in the Ambrosia Lake Mining District in the San Mateo Creek watershed, a tributary of Rio Grande (Fig. 13). Figures 14 through 18 illustrate the changes in ranking depending on the individual variable mapped. Figure 19 is a map of final priority ranking that reflects the sum of all variable scores.

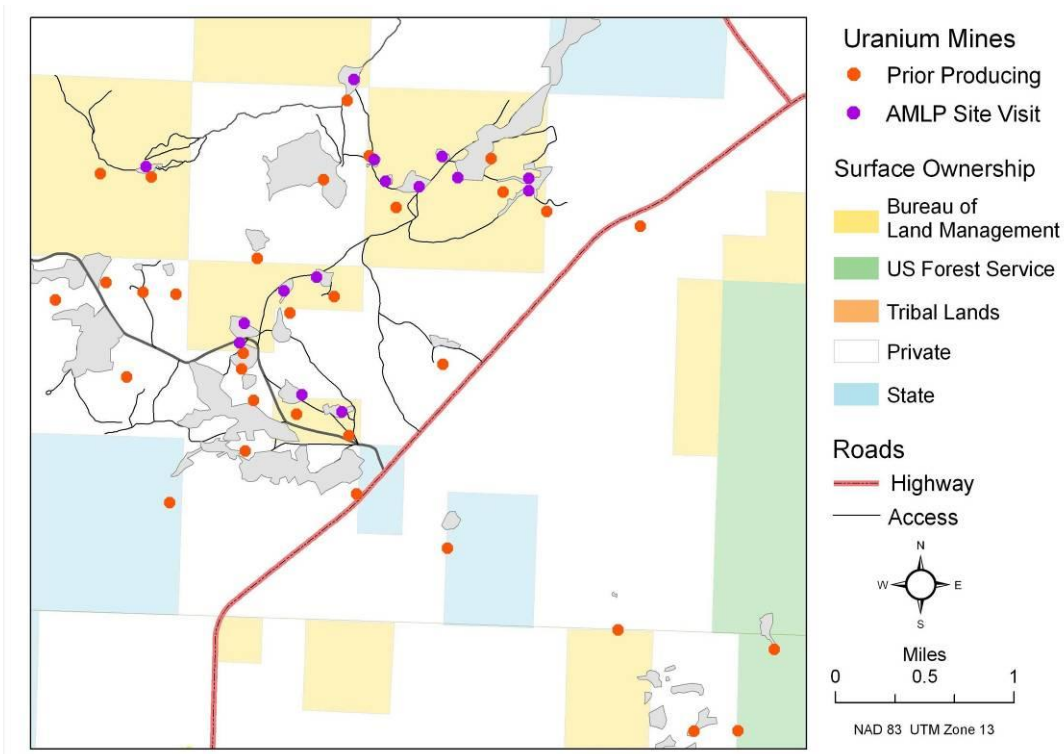

Figure 13. San Mateo Creek watershed includes 17 of the 38 mines included in the pilot study.

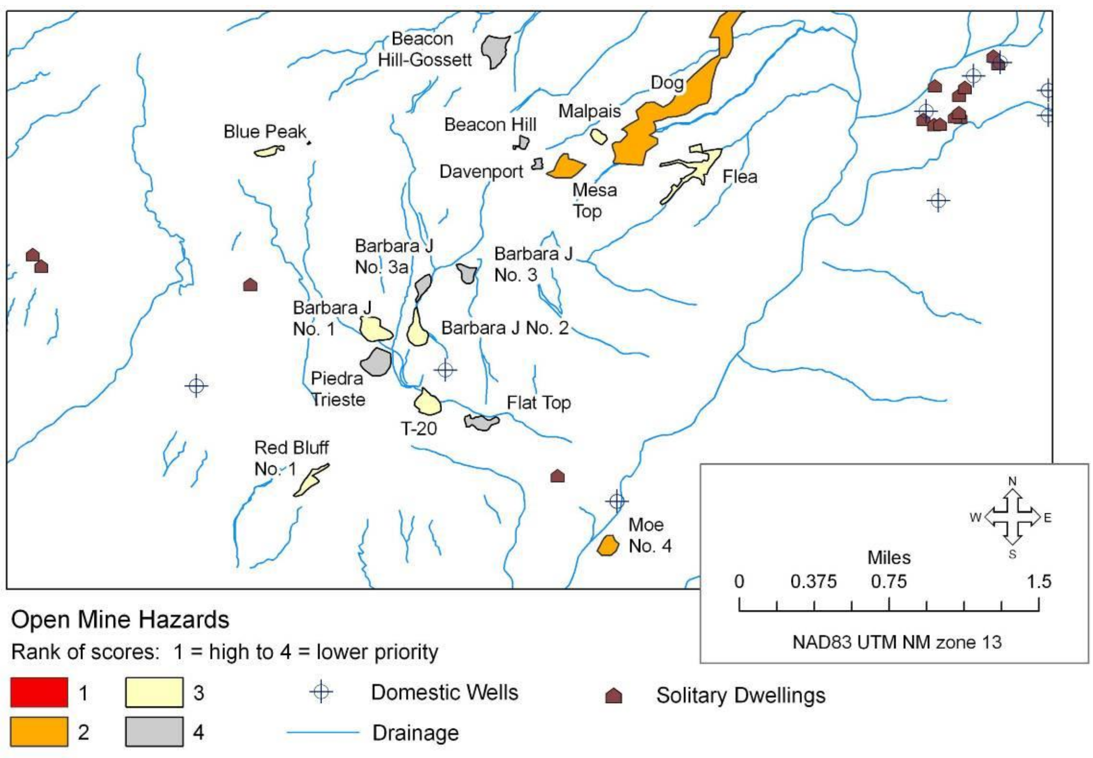

Figure 14. Priority ranking of abandoned uranium mines in the San Mateo Creek watershed based on the number of open hazards.

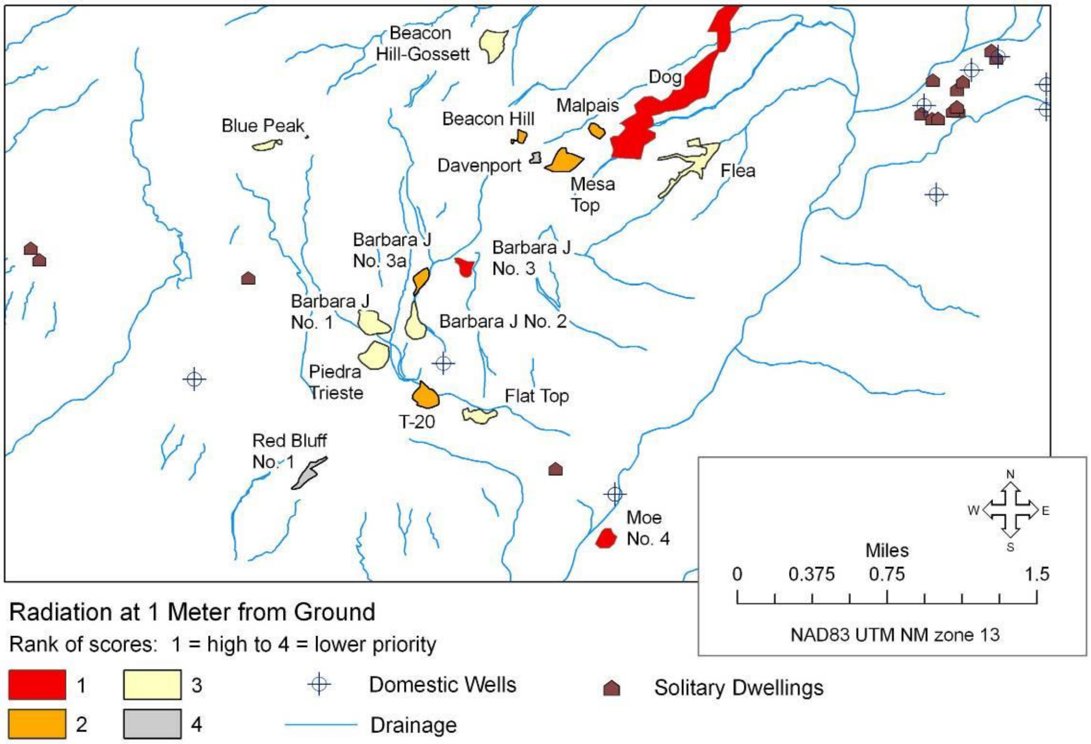

Figure 15. Priority ranking of abandoned uranium mines in the San Mateo Creek watershed based on scores radiation readings (μR/hr) at 1 meter.

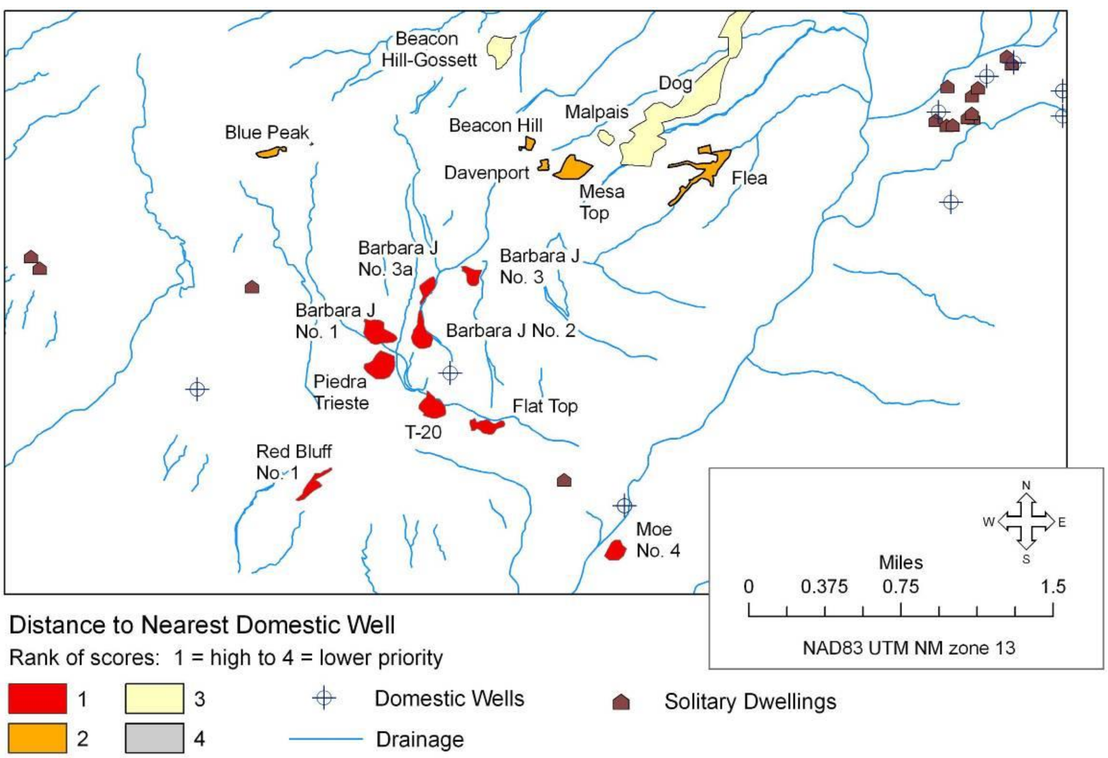

Figure 16. Priority ranking of abandoned uranium mines in the San Mateo Creek watershed based on distance to nearest domestic well.

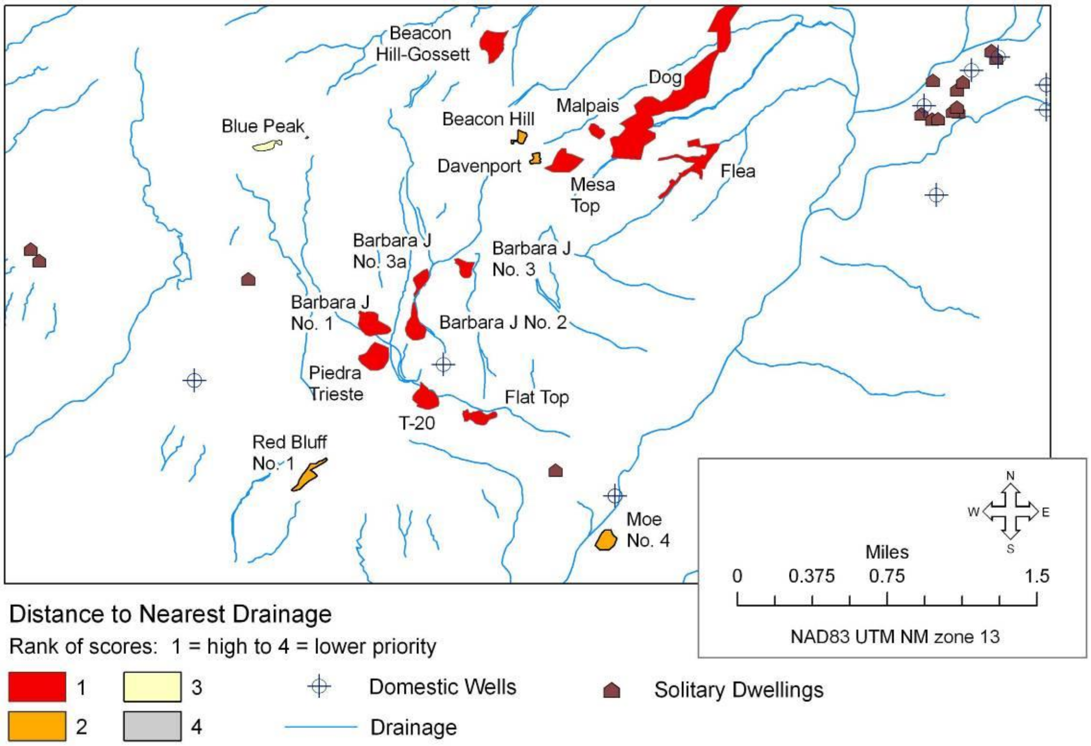

Figure 17. Priority ranking of abandoned uranium mines in the San Mateo Creek watershed based on distance to and spatial clustering of the nearest drainage.

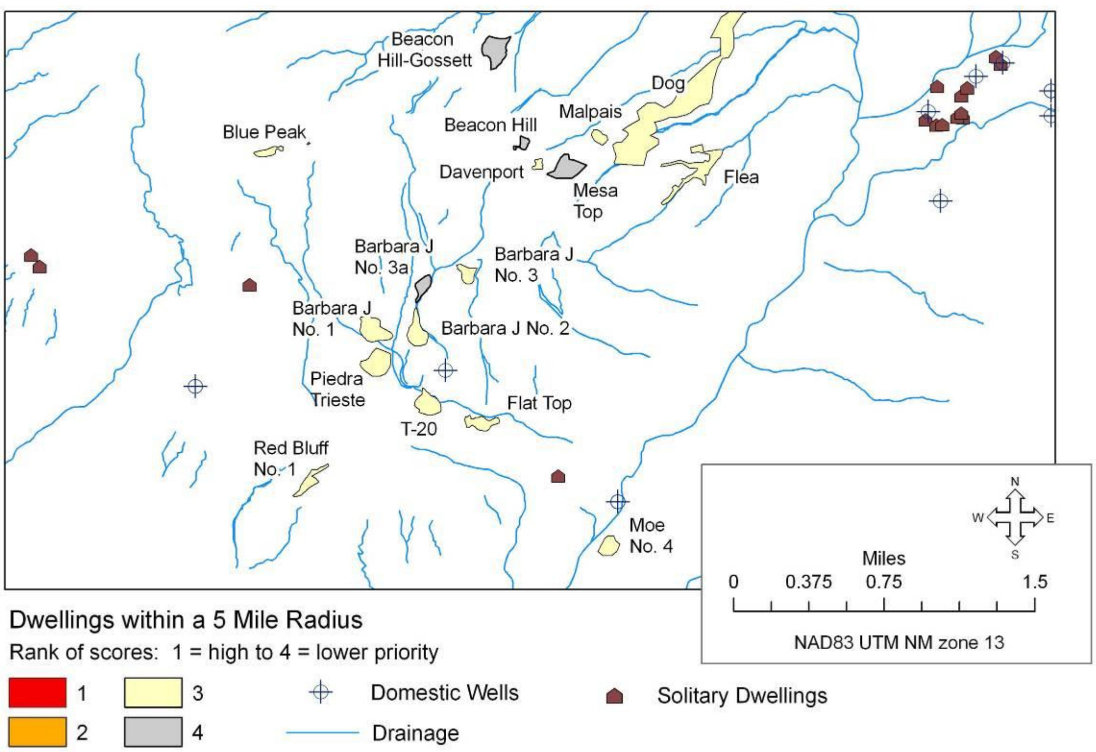

Figure 18. Priority ranking of abandoned uranium mines in the San Mateo Creek watershed based on proximity, number and spatial clustering of dwellings within a 5-mile radius.

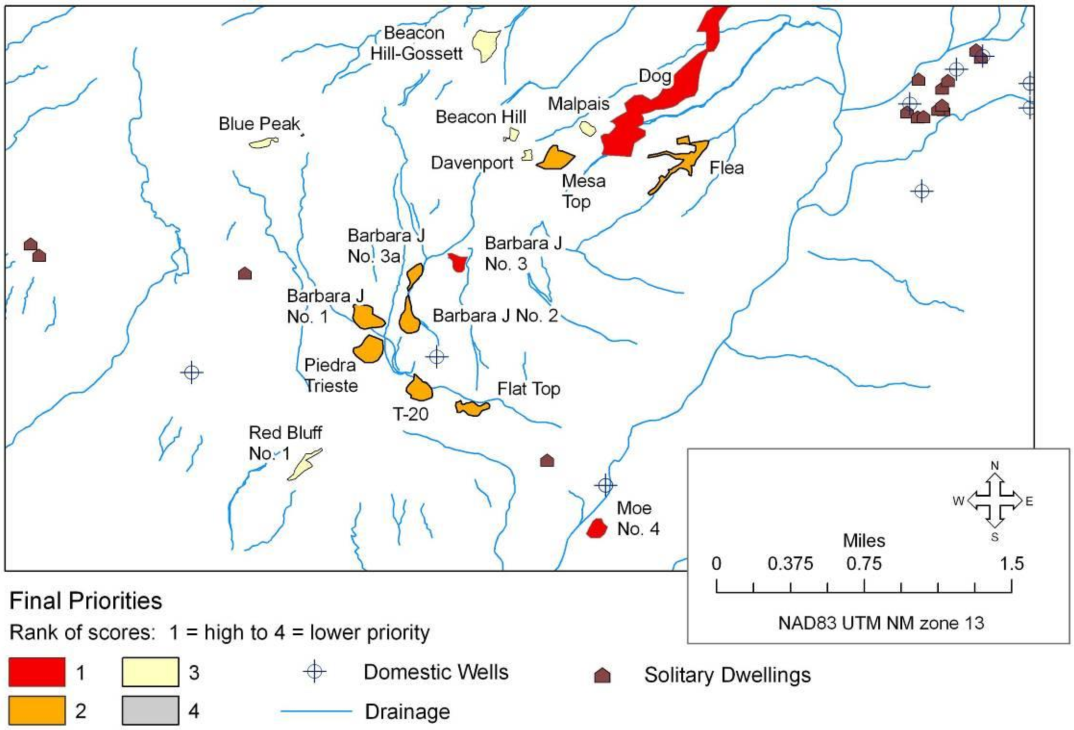

Figure 19. Final priority ranking of abandoned uranium mines (n=38) in the San Mateo Creek watershed.

In the San Mateo Creek watershed, the Dog, Moe No. 4, and Barbara J No. 3 mines all rank high-priority in the pilot study. The second analysis of the expanded superset set of AUMs (n=108) within the San Mateo Creek watershed shows these three mines move to a medium-high priority. Three different sites, not included in the first model, are a high priority in the second model: the Section 25 open pit, Section 25 decline, and Haystack Section 31 mines (Fig. 20). The Flea, Mesa Top, Barbara J No. 1, Barbara J No. 2, Barbara J No. 3a, Piedra Trieste, T-20, and Flat Top mines are medium-high priority in both models. The Blue Peak and Malpais mines moved from medium-low rank in the first model to medium-high rank in the second model. The Beacon Hill-Gossett, Beacon Hill, Davenport, and Red Bluff No. 1 mines all maintained a medium-low priority in both models. The absence of radiation readings and inclusion of additional wells in the second model caused the changes in priority.

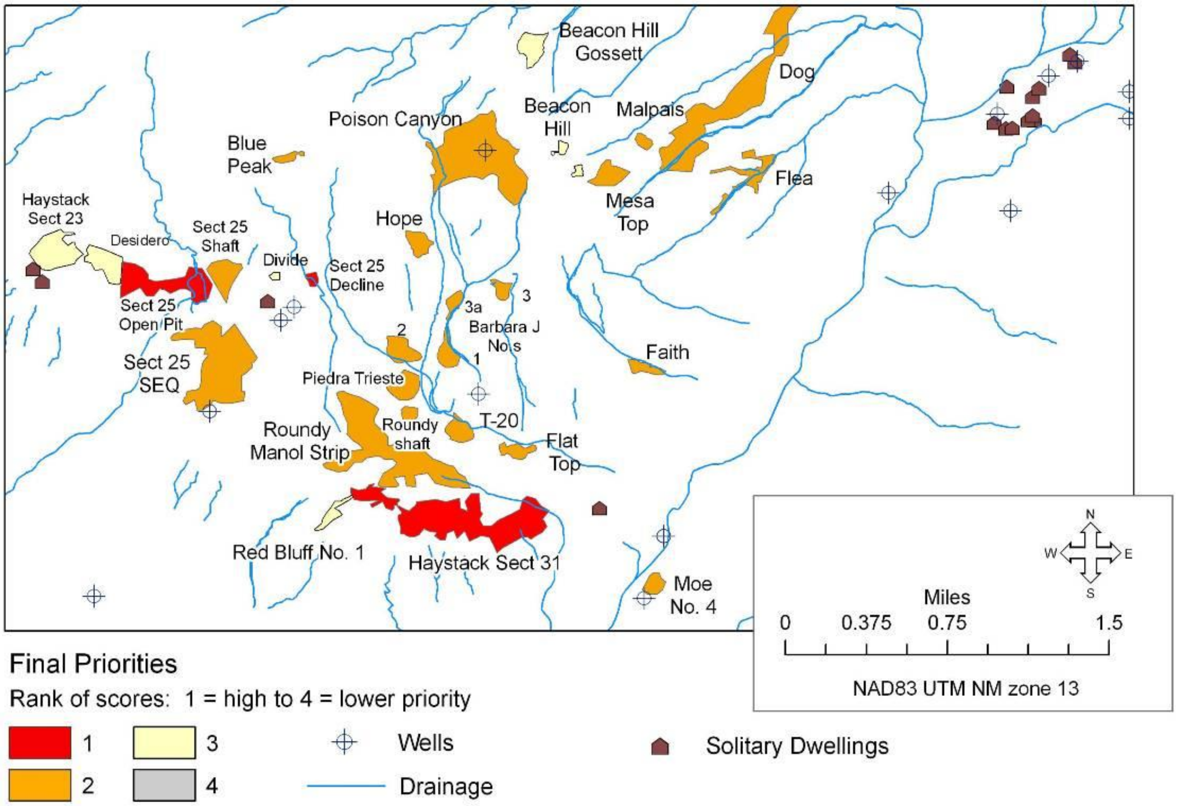

Figure 20. Final priority ranking of abandoned uranium mines (n=108) in the San Mateo Creek watershed.

Figure 21 displays a comparison of two high priority mines (Floyd Collins and Diamond No. 2) based on the sum of all five variables of the pilot model (n=38). The Floyd Collins mine, located in the Cow Spring Draw watershed, ranks high in the variables of open mine hazards and nearness to domestic wells. It also ranks moderately high in containing maximum radiation readings and proximity to dwellings and drainage. The map for the second model (n=108) shows that all the mines found within close proximity of each other in the Cow Spring Draw watershed are also high-priority sites (Fig. 22).

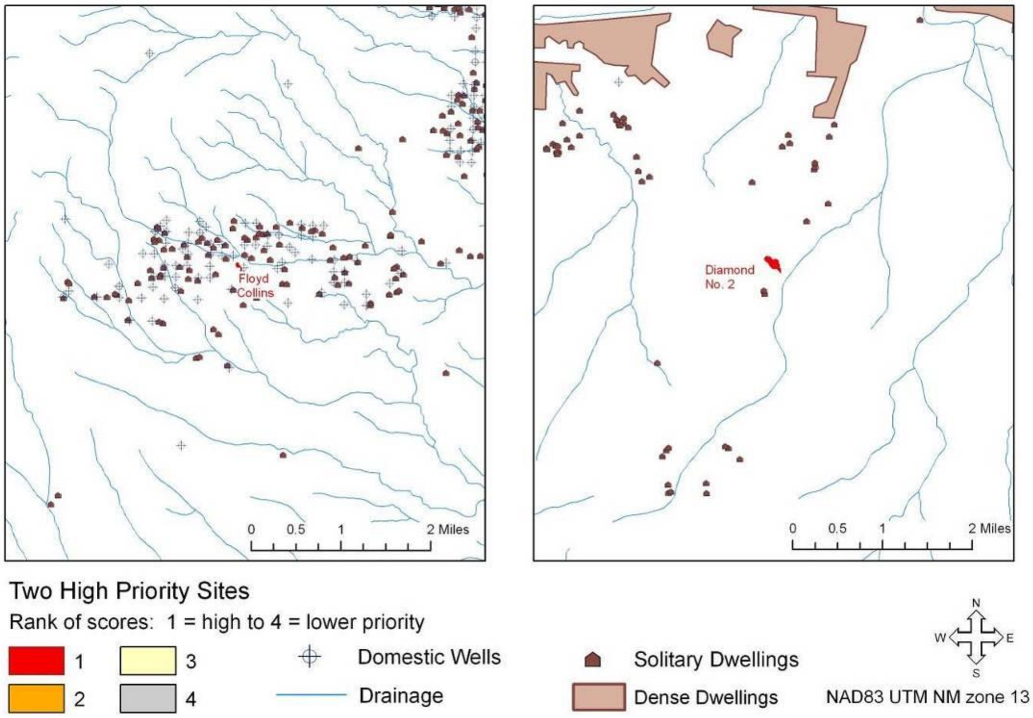

Figure 21. Two mine sites scoring high priority for all model variables in the pilot study (n=38). The Floyd Collins is located southwest of Silver City; the Diamond No. 2 is located southeast of Gallup.

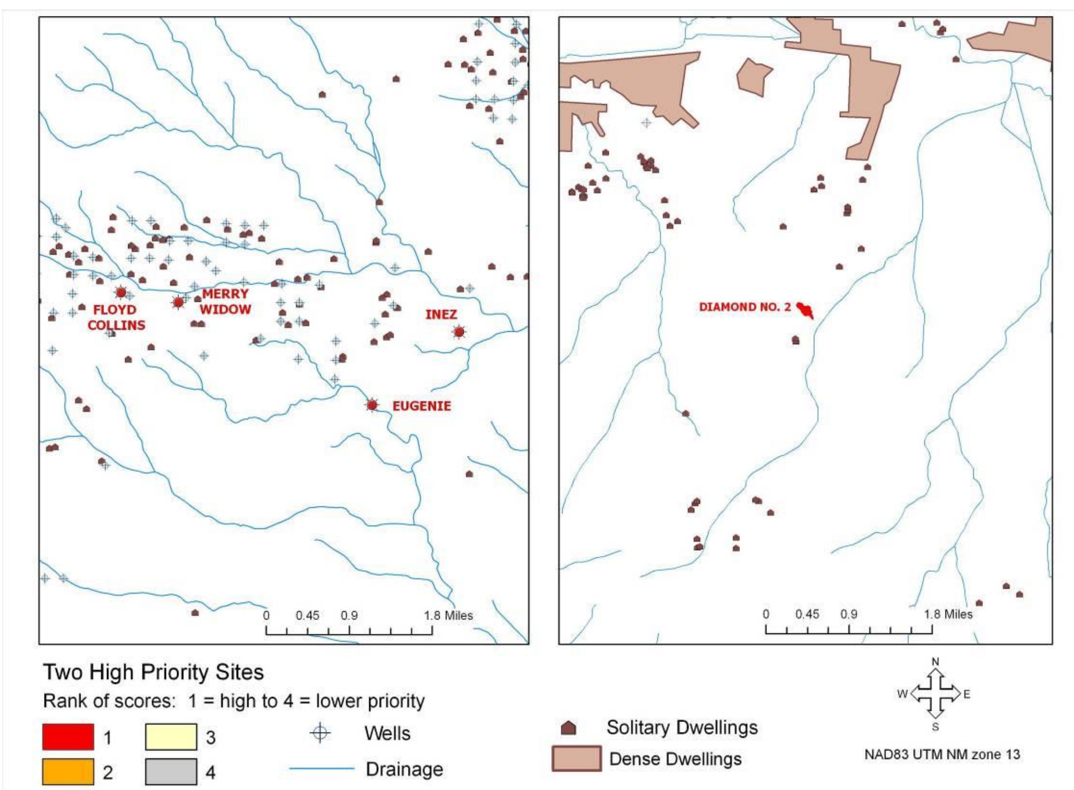

Figure 22. Two regions with high priority in terms of all model variables combined using the expanded superset data (n=108).

The Diamond No. 2 and Floyd Collins mines are both high priority reclamation candidates (total scores) based on both of our analyses. Floyd Collins retained the higher overall scores in both analyses, though variables in the models contributed differently to the ranking. All variables contributing to the total priority rank for Floyd Collins were moderate high to high. Two variables, the proximity to dwellings and the number of open hazards, were high ranking for the Diamond No. 2 Mine. If we only examine the proximity to dwellings, the Diamond No. 2 Mine gets a higher score. Close proximity to high density dwellings contributed the most to its score. If we decide that close proximity and clustering of single dwellings is of more concern, we could give more weight to that aspect in the model, and the Floyd Collins would gain a higher score than that of Diamond No. 2.

The consistency of priority results was examined for each variable of the final high- and low-priority sites among the 108 abandoned U mine disturbances. We specifically wanted to investigate two trends: 1.) the high-priority mine sites that consistently ranked high among all four variables, and 2.) the low-priority mine sites that maintained their low-priority status for all four variables. A matrix of high- and low-priority status may help to narrow the list of potential reclamation candidates (Tables 3 and 4). Twenty-three percent of the 22 top-ranking mines (ranks 1 to 9) maintained a high-priority rank in terms of the number of open hazards. Seventy-seven percent of high-priority AUMs maintained their status when examining proximity to wells, and 50% of the sites maintained high-priority status when examining their proximity to drainages or dwellings. From this analysis, the proximity of abandoned U mines to wells appears to have more influence in determining a high-priority site. If a decision was made that a mine site should be consistent in their status in two or more of the four variables to be considered a candidate for reclamation, then the list would decrease from 22 to 18. Using the same criteria of consistent status for the low-priority sites (ranks 22 to 30), the list would decrease from 19 to 7. The low-priority candidates overall remained low priority depending on the variable. At most, 16 percent of the 19 low-priority sites jumped to a high priority status based on their proximity to drainage; 11 percent jumped based on proximity to wells; and 6 percent based on number of open hazards.

Table 3. Consistency of ranks for high priority sites. The matrix compares the final rank with each constituent variable for the 22 high priority abandoned uranium mines in the second model (n=108).

Mine	Total Score	Final Rank	Variable Priority: Open Hazards	Proximity to Dwellings	Proximity to Drainage	Proximity to Wells	Number Variables Maintaining Status
Floyd Collins	265	1	high	high		high	3
Billy the Kid	260	2		high		high	2
Merry Widow	250	3		high	high	high	3
F33	250	3	low		high	high	2
Mount Taylor	245	4			high	high	2
Blackhawk Bunney	240	5	high		high	high	3
Diamond No. 2	240	5	high	high		low	2
Eugenie	235	6			high	high	2
Maddox & Teague	230	7		high		high	2
Section 25 Open Pit	230	7			high	high	2
Section 18	225	8		high	high	low	2
Inez	225	8				high	1
Zia	225	8	high				1
Haystack Section 31	220	9			high	high	2
San Mateo Mine	220	9			high	high	2
Tom	220	9	low	high		high	2
Section 9	220	9			high	high	2
Section 25 Decline	220	9			high	high	2
Cedar	220	9	high	high	low	high	3
Glover	220	9		high	low	high	2
Yucca	220	9		high			1
Silver Bit	220	9		high			1

Table 4. Consistency of ranks for low priority sites. The matrix compares the final rank with each constituent variable for the 19 low priority abandoned uranium mines in the second model (n=108).

Mine	Total Score	Final Rank	Variable Priority				Number Variables Maintaining Status
			Open Hazards	Proximity to Dwellings	Proximity to Drainage	Proximity to Wells	
United Western	155	22					
Desidero	155	22					
Lucky Don	155	22	high	low			
Section 35	150	23		low	high	low	2
Sandstone	150	23		low	high		
Section 24	150	23		low			
Section 22	150	23					
Section 10	150	23		low			
John Bull	150	23		low	high	low	2
Section 30 West	145	24			low	high	
Taffy	145	24					
Section 30	135	25	low				
Anne Lee	135	25					
Rio Puerco	125	26		low	low	high	2
Section 13	120	27			low		
Little Davie	115	28		low	low		2
Section 19	110	29	low	low	low		3
Section 17	110	29	low	low	low		3
Butler Brothers	95	30		low	low		2

Future Work

The model is based on a tabular system of scoring, ranking and then joining the attributes to shapefiles of the mine site disturbance. Scores and variables can be modified in the tables and will reflect in the maps (color coding of ranking). We would like to recreate the steps in ArcInfo ModelBuilder so that the steps are better documented and can be modified in a flowchart-graphical manner. The process would be more user-friendly and repeatable as additional mine sites are field surveyed.

We would like to expand the variables in the model to investigate additional factors such as the number and volume of waste rockpiles, depth to groundwater, radiation readings at surface contact, and land use. Number, homogeneity, and volume of waste rockpiles would be a useful variable to quantify radiological hazards for a mine site. Depth to groundwater would allow modeling of potential pathways for ground water contamination. Land use could be used to determine risk exposures to open hazards and radiological hazards. And surface / ground contact radiation readings can be calibrated to radiological soil activity.

After the AUM site ranking priorities have been assigned based on the model variables, we would like to investigate and include the variables of site accessibility, land ownership, and geographic proximity. For example, the cost of staging a reclamation project, moving equipment into place, and gaining site access are important to consider in reclamation cost estimations. With limited funding, costing factors are important variables in the AUM reclamation priorities. Between both models runs, six AUMs are ranked high priority in the San Mateo Creek watershed. Because the six mines are close in proximity to each other, it may be more cost effective to work on them together and then move on to the next high-priority site. It may also be more cost effective to mobilize equipment to reclaim the San Mateo watershed AUMs before addressing the Floyd Collins mine, which ranks as a high priorities but is geographically isolated in relation to other AUMs in the state. If the cost and efficiency of moving equipment is not a high priority, it may be better to travel around the state and reclaim only the mines ranking high priority, then medium-high, etc. There also may be more motivation to reclaim areas that are the closest to, or are surrounded by, populations and dwellings, regardless of their priority ranking system. While modeling costs is difficult due to the complexities of bid and contract documents, we could model a cost risk factor to identify mines or reclamation projects with high risks associated with costs.

Acknowledgements

We would like to thank the Navajo Abandoned Mine Land Reclamation Department for sponsoring several training sessions on health physics, radiation meter calibration and radiation meter field practice.

We would like to thank Rio Algom Mining LLC and Schmidtt Ranch for allowing us access through their Ambrosia Lake properties.

Literature Cited

Abandoned Mine Land Program. 1981-2008a. Hyde/Wingate, Wingate Hogback, Grants Uranium Phases I to III, San Mateo Mine project files. New Mexico Energy. Minerals and Natural Resources Department, Mining and Minerals Division, Santa Fe, New Mexico.

Abandoned Mine Land Program. 1981-2008b. Reconnaissance files. New Mexico Energy. Minerals and Natural Resources Department, Mining and Minerals Division, Santa Fe, New Mexico.

Anderson, O.J. 1981. Abandoned or inactive uranium mines in New Mexico. New Mexico Bureau of Mines and Mineral Resources. Open-File Report 148. Socorro, New Mexico

Bureau of Land Management. 1987. Uranium mine inventory inspections. United States Department of the Interior, Bureau of Land Management, New Mexico Office. Santa Fe, New Mexico.

Bureau of Land Management. 2002. Mining claim site inspections. United States Department of the Interior, Bureau of Land Management, New Mexico Office. Santa Fe, New Mexico

Drake, L. M. and K. H. Fuller. 1990. A cultural resource inventory of eight uranium mines near Grants, New Mexico. Submitted by Y. R. Oakes. Laboratory of Anthropology Notes No. 511. Santa Fe, New Mexico

Fuller, K. H. 1989. An archaeological survey of six uranium mines near Grants, New Mexico. Submitted by Y. R. Oakes. Laboratory of Anthropology Notes No. 488. Santa Fe, New Mexico.

McLemore, V. T., K. Donahue, C. B. Krueger, A. Rowe, L. Ulbricht, M. J. Jackson, M. R. Breese, G. Jones, and M. Wilks. 2002. Database of the uranium mines, prospects, occurrences, and mills in New Mexico. New Mexico Bureau of Geology and Mineral Resources. Open file Report 461. Socorro, New Mexico

McLemore, V. T. and W. L. Chenoweth. 1992, Uranium mines and deposits in the Grants district, Cibola and McKinley Counties, New Mexico, New Mexico Bureau of Geology and Mineral Resources, Open-File Report 353. Socorro, New Mexico

McLemore, V. T. 2007a. Uranium resources in New Mexico. Proceedings of the Society of Mining, Metallurgy and Exploration Annual Meeting. (February 25-28, 2007) Denver, Colorado.

McLemore, V. T. 2007b (unpublished). Database of the uranium mines, prospects, occurrences, and mills in New Mexico. New Mexico Bureau of Geology and Mineral Resources. Socorro, New Mexico.

Mine Registration Program. 1989-2008. Mine registration, annual reports, suspension and inspection files. New Mexico Energy, Minerals and Natural Resources Department, Mining and Minerals Division. Santa Fe, New Mexico.

Schuster, F. P. 1985. Pilot Project Field Report: Hazardous waste inventory, abandoned uranium mines, McKinley County, New Mexico. United States Department of the Interior, Bureau of Land Management, New Mexico Office. Santa Fe, New Mexico.

Souder, Miller & Associates. 2008. Abandoned uranium mine field survey project. Souder, Miller & Associates. Albuquerque, New Mexico.

State Mine Inspector. 1954-1980. Inactive uranium mines card file. New Mexico Institute of Mining and Technology, New Mexico Bureau of Mine Safety. Socorro, New Mexico.

Published GIS Datasets Used in the Personal Geodatabase

U.S. Bureau of Land Management. New Mexico State Office, Santa Fe, New Mexico. 2006.

- Land Surface Ownership shapefiles.
- Mineral Ownership shapefiles.
- Public Land Survey System shapefiles.

U.S. Department of Agriculture. Natural Resources Conservation Service, Fort Worth, Texas. 2005.

- Subwatershed Hydrologic Unit Boundaries (10-digit) of New Mexico shapefiles.

New Mexico Resource Geographic Information System. Albuquerque, New Mexico.

- Digital Orthophoto Quarter-Quadrangles aerial imagery for the State of New Mexico. 1 meter resolution, flown 2005-2006. Compressed ECW format. Processing by Bohannan-Huston, Inc. Albuquerque, New Mexico.

U.S. Geological Survey. Reston, Virginia

- USGS Digital Raster Graphics (DRG). U.S. 7.5min Topographic Map. GeoTIF files and mosaics.
- USGS National Hydrographic Dataset shapefile. 1999-2001.

New Mexico Office of the State Engineer. 2008.

- iWATERS Well data shapefile, iWATERS database.