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Introduction

The Utah Abandoned Mine Reclamation Program (UAMRP) is the agency in Utah responsible for reclaiming abandoned mines in the state under the authority of Title IV of the Surface Mining Control and Reclamation Act (SMCRA, P.L. 95-87). In order for the UAMRP to achieve primacy under SMCRA, it needed an approved plan outlining its policies and procedures for implementing the act. One significant requirement of the plan was a section required by 30 CFR 884.13(c)(2) detailing how abandoned mine sites would be ranked and selected for reclamation. (UAMRP, 1983)

There are several ways a state reclamation agency could rank mines for reclamation. It could reclaim them alphabetically by name or simply work across the state from north to south. While systematic, these two approaches ignore the public safety and environmental priorities built into SMCRA. Alternatively, projects could be ranked by tapping the knowledge of the program staff about where the worst mines are located. Such intuitive or common sense ranking is easy for the handful of highest priority mines with the most severe problems; one need only look at the newspaper headlines to find them. The difficulty comes in choosing from among the dozens of second tier mines vying for the next slots on the project schedule. A reclamation program needs a systematic, logical process able to discriminate among many similar project contenders to meet the needs of SMCRA and to be legally defensible.

The approach the UAMRP took in 1982 in preparing the state reclamation plan looked at the “badness” of a mine site (and its priority for reclamation) as a function of the number and type of problems at the site and the likelihood that people would encounter them. The latter was considered to be a function of the population near the site and the accessibility of the mine to that population (as inferred from the distance, degree, and type of road development). The mines would be scored numerically based on their site features, proximity to people, and accessibility, and then ranked by their scores.

This approach was tailor-made for GIS systems, but it would take eighteen years for GIS to be fully incorporated into the UAMRP planning. This paper describes the UAMRP’s experience with GIS in ranking and selecting projects. It revisits ground previously covered by Southwick, et al. (2000), Southwick, et al. (2002), and Fortner, et al. (2004), with additional elaboration of
the internal nuts and bolts of the model and a look at the UAMRP’s eight years of experience incorporating this GIS model into UAMRP planning.

**Background to the GIS Model**

When the Utah reclamation plan was written in 1982, the UAMRP fully expected the ranking process to be automated. The approach anticipated a GIS, but the available GIS software at the time was rudimentary and cumbersome and suitable GIS data were not available. GIS-type operations, such as figuring the population within a specified radius of a site, were done manually (by placing a template over a map and consulting census tables). Besides being crude and slow, this necessitated breaking data types into coarse categories or ranges for simplicity. Instead of calculating a score based on the actual population of an area, for instance, scores were based on population ranges of 0-1000, 1001-5000, 5001-10,000, 10,001-25,000, and >25,000. Nuances in the data were lost and the scoring became a “point in time” snapshot (and a low resolution one, at that) that was not easily updated as conditions changed.

The UAMRP ranking system depended on field inventory data for its scoring. It was originally conceived as working from a data pool with complete or nearly complete statewide field inventory data. In actual practice, the UAMRP could not complete a statewide inventory in a meaningful timeframe (the working estimate is that there are 17,000 abandoned noncoal mine openings in the state, see Wright, et al. 1991). The UAMRP proceeded with reclamation as it continued its field inventory effort. Construction projects were selected from the pool of sites with available field data, but since the field inventory generally advanced only a year or two ahead of the construction, the choice of areas to inventory was becoming the *de facto* selection of construction projects.

By the mid to late 1990s, most of the state’s coal mine reclamation work had been completed and more and more non-coal projects were being targeted. The manual ranking model had worked reasonably well for selecting coal projects. There were fewer coal mines (hundreds, not thousands) and the field inventory was more complete for coal. The abandoned coal mines occurred as distinct operational units that were amenable to ranking.

Noncoal mines, on the other hand, were less amenable to ranking as sites. In Utah, noncoal mines often occur in high concentrations. Further, the restriction in Section 409 of SMCRA of
funds to Priority 1 and 2 problems for noncoal projects narrowed the focus to hazards, to individual shafts and adits rather than entire operations. Noncoal projects became defined as all of the mine openings in a particular watershed or mountain range without regard to any historic operational or business identities the mines might have had (e.g. the So-and-so mine). This was a break from the coal practice. The basic nature of noncoal mines is that it is more appropriate to rank aggregations of point features, that is, to treat groups of mines or regions as the ranking unit rather than individual mines.

With the UAMRP’s gradual programmatic shift from coal to noncoal projects, by the late 1990s it was becoming increasingly clear that the UAMRP project ranking and selection process needed refinement. The underlying philosophical assumptions of risk being a function of mine features, population, and accessibility were still considered sound, but there needed to be a more systematic application of the ranking and selection principles to the selection of field inventory areas. This required a suitable body of data from non-field sources to work with. Fortunately, advancements in GIS over the years had made such data available and had provided an automated system in which to analyze them conveniently.

**Formulation of the GIS Model**

The UAMRP’s current GIS ranking model, like its manual predecessor, looks at three main factors that ought to influence the potential hazard of a mining area. These factors are the extent of mining activity or number of mining features present, the population in proximity to the mining areas, and the ease of access to the mining areas. Mine closure priorities should be set in a way that reflects the potential for public exposure to the mines. The different factors are assigned scores or weights by the model and these scores are summed to generate a composite score for an area that should indicate its level of risk compared to other areas. Higher scoring areas are higher risk and higher priority for reclamation.

The model makes some simple *ceteris paribus* assumptions that are grounded in common sense: All else being equal, an area with multiple mine openings is a higher risk than an area with only one opening. All else being equal, an area close to a population center is a higher risk than one farther away. All else being equal, a mine in an area serviced by roads is a higher risk than one in a roadless area.
Translating this conceptual model into a GIS required having an appropriate software application and suitable georeferenced data. By the time the Utah ranking model was being developed, the GIS software market had matured and consumer applications were common; the UAMRP owned and was already using GIS applications (but primarily as a cartographic tool for its mapping needs, not as an analytical tool). Finding good georeferenced data was trickier.

In Utah, the Automated Geographic Reference Center (AGRC) maintains a vast array of statewide data sets. They were our most valuable resource. But by contacting numerous other state and federal agencies we were able to collect some potentially useful data sets as well as to anticipate what data sets might become available over the coming years. For instance, one valuable non-AGRC data set used in the mining component was Utah Mineral Occurrence System (UMOS), a database developed by the Utah Geological Survey. UMOS has nearly 7,000 records on mineral occurrences in Utah.

For the access component of the model, we found a very complete roads coverage that included everything from obscure Jeep trails to interstate highways, with each line segment coded by the type of road. For the population component, the 2000 census data were available.

It was more difficult to model the mine component. In the absence of a statewide ground-truthed inventory of abandoned mines, we had to resort to proxies that would let us infer where the mines are likely to be. The most specific mining data set was the UMOS, which has fairly complete and accurate data on mineral locations and development. This was supplemented with coverages mapping geologic formations known to have mining, particularly valuable for gilsonite and phosphate deposits. Other sources providing a backdoor prediction of where mines might be expected to occur were a map of mining districts and a coverage that gave a count of patented mining claims in each square-mile section of the public land survey.

The biggest limiting factor in determining which data were useful was whether the data set was available statewide. For example, by 2000 the U.S. Forest Service had digitized all adit and shaft symbols on the U.S. Geological Survey 7.5 minute topographic quadrangle maps containing Forest Service lands. The USGS map symbols are an extremely useful set of data, as they show known mines in precise locations. Unfortunately, when the GIS model was originally set up in 2000 it had to ignore the Forest Service map symbol coverage because it was not statewide in extent; if used, it would have biased the ranking towards Forest Service holdings.
Co-author Smith rectified this deficiency in 2004 by digitizing 10,263 mine symbols on the 1,594 USGS quadrangles covering Utah. It is now a key data set in the current GIS model.

Once we determined what data sets were available we looked at the data’s attributes and began to determine which attributes would provide information for our model. For example the roads data set contains attribute information detailing the road surface and class (e.g. state or federal). These attributes give us a clearer picture of the functional mobility they provide beyond just whether a road is or is not present. Although the model generally sees paved surfaces and multiple lanes as improving mobility, the model downgrades interstate highways because they are controlled access; traffic cannot legally pull off an interstate highway to visit a mine.

**Technical Implementation of the Model**

The geographic data sets are processed using Environmental System Research Institute’s (ESRI) Arc/Info software including the Grid extension. The processing of each data set is programmed in ESRI’s Arc Marco Language (AML). By using AML’s to process the data sets, attribute values can be easily changed to see how the output results vary with different input attribute values. Early development of the model entailed extensive tweaking of variables (buffer zone widths, weighting factors, etc.) to produce a satisfactory result.

Three main groups of data are used for the GIS model reflecting the three main components of the conceptual model (mines, population, access). The access component uses two roads data layers. The population component consists of the 2000 census data. The mines component uses a variety of mining data sets. See the “Data Sets and Settings” section below for a description of the key data sets.

All of the data sets are converted to grids with 0.4 km by 0.4 km (0.25 mile by 0.25 mile) cells yielding 16 hectare (40 acre) grid cells using the Grid extension. It takes over 1.3 million grid cells to cover the state. Weighted values are assigned to the various attribute components. In the case of the roads and census data, densities are calculated using FOCALSUM calculations. In addition, a “point density” function is used on certain mining layers representing point features.

The gridding process calculates a numerical score for each grid cell based on the attribute values of the data sets as modified by the weighting factors. The result is an \((x, y)\) array of grid
cells, each with a $z$ value. In this model, each grid cell (with its own $(x, y)$ coordinate address) has a $z$ value for the mines component, a $z$ for the population component, and a $z$ for the access component. The grids are then merged to form a final composite coverage. In other words, the different $z$ values for each grid cell are summed to produce a final composite $z$ value for the cell. This calculation is done for every grid cell in the state.

Since the gridding process generates a set of $(x, y, z)$ values where the $x$ and $y$ coordinates define a geographic region, it is natural, intuitive, and convenient to think of the $z$ values as elevations defining a surface and to use terrain or landscape metaphors to describe it. At this point in the GIS model development, the resulting surface is extremely spiky and jagged, a badlands of hoodoos and spires. This is an expression of the many point and polyline features. Where a grid cell contains high-scoring features, that cell shoots a slender peak up above the surrounding landscape.

The GIS model so far yields thousands of tiny peaks, each representing one or a few mine openings in a single grid cell. This would be fine if reclamation projects addressed single mines. We could find the highest peak, reclaim the mine there, and then go to the second-highest peak, and so on. However, the typical UAMRP noncoal reclamation project may take in 10-50 square kilometers (about 5-20 square miles) and 100-300 mine openings—logistically, it is more efficient to move into a large area and take care of all the problems there at once. The GIS model does not yet adequately reflect UAMRP practice up to this step.

To deal with this situation, we run a ZONALSUM calculation. For each grid cell, the calculation looks at neighboring cells and sums the values. The effect is to smooth the surface and merge clusters of spikes into larger mountains. In higher density areas, the valleys between spikes get lifted by the influence of the adjacent peaks. Isolated spikes, with no contribution from their neighboring cells, tend to get flattened relative to clustered spikes. Thus regions with higher densities of the risk components (mines, people, roads) get ranked higher than lower density areas, which is consistent with the conceptual model. This ZONALSUM calculation step merges thousands of tiny potential projects into a manageable dozens of peaks representing more typical projects.

The GIS model has now generated a landscape where elevation represents the estimated risk to the public (based on the model’s assumptions). The peaks are the riskiest and highest priority for reclamation. The next step identifies and ranks potential project areas.
Potential project areas are identified by looking at the highest peaks. The UAMRP uses one standard deviation below the maximum score (elevation) as a cutoff, which is roughly the 80th percentile. The GIS software locates all of the cells scoring above the cutoff level. This step is like raising the sea level to about 80% of the maximum elevation. The resulting islands are the potential project areas, with their shorelines being project boundaries. Next, the scores of the cells within each island are summed to give a composite score for that island. These composite scores can be ranked. Because of the previous ZONALSUM operation and the summation here, the high scoring cells tend to occur in contiguous clusters of about 20-50 square kilometers (about 10-20 square miles), or in the size range of typical construction projects. For presentation purposes, the islands of potential project areas are plotted on a map with ramped colors portraying the composite score values for easy visualization.

Projects are chosen at an annual planning meeting. The top twenty potential project areas identified by the ranking model, ranked by their scores, are presented to the UAMRP staff for evaluation and discussion. Additional data external to the GIS model, such as staff knowledge of specific mines, knowledge of incidents or public complaints, workloads, schedules, etc. are introduced. From this more subjective evaluation, the staff selects the top projects to carry forward for planning and funding.

**Simplified Example of the GIS Model**

Consider the hypothetical region shown below to graphically illustrate how the GIS model works.

A paved road (→) intersects a dirt road (∥). There are three mine openings (✗). The census shows a high population density in the south (indicated by hatching) and a low population density in the north (no hatching).
The region is first gridded into cells. The software then examines the contents of each cell and assigns values as specified by the operator depending on the attributes of the different data layers.

### “Mines” Layer.
Values Assigned to Cell Attributes:
- mine opening = 20
- buffer (1 cell) = 2

### “Access” Layer.
Values Assigned to Cell Attributes:
- paved road = 5
- dirt road = 3
- buffer (1 cell) = 1

### “Population” Layer.
Values Assigned to Cell Attributes:
- high density = 3
- low density = 1
Composite grid cell value calculated by adding the mines, access, and population values together.

<table>
<thead>
<tr>
<th>3</th>
<th>4</th>
<th>6</th>
<th>2</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
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<td>22</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

ZONALSUM scores calculated by adding the values of the adjacent cells to each cell value.

Maximum score = 67
Standard Deviation = $\sigma = 14.6$
Maximum $- \sigma = 52.6$
Cells with values exceeding 52.6 are outlined as top priority cells.

The effect of this step on the model is to reduce the influence of isolated high values and to increase the influence of clustered high values. The figures below plot surfaces of the composite grid cell scores (left) and the ZONALSUM scores (right). The spikes at left represent the three highly weighted (20 points) mine openings. In the right-hand figure, the two nearby spikes at right have nearly merged into a single mountain peak because their proximity raises the score of the valley between them during the ZONALSUM operation. Views are looking east with the southwest corner at the right foreground.
Islands of top priority cells are grouped as potential projects and are outlined. They are ranked by their composite scores as shown by the ramped shades of gray.

Composite Scores of Islands:

- 111
- 132
- 185 (highest score/priority)

This example is oversimplified for the sake of illustrating the nature of the calculations. (Astute observers will note that two of the mines actually fall outside of the potential project area boundaries identified. This is due to the weighting factors and the very low resolution grid used.) The example uses buffering for the Roads and Mining layers. The UAMRP model does not use buffers. Instead, it uses FOCALSUM calculations. Although the software processes the two differently, both methods have the similar effect of creating a zone of influence around a feature that can be assigned a weight or score.

**Real World (i.e. Utah) Example**

Figures 1-6 on the following pages show output from the GIS model using actual data for Utah for 2008. In Figures 1-5, deeper intensity of color on the yellow-red ramp indicates higher values.

Figure 5 shows the final composite scores as a three-dimensional surface with the highest peaks representing the highest scores. From Figure 5 it is easy to visualize a horizontal plane (or sea level rise) slicing off the tops of the peaks at a specified level—Utah uses one standard deviation below the maximum—to isolate the highest peaks as “islands.” The islands with the greatest sum of composite cell scores, i.e. volume (not necessarily the highest elevation or largest plan view area) become potential project areas and are carried over to the map in Figure 6. The final projects chosen for a particular grant cycle are selected from the semifinalists in Figure 6.
Figure 1. Map of Utah showing the mining component of the GIS model.
Figure 2. Map of Utah showing the population component of the GIS model.
Figure 3. Map of Utah showing the access (roads) component of the GIS model.
Figure 4. Map of Utah showing the mining, population, and access (roads) components of the GIS model summed into a composite score.
Figure 5. Map of Utah showing the composite grid scores as a three-dimensional surface. View is looking from southeast to northwest.
Figure 6. Planning map showing the twenty top-ranking potential project areas based on the sums of their composite scores.
Data Sets And Settings

The UAMRP GIS model uses the following statewide data layers:

<table>
<thead>
<tr>
<th>Model Component</th>
<th>Layer</th>
<th>Data Source</th>
<th>Scale</th>
<th>Attributes</th>
<th>Cell Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mines</td>
<td>Utah Mineral Occurrence System (UMOS)</td>
<td>Utah Geological Survey</td>
<td>1:500,000+</td>
<td>Mine Production, Density</td>
<td>20, 30, 60, 100</td>
</tr>
<tr>
<td>Mines</td>
<td>Mineral Resources Occurring in Veins</td>
<td>AGRC</td>
<td>1:500,000+</td>
<td>Vein Present/Absent</td>
<td>50</td>
</tr>
<tr>
<td>Mines</td>
<td>Phosphate Resources</td>
<td>AGRC</td>
<td>1:500,000+</td>
<td>Phosphate Resource Present/Absent</td>
<td>50</td>
</tr>
<tr>
<td>Mines</td>
<td>Mining Districts</td>
<td>UAMRP (digitized from Doelling and Tooker, 1983)</td>
<td>1:750,000</td>
<td>Mining District Present/Absent</td>
<td>50</td>
</tr>
<tr>
<td>Mines</td>
<td>Mining Claims</td>
<td>US BLM</td>
<td>1:100,000</td>
<td>Mining Claim Present/Absent in Section</td>
<td>50</td>
</tr>
<tr>
<td>Mines</td>
<td>USGS Map Symbols</td>
<td>UAMRP (digitized from USGS topographic quads)</td>
<td>1:24,000</td>
<td>Adit, Shaft, Prospect</td>
<td>100, 200</td>
</tr>
<tr>
<td>Access</td>
<td>Roads</td>
<td>AGRC</td>
<td>1:24,000</td>
<td>Type (Primary, Secondary, Dirt, Trail)</td>
<td>1, 2, 5</td>
</tr>
<tr>
<td>Population</td>
<td>2000 Census</td>
<td>AGRC</td>
<td></td>
<td>Population/square mile</td>
<td>1-8</td>
</tr>
</tbody>
</table>

Utah’s Experience With the GIS Model

The UAMRP has used this ranking system since 2000. In that time it has proven very useful and has required only minor tweaking. The software allows a variety of modes for graphical
presentation of the output to help non-GIS-savvy users understand the results. A significant improvement occurred in 2004 with the addition of the USGS mine symbol data.

As projects are completed, they should no longer be priority areas for reclamation; the problems there have been addressed. However, the data sets still contain data indicating the presence of mine features. In the model, boundaries of completed projects are masked out by forcing cell values to zero to eliminate them from consideration and remove their contribution to scoring.

One of the major mining data layers with a significant contribution to the total scoring in the GIS model is the one for mining districts, whose boundaries tend to be oval or curvilinear (Doelling and Tooker, 1983). UAMRP project boundaries tend to be more rectilinear, following section lines, highways, and watershed divides. The UAMRP has customarily drawn project boundaries fairly close to the mines, smaller than the more generously drawn mining district boundaries. The unexpected consequence of this is that after a reclamation project is completed and its extent is masked out in the model, the model produces haloes or slivers of high ranking regions around the completed projects due to the strong influence of the mining districts in the scoring. In reality, these slivers usually have minimal actual mining presence and should be lower priority. They are artificially inflated by a single coverage (mining districts) with broadly drawn boundaries.

To deal with this issue the UAMRP are considering several options. One approach acknowledges the role of the ranking model in program administration and would enlarge project boundaries to eliminate the slivers. Within these new larger projects there could be subregions: a more narrowly defined construction project boundary for environmental assessments, areas of lower likelihood of mining to be inventoried by literature research instead of pedestrian surveys, etc. Another approach would be to downgrade the weight of the mining districts in the model. This is a recent issue and is still not resolved.

One persistent problem is the absence of good statewide data for certain types of information. The model currently does not handle transient populations exposed to abandoned mines, even though the UAMRP recognizes that recreational use of the backcountry puts substantial numbers of people at risk. The model uses census data, but this only addresses resident populations. There are no good data sets at present that provide statewide information on where, how much, and what kind of outdoor recreation occurs. State and national parks keep records of visitation
and designated recreation areas are identified in land use coverages, but useful data on the extensive recreational use of the vast public lands managed by the U.S. Bureau of Land Management (42% of Utah land area) are lacking. The UAMRP explored looking at ATV registrations as a proxy for one type of recreational use, but ATV’s are registered where their owners live, not where the ATV’s are used, so this in effect simply duplicated census data. A GIS coverage indicating where people go to play and in what numbers would greatly improve the model’s ability to identify areas of risk.

Currently, the model is used at the front end of the project process to identify areas in which to work. In theory, it can also be used at the back end to track progress. The GIS model generates a landscape where elevation represents the estimated risk to the public (based on the model’s assumptions). The peaks are the riskiest and highest priority for reclamation. The scores represent a quantified (but dimensionless) index of “badness” that incorporates hazards present and relative risks. A score could be calculated for a project area by summing the values of all of the cells within the project boundary (in calculus terms, this would be integrating the volume beneath the surface inside the project boundary). As projects are completed, those scores could be used as an additional performance measure in the same way that the number of mine closures completed or the number of acres of land restored is used.

The GIS model is helping us to concentrate our efforts and resources in those areas where they can do the most good. It has substantial advantages over its manual predecessor in using higher resolution data and data that can be constantly updated. Other than the initial setup effort, the model requires little administrative time. Most important, the potential project areas identified by the model and their rankings pass the common sense test. They have been reasonable and logical, which builds confidence that the model does what it was intended to do.

**Literature Cited**


