Introduction

Peabody Western Coal Company's (PWCC) Geographic Information System (GIS) program is an integral tool used for satisfying a variety of operational, environmental, and administrative needs. The GIS program has evolved with improvements in technology, leading to greater understanding of the program utility with respect to fulfilling the day-to-day requirements at the Black Mesa Complex.

Environmental Setting and Background

PWCC's Black Mesa Complex, comprised of the Kayenta and Black Mesa coal mines, is located on the northeastern portion of Black Mesa. Elevations in this area range from 6,600 feet to over 7,200 feet. The climate is arid; precipitation averages 7 to 9 inches per year, and temperatures range between -15° and 100° F. Topography is characterized by rolling hills with gentle to steep sideslopes, dissected by valleys and drainages with deeply incised washes. Scoria, interbedded sandstones, and shale give the rolling hills a rough, broken appearance. Soils are shallow on the steep hill slopes and deep in the valleys.

The dominant vegetation communities include pinyon-juniper woodland and sagebrush shrubland. The area is predominantly grazeable woodland and rangeland, supporting a traditional native lifestyle centered around livestock grazing and cultural plant use. Individual family or extended family homesites and camps are dispersed throughout Black Mesa in what is referred to as customary land use areas. Approximately 200 residents live within or immediately adjacent to the 100-square-mile Black Mesa lease area

The Kayenta Mine operates pursuant to Permit AZ-0001D, while the Black Mesa Mine operates under Permit AZ-0001, both issued by the Office of Surface Mining Reclamation and Enforcement (OSMRE), the lead regulatory agency. The Kayenta Mine has been in operation since 1973, producing about 8 million tons of coal annually. The Black Mesa Mine has been operating since 1970 and produces about 5 million tons of coal per year. Both mines are surface operations that use draglines to remove overburden and expose multiple coal seams. Three sub areas are currently being mined at the Kayenta Mine and two at the Black Mesa Mine, resulting in surface disturbance of about 400 and 200 acres per year, respectively. Peabody has reclaimed

over 12,000 acres to date.

PWCC's Need for a Geographical Information System

The last twenty years have seen significant technological advancement, especially in the area of information systems and the use of digital data. Additionally, detailed cost effective imagery has become readily available along with the ability to accurately collect extensive ground surveyed information. The development and sophistication of global positioning systems (GPS) for surveying and collecting polygon, point, or line data allows accurate, real-time data to be collected quickly with minimal resources. Versatile and more user friendly systems have also been developed for graphical presentation of information and product output. For those who have operated in the old system of hand drawn maps and hard copy data, the new opportunities provided by improvements in computers and GIS is in stark contrast.

By necessity, and with a desire to conduct more cost effective and efficient operations, mining companies have embraced this new technology and assimilated large amounts of data covering mining operations, reclamation, environmental areas, and administration. The increased quantity and quality of data combined with continuing sophistication of information systems allows for a wide range of analysis, reporting, and displaying of information.

Analysis, reporting, and displaying information have been historically important for accurately planning operations or documenting results. Prior to the information age the same approach was usually accomplished by using unrectified aerial photography, ground surveys, hand drafted maps, and associated hard copy information and reports. Whether the use was for military intelligence, conservation planning, or a mining operation, large amounts of information was available that was cumbersome and not user friendly. The accuracy of hand drawn maps was dependent on the draftsperson and quality of survey information. Analysis of information could be difficult and time consuming while critical historic information might be unavailable due to lost or misplaced reports and maps. Once rectified imagery and accurate GPS data became available, it became obvious that older information was not always accurate or dependable.

PWCC operates under a number of circumstances that make the Black Mesa Complex unique among surface coal mines. This unique operating situation demonstrates how important GIS and

powerful information systems have become to the mining industry. The leasehold for the Black Mesa Complex is situated on both Navajo Nation and Hopi tribal lands and includes both the Black Mesa and Kayenta Mines. These two mines have separate contracts and customers. Furthermore, the 1882 Executive Order Line splits the lease area in the center, north to south. In addition to other issues, this line provides for Navajo only coal royalties north of the line and joint Navajo-Hopi royalties (50/50 split) south of the line. Additional boundaries in the southern portion of the leasehold include the Hopi Partition Line where surface ownership to the north of the line is Navajo and surface to the south of the line is Hopi.

The location of the Black Mesa Complex on Indian lands places it under the jurisdiction of the federal regulatory program administered by OSMRE. Regulatory personnel from the Navajo Nation and Hopi Tribe also inspect the mines and provide administrative review of permitting documents to OSMRE. Further complicating the regulatory situation are the various regulations and corresponding permits the mines have or are currently operating under. Regulations were not in place during the earliest operating years and hence these lands are classified as Prelaw. There is however, a requirement for reclamation of these lands in the lease agreement with the Navajo Tribe. After passage of the Surface Mine Control and Reclamation Act (SMCRA) in 1977 and approval of the initial program implementing regulations in 1978, mining and associated reclamation programs came under OSMRE jurisdiction as noted above. A further refinement of the regulations brought mined lands under Interim Program standards and requirements. Finally, in 1984 the permanent program regulations for Indian Lands were promulgated requiring an additional jurisdictional permit category.

This has resulted in four major jurisdictional categories of mined lands and associated facilities at the Black Mesa Complex. Within these jurisdictional areas, a number of sub areas or activities are present including grubbing and topsoil removal, active pit areas to be backfilled and graded, final graded areas, areas topsoiled, and revegetated lands. Associated with these jurisdictional areas and activities are costs and liabilities. These are further categorized as “short term” (those areas associated with active pit and reclamation operations) and “long term” (areas necessary to support life of mine operations such as haul and access roads, sediment ponds, facilities, etc.). A number of years ago, Peabody set up an internal accounting and tracking system for the above activities and categories. Accounting as well as the operations and reclamation departments used this information. Later, it served as the basis for reporting to the

regulatory authority. The system generated a vast amount of information to track and document mine land activities in an efficient and accurate manner using hard copy files and maps.

As if the above complexity was not sufficient, the Black Mesa Complex operates under yet another unique scenario. Through an agreement with the Navajo Nation, residents are allowed to live within the lease area. A number of residents also live adjacent to the lease area but have customary use areas that are located on the leasehold. Although PWCC has exclusive rights to operate within the leasehold, residents are compensated for loss of grazing or customary use lands as a result of mining and reclamation activities in their identified customary use area. This compensation is paid every five years until the lands have been successfully reclaimed and released back to the Tribes and the residents. The lands under compensation require accurate tracking of disturbance to determine the correct payments. In cases where residents are located on coal resource areas to be mined, the residents are relocated to an agreed location off any future mining areas. Other items that need to be documented and tracked include roads, traditional and cultural places (TCP), archaeological sites, resident homes and other structures. Infrastructure including the road network, powerlines, water lines, telephone lines, etc. must also be located and tracked.

Baseline data is extensive at the Black Mesa Complex and include archaeology, vegetation, soils, hydrology, wildlife, overburden, and drill hole data. Ongoing studies continually expand these databases. This baseline data is used extensively for a number of situations including watershed and pond designs, topsoil salvage, reclamation planning, mitigation, and mine planning. This information was historically documented and maintained on hard copy maps and files.

As can be readily seen, the complexity of operations at the Black Mesa Complex, the variety and amount of data, and the overlapping or interrelationship of a multitude of activities, both mining and nonmining, lends itself well to GIS. Indeed, it makes implementation of a GIS a virtual requirement. However, until the late 1980's and early 1990's much of the information and data was collected, documented, and maintained with large amounts of effort utilizing numerous personnel. Data was available in hard copy maps, files and reports, and was not always user friendly or readily available. The resulting difficulties centered on using the information generated with respect to accuracy and reliability issues and a consequent reduction in analytic capabilities and product output.

To address these needs and problems, PWCC implemented procedures that brought the information and data closer to a functional GIS-like product. Digitizing maps and converting information to polygons was accomplished with early AutoCAD and in-house developed programs. Lotus generated spreadsheets and database programs such as Paradox were used to organize and analyze information. However, these more accurate paper maps and electronic files and reports still did not meet the needs for spatial information management.

In the early 1990's, intensive efforts were made to develop in-house databases for a variety of disciplines and implement the ESRI (Environmental Systems Research Institute) product ArcInfo as the PWCC GIS tool. This required major efforts to provide the electronic information necessary to create the many coverages required for a fully functional GIS while maintaining utility to the various users and regulatory activities. PWCC required a large number of temporary staff to convert hard copy information to electronic format and organize existing electronic files. PWCC staff spent many hours checking, correcting, and verifying information. A staff of four or more full and part time ArcInfo programmers was utilized to implement this program at PWCC and provide the products required by the PWCC user community. Though ArcInfo had its own database, PWCC used an INGRESS database for tabular data that was interfaced with ArcInfo with limited success. This lack of success with INGRESS led to the full implementation of an ArcInfo database.

The drawback to ArcInfo, a very capable and powerful tool, was its complexity and requirement for programmers to write the various AML (Arc Macro Language) programs and files necessary to produce ArcInfo products for data analysis and map creation. Reductions in staff and the need for less complicated tools moved PWCC to the next generation ESRI product, ArcView. This program contains native analytical and mapping capability, is more user friendly, and can be readily used for a number of applications by desktop PC users. It is especially suited to ad hoc data analysis and map production. Although ArcView is less complicated, ArcInfo continues to be used for the intensive SMCRA reporting and associated database management.

PWCC's Refinement of the Geographic Information System

GIS has become an integral part of the operations at PWCC's Kayenta and Black Mesa mines, particularly in the environmental department. The mines currently employ a full-time GIS specialist, whose responsibilities include managing data acquisition, keeping spatial

databases current, and generating maps and reports. Consultants are also utilized for day-to-day mapping needs, and for maintaining and updating the customized scripts and programs.

The primary GIS software used by PWCC is ArcView 3.3 from ESRI. ArcView is installed on approximately 7 PC's with users including GIS professionals, reclamation scientists, and engineers. ArcView 3.3, although not the most current version, has proven to be an effective platform for maintaining and updating the GIS, for designing complex map layouts, and for allowing non-GIS users to access and manipulate spatial data. PWCC has increased the functionality of ArcView significantly with the addition of customized extensions and scripts.

The core of PWCC's GIS is ArcInfo 7 which is currently being upgraded to ArcGis 9. This version of ArcInfo is installed on only 2 PC's with use limited to trained GIS professionals. The primary use of ArcInfo is to maintain a highly complex data set depicting detailed land status. This land status layer, called ACTALL, contains polygon information showing all mining related activities from inception date through the present. Related coverages support ACTALL and are used to determine status of mine site activities. ArcInfo macros have been written to automate the process of updating ACTALL and to extract current activity status reports that are then exported to shapefiles for use in ArcView. Most of the functions of ArcInfo occur in the background with little or no user intervention, making ArcInfo a key GIS element, but its importance is easy to overlook.

Data acquisition is a very important element in the PWCC GIS. The dynamic nature of the landscape features in a surface mining environment means that features are constantly changing and must be added or revised within the GIS database. Global positioning systems (GPS) have become the primary means for acquiring new data at the Kayenta and Black Mesa mines. The mines use survey grade GPS equipment for any mapping requiring a high level of accuracy. For everyday mapping needs, the more affordable "sub-meter" technology is sufficient, with several backpack units available as well as compact hand-held receivers. Another means of data acquisition is on-screen digitizing from rectified aerial photography. This method is less desirable since there are many factors that negatively affect the accuracy. Scanning and rectifying air photos is a quick and easy way to get information into the GIS, but spatial inaccuracies of more than 100 feet are not uncommon. Even orthophotos contain inherent inaccuracies, so care must be taken when using these sources. PWCC has focused on the importance of maintaining an accurate spatial database. The accuracy of the data within the GIS

is always improving. Better technology allows for more accurate data to be collected, and existing data are being improved with ongoing updates and maintenance. Considerable effort has gone into editing and verifying older data to insure this older information reflects the actual site conditions and will interface smoothly with current data.

The next phase, once data have been collected and checked for quality and correctness, is to generate products. The analysis environment of ArcInfo, combined with customized macros, produces information vital for internal planning purposes and allows the mine to generate the monthly reports required by federal regulators and PWCC's internal requirements. The ArcInfo coverage ACTALL, as mentioned earlier, tracks the status of activities occurring on the mine property. Following is a detailed description of the ACTALL coverage and an overview of the AML programs used for analysis and reporting.

ACTALL is an ArcInfo "region" coverage. Regions are an expansion of the polygon feature class, allowing more complex modeling of areal features. Region coverages can contain overlapping polygons, maintain the hierarchy of features, and establish associations between polygons. The ACTALL coverage contains features representing all activities occurring at the mine site. Table 1 shows a list of these activities tracked by ACTALL. The activity status of a single parcel of land will change over time as the area is initially disturbed, actively mined, graded, and finally revegetated. Given this scenario, it is clear why this data layer must contain overlapping polygons. The hierarchy of polygons is typically determined by the date, i.e. more recent activities supercede older activities in their importance.

Macros were written in AML to extract current activities from ACTALL and related coverage files such as Longterm, Lawtype, Drillhole, and Presoil to generate reports. Activity coverages are updated on a monthly basis by querying ACTALL for the most recent activity occurring at each location. A separate coverage is then created representing each current activity class. For example, a coverage showing only final graded (FGR) areas is created, representing all areas that have been graded and are ready for topsoil application. The macro will then compare this coverage to the previous month's FGR coverage, thereby determining the areas graded during the reporting month. Results of the analyses are exported as shapefiles and customized ArcView scripts are used to generate tabular reports. This information is then used to create the monthly SMCRA reports and annual reports for submittal to OSMRE. Similar routines are used for the other activities tracked by ACTALL.

Table 1. Mining and Reclamation Activities Tracked by ArcInfo Region Coverage ACTALL, Black Mesa and Kayenta Mines, PWCC.

Activity	Sub-Activity	Description
DIS		Disturbed Lands
	GRB	Grubbed Vegetation Removed
	TSR	Topsoil Removed
PIT		Advanced Pit Mining Areas
	APT	Active Pit (Unavailable for Grading)
	RMP	Ramp (Access to Pit – Unavailable for Grading)
	OUT	Beyond 2 Spoils (Available for Grading)
	SP2	Within 2 Spoils of Active Pit (Unavailable for Grading)
FGR		Final Grade – Spoils Final Graded to AOC
TSP		Topsoil Pile – Topsoil Reserved for Reclamation
TSD		Topsoil Down – Topsoil Applied to Regraded Areas
REV		Revegetated – Final Seeded and Planted
REL		Released – Termination of Jurisdiction by the Regulatory Authority or Final Bond Release

Another primary function of the GIS is generating maps for permitting purposes. Four map series are continually updated and submitted to OSMRE to keep the permit current. The first map: Drainage Area and Facilities Map – Drawing No. 85400, is a series of 26 sheets at "400 scale" (one inch equals 400 feet), showing features related to storm water drainage including all water control structures. These structures include ponds, culverts, down drains, sediment control structures, stream channels. Watersheds are also shown. The Mine Plan Map – Drawing No. 85210, is a "1000 scale" (one inch equals 1000 feet) series in six sheets showing the best estimate of future mining activities. Proposed mining disturbance is shown in some detail for the first 5-years, with the remaining areas grouped into a six to 10 year category and a beyond 10 year category. The next permit map is the Jurisdictional Permit and Affected Lands Map – Drawing No. 85360 (JPM). This is also a six map series at 1000 scale, showing the regulatory permit areas, affected lands, and other jurisdiction covering the areas affected by mining. The jurisdiction categories and their descriptions as shown on the JPM map are listed in Table 2.

Table 2. Categories Included on Drawing 85360 - Jurisdictional Permit and Affected Lands Map, Black Mesa and Kayenta Mines, PWCC.

Categories	Description
Pre–Law	Lands Affected Prior to 12/16/77; No OSMRE Regulations
Interim Program	All Lands Affected Between 12/16/77 and 2/1/82; Interim Program OSMRE Regulations
Interim Permit AZ-0001	Lands Affected Between 2/1/82 and 7/6/90 for the Kayenta Mine and Lands affected from 2/1/82 to the Present for the Black Mesa Mine; Interim Program OSMRE Regulations
Permanent Permit AZ-0002A	Kayenta Mine Lands at J-21 Affected from 12/28/84 to 7/6/90
Permanent Permit AZ-0001D	Kayenta Mine Lands Affected from 7/6/90 to 7/5/05
Permit AZ-0001D Beyond 2005	Kayenta Mine Lands to be Affected from 2005 to 2011

Finally, the Bonding Map – Drawing No. 89800, also at 1000 scale in six sheets, shows the bond liability categories associated with mining disturbance. This map is used for liability estimates based on jurisdictional permits. It is also used to determine how much bond would be required for final reclamation of mined lands if the mine were to shut down. Table 3 lists the categories illustrated on the bonding map.

There are many additional products produced by the PWCC GIS. Vegetation sampling, spoil sampling, wildlife monitoring, final grading, topsoiling, and revegetation planning are some of the activities that depend on the GIS at Kayenta Mine. Scientists depend on GIS maps while conducting surveys in the field. Engineers use the data and maps for planning and design purposes including mine planning and providing field maps for field supervisors. Management relies on the information for internal accounting, reporting, and business planning. These day-to-day mapping projects are not as automated as the repetitive tasks mentioned earlier. Managers and scientists work together with the GIS staff to create maps specific to the current task at hand.

These very important ad hoc mapping efforts have a high level of utility for issue resolution, demonstrating conceptual concepts, aiding in tours and educational efforts, and working with local residents on grazing programs or infrastructure issues. This mentions just a few of the many and varied projects facilitated by PWCC's highly effective GIS. More and more, these

Table 3. Categories Included on Drawing 89800 – Bonding Map, Black Mesa and Kayenta Mines, PWCC.

Category	Title	Description
I	Permanent Program Final Pit Reclamation	Areas Requiring Reclamation Under Current Permit Regulations
II	Permanent Program Revegetated Facilities	Areas Outside of Major Support Facilities Requiring Reclamation (roads, ponds, etc.)
IIA	Permanent Program Areas, Held for Bond Release	Areas that Require Bond Release Under Permanent Program Regulations
III	Interim Program Areas	Areas that Require Termination of Jurisdiction or Bond Release Under Interim Program Regulations
IV	Pre-Law Affected Lands	Areas that Require Approval of the Navajo Nation and Bureau of Indian Affairs and Meet Lease Specified Reclamation Requirements
V	Lands Under Major Facilities	Major Facilities Requiring Reclamtion Under Interim or Permanent Program Regulations

products are attainable by the managers and scientists without the help of GIS professionals. Minimal training and experience allows these non-GIS users to access and manipulate data for their own purposes. The more user friendly nature of ArcView allows opportunities for hands on use by personnel to increase the use and understanding of PWCC's GIS tools to increase job efficiency and improve product output. PWCC continues to provide the training and tools necessary to make these capabilities better understood and more accessible to the many current and new users. New tools such as ArcGis 9 can bring the power of ArcInfo to users without its complexity. If the past is any indication, more powerful characteristics in conjunction with increased user friendliness is the expected future of GIS.

Conclusion

The unique and varied activities within the PWCC leasehold, the nature of mining operations, and the widespread mapping and reporting requirements of PWCC's Black Mesa Complex, clearly illustrate the need for a GIS. The initial implementation of PWCC's GIS was a complex and time-consuming undertaking, requiring a large staff of highly trained GIS professionals assisted by PWCC engineering, environmental, and reclamation staff. The GIS software available in the early stages of implementation required extensive programming skills and education in GIS operations, making it essentially unavailable to non-GIS users. Modern software is more user-friendly than ever, making this technology available to a wider range of disciplines. With this in mind, PWCC has designed their GIS to cater to as many users as possible.

Currently, both ArcInfo and ArcView software are used in PWCC's GIS. ArcInfo is primarily used for updating and analyzing the detailed land status coverage ACTALL, currently being used to facilitate PWCC's internal SMCRA reporting system. ArcView, combined with custom scripts, is used mainly for data entry, map production, and report generating. The large quantities of maps required for PWCC's permit are maintained within ArcView. GIS programs such as ArcView and ArcGis continue to improve and expand, making these tools not only more user friendly but also more powerful. PWCC will continue to upgrade based on the availability and applicability of these newer systems. GIS utility will certainly benefit staff productivity and efficiency.