THE USE OF GEOGRAPHICAL INFORMATION SYSTEM (GIS) TECHNOLOGY IN SURFACE MINE RECLAMATION MONITORING

by

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Abstract. The use of a Geographic Information System (GIS) and related technologies (eg. Digital cartographic tools, satellite image processing systems) can benefit the planning and monitoring of open-pit mine reclamation activities. PCI Geomatics, in conjunction with Luscar Limited's Line Creek Mine, has developed a GIS-based system designed to store information relevant to planning and assessing reclamation progress. Data that existed in various formats throughout the company, and which had been collected since the mine-planning phase, was integrated into the GIS. The system is used to summarize current reclamation activities and is linked to corporate costing procedures. Monitoring of reclamation activities and quantifying change in the mine area is easily done using the spatial analysis capabilities of the GIS. Assessments of the change in reclamation areas are enhanced by using satellite image data to produce inexpensive and timely information on the land base, and allow the comparison of the health of the vegetation in reclamation areas from year to year. The implemented system substantially reduces the time needed to generate statistics and produce maps for government or internal reports. Also, there are benefits in terms of both cost and effectiveness of reclamation planning.

Additional Key Words: remote sensing, geomatics, coal mining, cartography, satellite imagery

Context

PCI Geomatics has worked with Line Creek Mine, an open-pit coal mine located in the Elk Valley in eastern British Columbia, for approximately three years. PCI has been involved at many phases of the development of the mine's reclamation geographic information system (GIS) and database, from system and requirements design through the implementation of the system.

Reclamation of disturbed lands is a critical, on-going part of the operation of an open-pit coalmine. Reclamation includes a range of data collection and analysis activities undertaken to build a map-based 'picture' of the land base and any mining activities that are happening on this land. Government legislation and regulations, as well as internal management activities, mandate spatial data collection and analysis, and maps and reports are produced to accompany this analysis.

Producing the necessary documentation for reclamation requires the collection and compilation of large amounts of geographical data from a range of sources, the building of a spatial environmental data set, and analyzing the data collected. GIS can be a laborsaving tool for analyzing land-data and presenting the types of results required, increasing the accuracy, speed, and quality of this analysis. To describe the types of analyses performed in support of reclamation, one can generally say that the state of the land before mining activities is compared to the state of the land during and after disturbance. Graphical, tabular, and statistical output is generated to illustrate this change. These output can then be used for planning the mine's reclamation activities. In addition to collecting and nsing the data strictly for reclamation purposes, the flexibility of a digital data base means that the information can be used for other purposes, such as avalanche prediction and monitoring, forest-land management around the mine site, and mine-site planning.

Introduction to the Technology

Geographic Information Systems – General Overview

In his book, *GIS: a Management Perspective*, author Stan Aronoff (1993) states "Geographic Information Systems are computer-based systems that

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are used to store and manipulate geographic information. This technology has developed so rapidly over the past two decades that it is now accepted as an essential tool for the effective use of geographic information." From its beginnings in the late 1960's to the present date, GIS technology has advanced in leaps and bounds and has, by and large, become mainstream technology. Even the novice user can now quickly and easily perform mapping and analytic tasks that were previously done using manual methods. The range of available analytic complexity has been vastly increased by the use of GIS, and continues to grow as the technology matures, thus enabling the use of GIS in more diverse application areas.

Although a usable technical definition of GIS has escaped all who have tried, simply put, GIS is a tool designed "for the collection, storage, and analysis of objects and phenomena where geographic location is an important characteristic or critical to the analysis." A GIS integrates satellite data, aerial photographs, digital maps, and other data that can be linked to a location to analyze relationships and identify spatial patterns. Impediments to the early use of GIS – lack of digital data, complexity, and high cost – have largely disappeared, as more and more digital data is available. As social, geographical, environmental and natural resource issues increase, the need for a powerful tool for analyzing the inter-related systems involved in these types of problems increases. Geography deeply influences almost every decision we make, and GIS is changing the way we see and use geographic information. We need to answer which options would affect what areas in what ways, and what issues are tied to what areas. GIS helps examine spatial relationships between issues and options so we can fully understand the impacts.

The use of GIS in the natural resources and environmental application areas is long-standing. Governments and private companies involved in natural resources and environmental management were among the first users of GIS and other related technologies (such as remote sensing and global positioning systems). However, while GIS has been around for more than 30 years, its use in the mining industry has been a more recent phenomenon. As the technology becomes easier to use and more mainstream, it is anticipated that more mining companies will use GIS, particularly in their reclamation efforts.

Recent development in GIS software has focused on making these tools more available to a wider variety of users. New software is 'customizable', allowing programs to be tailored to meet specific requirements of specific users in an intuitive, easy-to-use environment. Additionally, there are a host of new internet-based map query and browsing tools that allow information to be quickly and easily distributed. New developments in data translation capabilities mean that systems are capable of reading and writing to many industry-standard data formats, reducing the need to select systems based on a particular data format. All of these innovations increase the accessibility of GIS systems to different levels of users as the software can be made to fit the type of user and their specific requirements rather than presenting analysis and mapping functions in a complicated, out-of-the-box environment.

The term 'geomatics' is now increasingly being applied to describe the full range of tools operating on spatial, or geographic, data. This includes a variety of tools; these include 'traditional' Geographic Information Systems, software devoted to the processing of satellite imagery, specific tools for digital photogrammetry, and software designed for producing high-quality, cartographic output. In the context of this study, all of these will be referred to under the general term 'GIS'. To varying degrees, all of these have application in the mining industry, particularly for performing monitoring and analysis in support of reclamation efforts.

<u>Reclamation – General Overview</u>

Reclamation is the combined process of land treatment that minimizes water degradation, air pollution, damage to aquatic or wildlife habitat, flooding, erosion, and other adverse surface effects from mining operations. These effects include adverse surface effects incidental to underground mines, so that mined lands are reclaimed to a usable condition which is readily adaptable for alternate land uses and create no danger to public health or safety. The process may extend to affected lands surrounding mined lands, and may require backfilling, grading, resoiling, revegetation, soil compaction, stabilization, or other measures. The main environmental impacts of open-pit coal mining, for example, are surface disturbance and disposal of mining wastes.

Land reclamation can lead to habitat restoration when the intent of the reclamation project is to restore native vegetation and recreate wildlife babitat reflecting the biodiversity of the region. This goal can only be achieved when the natural processes required for a self-sustainable ecosystem are also restored to the reclaimed site. Mine reclamation plans frequently contain provisions for restoring native vegetation and wildlife habitat on part or the entire reclaimed site.

Largely in response to public concerns over the effects of mining on the environment, legislation has been enacted at both the Federal and Provincial level in Canada. The federal legislation consists of quality standards enforced on fisheries, air and water, which provide a framework for provincial agencies to base reclamation standards.

All mines are required to carry out programs of environmental protection and at closure, reclaim the land and watercourses to a condition equal to or better than existed before disturbance. Regulation is achieved through a permit system including company submission of mine plans, acid rock drainage management plans, and reclamation plans; review by an interagency committee of government; security bonding; inspections; and annual reporting and review.

The Forest Practices Code of British Columbia also has significant implications for the mining industry, as protection of forest resources is given a very high profile. Primary concerns for the mining industry are ensuring that appropriate authorization is in place before felling trees, constructing, maintaining and deactivating roads and access trails to high standards, and conserving soil.

At the beginning of a mine's life, the ultimate reclaimed land use objective is set out, and the proposed Reclamation Plan is put before a regional multi-agency review. Reviewing agencies can include the BC Ministries of Environment, Lands and Parks, Forests, and Energy and Mines, as well as the Federal Government agencies Natural Resources Canada and Department of Fisheries and Oceans. The stated end land-use objective would be accepted or rejected based on the results of the review. In the early days of coal mining in British Columbia there was a lot of concern over displacement of wildlife due to changing habitat. A major goal of reclamation is to reduce that. Since then things have changed, and forestry as an objective is also common. Of course, the end reclamation objectives vary depending on the original state of the undisturbed land. The reclamation results themselves are the subject of many topical debates – what does productivity mean? – how do you know when you have achieved your objective?

An examination of the basics of surface mine reclamation show much potential for the use of GIS. First and foremost, a GIS must be useful and effective as an operational tool that allows mine personnel to analyze their land base and produce output in an efficient manner. Secondly, GIS and related technologies have the potential to increase the value of existing data by allowing more sophisticated modelling to be applied, thus extracting more 'interpreted' information from data that is already available.

<u>Line Creek Mine: Reclamation efforts and GIS</u>

Line Creek Mine is undertaking to implement a GIS system to assist its Environmental Planners, who are chiefly concerned with reclamation activities, in their efforts to maintain data, monitor, and evaluate the mine's land base and reclamation efforts.

The process of defining the requirements of the system and designing the actual implementation involved the participation of a number of parties. The process included a workshop between reclamation staff, other providers of data from within the mine organization, habitat consultants, government officials, and technical experts in GIS design and implementation.

An initial design phase produced a comprehensive plan that addressed a number of issues that were critical to the successful implementation of the system at Line Creek Mine. The design identified and described activities that could be supplemented through automated data analysis. These were set as the primary goals of the system; secondary goals included creating provision for enhancing decision-making by making available the processing power of the GIS to perform queries and analysis that were not currently being done. In addition, the previous methods of collecting and storing corporate data were analyzed to see if they could be integrated into a GIS. Finally, the types of users of the system were described in order that the 'right tool for the right job' was recommended and that the system was accessible.

The process of implementing the GIS at Line Creek involved a number of steps. These included:

1. An education process to inform involved parties of the capabilities of GIS and how this technology is typically used
2. A workshop session, during which the expected results of the system were detailed, and an inventory of relevant data was generated
3. An assessment of the data and a determination of how each piece of data contributed to the system goals. This resulted in a rationalization of the work required to build the system and a priority list of expected outputs from the system and data entry tasks
4. A comprehensive plan for establishing the system 'backbone' – that is a description of the physical

system, its users, the data it will incorporate, and the analysis and output it will generate
5. Physical implementation, which included the actual setup of the GIS system and loading onto it the reclamation data set.
6. Customized user training and support

Line Creek's Reclamation Goals and Activities

Line Creek has established its primary reclamation goal as the restoration of ungulate habitat to levels equal to or better than pre-disturbance levels. The Elk Valley, in which the mine is situated, is an area of significant importance as habitat for Elk, Rocky Mountain Sheep, and Moose. The Line Creek mine area includes critical winter habitat for sheep, summer and winter habitat for sheep and elk, summer moose habitat, and migration paths for both sheep and elk. The disturbed area itself affects summer habitat for sheep and elk, and migration paths to winter ranges.

Line Creek environmental staff are responsible for replacing disturbed habitats. Their day-to-day and annual activities include:

1. planning the re-sloping and re-seeding of dump areas to facilitate vegetaion growth
2. monitoring and assessing the success of past reclamation efforts
3. monitoring and assessing the success of current reclamation efforts
4. producing annual reports for submission to government agencies that include quantitative summaries of the activities undertaken
5. avalanche control in winter
6. monitoring ungulate activity within the mine area (including areas outside the disturbed area) and assessing the effects of mining on this activity
7. quantifying the amount of habitat lost to mining and the amount replaced through reclamation efforts
8. environmental monitoring of Line Creek riparian area and fish habitat/stocks

Significant portions of the year's efforts go into producing summaries of the activities for both government reports and for internal decision-making. To produce these reports, reclaimed areas must be quantified, costs calculated, and future prescriptions made based on the current year's success, all of which could be assisted by geomatics technology.

Specifically, it was determined that GIS, Image Analysis, and presentation tools (cartographic or visualization) would be useful for Lime Creek Mine. Initially, the spatial database is a repository and storage mechanism for the large amonnt of information that has been collected over time. The long-range cost savings for use in this manner may be significant.

Secondly, the geomatics tools can quickly and easily generate summary statistics on reclamation areas.. For Line Creek Annual Reclamation Reports, the habitat ranges for Elk, Mouse, and Bighorn Sheep need to be assessed. Once the system is in place, progress can be summarized as frequently as desired, at little additional cost.

Longer-term ambitions include using the system to forecast reclamation success and to perform the more complex spatial analysis, such as simulating reclaimed habitats, surrounding topographical features, geo-physical stability, and pleasing aesthetic qualities

Line Creek required a system that will be held and maintained in-house, with on-going assistance in data upkeep and in developing new analytic routines. The system must allow in-house, non-expert users to generate statistics and maps, and to perform analysis once this has been designed.

Work with Line Creek staff identified three broad objectives for the system; each piece of data owned by the organizations was mapped to one or more objective (Figure I). The objectives were then prioritized in order of their return to the company – both in terms of cost savings. The design of analysis and the input of the data were then prioritized accordingly.

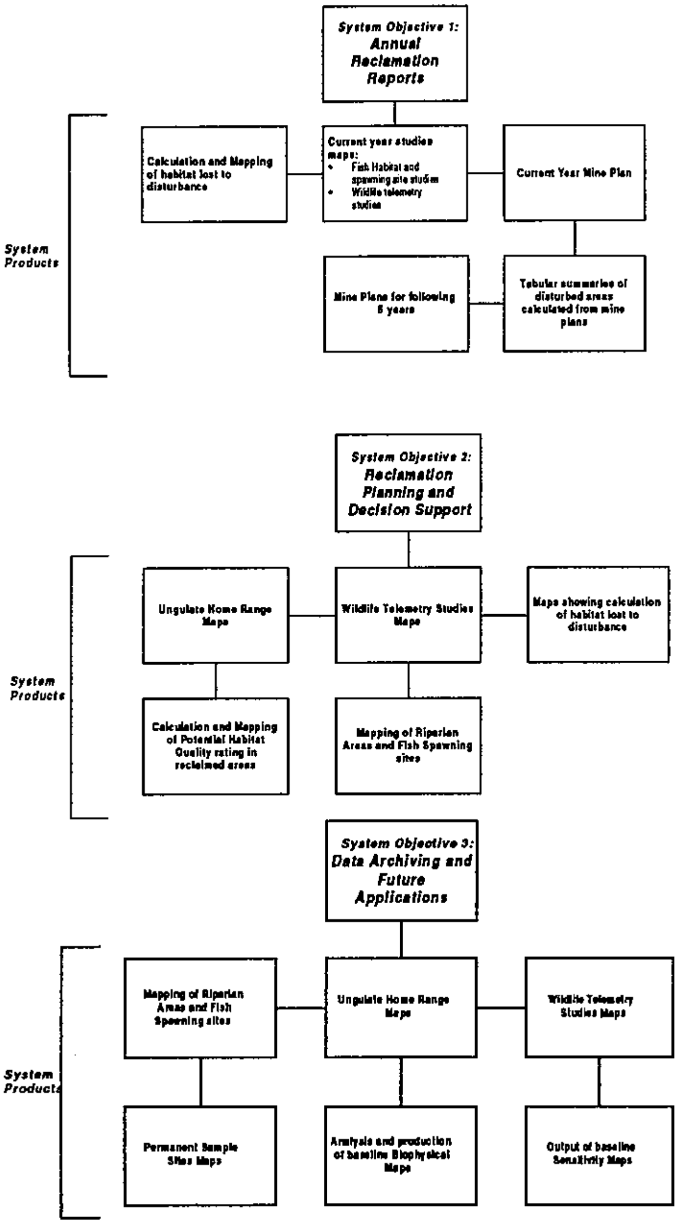

Figure I. Line Creek Mine GIS System Objectives

Data

Since the beginnings of Line Creek Mine in the early 1980s, a vast amount of land-based data has been collected. These include baseline data collected for Environmental Impact Assessment processes, yearly mine operations plans, various habitat and wildlife surveys, and aerial photography. Almost all of the data was determined to be useful in producing the reports and performing the analysis required by Line Creek.

Baseline Biophysical Data. Biophysical data was collected during Environmental Impact Assessments (EIA) at the time that the mine was originally proposed and planned. This data includes inventory information describing various wildlife and vegetation habitats at the mine site and in the area surrounding the mine. Among this information are maps showing areas of fisheries importance, sensitive fluvial and terrain areas, and wildlife habitat eco-regions that highlight and classify winter and summer ranges of elk, goats, mule deer, whitetail deer, moose, and sheep. Also included are specific features such as migration routes, mineral licks, important 'habitat requisites' and traditional ungulate crossings. These data attempt to portray the pre-disturbance habitat of the mine site and the area surrounding the mine upon which mine activity will have indirect or direct impact. The pre-disturbance vegetation has also been inventoried. The result of this data compilation is a comprehensive data set that includes habitat inventories, and bio-physical data that is pertinent to the presence and re-creation of the wildlife habitat.

Operational Data. In addition to the broader, baseline information required to define reclamation goals, the GIS includes a number of operational data layers that describe in detail the mine area and disturbance. These maps are updated frequently to reflect current mine activity.

- original ground, including 3M contour lines
- present pits
- present dumps
- 'reclaimed to date'
- yearly reclamation
- yearly flat
- yearly re-sloping
- roads
- ponds

Supplementary Data. There are a variety of data that can be accessed through public and private sources, or which can be derived from information collected for other processes. Most provinces in Canada have undergone significant digital data-collection initiatives resulting in a supply of data including cadastral and land-ownership information, hydrographic data, and infrastructure data detailing roads and other man-made features. Also common are datasets compiled by organizations such as the British Columbia Ministry of Forests which delineate and provide information on forest cover, or the BC Ministry of Environment, Lands, and Parks thematic mapping exercises which contain baseline land-use information. Private companies, such as forest lease-holders, may be a source of digital land-use data.

The BC MOELP 'TRIM' (Terrain Resource Information Management) files, collected at 1:20,000 scale, were purchased and incorporated into the Line Creek dataset to provide entire study area elevation and base map data. The Line Creek mine plans included 3 metre contour lines, which were used to derive additional information in the GIS. Using PAMAP GIS's 3-D modelling capabilities a 'Digital Elevation Model' (DEM), a slope map, and an aspect map were produced. One of the key advantages of using a GIS is the availability of functions that automatically produce new, and required data - such as the slope cover - from existing data, in this case a set of contour lines.

Image Data. Line Creek Mine has an archive of several years of digital orthophotos – aerial photos that have been photogrammetrically corrected for distortions caused by camera, angle of photography, and terrain, as well has having been geographically located in their true location. These aerial photos will form part of the GIS data set to allow changes from year-to-year to be compared, and to allow new information to be digitized from current photos.

Recently, work has been undertaken to use satellite imagery to enhance reclamation monitoring and planning. IRS 1C 23 metre multi-spectral satellite images were acquired to help assess the success of re-vegetation efforts on reclaimed land at the mine. By using specific bands of the imagery, a Normalized Difference Vegetation Index was prepared. This provided a measure of the overall health of vegetated areas by displaying areas according to their green-ness and the density of plant canopy. By using this, and validating results through ground surveys, the health of plants in reclaimed areas were assessed. Data from the IRS 1C satellite for a particular area can be updated frequently, so images can be collected during different times of the year and at the same time in different years. Using this, the change in vegetation health between years can be determined. This can allow a more focused approach to applying particular prescriptions to land areas in which vegetation is less successful, and in quickly determining the overall success of re-vegetation efforts.

Operational Analysis and Output

PAMAP GIS, the system provided to Line Creek as the core of the GIS system, provides a comprehensive suite of tools that are used in producing information for supporting the Environmental Department's decision making, generation of summary information, and producing maps for presentation in an Annual Reclamation Report.

Annual Reclamation Reporting. Annual Reclamation Reports, which are prepared for submission to the BC Ministry of Energy and Mines, review the degrees to which the overall reclamation objectives are being met. Completing these reports requires that the mine disturbance be analyzed in comparison to baseline bio-physical data. Generating statistics and maps for the Annual Reports involves collecting current mine planning information, which shows the locations and areas of pits, dumps, and reclaimed areas. These plans represent the current year's activities, and they are analyzed in comparison to the baseline habitat information collected prior to disturbance. In this manner, a GIS overlay can be used to determine how much of each habitat type has been affected in a current year, or throughout the mine's life. Information about each area on the mine is stored as a database attribute of that area, and they ability of the GIS to perform spatial queries makes a simple task of calculating statistics for the Annual Report. Generating information such as 'what is the total area of waste dumps seeded in 1998' is thus a simple process. After analysis and statistics have been generated, hard copy maps are plotted for inclusion in the Annual Report.

Generation of Summary Statistics. The entire mine site has been planned and mapped for operational planning purposes using Line Creek's existing Computer Assisted Drafting (CAD) system. This provides detailed, high-accuracy information about the present state of the mine. The data was imported into the GIS via DXF, an industry-standard format, and converted into a *polygon cover*. A polygon cover, in PAMAP GIS, contains discrete, homogeneous areas with associated attribute information contained in a database. Each polygon, representing an individual area such as a dump, has an area (measured in hectares) and perimeter (measured in metres) that are automatically generated by the system, as well as descriptive information such as the age of the dump, the type of habitat, and other user-definable data. Additional polygon covers in the map contain the baseline habitat information, and historic disturbance information (each year's mine plan forms a separate polygon cover, so the change between years can be evaluated). Using the 3 metre contours, secondary information describing the terrain was produced: a digital elevation model (which is a continuous surface cover containing elevation information about every point in the terrain), a cover indicating the slope of each point in the map, and a cover indicating the aspect of the slope (i.e. The compass direction in which the slope faces).

Using the information in one or more level in the map, summary information can be generated. Two such scenarios are discussed here:

Change in reclamation areas between years. By 'overlaying' the mine plan polygon covers for different years, a new map can be created showing thematic information such as how much previously reclaimed area has been affected by this year's mining activities.

Reporting on the amount and percentage of habitat that has been affected by mine disturbance and reclamation activities. For each habitat range outlined in the reclamation goals, the amount of hectares disturbed for a given year can be generated by overlaying mine data on baseline data. This can be expressed as total hectares disturbed, or as a percentage of the total habitat area or total mine area. Again, by overlaying the mine data polygons for different years, the change in habitat between years can be calculated.

Estimating potential habitat values in reclaimed areas. The process of determining the mine's effect on habitat areas can be taken one step further. In assessing the success of reclamation efforts, for example, an indication of the habitat potential of a reclaimed area can be estimated by considering other GIS data such as slope, aspect, and vegetation cover. This illustrates one of the important benefits of using a GIS for data management and analysis: data that has been captured and stored for one purpose can quickly be modelled and viewed in the GIS in new ways; this flexibility enhances the overall value of the system.

Future Applications

One of the advantages of holding complex land information in a GIS is the ability to use that data for a number of applications that may not be evident or planned for at the time the data is collected, but which may easily be done at a later stage. In the case of the Line Creek mine, a number of potential applications were highlighted during the workshop, such as the following.

Site planning. Using the GIS, a map can easily be prepared which would show locations for future site features. For instance, if a new tipple was required, parameters such as 'must be at least 100ha in size and on a slope between 0 and 10%' could be fed the GIS and a map showing potential sites would be generated.

Avalanche potential. Because the system allowed a slope map to be generated, potential avalanche sites could be predicted.

Forest management. The harvestable timber available on the mine site can be monitored and managed using the GIS.

Viewscape Modeling. Using the GIS and the 3-D data, 'perspective views' can show what a piece of terrain would look like from given viewpoints. The visual impacts of new mine pits or the land following reclamation can be estimated. The software can also simulate a live 'fly-through' of the terrain.

Monitoring vegetation health in reclamation areas. The availability of high-resolution multi-spectral satellite data will allow yearly monitoring of reclamation areas and change detection analysis. By using standard image processing procedures such as generating a Normalized Differential Vegetation Index (NDVI), the health of plants can be determined. By comparing NDVI images between years, change in the vegetative health of a reclamation area can be identified, and remedies can be prescribed for the area.

Although the initial system objectives will demonstrate the cost-effectiveness and benefits of the system, it is expected that substantial benefits will accrue in the long-term. The changes to geomatics technology have made adding information from sources such satellite imagery easier and have added value and complexity to the types of analysis and output available from the system.

Summary

Increasing legislative and public pressures on natural resource companies are necessitating the use of GIS technology. The ability to analyze and forecast reclamation processes, to generate visibility models, to model and predict environmental problems before they occur, are available through the power of GIS. In the case of Line Creek Mine, the GIS will significantly reduce the time required to generate annual and site-specific Reclamation Plans, and will aid in day to day activities.

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