TOOLS FOR THE RAPID SCREENING AND CHARACTERIZATION OF HISTORICAL METAL-MINING WASTE DUMPS

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ABSTRACT

Assessment of metal mobility, acid-drainage production, and toxic effects from the weathering of historical mine-waste dumps is an area of growing need as the environmental effects of inactive mine-waste sites across the country are being evaluated and mitigated. The U.S. Geological Survey Mine Waste Characterization Project has taken a multidisciplinary approach to assemble, develop, and refine methods and tools for characterizing and screening weathered solid-mine wastes. Researchers from a variety of disciplines, including geophysics, geochemistry, analytical chemistry, geology, mineralogy, geomicrobiology, remote sensing, spatial modeling, and aquatic toxicology, have worked together at several metal mining waste sites to develop an integrated "tool kit" for the rapid screening and characterization of historical mine-waste sites. This paper provides a brief overview of some of these tools.

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INTRODUCTION

There are thousands of historical mine-waste dumps present on inactive metal-mining sites, some of which are on Federal lands and have been abandoned. Since these are historical dumps, generally they are relatively small. However, the potential release of dissolved metals, acidity, or suspended particulates from mine-waste dumps can be a serious and long-lasting problem. Assessment of the potential environmental effects of historical mine-waste dumps is an area of growing need. The U.S. Geological Survey Mine Waste Characterization Project has taken a multidisciplinary approach to assemble, develop, and refine methods and tools for characterizing and screening weathered solid-mine wastes. Researchers from a variety of disciplines have worked together at several metal-mining waste sites in Colorado and New Mexico to develop an integrated "tool kit" for the rapid screening and characterization of historical mine-waste sites. Tools developed from this work can be used in ranking and prioritizing historical mine-waste dumps. A brief overview of several of these tools is given below.

SCREENING TOOLS

Sampling Strategy

We sought to develop a statistically based, cost-effective sampling strategy that could provide the foundation for screening and prioritizing mine-waste dumps on a regional or watershed basis. Because we are concerned with average properties, our sampling strategy entails collection of a composite sample from each waste dump. When more detailed site characterization is required, other sampling strategies might be employed, depending on the objectives of the work. A detailed discussion of our sampling strategy is given in K.S. Smith et al. (2000). In order to minimize sampling errors, our strategy requires that a composite sample consist of at least 30 increments (subsamples). Hence, we divide a mine dump into at least 30 cells of roughly equal surface area. Multiple surficial samples of roughly equal mass are collected from each cell with a trowel, successively placed in a bucket, and mixed to create a mine-dump composite sample. The sample is air-dried and dry-sieved to < 2 mm. The resulting < 2 mm mine-dump composite sample should weigh at least one kilogram. For screening and prioritizing historical mine-waste dumps, use of the < 2 mm size fraction generally should provide a worst-case scenario for metal leachability and appears to be a good choice to reduce the sampling error and reduce the sample size to one reasonable for reconnaissance field collection (K.S. Smith et al., 2000).

Metal Leachability Determination

Leaching tests are one of the main screening procedures used to evaluate and prioritize mine-waste dumps. We sought to develop a test that easily could be performed in the field, could provide on-site pH and conductivity information, and could furnish samples for metal analyses. The Field Leach Test is described in detail by Hageman and Briggs (2000). It is based on the premise that the most chemically reactive material in weathered mine waste consists of relatively soluble components in the fine fraction (< 2 mm) of the waste. The test involves combining 50 grams of < 2 mm mine-dump composite sample (see above) with 1,000 grams of deionized water in a capped one-liter polyethylene bottle. The mixture is vigorously shaken for five minutes, and then allowed to settle for 10 minutes. Specific conductance and pH can be measured in the field, and subsamples can be filtered and preserved for analyses of chemical constituents. Hageman and Briggs (2000) show that results from the Field Leach Test reveal geochemical trends that correlate favorably with results from the routinely used Synthetic Precipitation Leaching Procedure (U.S. Environmental Protection Agency, 1994).

Net Acid Production Determination

There are a variety of methods to determine the potential of a mine-waste material to produce acid. Many of these methods are designed for coal-mine waste or for fresh waste material. For historical metal-mining waste dumps that consist of weathered material, it is necessary to adopt a method that incorporates the potential acid production of secondary and tertiary minerals and the potential acid-consuming capacity of host-rock minerals (e.g., carbonates, chlorite, biotite). We have adopted a slightly modified version of the net acid production (NAP) method of Lapakko and Lawrence (1993). In this method, a sample of pulverized waste material is digested with a heated solution of 30% hydrogen peroxide. Acidic filtrates are titrated to pH 7 and NAP is calculated in terms of kilograms $CaCO_3$ per metric ton of waste. Fey et al. (2000) demonstrate that mine-waste dumps segregate into different groups when NAP is plotted against either the sum of five leachable metals (arsenic, cadmium, copper, lead, and zinc) or against leachable iron.

Microbial Activity Determination

Microbial processes can contribute to many of the geochemical parameters (e.g., acid production, metal release) determined in mine-waste dumps. The level and type of microbial activity in mine waste may be variable depending on such factors as temperature, acidity, water content, and sunlight. Many techniques, such as culture methods, direct counts, diagnostic molecular methods (e.g., chemotyping of lipids, proteins, cell wall materials), DNA/RNA sequencing techniques, and isotopic fractionation of the "bioelements" C, H, O, N, and S, can be used to determine microbial activity in mine-waste materials. Relative microbiological activities attributable to different groups of bacteria can be determined in the field (or laboratory) using BART (**B**iological **A**ctivity **R**eaction **T**ests; Hach Chemical Co., 1998).

Toxic Effects of Metals from Mine-Waste Dump Effluent (Aquatic Toxicology)

Toxicity Identification Evaluation (TIE) procedures (U.S. Environmental Protection Agency, 1991, 1993a, 1993b) offer a biological approach to identify chemical constituents that are potentially harmful to the aquatic environment. We used a modified version of these procedures to expose aquatic organisms to sample manipulations (e.g., increased/decreased pH, dilution, filtration, aeration, ligand titrations) of mine-waste dump leachates. Biological response of the test organisms revealed different types of toxicant(s) or toxicant characteristics. Metal(s) of biological concern in mine-waste dump effluents can be determined using these TIE procedures.

NON-INVASIVE RAPID-SCREENING TOOLS

Remote Sensing

Swayze et al. (2000a, 2000b) have demonstrated that airborne or orbital imaging spectrometers can be used to map minerals resulting from weathering of acidic mine waste. This approach is based on identifying iron-bearing secondary minerals that form on the surface of mine-waste dumps under acidic conditions. The best indicator mineral for acidic conditions appears to be jarosite. These remote-sensing tools can be used to screen large areas for potentially acidic mine-waste material and to identify sites that warrant closer examination. Hand-held spectrometers also can be used for on-site work.

Geophysical Methods

Combining geological mapping with airborne geophysical surveying facilitates the task of screening large areas to locate historical mine dumps and assigning them initial priorities for further study. Airborne techniques include radiometric, magnetic, and electromagnetic mapping and can be used to map subsurface lithology, structure, and ground-water flow. B.D. Smith et al. (2000) illustrate how airborne geophysical techniques can be applied at both a regional scale (e.g., state) and a local scale (e.g., watershed, mine site). Geoelectrical methods, such as direct current resistivity, electromagnetic, and induced polarization, can be used to study conditions at depth within particular mine-waste dumps. These methods can infer information about lithology, mineralogy (especially sulfide minerals), pore-water saturation, or location of pore water or groundwater containing high total-dissolved solids. Hence, these methods can be used to trace plumes of contaminated water and discern compositional variations in mine-waste dumps. Campbell and Fitterman (2000) and Campbell et al. (1999) provide an overview of geophysical methods in mine-waste characterization.

DETERMINING THE RESIDENCE PHASE(S) OF METALS

In the study of the potential impact of mined sites on the environment, it is important to understand the source(s) of possible metal contaminants, the processes controlling their release into the environment, and their transport mechanisms. The concept of the availability of metals from natural materials, referred to as the geoavailability, is defined as that portion of a chemical element's or a compound's total content in an earth material that can be liberated to the surficial or near-surface environment (or biosphere) through mechanical, chemical, or biological processes. The geoavailability of a chemical element or a compound is related to the susceptibility and availability of its resident mineral phase(s) to alteration and weathering reactions (Smith and Huyck, 1999).

Detailed examination of the residence phase(s) of metals in mine-waste material is necessary to understand the geoavailability of metals in mine-waste dumps. A combination of X-ray diffraction, bulk chemical analyses, chemical-extraction techniques, and X-ray microanalysis can shed light on metal geoavailability and subsequent mobility from mine-waste material (Smith et al., 1999). This type of information is key to the understanding of processes controlling metal release from mine-waste materials. Once these processes are understood, informed decisions can be made about mitigation, cleanup, disposal, and remediation of mined sites.

X-Ray Diffraction

X-ray diffraction (XRD) methods can be used to identify mineral phases in mine-waste samples. This information can be combined with bulk chemical analyses to try to account for residence phase(s) of chemical constituents. However, weathered mine-waste material commonly contains a significant portion (often as high as 40-50%) of non- or poorly crystalline material that is amorphous to XRD techniques. This amorphous material likely contributes to the geoavailability and subsequent mobility of some chemical elements. Hence, it is necessary to combine XRD methods with other methods that can address the amorphous phases in the mine-waste material.

Sequential Chemical Extractions

In sequential chemical extractions, metals are extracted from some or all of a sequence of operationally defined phases (Chao, 1984). The sequence of extractions exposes the sample to increasingly rigorous chemical treatments. This provides a means for evaluating the potential mobility of metals extracted from the various phases. The operationally defined phases adopted for our work include water soluble, ion-exchangeable, carbonate, amorphous iron oxide, crystalline iron oxide, sulfide, and silicate. Leinz et al. (1999, 2000) describe the details of the sequential chemical extractions used in our work.

X-Ray Microanalysis

Metals of interest generally reside in microscopic phases within mine-waste materials. Microanalysis techniques, including x-ray mapping, x-ray point analysis, and electron microscopy, can locate particles as small as 1 micrometer that contain trace elements. These particles can be individually analyzed to determine mineral chemistry, mineral identification, and weathering sequences.

PUTTING MINE SITES INTO CONTEXT

Use of Geologic Information

Geologic information can contribute a wealth of information about a mined site. For example, geologic setting can provide information about the pH buffering capacity of surrounding rocks, the potential ease of subsurface contaminant transport, and possible routes to receptors. The type of mineral deposit can reveal which metals are present and allow for estimation of the acid-generating and acid-consuming capacity of the waste material (Plumlee et al., 1999). Knowledge of historical mining, milling, and metal-recovery processes can help determine the efficiency of sulfide removal and anticipate the presence of other contaminants of concern (e.g., mercury, cyanide).

Use of Spatial Modeling

Multidimensional spatial modeling techniques can be used to integrate and synthesize disparate information about a mine site. This approach can be a visually intuitive tool to examine spatial relationships and to view digital data. Yager and Stanton (2000) provide an example of spatial modeling by combining topographical, geophysical, and geochemical data for a mine-waste dump.

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REFERENCES

Campbell, D.L., Horton, R.J., Bisdorf, R.J., Fey, D.L., Powers, M.H., and Fitterman, D.V. 1999. Some geophysical methods for tailings/mine waste work, pp. 35-43 In: Tailings and Mine Waste '99 - Proceedings of the Sixth International Conference on Tailings and Mine Waste, Fort Collins, Colorado, January 24-27, 1999. A.A. Balkema, Rotterdam.

Campbell, D.L., and Fitterman, D.V. 2000 (in press). Geoelectrical methods for investigating mine dumps, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Chao, T.T. 1984. Use of partial dissolution techniques in geochemical exploration. J. Geochem. Explor. 20:101-135.

Fey, D.L., Desborough, G.A., and Church, S.E. 2000 (in press). Comparison of two leach procedures applied to metal-mining related wastes in Colorado and Montana and a relative ranking method for mine wastes, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Hach Chemical Co. 1998. BART user's manual. Loveland, Colorado.

Hageman, P.L., and Briggs, P.H. 2000 (in press). A simple field leach test for rapid screening and qualitative characterization of mine waste dump material on abandoned lands, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Lapakko, K.A., and Lawrence, R.W. 1993. Modification of the Net Acid Production (NAP) Test, pp. 145-159 In: Proceedings, British Columbia Mine Reclamation Symposium, Port Hardy, B.C., May 4-7, 1993.

Leinz, R.W., Sutley, S.J., and Briggs, P.H. 1999. The use of sequential extractions for the chemical speciation of mine wastes, pp. 555-561 In: Tailings and Mine Waste '99 - Proceedings of the Sixth International Conference on Tailings and Mine Waste, Fort Collins, Colorado, January 24-27, 1999. A.A. Balkema, Rotterdam.

Leinz, R.W., Sutley, S.J., Desborough, G.A., and Briggs, P.H. 2000 (in press). An investigation of the partitioning of metals in mine wastes using sequential extractions, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Plumlee, G.S., Smith, K.S., Montour, M.R., Ficklin, W.H., and Mosier, E.L. 1999. Geologic controls on the composition of natural waters and mine waters draining diverse mineral-deposit types, pp. 373-432 In: Filipek, L.H., and Plumlee, G.S. (eds.), The Environmental Geochemistry of Mineral Deposits, Part B. Society of Economic Geologists, Reviews in Economic Geology, v. 6B.

Smith, B.D., McCafferty, A.E., and McDougal, R.R. 2000 (in press). Utilization of airborne magnetic, electromagnetic, and radiometric data in abandoned mine land investigations, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Smith, K.S. and Huyck, H.L.O. 1999. An overview of the abundance, relative mobility, bioavailability, and human toxicity of metals, pp. 29-70 In: Plumlee, G.S., and Logsdon, M.J. (eds.), The Environmental Geochemistry of Mineral Deposits, Part A. Society of Economic Geologists, Reviews in Economic Geology, v. 6A.

Smith, K.S., Meeker, G.P., Leinz, R.W., Sutley, S.J., Huyck, H.L.O., and Desborough, G.A. 1999. Geoavailability of metals in a mine-waste material, abstract #7500 In: Ninth Annual V.M. Goldschmidt Conference, LPI Contribution No. 971. Lunar and Planetary Institute, Houston (CD-ROM).

Smith, K.S., Ramsey, C.A., and Hageman, P.L. 2000 (in press). Sampling strategy for the rapid screening of mine-waste dumps on abandoned mine lands, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Swayze, G.A., Smith, K.S., Clark, R.N., and Sutley, S.J. 2000a (in press). Imaging spectroscopy: a new screening tool for mapping acidic mine waste, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Swayze, G.A., Smith, K.S., Clark, R.N., Sutley, S.J., Pearson, R.M., Vance, J.S., Hageman, P.L., Briggs, P.H., Meier, A.L., Singleton, M.J., and Roth, S. 2000b. Using imaging spectroscopy to map acidic mine waste. Environmental Science and Technology 34:47-54.

U.S. Environmental Protection Agency. 1991. Methods for aquatic toxicity identification evaluations: Phase I Toxicity characterization procedures. EPA-600/6-91/003.

U.S. Environmental Protection Agency. 1993a. Methods for aquatic toxicity identification evaluations: Phase II Toxicity identification procedures for samples exhibiting acute and chronic toxicity. EPA-600/R-92/080.

U.S. Environmental Protection Agency. 1993b. Methods for aquatic toxicity identification evaluations: Phase III Toxicity confirmation procedures for samples exhibiting acute and chronic toxicity. EPA-600/R-92/081.

U.S. Environmental Protection Agency. 1994. Test methods for evaluating solid waste, physical/chemical methods (SW-846), 3rd edition, update 2B. Environmental Protection Agency, National Center for Environmental Publications, Cincinnati, OH 45268, telephone 800-553-6847, order number EPASW-846.3.2B. Accessed (12/1/99) at URL <http://www.epa.gov/epaoswer/hazwaste/test/sw846.htm>.

Yager, D.B., and Stanton, M.R. 2000 (in press). Multidimensional spatial modeling of the May Day Mine Waste Pile, Silverton, Colorado, In: Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Research and Development of a GIS-Based Data Management and Model Integration Tool For Coal Mine Reclamation in Wyoming

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The bond release process places heavy demands on applicants relative to the management and analysis of data necessary for reclamation monitoring. While a number of coordinated efforts have addressed these information management needs, a broader need still exists for the development of computer application tools capable of: 1) managing large quantities of spatial and non-spatial digital mine and reclamation data; and 2) providing an efficient means for utilizing such information in an integrated data management, analysis, and modeling environment. Our study is addressing these needs through the development of a geographic information system-based software application for the management, analysis and reporting of data associated with major components of coal mine reclamation and bond release requirements in Wyoming. Funded by the Abandoned Coal Mine Land Research Program at the University of Wyoming, the study will focus on enhancing the application of GIS technology in the hydrologic modeling arena, as well as an expansion of its use to address soils, re-vegetation, and wildlife management needs in coal mine reclamation. The overall goal of the study will be to provide resource managers with a powerful resource analysis and reclamation-tracking tool. Culmination of this effort (completion May 2001) will result in delivery of a Reclamation Management Tool (RMT) GIS software application containing components for management, analysis, and/or modeling of hydrology, soils, vegetation, and wildlife data. The RMT will be designed as an extension of a major desktop GIS software product, with support for Cad and relational database management structures compatible with generic mine data formatting requirements.

Key Words: coal mine reclamation, GIS, data management, bond release

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2000 BILLINGS LAND RECLAMATION SYMPOSIUM

USE OF GIS FOR AN INTEGRATED LAND RECLAMATION DESIGN: A PRACTICAL EXAMPLE AT A COMPLEX MONTANA SUPERFUND SITE

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ABSTRACT

Site characterization to support Remedial Design for the Uplands Portion of the Anaconda Regional Water, Waste & Soils Operable Unit of the Anaconda Smelter Superfund Site is currently underway. Design professionals are faced with the task of developing the remedial design for the site, which was impacted to various degrees by past smelter and related operations. Reclamation requirements vary from no-action to in-situ treatment of soil and revegetation with grass, trees and shrubs for various terrain and within design units, ranging in size from a few acres to over 450 acres. An integrated GIS system was used to store and evaluate very large quantities of environmental data, land ownership data, surface water and groundwater data, soils data and land use data, all of which will be utilized to present the basis for the remedial design. Additionally, the GIS database system will be used in the future to store data and evaluate and modify the post-remedy monitoring programs, land use, development, etc.

The project database consists of over 70,000 records of previously collected environmental data, over 2,000 additional environmental data records from design investigations and evaluations, as well as ortho-corrected aerial photography, topography, land use, geopolitical and other geographic data. In addition to the geographical information, environmental data has been integrated into the project database electronically from previous archives and laboratory reports and from GPS surveys. This data was categorized by various "themes," identified at the inception of design concept development, for use in design evaluations and presentations. Subsequently, the data is being queried, manipulated and evaluated in accordance with a defined set of protocols, developed to meet the requirements of the Superfund remedy and to develop and present the final designs for the numerous design units.

Additional Key Words: revegetation, remedial design, database management, treatment, heavy metals

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INTRODUCTION

Several investigation efforts conducted over many years within the Anaconda Smelter NPL Site (Smelter Site) have resulted in an extremely large amount of data over a sizable project area. It was necessary to organize, store and utilize design, construction, maintenance and monitoring information so it could be most effectively used. In order to accomplish this, a Geographic Information System (GIS) was established. This substantially aided the design and monitoring of the remedy over the large area of the Anaconda Regional Water, Waste and Soils Operable Unit (ARWWS OU).

The development of the Smelter Site GIS began in October 1997. The system became operational in January of 1998. The system is currently operational and data is continually being added and manipulated to meet the needs of it's users.

GIS technology integrates common database operations such as queries and statistical analyses with the unique visualization and geographic analysis benefits offered by the graphical interface (maps). This simple but extremely powerful and versatile concept has proven to be a valuable tool for performing analyses and producing graphics that convey the results of analyses to decision-makers.

Specifically related to the Smelter Site, GIS addresses the following needs:

- Allows designers expeditious and "hands-on" access of data and system for preparing design;
- Allows existing and future data to be used during the development of the remedial design;
- Records specified Construction Quality Assurance (CQA) data obtained during the remedial action;
- Support the O&M phase of this project; and
- Provide an accessible record of compliance data for this project.

Although this system has been specifically developed for the Smelter Site Project it is easily adaptable to other mine reclamation sites and projects.

BACKGROUND

Project Description

The Smelter Superfund Site is located in Southwest Montana and covers an area of approximately 30,000 acres. The site has been subdivided into numerous Operable Units (OU) and further divided into design units. This paper focuses on the use of GIS primarily for the Uplands Revegetation component of a single OU.

Reclamation requirements vary from no-action to in-situ treatment of soil and revegetation with grass, trees and shrubs for various terrain and within design units, ranging in size from a few acres to over 450 acres.

The project database consists of over 70,000 records of previously collected environmental data, over 2,000 additional environmental data records from design investigations and evaluations, as well as ortho-corrected aerial photography, topography, land use, geopolitical and other geographic data.

GIS SYSTEM

System Requirements

The GIS was developed to meet the following objectives:

- Support the interactive framework of the remedial design (RD), remedial action (RA) and operation, monitoring and maintenance (O&M) processes. The Smelter Site is unique in the sense that the remedial work will be conducted over a large area within several distinct land parcels or "polygons." This system allows for design and O&M plans to be optimized by graphically displaying data and analysis results.
- Keep accurate information for the RD, RA and O&M processes. Due to the large amounts of information involved at this site, it is critical to maintain control of and manage data to provide consistency and accuracy for effective remedial designs and O&M programs.
- Allow effective communication between the owner, Agencies, contractors and other users. By using the Smelter Site GIS and the data contained within, all interested parties will be using the same information. This eliminates miscommunication and different analytical findings resulting from use of different data.
- Use as much existing data from previous remedial investigation (RI), feasibility study (FS), and RD phases to minimize unnecessary additional data collection. All relevant data from previously conducted investigations was used in conjunction with new data to perform evaluations, complete the RD and analyze trends toward compliance.
- Provide a record of O&M data over time to evaluate delisting of remediated areas. This system will be used, over time, to evaluate remedy performance, thus allowing for potential delisting.

System Components

A number of specific terms are used to describe the components of the Smelter Site GIS. Some of these often-used terms are defined below.

Views – Names of data categories where information is stored (i.e. Land Use, Environmental).

Themes – A set of individual data layers. "Roads" is a theme that contains all features identified as roads (i.e. Highway 1). The "Roads" theme is located under the *Land Use* view.

Attribute – Information about a feature (point, line or shape). For example, attributes of Highway 1 would include the type of line (road) and type of road (highway) and name (Highway 1).

Layout – The graphical presentation (map) resulting from overlaying multiple themes, tables and text into one frame.

Database – The "storage unit" where themes for the Smelter Site are found.

GIS Hardware/Software

The current computer used to drive the Smelter Site GIS contains a Pentium II processor with 260 MHz processing speed and 120 megabytes of RAM. These specifications are the minimum required. Additional peripherals used for data collection include a Trimble Pathfinder GPS and a Summagraphics Summagrid IV digitizing tablet. The software used for the Smelter Site GIS is ArcView v.3.1 developed by the Environmental Systems Research Institute Inc. (ESRI).

GIS OPERATION

GIS Input Procedures

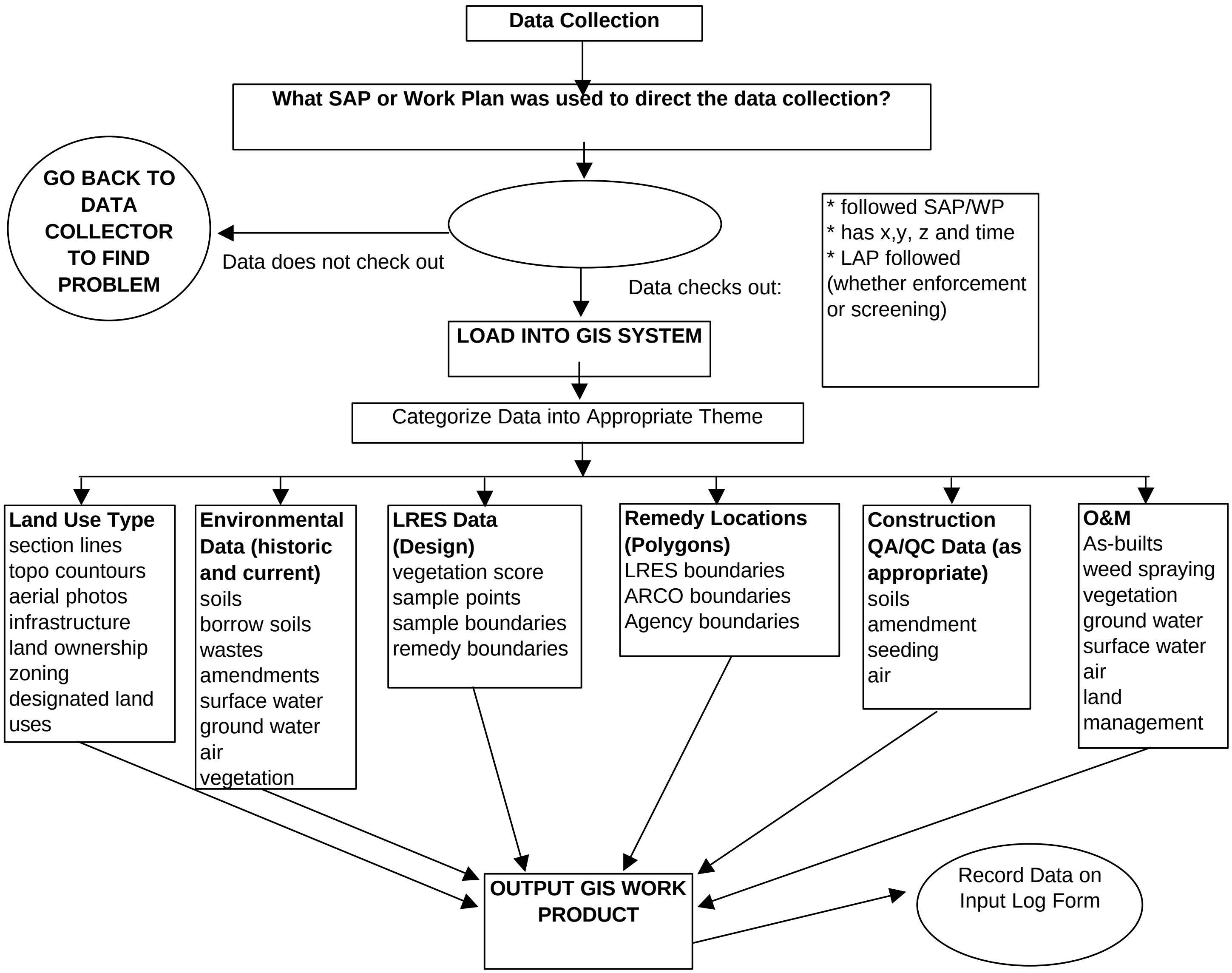
The input data is the most critical component of the Smelter Site GIS. There are many different types of data that have been included or may be input to the system, as long as the data or information can be referenced to a known location. A schematic diagram illustrating the major steps of data input into the system is shown on Figure 1.

The types of data contained in this system include aerial photos, topography, site features and other physical property data, land use/type data, environmental data (soil, waste, ground water and surface /storm water), remedy designs, construction quality assurance and O&M information. A number of sources have been used to construct the Smelter Site GIS. These sources include:

- Base topography was created from an aerial survey. Aerial photos were developed from this aerial survey and were ortho-corrected. Eventually, a digital surface model or triangulated irregular network (TIN) surface map was developed which contained topography at five and fifty foot contour intervals.
- Clark Fork Data Management System [CFDMS] data (historical environmental data) was imported to the Smelter Site GIS. This information set included tens of thousands of environmental data points within an Access database.
- Land Use/Type data included in the Smelter Site GIS was retrieved from a local county GIS Department. This information includes zoning boundaries, property ownership and other local information.
- Data from design data collection activities as well as past reclamation and maintenance activities.

Data input into the Smelter Site GIS consists of spatial, non-spatial or image data. Spatial data consists of features that can be represented by a point, line or polygon. These features

Figure 1 - GIS INPUT SCHEMATIC DIAGRAM



must be in a frame that is georeferenced (has a known coordinate system). Acceptable data file formats include shape files, ArcInfo export files and DWG or DXF files.

Non-spatial data, such as tabular data, includes analytical data, field observations or other information. This data must also include the location of the data by referencing coordinates or station locations (such as a ground water well at a specific and permanent location) with coordinates identified in other data sets. Typical data file formats include Excel, Access Dbase or ASCII.

Image data includes such items as O&M photographs or aerial photographs. Georeference information must also be included with image data, (such as photo location, direction of picture) as well as time and date that the photograph was taken and a general description of the photograph. Aerial photographs must also have a projection specified in which they were taken as well as time, date and altitude. Typical data file formats include TIFF, JPEG, IMAGINE, NITF, MrSID, CIB, CADRG and ADGR.

Data received must all be in the same projection and datum such as Montana State Plane (NAD83).

Categorizing GIS Data into Themes

Due to the large amount and varying types of information available at the Smelter Site, it is critical that the data is appropriately categorized and filed so that users of the Smelter Site GIS can effectively locate and use it. In GIS, these data categories are called "views." These GIS views are the categories under which the data is stored and can be accessed. The major views, along with GIS themes and definitions for each view, are described below. These major views include:

- Land Use/Type Data;
- Environmental Data (soils, ground water, surface water, air);
- Land Reclamation Evaluation System (LRES) Phase II Data (Design);
- Remedy Location (As-Built) Data;
- Certain Construction Quality Assurance Data; and
- O&M Data.

Land Use/Type View

The Land Use/Type view contains themes associated with land uses or types. These themes include contour lines, section lines, certain 1999 infrastructure (roads, buildings, and utility lines), 1999 land ownership, and waste management areas. The intended use of these themes is to provide reference and locational information, in the form of base maps, for other information from the RD, RA and O&M phases.

Environmental Data View

The Environmental Data view contains themes associated with environmental analytical or field data. These themes are further organized into four sub-themes based on media type. These sub-themes are soils data, ground water/surface water/air monitoring data, storm water data and vegetation data. These themes contain all data from laboratory and field analysis relating to soil, waste, water, vegetation and air media.

Land Reclamation Evaluation System (LRES) Data View

The LRES Data view contains themes associated with the data collected during the design phase for the Smelter Site. This view contains sample points associated with the LRES field and laboratory investigation.

Remedy Location View

The "Remedy Location" view contains themes that are primarily made up of polygons depicting specific remedial designs. The polygons are specified shapes that are represented by specific remedial techniques.

Construction Quality Assurance (CQA) View

The CQA Data view includes data collected during the RA phase of the project. This may include themes relating to soil amendment and revegetation such as: lime rates, seed mix, application rate, etc. These themes are developed to categorize data that will be collected during the implementation of the remedy to ensure the remedy was constructed as the design intended.

Operations and Maintenance View

The O&M Data view contains themes that are anticipated to be used once the remedy is implemented for a specified area. In some areas of the Smelter Site, O&M activities are already being performed. For other areas, O&M activities will not be performed for a number of years, since planned remedies will not be conducted for a period of 15 to 20 years.

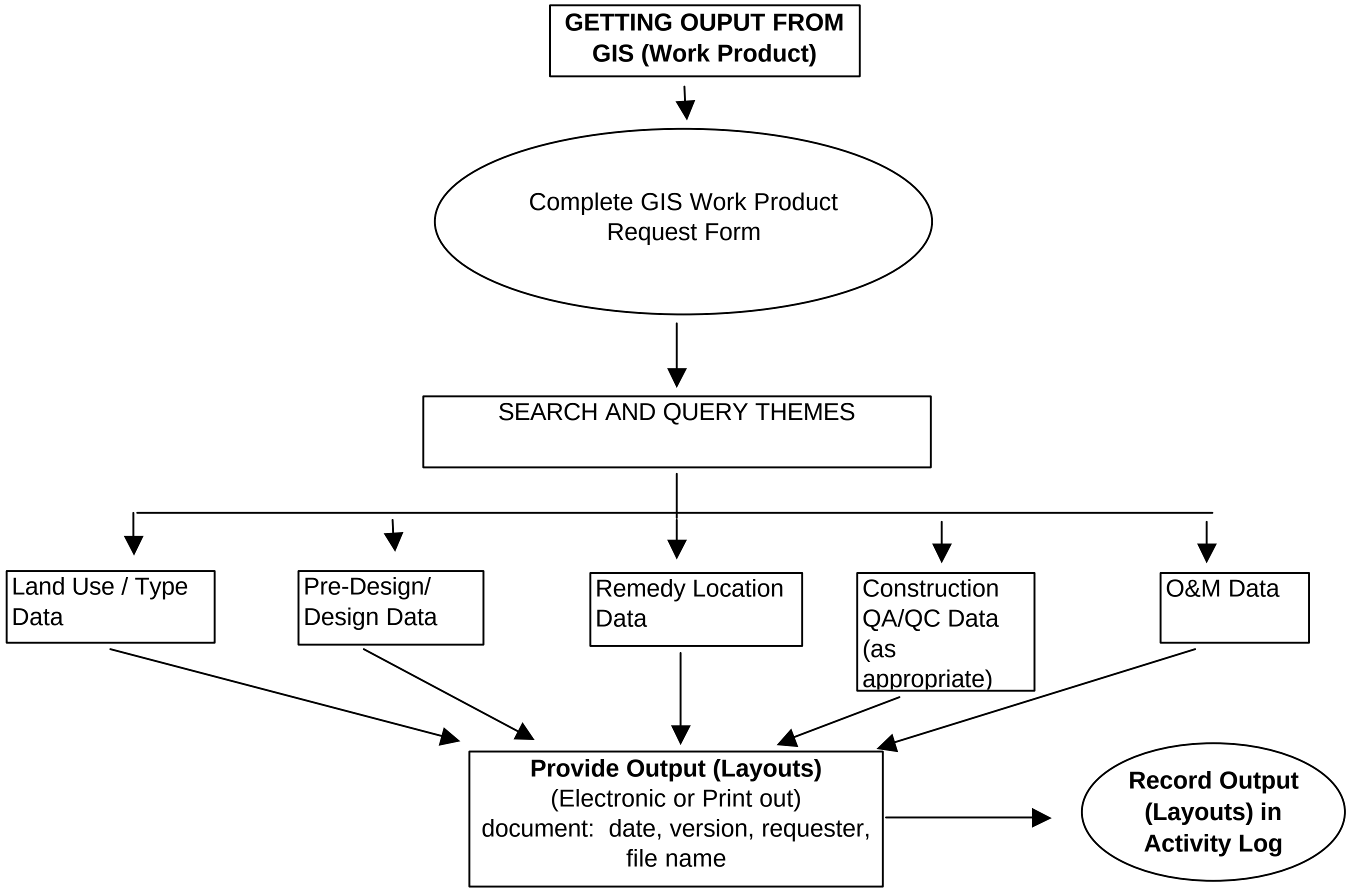
The O&M themes include: As-built drawings, Weed Spraying Control, Storm Water, Ground Water, Soils, Revegetation, Waste Management Areas/Repositories, Land Management, and the Anaconda/Deer Lodge County Development Permit System. These themes will contain spatial data (polygons) where observations have noted maintenance concerns where work was performed (i.e. revegetation or weed spraying).

The themes also contain non-spatial information relating to the analytical data at specified points of compliance. The O&M themes will also contain land management data which specifies the land ownership, zoning requirements and land use. The intent of these data themes is to provide data as it relates to ICs at the Smelter Site. These data and themes will be updated as the remedial action is completed and the O&M requirements are more fully defined.

GIS Output Procedures (Work Product)

The primary goal of the Smelter Site GIS is to provide the tools to efficiently store, manipulate, evaluate and present data such that the designers, decision makers and other appropriate personnel can design, construct and monitor the remedy for the Smelter Site. The following presents the procedures to obtain output (or work product) from the Smelter Site GIS. A schematic diagram illustrating the major steps of providing output from the Smelter Site GIS is shown on Figure 2.

Figure 2 - GIS OUTPUT SCHEMATIC DIAGRAM



Theme Query and Layout Compilation

Layouts are generated by locating the themes within the projects views. These themes are copied into a temporary view. A layout template is created to graphically represent the spatial relationships of the data. A live link exists between the temporary view and the layout template. This means that changes the operator makes to the view will be reflected in the layout. These changes may include turning themes on or off, zooming in or out, symbol changes, etc. After the desired data is represented in the layout, other map components can be added. This could be text or graphics, scale bar, north arrow, tables, legend, pictures, etc. After all desired components are represented, the live link option can be turned off and the layout can be printed to a plotter or archived as a plot file. The layout is also saved within the project folder if future revisions are needed.

Uplands Revegetation Design Example

An example of the design process is best described through graphical plots of the design drawings. However, due to the restrictions on the size of this paper it is not possible to include the example drawings. Therefore, the following presents a description of what each design drawing contains and the GIS data that were queried/compiled to create the drawing.

In order to develop drawings of a workable size, the site was divided into 47 plates to cover the Upland Revegetation area. One set of design drawings for each plate was prepared and include: the Site Location, Aerial View Base Map and Steep Slopes, Data, Land Ownership, Land Use and Institutional Controls, Storm Water controls and the Remedy per polygon. The following describes the different types of drawings that were produced. A drawing numbering system was developed as illustrated below and includes the design unit number (in this case 2), the plate number (in this case 11) and the drawing number (i.e., 1 through 7)

INDEX (Scale: 1”=2000’). An index grid (plates) over the entire OU was prepared to organize how drawings will be viewed. Characteristics of this drawing include:

- Each grid is sized to present a 1” = 500’ scale on an 11x17 page format.
- The index drawing includes: plate boundaries, plate numbers, RDU boundaries, polygon boundaries and major roads (as defined in the Theme Definition Table).

2.0 Remedial Design Unit (RDU) LOCATION (Scale: variable) – This drawing shows the entire RDU and illustrates the plates and polygons associated with a specific RDU along with topographic contours and planimetric features. It provides a reference at a smaller scale than the Index drawing. The GIS information used to create this drawing includes:

- RDU location,
- Contours (with elevation annotations),
- Plate boundaries,
- Roads,
- Section numbers,
- Streams, ponds and drainages,
- Polygon boundaries,
- Land ownership by five major categories (ARCO, ADL county, State, Federal, and private).

2.11.1 AERIAL BASE AND STEEP SLOPES (Scale: 1”=500’) – The main purposes of this drawing are to show the aerial detail of the plate, areas where slopes are greater than 3:1 and the delineation of sub-polygons. The GIS information used to create this drawing includes:

- Aerial photo (base),
- Polygons,
- Sub polygons,
- Identification of slopes steeper than 3:1,
- Section Lines,
- Roads,
- Hydrological Features (streams, ponds), and
- Match lines to other plates.

2.11.2 DATA (Scale: 1”=500’) – The purpose of this drawing is to display the location of different data types used to determine the remedial design. This drawing is accompanied by a data table, which summarizes the data results. The GIS information used to create this drawing includes:

- Soil Data locations (including LRES sample locations),
- Ground water data locations,
- Monitoring Well locations,
- Domestic Water Supply Well locations,
- Cultural and Protected Resource area locations,
- Polygon Boundaries,
- Sub-polygon boundaries,
- Surface water, and
- Topographic contours.

2.11.3 LAND OWNERSHIP (Scale: 1”=500’) – The purpose of this drawing is to identify the property boundaries of various owners in relation to the design remedy. The GIS information used to create this drawing includes:

- Existing roads,
- Topographic contours,
- Location of private landowners,
- County, State and Federal property,
- Restrictive covenant areas, and
- ARCO-owned and -leased lands.

2.11.4 LAND USE and INSTITUTIONAL CONTROLS (Scale: 1”=500’) – The purpose of this drawing is to show current and reasonably anticipated future land uses, land use restrictions, proposed access road locations and amendment stockpile locations. The GIS information used to create this drawing includes:

- Existing utilities,
- Existing wetlands,
- Soil amendment storage areas,
- Groundwater technical impracticability (TI) zones,
- Land management practices,
- Dedicated Developments,

- Waste Management Areas,
- New and existing roads,
- Repositories,
- Restrictive covenants,
- Master plan designation, and
- Polygons/sub-polygons.

2.11.5 MISCELLANEOUS INFORMATION (Scale: 1”=500’) – Certain RDUs and polygons may require site-specific details for the completion of the design drawings that are not identified on any of the other drawings in the design set.

2.11.6 STORM WATER CONTROLS (Scale: Varies) – Some plates may contain storm water features to be displayed on design drawings. The GIS information used to create this drawing includes:

- Storm water basin catchment areas,
- Channels,
- Ponds,
- Streams, and
- Wetlands.

2.11.7 REMEDY DESIGNATION (Scale:1”=500’) – The purpose of this drawing is to provide remedy details. Information provided on this drawing includes the following, as applicable:

- Remedy type by polygon,
- Cross reference to applicable specifications, and
- Reference to text detail for any modifications to documents standard (specifications, CQAP, etc.).

Conclusions

GIS is a valuable tool for the development of designs for land reclamation. It provides a system for the management of large amounts of data, creating large numbers of design drawings, easy and consistent retrieval of data and designs and for analyzing trends in the performance of reclamation efforts. The system also allows for multiple users from different companies/agencies to use the data to perform evaluations and to check designs performed by others. The system was also designed so that it can be used by those with minimal experience in GIS.

2000 Billings Land Reclamation Symposium

A GEOSTATISTICAL TOOL TO DETERMINE OPTIMUM SAMPLING FREQUENCY TO ASSESS MINE SOIL SUITABILITY

D. J. DOLLHOPF[1]

ABSTRACT

The frequency that mine soils must be sampled across a backfilled landscape to determine physicochemical suitability is a function of site characteristics and should not be based on a universal guideline specified by a State regulatory program. Using mine soil physical and chemical data from a site, a variogram model can be developed for each mine soil parameter. Each model and associated sensitivity tests are used to ascertain the optimum sampling frequency across the minesoil landscape. Different sampling frequencies are evaluated for accuracy in characterizing mine soil characteristics using kriging procedures. Case examples are presented where mine soil sampling requirements for coal mine facilities were changed as a result of using these procedures.

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INTRODUCTION

At surface coal mines, the physicochemical traits across a mined backfill area must be assessed prior to placement of coversoil. For example, in post-mine environments, portions of the graded backfill may be too acidic, sodic, saline, or clayey to ensure acceptable plant growth. Sampling strategies must be designed to delineate unsuitable soil so that remediation procedures can be implemented.

The following discussion will focus on sampling strategies for mine soils composed of graded backfill material.

State Regulatory Programs

In response to the Surface Mining Control and Reclamation Act (OSM 1977), most state coal regulatory programs require that the 0 to 4 foot depth increment of the spoil backfill contain materials suitable for plant growth. Consequently, state regulatory programs require mine operators to assess mine soil suitability for plant growth. Postmine sampling procedures are intended to identify whether suitable materials are present so that revegetation can be successfully implemented.

Each state regulatory program has different sampling guidelines since it has been uncertain what constitutes an adequate sampling intensity. For example, in Montana, regraded spoils are sampled with cores every 2.5 acres across the landscape (Montana Department of State Lands, 1983). In Wyoming, samples are collected every 250 to 1000 feet across the landscape (Wyoming Department of Environmental Quality, 1984). In North Dakota, postmine mine soils are sampled every 400 feet across the landscape (Public Service Commission, 1987). In Texas, mine soils are sampled approximately every 1.0 acre across the landscape (Railroad Commission of Texas, 1988). This diversity of sampling intensities across the USA emanates from professionals in each state instituting their best judgment based on experience.

DETERMINATION OF THE OPTIMUM SAMPLING FREQUENCY ACROSS A GRADED SPOIL BACKFILL

Initial Backfill Sampling Considerations

In order to apply geostatistical procedures an initial set of data is required for the analyte(s) of interest. The sample collection geometry across the landscape does not need to be in a regimented pattern of grids. Sample locations can be based on random, judgmental or systematic formats and, thus, be in any geometrical pattern. A minimum of approximately 30 sample sites are required, although more sites are desirable to improve representativeness, and a hundred or more sampled locations is not uncommon for this analysis. These sample sites should traverse the entire project area. Ideally, at several locations, samples should be collected more intensively. This step enables an assessment of analyte variability across short distances at different positions in the project area. This sampling protocol will help improve the accuracy of the variogram model. However, these localized areas of intense sampling are not required to develop a reliable model.

The project area boundary can be of any geometrical shape and does not have to be, for example, square or rectangular. The sampled project area does not have to be contiguous. Large gaps with no sample data may exist in the landscape that completely bisect the sampled areas. These gaps may be as large as several kilometers, or more.

A **misapplication of geostatistics** may result when, e.g. a 5000 acre project area exists but due to budget or time constituents, only a "test area" is sampled. The test area, e.g. 200 acre, is sampled intensively, and a variogram model is produced for an analyte. Extrapolating variogram results from the 200 acre area to the entire 5000 acre area runs the risk of producing a misleading result. Analyte variability is likely different across the 500 acre area and the model should be developed from samples collected from all portions of the site.

Coal surface mine project areas typically have extensive spoil backfill data across several thousand acres of the landscape as a result of years of sample collection. It has been common practice to use these data to develop variograms to guide sampling in future graded spoil backfill areas. Although these variograms were developed using data from historical backfill areas, the error in using these results to guide sampling in future spoil backfill areas may be small unless the geochemical setting changes notably.

The Variogram

Geostatistical theory, the mathematics and computer software associated with development of a variogram will not be presented in this paper. Instead, results from completed minesoil geostatistical investigations will be discussed to demonstrate to the reader the applicability of this science to mine soil landscapes. In brief, each sampled location is digitized to produce a northing (x) and easting (y) coordinate value to identify the spacial location within the graded spoil backfill. Summary statistics are produced to determine whether a data set for a physicochemical parameter approximates a normal distribution. Non-normal distributions are transformed prior to development of the variogram. Geostatistical software is used to calculate the variogram which undergoes a validation procedure.

Three key results are expressed in a variogram that are important in determining the optimum sampling procedure for a spoil backfilled landscape. A variogram is a graphical plot relating **semivariance** (y-axis) to **distance** (x-axis) between sample sites in the landscape (Figure 1). The variogram shows that as distance between sampled sites increases the semivariance increases, but eventually semivariance reaches a plateau when distance between samples is large. This plateau is termed the **sill**, and is the distance between sampled sites, 3000 to 10000 feet (Figure 1), when there is absolutely no relationship between data collected in the landscape. Conversely, when samples were

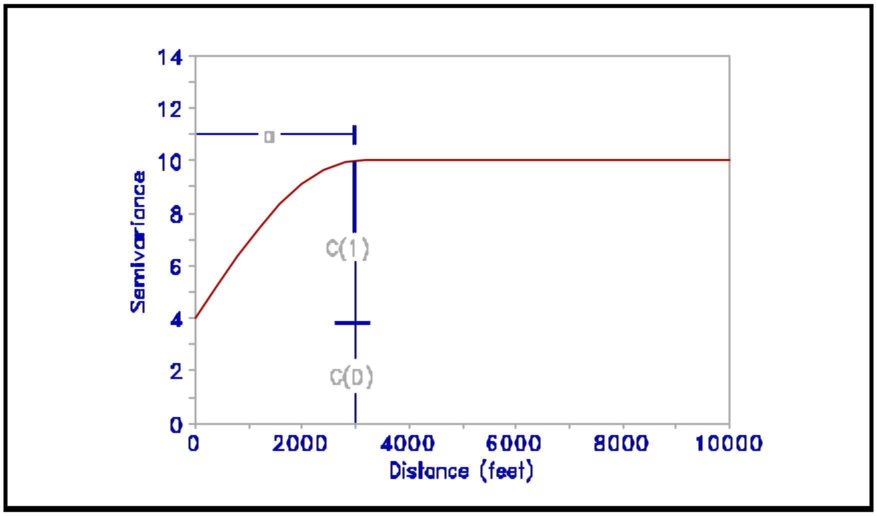

Figure 1. Idealized spherical variogram model with nugget variance, $C_{(0)}$=4; sill, $C_{(0)}+C_{(1)}$=10; and range of influence, a=3000.

collected across the landscape less than 3000 feet apart (Figure 1), then semivariance decreased indicating that the samples were starting to account for variability in the landscape, meaning we were truly beginning to characterize the landscape parameter of interest, e.g. soil pH. The **range of influence**, 0 to 3000 feet (Figure 1), is that portion of the variogram model where variance between samples is progressively decreasing as distance between samples decreases. Clearly, as distance between samples decreases, we more accurately characterize the physicochemical traits of the spoil backfill. Therefore, we need to sample the spoil backfill within the range of influence. Note that even if we had sample points inches apart across the spoil backfill, we could not perfectly characterize the physicochemical parameter of interest since a notable amount of semivariance (4.0 in Figure 1) remains unaccounted for; this is termed the **nugget variance.** The nugget value represents a random component to the semivariance. The nugget value cannot be explained by sample spatial location and is due to errors in measurement (e.g. laboratory error) and micro-variabilities of the parameter of interest.

Variograms For Graded Spoil Backfill At Surface Coal Mines

Case Example For Spoil pH

At surface coal mine sites in Texas, the state regulatory authority (Texas Railroad

Commissio n) requires
that graded spoil
backfill be sampled
every 5.7 acres
(composite from
subsample s collected
in each one acre area),
meaning every 498
feet, across the
landscape and
samples analyzed for
several parameters
to demonstrat
e whether spoil is
chemically and
physically suitable for plant growth. The Alcoa Sandow Mine historically sampled their spoil backfill on a 20 acre grid basis (composite subsample collected from each one acre area), meaning every 933 feet, and were concerned about adopting the more intense sampling requirement specified by the regulatory authority.

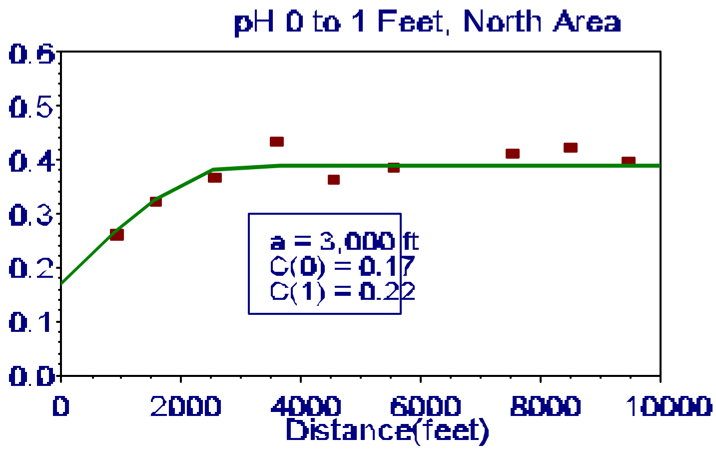

Figure 2. Variogram comparing semivariance and sample separation distance for spoil backfill pH in the 0-1 foot depth increment at the Alcoa Sandow Mine in Texas.

Variograms were developed for the spoil backfill area (3500 acres) for those parameters that frequently exceeded spoil suitability criteria, pH and acid-base account. As shown in Figure 2, the range of influence indicated samples collected more than 3000 feet apart were **independent**, meaning there was no relationship between locations and thus, an understanding of where pH was suitable or not suitable could not be determined. However, as sample separation distance ranged below 3000 feet sampled locations were **dependent** on each other, indicating there was a relationship between sampled sites and progress was being made towards understanding where spoil pH was suitable and not suitable. Therefore, it was determined that the 20 acre grid sampling, a sample every 988 feet, that the mine had been doing for years was well within the range of influence and was effective at delineating suitable and unsuitable material.

The regulatory agencies recommendation to sample the graded spoil backfill every 5.7 acres, meaning every 498 feet, would improve the accuracy in delineating pH in the landscape, since more samples will always result in better delineation of a parameter of interest. However, it can be seen in Figure 2 that a 498 foot versus a 988 foot sampling grid would decrease semivariance (y-axis) only 0.05 units, meaning a 12.8 % decrease in the total semivariance (0.39) in the variogram. This 12.8 % decrease in semivariance comes at a cost of collecting 350 % more samples.

Variograms for acid-base account were similar to those for spoil pH. Based on these results, the regulatory agency concurred that the 20 acre grid sampling program was acceptable and did not require the Sandow Mine to convert to the more intense 5.7 acre sampling grid specified in the regulations.

The variogram in Figure 2 provides in-site into another sampling concern. Note that even if drill hole separation distance were only a few feet apart, unaccounted for semivariance is still present. That is, we cannot decrease the semivariance below the nugget value (C_o), i.e. where the variogram intercepts the y-axis. In practice, this means we can never perfectly delineate spoil backfill physicochemistry because unaccounted for problem variation will be present even with samples a few feet apart. The nugget value represents a random, as opposed to systematic, component to the semivariance. The nugget value cannot be explained by spoil backfill sample spatial location. The nugget value is due to *sampling error*, e.g. different personnel collecting a set of samples, *laboratory error*, i.e. precision, and *micro-variabilities* of, for example, pH. Pitard (1990) evaluated laboratory precision, using Alcoa Sandow Mine samples in Texas and determined a notable portion of the nugget semivariance was attributable to laboratory precision. Simply stated, even excellent laboratory analytical work will yield error in the reported value. This laboratory error is carried into the nugget semivariance. An example of a spoil backfill microvariability problem is the presence of either a $CaCO_3$ stone entering the sample stream or FeS_2 nugget entering the sample stream. Neither is representative of the spoil backfill chemistry, but laboratory analysis will yield a very positive or very negative acid-base account, respectively. This is a random sampling error that can be minimized with compositing but never eliminated. In summary, the nugget semivariance is due to random sampling error and analytical error. Laboratory quality control procedures to increase precision and sample compositing can help minimize but not eliminate this problem. Thus the variogram can indicate whether field compositing procedures should be enhanced in order to decrease the nugget semivariance.

USING GEOSTATISTICS TO SOLVE SAMPLING PROBLEMS AT SURFACE MINE SITES

Variograms for physicochemical characteristics in graded spoil backfill areas have been developed for six other surface coal mines located in Texas, Washington and Montana. In all cases, validated variograms provided guidance as to frequency of sampling required across the spoil landscape. Regulatory agencies in these states have accepted results presented in these variograms, resulting in lower sampling costs to the mine operator. Regulatory agencies have been willing to implement spoil backfill sampling frequencies different than that specified in the regulations when specific site investigations demonstrated the merit of less intense, or more intense, sampling is appropriate across the landscape.

REFERENCES

Montana Department of State Lands. 1983. Soil and overburden guidelines. Dept. of Environ. Qual., Reclamation Div., Coal and Uranium Bur., Helena, MT. 42 p.

Office of Surface Mining. 1977. Surface mining control and reclamation act. Public Law 95-87.91, Stat. 445 (30 USC 1201 et. seq.), Washington, DC.

Public Service Commission. 1987. Suitable plant growth material removal and redistribution. Policy Memorandum No. 17 to Mine Operators, Reclamation Div., Bismarck, ND. 37 p.

Railroad Commission of Texas. 1988. Mine soil and monitoring plan. Surface Mining and Reclamation Division, Tech. Release No. SA-4, Austin, TX. 9 p.

Wyoming Department of Environmental Quality. 1984. Guideline number 1, topsoil and overburden. Land Quality Division, Cheyenne, WY. 17 p.

2000 Billings Land Reclamation Symposium

RECENT DEVELOPMENTS IN LAND RECLAMATION / REVEGETATION EQUIPMENT

John M. Inkret[1] and Bernie Jensen[1]

ABSTRACT

Over the past decade, land reclamation implementation practices have evolved and improved through modifications of revegetation equipment, as dictated by field-testing and necessity. Standard agricultural machines and implements designed for use on quality soils and level topography can exhibit limitations and breakdowns when performing on the rockier, often compacted, soils and steeper slopes so often encountered in land reclamation. Some factory agricultural equipment, without modification, has proven very useful and effective under extreme field conditions. However most standard agricultural implements and machines must be substantially modified with respect to strength, stability, durability, dependability, and power. There are certain activities (e.g. drill seeding, lime spreading) or regulatory agency requirements (e.g. tillage depth) where no such equipment is commercially available, and this must be custom built. Extensive experience and field-testing is mandatory for the efficient and effective design and construction of custom land reclamation equipment. This paper reviews some of the more recent, specialized machinery and implements, with respective modifications and innovations, being employed by Western Reclamation Inc. on various land reclamation projects in the Clark Fork River Basin, Montana. Equipment is evaluated with respect to function, description, techniques, capabilities, limitations, and production rates.

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INTRODUCTION

Land reclamation standards have become more stringent over the past ten years. These standards apply to the physical and chemical properties of topsoil, seedbed preparation, mulching, seeding, and fertilizing. Historically, regulatory agencies have attempted to implement reclamation activities with standard agricultural farming equipment. This equipment is designed for relatively level, smooth, rock-free, non-compacted soils – it does not have the durability or capacity to operate on many of the more industrial types of reclamation projects. Frequent breakdowns are to be expected. Modern reclamation standards often include surface modifications and amendment incorporation ranging in depth for 6” to 24”. Most standard farming implements are designed to operate to a depth of 10” or less. This paper reviews some recent developments in specialized reclamation equipment designed and built by Bernie Jensen of Western Reclamation Inc. This paper and presentation are limited to the most frequently problematic operations – primarily amendment spreading, amendment incorporation, drill seeding, and straw and hay mulching.

TERRAGATOR SPREADER

The TerraGator (Figure 1) chassis is designed to haul and spread large loads of material on rough, off-road areas of limited load bearing soils. The TerraGator is based upon a high strength, ridged frame that articulates and oscillates to enable hydraulic cylinder steering. It is powered with a 185 horsepower diesel engine that drives a six-speed power shift transmission. The differentials are low speed inboard planetary reduction differentials manufactured by John Deere. The four wheels have 66 x 43.00-25 terra grip high-flotation tires. A new TerraGator chassis sells for approximately $150,000.

This unit can be fitted with dry lime spreaders, manure and compost spreaders, fertilizer spreaders, liquid spreaders, or other material hauling type boxes. It is the best machine available for implementing large-scale projects under adverse conditions. It can be operated as two or four wheel drive. It can also be used as a tractor to tow agricultural implements.

The soil amendment spreading equipment mounted on the TerraGator chassis frequently consists of commercially available, or modified versions of, highway sanding boxes. Western Reclamation designed and constructed a spreader box specifically for spreading dusty, fine-grain kiln dust, lime, and compost. The unit is capable of hauling ten ton loads of lime material with minimal fugitive dust. Specially designed heavy-duty bottom chains, material dividing channels, and very low speed spinners make this unit the best choice for spreading fine-grain lime material. Wind deflecting skirts can also be attached to the spreader unit.

Figure 1. TerraGator Spreader

COMMERCIAL MANURE SPREADERS

Commercial spreading equipment (Figure 2) has significant limitations, but can be used successfully for spreading lime, compost, and manure on smaller projects. The spreader must have a minimum of two separate heavy-duty bottom conveyor chains with closely spaced heavy-duty cross bars. Uniform calibration and spreading can be achieved only if the unit is equipped with an optional end gate located in front of the beaters (referred to as a slop gate). This type of spreader has zero tolerance for hard fragments of material such as large rocks or debris. Clean material is mandatory. In most cases, the commercial manure spreader cannot spread lime at rates less than ten tons per acre. The John Deere 680 manure spreader used by Western Reclamation has been completely rebuilt – including the running gear, spreader chains, spreader box, PTO drive line, and calibration gate.

Figure 2. Commercial Manure Spreader.

WESTERN RECLAMATION DISK PLOW

The Western Reclamation Disk Plow (Figure 3) is designed and constructed to mix soil amendments to a depth of 24 inches in adverse, non-agricultural areas. A D-6, low ground pressure (LGP) Caterpillar with a front blade is used to support and tow the plow unit. A reverse C-Frame with lift cylinders mounted on the back of the crawler serves as the plow hitch. The plow frame is constructed of heavy weight 10 and 12 inch square tubing with a special pivot point. The three heavy weight, concave, circular plow blades (32 to 38 inch diameter) are mounted on specially designed bearing assemblies and adjustable shanks welded into a twelve inch square tube main plow beam. The plow beam is designed to swing right or left 40 degrees from the line of travel.

The D-6, LGP with a heavy blade mounted on the front as a counterweight pulls the main plow beam and blades at an angle of approximately 35 degrees to the direction of travel. The crawler mounted C-Frame and hydraulic lift cylinders are used to establish the depth of plow blade penetration. The circular plow blades rotate slowly as they are pulled forward, effectively lifting bottom soils to the surface and mixing surface soils with the plowed profile. At the end of the field, the crawler tractor operator turns around and moves the main plow beam 70 degrees (35 degrees to the opposite side of the previous position) and then lowers the blades and proceeds to plow back along the furrow from the previous pass.

The capabilities of this plow are dependent on variables such as soil characteristics, steepness of sloping ground, and the size of the parcel being plowed. Small areas require extensive turning and backing up time, thus lowering efficiency. Steep slopes lower plowing efficiency and require a change in plowing techniques. Steep slope contour plowing ceases to be efficient at an approximate 3:1 slope. On steeper slopes, the plowed and turned soil tends to fall back into the furrow. Also, the crawler tractor slides and moves laterally downhill and cannot keep on line with the furrow of the previous pass. The deep plowing of steep hills can be accomplished by plowing straight down the slope. This technique was demonstrated on the Smelter Hill ARTS test plot locations. Rocky and compacted soils must be ripped on two-foot centers, prior to plowing, for the plow to achieve the required depth.

The original designers and manufacturers of disk plows specified that they were unsuitable for rocky and compacted soils. Extensive ripping to loosen soils and large rocks overcomes this negative plow characteristic. This plow will penetrate to a depth of 18 to 24 inches in rocky, heavy clay soils after ripping. Loose, sandy soils and tailings can be plowed to a depth of 24 to 36 inches without ripping if multiple passes are completed.

Figure 3. Western Reclamation Disk Plow

OFFSET DISKS

Offset disks are designed to chop and turn surface debris under and to incorporate soil amendments.They consist of two rows, or gangs, of disks offset at an angle to each other. Each gang has a separate frame and axle assembly. The angle is adjustable for varying soil conditions. The disks may have notched or straight edges. Most offset disks have wheels that are raised or lowered hydraulically for transport and to regulate operating depth. The Rome Engineering and Manufacturing Company specializes in custom building extra heavy-duty industrial strength offset disks. They can produce implements with extra large and heavy-duty blades (up to 42 inches in diameter and ½ inch thick) to withstand rocky soils. Blades can be spaced further apart to enhance penetration of compacted soils and aid in soil amendment mixing. Frames are designed extra heavy duty to withstand the rigors of being towed with crawler tractors.

Western Reclamation's Rome Disk (Figures 4 and 5) is 12 feet wide, has 42" diameter disk blades with over 1,000 pounds of down pressure on each cutting blade and requires a 200 to 300 draw bar horsepower tractor. This implement costs over $35,000 and requires several months of lead time as they are custom built on special order.

As offset disks are pulled over the area to be treated, the front gang of disks turns the soil one way and the rear gang turns it the other, giving a double disking action. Debris or brush is chopped up and incorporated into the soil. Offset disks can effectively control weedy plant growth while preparing an adequate seedbed and often break up surface soil compaction on reclamation areas or construction sites. They are well suited to dry, heavy soil and can be used on moderately rocky soil. These implements become less effective and more difficult to operate as slopes approach 3:1 grades. Soil amendments such as lime or compost require two or three passes to achieve good mixing to a depth of 12 inches. This depth is dependent upon the degree of soil compaction and the quantity of rocks limiting blade penetration. A Rome Disk (12 feet wide), towed at an average speed of two miles per hour under reasonable working conditions, should average approximately two acres per hour. Light-duty disks designed for agricultural fields cannot penetrate rocky and/or compacted soils and cannot achieve 12 inch mixing depths. Frequent breakage occurs if this type of disk is used for industrial lands.

Figure 4. Rome Disk

Figure 5. Rome Disk

CUSTOM-BUILT, HEAVY-DUTY RECLAMATION DRILLS

Custom heavy-duty reclamation drill seeders are designed and fabricated by experienced reclamation specialists who have experimented and field tested commercial drills over thousands of hours of adverse drilling conditions. Observations of the most frequent breakage allow for more durable and reliable designs for drilling in rough, rocky, and steep terrain.

Custom drills should have very long, heavy-duty trailing arms and extra heavy-duty disk type openers. Heavy-duty spring loaders on the trailing arms enable each arm to ride independently over rocks, irregular contours, and debris. Depth bands should be utilized to control seeding depth. Custom drills may be drawn by tractor but the most effective rough terrain reclamation drills are mounted on articulating, four wheel drive machines (Figure 6) equipped with wide flotation tires. Separating, divider plates within the seedbox are necessary to prevent the bulk of seed in the hopper from shifting to the downhill side and depriving the uphill openers of seed.

Custom drills use the same basic seed placement techniques as agricultural drills. The primary differences are as follows: a well built custom drill can accomplish precise seed placement under adverse seedbed and slope conditions and continue to operate on steeper and rougher terrain without malfunction and/or breakdowns.

These custom machines are specifically designed for seeding rough, rocky, and steep terrain. An experienced operator, with a well-designed custom drill, can drill seed areas totally inaccessible to conventional drills. However they are just as effective as conventional drills, and faster, on flat, rock-free areas. They can plant a variety of seed mixes at any rate desirable. Seeding depth is easily controlled. Minimal down time is a good indicator of a well-designed, custom-built, heavy-duty reclamation drill. They require extensive lead time to be manufactured. Tractor drawn custom drills are limited to 3:1 slopes but four wheel drive machines can negotiate 2.5:1 slopes on the contour if the soil is stable. Production rates of two and a half acres per hour can be expected if the terrain and soil conditions are reasonable. Drill seeder widths should not exceed much more than eight feet so that all the seed openers can effectively follow uneven surface contours and negotiate erosion control ditch berms.

Figure 6. Custom-Built, Heavy-Duty, Four-Wheel Drive Reclamation Drill

STRAW AND HAY MULCH SPREADERS

Straw and hay mulch spreaders are used to uniformly distribute organic stem and leaf materials over a prepared seedbed. A popular, commercially manufactured mulch spreader (Finn Corp) consists of a small (approximately 50 lb.) bale feed tray, high speed beaters, a blower powered by a large gasoline engine, and a pivoting distribution nozzle. The entire apparatus is mounted on a two-wheel trailer. After the beaters break up the bale, the blower picks up and mixes the material with a large volume of high velocity air. The material is carried up to fifty feet distant from the blower machine. This equipment is labor intensive as it requires a tow tractor operator, a spreader nozzle operator, and two to three bale handlers. It can be somewhat dangerous – the beaters and blowers can eject rocks or other projectiles. Another significant hazard is the operators standing and moving around on a trailer being towed over rough terrain.

Bernie Jensen of Western Reclamation Inc. has developed a spreader (Figure 7) that uses 1000 pound straw bales and requires only one operator located inside the enclosed cab of the towing tractor. Large bales are placed upon a controlled, chain feed apron using a second tractor (usually the crimper) equipped with a large bale handling grapple mounted on the loader bucket. The chain feed moves the bales into slow rotation rollers that meter the mulch to the flails and spreading spinners. The Western Reclamation spreader, using two operators working safely inside air-conditioned cabs, can spread and crimp mulch at a faster rate than five people operating a blower spreader. Also, slow speed rollers, as opposed to high-speed beaters, do not chop the material into short lengths. Longer stem mulch can be crimped into the soil much more effectively than short stem. The blower machine, however, can spread mulch on short distance slopes too steep for tractors.

Figure 7. Western Reclamation Straw Spreader

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RECLAIMING LANDSCAPE VISUAL QUALITY ON SURFACE MINING SITES USING COMPUTER VISUAL SIMULATIONS

John C. Ellsworth, ASLA[1]

ABSTRACT

Restoring visual quality is an important goal for reclamation of surface mines and other drastically disturbed landscapes. Visual quality management on USDA Forest Service and USDI Bureau of Land Management lands is accomplished with a variety of techniques, including the use of sophisticated computer visual simulations. The basic concepts, policies, analytical systems and procedures of these two agencies' visual resource management systems are discussed, with emphasis on computer visual simulation applied to surface mined lands.

Computer visual simulations are used to portray proposed landscape changes with photo-realistic quality. This sophisticated technology is a valuable tool for planners, landscape architects, reclamation specialists, engineers, environmental consultants, government agencies and private operators in the design and planning of surface mining operations. Several surface mining reclamation case studies, completed by the author over the course of the last ten years in the intermountain west, are presented. Detailed discussion covers the value of computer visual simulations not only in visual resource reclamation planning, but also for the design of post-mining landform, revegetation, and erosion control. Discussion of the use of this technology in facilitating stakeholder involvement is included. The issues of computer visual simulation accuracy, realism, credibility, representativeness, defensibility, and bias are discussed. Computer visual simulations are shown to be powerful and effective tools for setting reclamation goals, facilitating interdisciplinary discussion and decision making, project permitting, and evaluating reclamation success.

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Author's note: The presentation of this paper included many color slides of computer visual simulations and other images, which could not be adequately reproduced here due to space and black and white only printing restrictions.

INTRODUCTION

Surface mining sites are often located on public lands, federal or state, and are subject to reclamation laws and regulations. Restoration of visual, or scenic, quality is an important goal for reclamation of surface mines and other drastically disturbed landscapes. Computer visual simulations are an effective tool for visualizing the effects of proposed surface mining activities on visual resources as well as on various other natural and cultural resources.

Visual Resource Management and US Federal Land Management Agencies

Visual quality management on federal lands managed by the USDA Forest Service, USDI Bureau of Land Management, and other agencies is conducted with a variety of analytical techniques. Computer visual simulations are frequently used to visualize the impacts to visual and other natural resources. The basic concepts and procedures of these visual resource management systems were established over two decades ago, with ongoing updates and revisions.

USDA Forest Service VMS and SMS

In the early 1970's, the US Forest Service was the first federal agency to develop a systems approach to the inventory, analysis, and management of landscape visual resources (USDA Forest Service 1973; 1974). Their Visual Management System, or VMS, process established visual quality objectives (VQO's) through an analysis of the landscape's physical/scenic character, its visual variety, and visitors' concerns for scenic quality (called sensitivity levels). These visual quality objectives were intended to measure "degrees of acceptable alteration of the natural landscape" (USDA Forest Service 1974, p. 9). Visual simulations, some developed with the use of computers, were often used by National Forest landscape architects and others to depict the impact of proposed activities on the forest landscape's visual quality. A series of Forest Service VMS handbooks addressed visual resource management for various activities, including utilities, range management, roads, timber management, fire, ski areas, and other forms of recreation (USDA Forest Service 1975; 1977a; 1977b; 1980; 1985a; 1985b; 1987).

In 1995 the VMS was superceded by the updated and revised Scenery Management System, or SMS (USDA Forest Service 1995). The SMS retained many of the basic VMS concepts, with new emphasis placed on understanding the needs and concerns of the public and forest users ("constituents", sometimes referred to as "stakeholders"). It also encouraged the use of Geographic Information Systems (GIS) in the mapping of not only the physical attributes of the forest landscape, but also the visual and perceptual aspects such as the influence of the viewers' distance from the activity and concern for scenic values. The specific VMS activities handbooks, listed above, were retained as part of the SMS and continue to provide some guidance for use of visual simulation in managing forest visual resources.

USDI Bureau of Land Management VRM

As with the US Forest Service, the Bureau of Land Management is responsible for the care and management of millions of acres of public lands, primarily in the western US including Alaska. In 1980, BLM initiated their Visual Resource Management (VRM) program (USDI Bureau of Land Management 1980a; 1984; 1986b). The VRM process incorporates three major steps: inventory/evaluation, visual management class designation, and contrast rating. The first two steps are similar in many ways to the Forest Service VMS. They address the landscape's visual quality (based on physical and cultural attributes), viewer sensitivity to visual change in the landscape, and viewer distance from the landscape. These two steps result in the establishment of up to four visual management classes, ranging from no allowable visual resource disturbance to extensive disturbance.

The BLM VRM system differs from the Forest Service's VMS by addressing project scale analysis as part of the basic process. Using the third step of VRM, called contrast rating (USDI Bureau of Land Management 1986a), the land manager, often a landscape architect, determines the degree to which a particular project (for example, a road, power plant, or surface mine) visually contrasts with the existing landscape. This contrast analysis is based on visual design principles and elements such as form, line, color, and texture.

VRM specifically mandates the use of visual simulations in this contrast rating analysis (USDI Bureau of Land Management 1980b). In simplest terms, the proposed project is simulated as it would appear in the landscape, then its contrast (in form, line, color, and texture) with the existing landscape is evaluated. If the contrast is too great, the project may require redesign in order to reduce its visual impact, or in extreme cases the project may not be approved at all. The development of visual simulations by manual (hand drawn) techniques is the subject of a training seminar conducted by the BLM at their National Training Center in Phoenix, Arizona (USDI Bureau of Land Management n/d). The author is currently developing an extensive training course in computer visual simulation for the BLM National Training Center (Ellsworth 2000).

Other Federal Land Management Agencies

Some other federal agencies have initiated landscape scenic management systems. Most are less extensive in scope and process due in part to the smaller and more specific landscape types managed.

The US Federal Highway Administration developed a system in the late 1970's called Visual Impact Assessment Procedures for Highway Projects (US Federal Highway Administration n/d). This system is distinguished by its detailed and flexible step-by-step approach to assessing the visual impacts of highway projects of various scales (and of associated land disturbing activities such as borrow pits and cut and fill excavations).

The US Army Corps of Engineers (Smardon, et al 1988) developed their own system for assessing the visual impacts of water and related projects. Their Visual Resource Assessment Procedure (VRAP) shares some features with the Forest Service and BLM systems, in particular two major steps of management classification and visual impact assessment. The procedure requires ten specific steps, using detailed paperwork forms, in order to complete the visual resource assessment.

Computer Visual Simulations

Computer visual simulations are used to portray proposed landscape changes with photo-realistic quality. When done well, they illustrate the proposed conditions of a multitude of natural and cultural resource values.

Value of Computer Visual Simulations

For landscape architects and others with a primary concern for design and visual values, computer visual simulations are an indispensable design, analysis, and communication tool. Revegetation and hydrology/erosion control specialists can see how their plans will take physical form and the relationships among plants, structures, soils, and slopes. Mining engineers and planners can more effectively explore and evaluate alternative excavation, processing, facilities siting, and reclamation strategies when seen in credible, full color visual simulations. Environmental consultants and government agencies with a responsibility to their clients and the public use computer visual simulations to facilitate design reviews and public/stakeholder involvement, and to assure compliance with environmental laws and regulations.

The Technology

Today, computer visual simulations are developed using desktop computer technology. The essential elements include a camera (film or digital), computer with graphics software, high resolution monitor and color scanner, and high quality color printer (or film recorder for making slides). When this readily available hardware and software is used by skilled and trained designers and resource managers, it can result in highly useful and affordable visual simulations.

Computer Visual Simulation Issues

The development and use of computer visual simulations present a number of issues, both technical and ethical. They include accuracy, realism, credibility, representativeness, defensibility, and bias (Ellsworth 1996a; 1996b; Sheppard 1989).

Accuracy is considered one of the most important, yet least understood computer visual simulation issues (Ellsworth 1999). It is often assumed that a photographic quality visual simulation must be perfectly accurate in order to be an effective evaluation tool. In fact, this is not necessarily true. For example, research has shown that most observers cannot detect scale inaccuracy until it approaches almost +/-15% (Watzek and Ellsworth 1994). Since this level of accuracy can be readily and affordably achieved in almost all visual simulation work, there is little value in the added time and expense required to achieve nearly perfect accuracy.

Realism, or a lifelike appearance (Sheppard 1989), is related to accuracy and credibility. With today's highly sophisticated technology, almost anything can appear real (we have probably all seen films like Jurassic Park or the Terminator). The challenge in computer visual simulation for surface mining is to depict conditions that could actually be real, not just appear real. In other words, conditions that are actually part of the mining or reclamation plan and are achievable in the real world, not just wishful thinking.

Representativeness is the extent to which a simulation shows typical views of a proposed project (Sheppard 1989). This is an important part of both the Forest Service and BLM procedures. Typical viewpoints, called key observation points (KOP's) in the VRM system, are often identified by an inter-disciplinary team in consultation with users and the public.

Bias, related to defensibility (as are all of the above issues), occurs when the viewer's reaction to a visual simulation is favorably or unfavorably affected for no valid reason (Chenoweth 1989; Sheppard 1989). Bias can take many forms such as alterations in form, line, color, texture, scale or the introduction or omission of specific elements or objects. Unintentional or careless bias can be frustrating, time consuming, and expensive when discovered. Intentional bias may result in much more serious consequences, both for the clients and users, and for the landscape if not detected before project implementation.

Computer Visual Simulation Applications for Surface Mining

Several surface mining reclamation case studies have been completed by the author over the course of the last ten years in the intermountain west. These projects were done for a variety of clients, on both private and public lands. Some were part of environmental assessment (EA) or environmental impact statement (EIS) processes. The basic desktop computer technology, as discussed above, was used on all projects. As the sophistication of the technology (especially image resolution and color depth) has improved over the years, the viewer will note a marked increase in the quality of the images.

Palomar Aggregates Mine

This project was done by the author more than ten years ago, using the technology of the time (an IBM 286 computer running at 12 megahertz with a whopping 2mb of memory and an 80mb hard drive!). The site is in southern California, near San Diego.

The client, an engineering firm, was involved in the planning for a proposed aggregates mine. Visibility was an important issue due to the proximity of the site to a major interstate highway and to a recreation area.

The most important visual disturbances were a six hundred foot highwall and the removal of the top of the peak. These would be easily seen from the highway and the recreation area. In order to assess the visual impacts, a series of computer visual simulations were developed from various viewpoints along the highway and at the recreation site. The simulations were done in the early stages of planning, and were of great benefit in refining and communicating the subsequent stages of mine plan development.

Black Pine Gold Mine

This project began in 1993 (using newer, faster, and higher image quality technology). It is a heap leach gold mining operation, located in southeastern Idaho near Burley. The client, Pegasus Gold, was in the process of planning for mine reclamation over five years. It is on US Forest Service land. Computer visual simulations were considered a valuable and necessary reclamation planning tool.

The visual simulations represented mine expansion and reclamation over a five to ten year period. The consulting landscape architects were asked to visually show new landform design as visually similar, in terms of topography and slope, to the surrounding landscape. Based on reclamation experience on-site, the mine reclamation specialists predicted 50% to 70% revegetation success.

Several mining activities were simulated, giving a clear picture of recontouring, revegetation, landform design, and erosion control. An existing mine exploration road was shown fully revegetated in three to five years, based on success at a similar altitude and aspect. A waste pile was shown regraded, and revegetated. A visual simulation of an existing mine haul road emphasized steep slope regrading, drainage channel restoration, and revegetation. The visual simulations were an essential part of the mine expansion and reclamation/closure plan submitted for agency review.

Rattlesnake Hills Quarry

The Bureau of Land Management required Umetco Minerals to produce an environmental assessment for their proposed Rattlesnake Hills Quarry in central Wyoming. The company was in the process of reclaiming and closing its nearby Gas Hills Uranium Mine and Mill to comply with regulations promulgated under the federal Uranium Mill Tailings Radiation Control Act of 1978. This would require stabilizing approximately 10 million tons of radioactive mill tailings by placement of earthen, vegetative, and rock cover durable for a minimum of 200 years (1,000 preferred). Quartzite rock on BLM land in the Rattlesnake Hills was determined suitable for these purposes, and an EA was submitted to BLM for the mineral sale. Approximately 500,000 cubic yards would be excavated from the 145 acre site over about three years.

Using the BLM VRM system, a series of key observation points (KOP's) were established by the author in consultation with state and federal agencies. Two of these KOP's were considered most useful, one from approximately .75 mile away and the other from 1.5 miles away. Computer visual simulations were developed, and used in the contrast rating process to determine the visual acceptability of the project. This process determined that the project met the visual quality requirements of the designated visual management class for the area. The contrast rating and computer visual simulations were submitted as part of the EA and at public meetings. The project was recently approved by BLM.

SUMMARY

Computer visual simulations have proven to be powerful and effective tools for achieving surface mining reclamation goals. They are useful in facilitating interdisciplinary discussion and decision making, project permitting, and reclamation success evaluation. Computer visual simulations can play a valuable and important role in surface mine planning and design when used by skilled and experienced professionals who understand the range of applications, technological capabilities, and technical and ethical issues.

REFERENCES

Chenoweth, R. 1989. Aesthetic Policy Implications of Image Processing Technology. Presentation to the American Society of Landscape Architects Annual Meeting, Orlando, Florida.

Ellsworth, J.C. 1996a. Computer Visual Simulations and Surface Mine Closure: Three Case Studies. Paper and poster session at the 20th Annual British Columbia Mine Reclamation Symposium, Kamloops, BC, Canada, June 20

Ellsworth, J.C. 1996b. Computer Visual Simulations in the Design and Planning of Surface Mine Reclamation. Presentation and paper at the 1996 Annual Conference of the International Erosion Control Association, Seattle, Washington, February 29.

Ellsworth, J.C. 1999. Ten Years of Computer Visual Simulations on Large Scale Projects in the Western United States. Paper and presentation to the American Society for Surface Mining and Reclamation Annual Conference, Scottsdale, AZ, Aug. 13-19.

Ellsworth, J.C. 2000. Computer Visual Simulation Training Course. USDI Bureau of Land Management National Training Center (in progress). Phoenix, Arizona.

Sheppard, S.R.J. 1989. Visual Simulation: A User's Guide for Architects, Engineers, and Planners. New York: Van Nostrand Reinhold.

Smardon, R. C., J. F. Palmer, A. Knopf, and K. Grinde. 1988. Visual Resources Assessment Procedure for US Army Corps of Engineers. Instruction Report EL-88-1 for US Army Corps of Engineers. Washington, D.C.: Department of the Army, US Army Corps of Engineers.

USDA Forest Service. 1973. National Forest Landscape Management: Volume 1. Agriculture Handbook No. 434. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1974. National Forest Landscape Management: Volume 2, Chapter 1: The Visual Management System. Agriculture Handbook No. 462. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1975. National Forest Landscape Management: Volume 2, Chapter 2: Utilities. Agriculture Handbook No. 478. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1977a. National Forest Landscape Management: Volume 2, Chapter 3: Range. Agriculture Handbook No. 484. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1977b. National Forest Landscape Management: Volume 2, Chapter 4: Roads. Agriculture Handbook No. 483. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1980. National Forest Landscape Management: Volume 2, Chapter 5: Timber. Agriculture Handbook No. 559. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1985a. National Forest Landscape Management: Volume 2, Chapter 6: Fire. Agriculture Handbook No. 608. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1985b. National Forest Landscape Management: Volume 2, Chapter 7: Ski Areas. Agriculture Handbook No. 617. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1987. National Forest Landscape Management: Volume 2, Chapter 8: Recreation. Agriculture Handbook No. 462. Washington, D.C.: U.S. Department of Agriculture.

USDA Forest Service. 1995. Landscape Aesthetics: A Handbook for Scenery Management. Agriculture Handbook Number 701. Washington, D.C.: Government Printing Office.

USDI Bureau of Land Management. n/d. Visual Design Techniques for Surface Disturbing Activities. Phoenix Training Center, Handbook for Course Number FP 8400-2.

USDI Bureau of Land Management. 1980a. Visual Resource Management Program. Stock No. 024-011-00116-6. Washington, D.C.: Government Printing Office.

USDI Bureau of Land Management. 1980b. Visual Simulation Techniques. Stock No. 0-302-993. Washington, D.C.: Government Printing Office.

USDI Bureau of Land Management. 1984. Visual Resource Management. BLM Manual Section 8400 revision. Washington, D.C.: Government Printing Office.

USDI Bureau of Land Management. 1986a. Visual Resource Contrast Rating. BLM Manual Handbook 8431-1. Washington, D.C.: Government Printing Office.

USDI Bureau of Land Management. 1986b. Visual Resource Inventory. BLM Manual Handbook 8410-1. Washington, D.C.: Government Printing Office.

U.S. Federal Highway Administration. n/d. Visual Impact Assessment for Highway Projects. Washington, D.C.: American Society of Landscape Architects.

Watzek, K.A., and J.C. Ellsworth. 1994. Perceived Scale Accuracy of Computer Visual Simulations. Landscape Journal, Spring, pp. 21-36.

2000 Billings Land Reclamation Symposium

CONQUERING TABLE MOUNTAIN PIPELINE RESTORATION PROJECT BY HAND AND HELICOPTER

David R. Chenoweth[1]

ABSTRACT

Western States Reclamation, Inc. (WSRI) completed a difficult and diverse restoration project for Public Service Company of Colorado on the Table Mountain segment of the Natural Gas Pipeline Installation near Golden, Colorado. This portion of the pipeline project was of concern to Public Service Company because of the visual impacts it could create from the I-70 corridor, and members of the Coors family who resided at the base of Table Mountain. Also, the Table Mountain segment of the natural Gas Pipeline contains two dimensional steep slopes, which traversed both herbaceous and woody plant communities.

The objective of the land restoration efforts were initially to control erosion, while re-establishing both herbaceous and woody plant materials that would visually mask the pipeline disturbance as quickly as possible. Due to the steepness of the slopes and the inability to access this portion of the pipeline with hydroseeders or other standard seeding equipment, WSRI employed the use of all terrain vehicles to haul woody plant materials to the site for hand installation. Also, hand broadcast seeding and aerial applications of Bonded Fiber Matrix were completed.

This paper focuses on revegetation planning, adaptation of creative installation methodologies and materials, followed by an intensive monitoring and maintenance program. All of these important elements have led to today's notable high success of the self-sustaining cover for both herbaceous and woody plants.

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INTRODUCTION

Western States Reclamation, Inc. (WSRI) was contacted by Public Service Company of Colorado in March of 1998 to determine the best approach to control erosion and revegetate the Table Mountain segment of the Natural Gas Pipeline that traversed the west side of the City of Denver. The Table Mountain segment of the pipeline is located near Golden, Colorado and begins on the northern end of the Rolling Hills Golf Course and terminates on the south near the National Renewable Energy Laboratory (NREL). This project was highly sensitive because of the visual impacts it created for the I-70 corridor and homes occupied by the Coors family (related to the famous Coors Brewing Company).

The challenges in controlling erosion and revegetating the Table Mountain segment were limited access due to two dimensional slopes (both vertical and horizontal slopes) and the requirements to establish both herbaceous and woody plant cover similar to the pre-disturbance vegetative cover. As with many pipeline projects, the public's expectations were for good to exceptional vegetative cover as quick as possible to reduce the eyesore of the disturbance created by the actual pipeline installation.

REVEGETATION PLAN

Since access on over 60% of the pipeline prohibited safe use of traditional revegetation equipment, including hydroseeders/hydromulchers mounted on trucks and 4-wheel drive tractors with implements, other methods of seeding and erosion control had to be determined. WSRI worked with Public Service Company and their environmental consultant to arrive at a safe and efficient means of hauling and planting over 2,000 woody plants to the work zone, seeding, mulching, and installation of erosion control blankets.

The final plan for execution consisted of both extensive hand labor for seeding and woody plant installation. Seeding was followed by use of erosion control blankets on the more accessible portions of the slopes, and aerial applications of Bonded Fiber Matrix on the most inaccessible portions of steep slopes. Drill seeding and hydromulching with tackifier were used on all other accessible areas of the pipeline.

WSRI determined it would be best to install woody plant materials first, followed by broadcast seeding and installations of Bonded Fiber Matrix. On the other hand, the woody plants were installed after hand seeding and installation of erosion control blankets on the lower portion of the Rolling Hills Golf Course side of the pipeline.

The planting zones were divided by upper slope areas and lower slope areas. The woody plants on the upper slope areas included Wild Plum, Black Chokecherry, Skunkbush Sumac, and Western Snowberry.

The lower slope area woody plants consisted of Mountain Mahogany, Skunkbush Sumac, Wild Plum, and Western Snowberry.

REVEGETATION EXECUTION

Work commenced on the project during the first week of April, and the majority of the woody plant and grass planting was completed by mid-May. Work was interrupted twice during April because of spring snow showers and rain. These precipitation events proved later to be very instrumental in providing much needed moisture to the woody plants and grasses.

The size of the plant materials consisted of a mixture of 5 gallon, 1 gallon, and 2 1/4" pots, and were driven by the market availability of plants and the desire to complete all woody plant installations during early Spring. The objective in installing all woody plants was to attempt the highest possible survival rates and reduce the amount of re-planting during the maintenance period.

Also, the difficulty in re-accessing the site after initial planting was a strong consideration. Therefore, as individual plantings occurred, a brush mat or filter fabric was placed around each plant with dimensions of approximately 2 ft. in diameter. Oasis Tree Shelter Cones 24" in height were then slipped over each plant for protection. The shelter cones offered protection from deer browse, temperature extremes, and ultimately from overspray of Bonded Fiber Matrix.

WSRI utilized a Kawaski Mule ATV to haul the plant materials to the work zone. Shovels, hoedads, and plant dibbles were used for the actual installation of the plant materials.

On areas that received the erosion blanket, the plants were installed after application of the actual blanket by cutting an “X” slit in the blanket to accommodate each planting.

Three different grass seed mixtures were designed to accommodate different micro-climates and vegetation zones. These grass seed mixtures consisted of an upland, warm season, and steep slope seed mixtures. The grass species in each mix were native and/or indigenous to the project site. A number of native wildflowers were also added to each native grass mixture. The environmental consultant’s concern was the varying textures and sizes of each grass and wildflower species and how WSRI would maintain an even distribution of species. Therefore, WSRI purchased and utilized a Truax hand held broadcast seeder which is unique because of its aggressive agitation system when compared to other hand broadcast spreaders. In order to achieve good seed to soil contact, hard tine rakes were utilized to cover the seed lightly with soil.

The upper inaccessible portions of the slope area were then covered with Bonded Fiber Matrix in a unique application process. WSRI had researched and contacted other erosion control contractors in the Pacific Northwest regarding their use of aerial applications of hydromulch and Bonded Fiber Matrix. A decision was made to purchase a slurry bucket that was equipped with a gas powered hydraulic setup and electronic controls which could be affixed inside the cockpit of the helicopter. Since Public Service owns and operates its' own helicopter for use in patrolling transmission lines and natural gas pipelines, a decision was made to utilize their craft. The helicopter used was a Bell Long Ranger. While this model of helicopter is known for its comfort in transporting passengers, it has a limited lift capacity when compared to other helicopters.

WSRI realized the most critical element from a labor cost standpoint was quick cycle times between the loading/landing zone and the spray zone. A 4,000 gallon water truck was utilized to feed WSRI's 3,000 gallon Finn hydromulcher. This allowed continuous mixing and cycling of Bonded Fiber Matrix material. Three personnel were utilized for loading material into the slurry bucket, while the pilot continuously cycled between the loading zone and the spray zone. The pilot would hover as the bucket was loaded, saving time because we did not have to transition from reduced power.

To our delight the coverage from the slurry bucket was very impressive as the process advanced. The credit for the even application was Public Service Company's skilled pilot which completed the application. WSRI applied 3,000 pounds per acre of Bonded Fiber Matrix to all areas of the steep slope.

As previously mentioned, erosion control blankets were installed on the lower extremities of the steep slope areas where access was more prevalent. The erosion control blankets consisted of Bionet Straw Blankets with netting on both sides, Green Fix Model #WSO72B. This material was picked by WSRI and the environmental consultant because the netting would biodegrade the fastest.

Other portions of the pipeline project allowed access and use of a rangeland drill for drill seeding and a truck mounted hydromulcher for hydromulching.

REVEGETATION MAINTENANCE

During the planning stage of the revegetation efforts, WSRI suggested to Public Service Company and the environmental consultant that both monitoring and maintenance of the revegetation work efforts would be necessary. Initial monitoring was completed by WSRI, the environmental consultant and Public Service personnel during August of 1998. At that time an almost unheard of survival rate for woody plants was documented. Overall counts of all species indicated up to 90% survival rate for woody plants.

Native grass germination and fill-in was equally impressive. The middle to lower sections of the pipeline project was so dense it had the appearance of an irrigated pasture.

This in part was due to springs and seeps in the area and an intermittent drainage channel which gently flowed across the reclaimed site.

Upper portions of the pipeline project while good in grass cover were not quite as impressive. A notable stand of sunflowers and Canada thistle were present on this portion of the pipeline project.

WSRI feared that use of herbicide applications at this point would kill newly germinating grasses and damage ungerminated seed material in the soil surface. A decision was made to control the sunflowers and Canada thistle by use of weed eaters and cutting off the seed heads before further spread and germination of weed seeds could occur.

Another inspection of the site during this April 1999 indicated that the survival rates had not changed appreciably and maintained approximately 80%-85% survival. The weed cover persisted in being a problem on the upper slope portion. Even though it appeared the grass cover was better than witnessed in August 1998, a decision was made to apply herbicide with the use of backpack sprayers. An application of HI-DEP herbicide was utilized to help reduce weed cover and further enhance the herbaceous cover on what appears to be the only area of concern on the entire pipeline segment.

SUMMARY

In conclusion, WSRI attributes the high success of this revegetation project to the following.

1. The quality time spent in the planning stage which identified proper methods, materials and maintenance needed to encourage revegetation success.
2. Early spring plantings followed by spring snows and rainfall events.
3. The use of superior products to compliment the grass seeding and woody plant installations including the Brush Mats, Oasis Tree Shelter Cones, Bonded Fiber Matrix, and Green Fix erosion control blankets.
4. Public Service Company's commitment to allow WSRI to complete a monitoring and maintenance program and correct any problem areas/deficiencies as quickly as they were identified.

WSRI wishes to acknowledge the following vendors for their help on this project.

- Revex, Inc. for on-site assistance and timely delivery of Soil Guard, Mat Fiber Hydromulch, and Green Fix Erosion Control Blankets.

- Reforestation Technologies International in Monterey, CA for supplying Brush

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HYDRAULIC CHARACTERISTICS OF SUBSURFACE FLOW WETLANDS

W. J. Drury[1] and K. Mainzhausen[2]

ABSTRACT

Subsurface flow (SSF) wetlands were evaluated in a field study of treatment of water containing heavy metals. SSF wetlands convert sulfate to sulfide, which is an effective precipitant for copper and zinc. To produce the anaerobic environment required for sulfide production, the water surface must be below the wetland surface. Therefore, the flow rate that can be treated effectively is limited by the wetland dimensions and substrate permeability. Rapid catastrophic hydraulic failures have occurred in such systems due to the loss of substrate permeability.

Hydraulic conductivities (*K*) of four SSF wetlands were measured over a 2.5 year period. Two horizontal flow wetlands with a gravel-only substrate had *K* of 600 ft/d (2×10^{-3} m s^{-1}) at the end of the study period. A horizontal flow wetland with 20% (volume) compost in its substrate had a *K* of 200 ft /d (7×10^{-4} m s^{-1}). A vertical flow wetland containing 50% (volume) compost in its substrate had a *K* of 0.7 ft/d (2×10^{-6} m s^{-1}) after one year of operation. Subsequently, fracturing and non-Darcian flow occurred in this wetland.

Hydraulic conductivities decreased over time by over 90%, principally in the inlet regions of the wetlands. Filter fabric clogging was a problem. Downstream of the inlet zones, little change in *K* was observed.

Effective porosities were measured in the three horizontal flow wetlands annually using tracer (bromide) tests. After two years of operation, the effective porosities in all wetlands were 0.3 and decreased by an average of 11% from year one to year two. Dispersion numbers (*D/uL*) were approximately 0.1.

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INTRODUCTION

Acid drainage that contains heavy metals is an environmental problem that can occur at abandoned and closed mines. There are a number of proven treatment technologies for removing metals and acidity from water. However, the traditional technologies require significant operational attention and have high operations costs due to requirements for continuous chemical addition. Neither the government agencies reclaiming abandoned mine sites nor the mining corporations with closing mines wish to meet these requirements. Often the abandoned mine sites are inaccessible in winter. Maintaining electrical service from public utilities is difficult and costly. There is an interest in having treatment systems with low operational costs and requiring minimal maintenance.

A passive treatment system that has been used at abandoned and closed mines is constructed wetlands. Constructed wetlands can be built as surface flow (SF) systems or subsurface flow (SSF) systems (Kadlec and Knight, 1996). SF wetlands have the water in direct contact with the atmosphere and work best when oxidizing chemical processes are desired. They work poorly for water treatment when the primary metals of concern are copper (Cu) and zinc (Zn) (Wildeman *et al.*, 1993). In SSF wetlands, water flows through a gravel bed and the free water surface stays below the top of the gravel bed. SSF wetlands foster anaerobic, reducing chemistries such as sulfate reduction if the wetlands large enough to keep the water under the wetland surface. Sulfate reduction neutralizes acid (Wildeman *et al.*, 1993) and the sulfide produced by sulfate reduction is an excellent precipitant of Cu and Zn (Patterson, 1985).

Sulfate reduction requires a low oxidation-reduction (E_h) potential. At 25°C, a pH of 7, a H_2S concentration of 1 mg S/L and a SO_4^{2-} concentration of 100 mg S/L, the E_h must be –198 mV for sulfate reduction to occur. Such a low E_h corresponds to an oxygen partial pressure of 10^{-69} atm. For comparison, 1 mg O_2/L produces an E_h of +790 mV. For metal sulfide precipitation to occur, water must be kept below the substrate surface and away from the atmosphere.

Darcy's Law is used to determine the wetland cross-sectional area (*A*) for a chosen water flow rate *Q* and an estimated hydraulic conductivity (*K*) in SSF wetland design. Darcy's Law describes laminar flow through a porous medium:

$$Q = KA\frac{dh}{dl} \tag{1}$$

where *dh* is the change in head and *dl* is the length over which *dh* occurs. *K* is time-variable; it decreases over time from substrate compaction and loss of porosity due to filtration of solids in the influent water. Decrease in *K* can be quite sudden, leading to a rapid hydraulic failure where the substrate is unable to pass the influent flow through it and still keep the water surface underground.

The Atlantic Richfield Company (ARCO) was interested in use of constructed wetlands to treat water containing Cu and Zn. From 1993 to 1998 they cooperated with the Montana Tech of the University of Montana in researching the capabilities and limitations of such wetlands. This project culminated with pilot-scale field studies conducted in 1996-1998.

SITE DESCRIPTION

This paper utilizes data obtained from ARCO's test site in Butte, MT at the northwest corner of Kaw and George Streets. Water was pumped from the Metro Storm Drain (MSD), a channel carrying intercepted groundwater and surface runoff, into the test system. MSD water has a pH between 6.5 and 7.0, and contains significant colloidal iron (Fe) hydroxide and dissolved Zn. The treatment system consisted of a settling pond followed by four SSF wetlands in parallel, followed by two SF wetlands (Jones, 1997; Mainzhausen, 1998). SSF wetlands characteristics are listed in Table 1.

Table 1. Characteristics of the four SSF wetlands. Length and width are at the surfaces of the cells. Gravel and crushed limestone sizes were ¼- to ¾-inch.

Cell	Volume (ft^3)	Length (ft)	Width (ft)	Depth (ft)	Composition (volume %)
1	27,000	109	109	2.5	80% river gravel 20% limestone
2	16,250	53	94	4.0	20% compost 60% river gravel 20% limestone
3	6,400	44	44	6.0	50% compost 30% river gravel 20% limestone
4	12,950	76	76	2.5	80% river gravel 20% limestone

Cells 1, 2, and 4 were horizontal flow SSF wetlands. Length is the dimension parallel to the flow direction while width is perpendicular to the flow direction. Cell 3 was a vertical upflow SSF wetland. Flow rates varied from approximately zero to 14 gpm.

Hydraulic conductivity was measured on a monthly basis, except in winter when ice accumulation in vertical pipes prevented water elevation measurements (Jones, 1997). Water surfaces were measured in cleanout pipes on the influent and effluent manifold pipes as well as sampling wells in the horizontal flow SSF wetlands. In the vertical flow SSF wetland, water elevations were measured in a cleanout on the influent pipe, from horizontal sampling wells in the wetland substrate and in the hydraulic control structure on the effluent pipe. A well probe calibrated to 0.01 ft increments was used to determine water elevations relative to surveyed elevations of the tops of the various pipes, wells, and hydraulic control structure. Influent and effluent flow rates were metered continually. Hydraulic conductivity was calculated using Darcy's Law. Particle-based Reynold's numbers were two or less, making it acceptable to model SSF wetland hydraulics with Darcy's Law. Darcy's Law can be used only with laminar flow conditions represented by Reynold's numbers less than ten (Kadlec and Knight, 1996).

Tracer tests were performed in 1997 and 1998 on the horizontal flow SSF wetlands. Bromide was the tracer chemical. Effective porosities (η) were calculated from measured bromide concentrations (equation 2):

$$\eta = \frac{HRT * Q}{V} \qquad (2)$$

where HRT is the mean hydraulic residence time measured in the tracer tests and V is the total cell volume. HRT was calculated from the bromide concentrations. Tracer test methods and calculations can be found in Jones (1997) and Mainzhausen (1998).

RESULTS AND DISCUSSION

Hydraulic conductivities measured from inlet to outlet of all SSF wetlands decreased by over an order of magnitude over time. Across Cells 1 and 4, *K's* were 600 ft/d (2×10^{-3} m s^{-1}; Figures 1 and 2) at project completion. *K* was 200 ft /d (7×10^{-4} m s^{-1}; Figure 3) across Cell 2 at project completion. Initial measurement of *K* in Cell 3 was 12 ft/d (4×10^{-5} m s^{-1}). Within a year, it dropped to 0.7 ft/d (2×10^{-6} m s^{-1}).

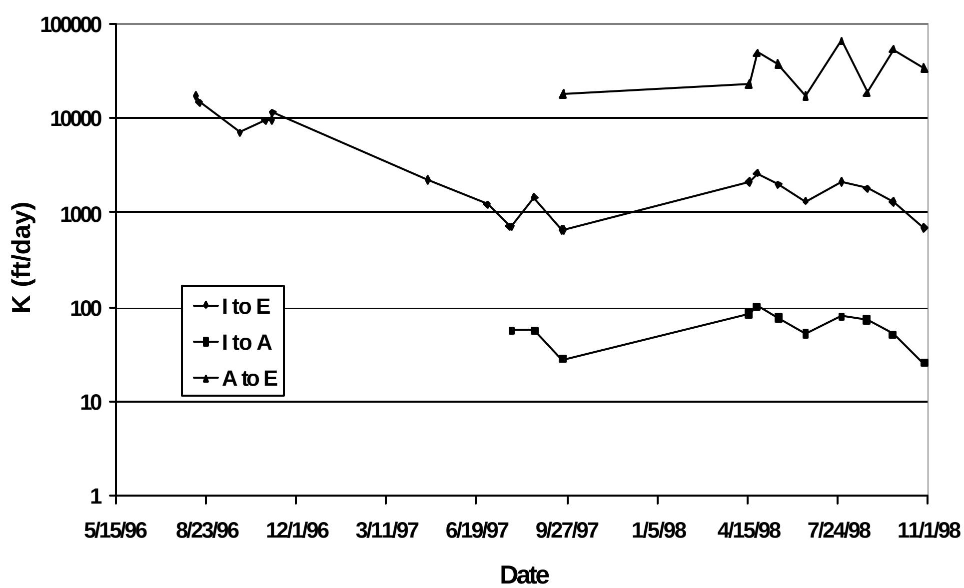

Figure 1. Hydraulic conductivity vs. date for Cell 1. "I" = influent manifold, "A" = piezometers immediately downstream from the influent manifold, and "E" = effluent manifold.

The majority of the head losses occurred at the entrances to these wetlands – from the influent manifold to the first row of sampling wells. The first row of sampling wells were located two to four feet downstream from the influent manifold in the horizontal flow SSF wetlands. Hydraulic conductivities downstream from the first row of sampling wells in these wetlands were constant over the 2.5 year project.

Inlet zones clogging of SSF wetlands may have been due to filtration of iron colloids and subsequent loss of substrate porosity. MSD water contains significant amounts of total iron – about 1 to 6 mg Fe/L. The iron colloids settled poorly in the settling pond. Thus, the influent water to the SSF wetlands contained iron colloids that filtered out on the substrates and filter fabric, clogging the pores and reducing *K*'s. It is unlikely that compaction would have caused longitudinal heterogeneity in *K*.

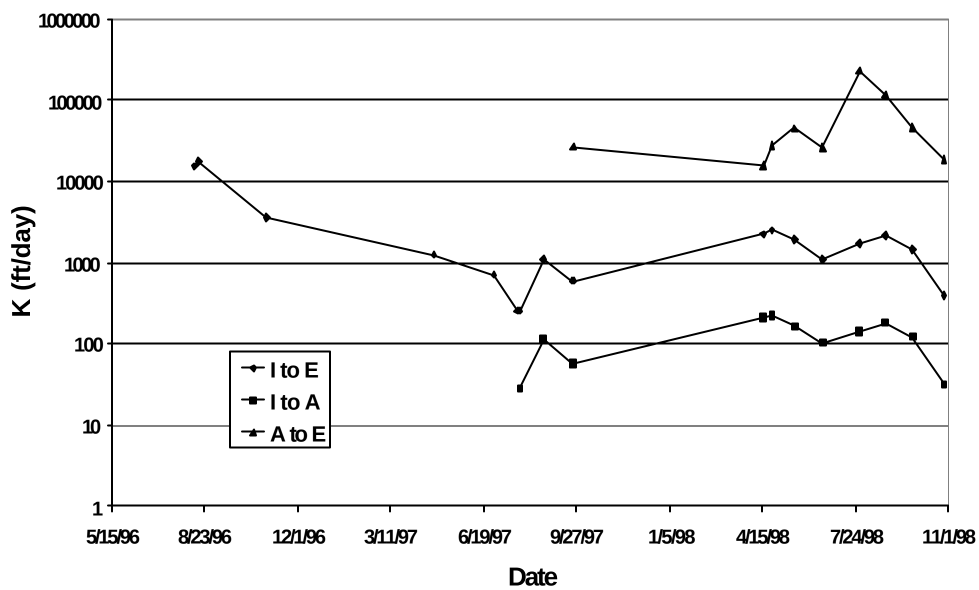

Figure 2. Hydraulic conductivity vs. date for Cell 4. "I" = influent manifold, "A" = piezometers immediately downstream from the influent manifold, and "E" = effluent manifold.

Filter fabric contributed to high head loss in the inlet regions of the SSF wetlands. In the horizontal flow SSF wetlands, water was distributed across the widths by buried perforated pipes. These pipes were surrounded by gravel packs, which in turn were surrounded by non-woven polyester filter fabric. The fabric clogged rapidly as they filtered solids out of the water. Filter fabric clogging in Cell 2 was visible within four months after start-up, and the filter fabric on the downstream side of the inlet zone was removed. Filter fabric clogging of the Cell 4 inlet was visible after 14 months of operation. While the inlet filter fabric in Cell 2 was exposed and visible to the eye, the filter fabric in the other wetlands was buried under the gravel substrates. Therefore, filter fabric clogging was difficult to observe in Cells 1 and 4. Eventually the fabric in Cell 4 ballooned to the wetland surface because of the higher pressure within the fabric-wrapped zone, and the bulging and leakage through folds at one end of the fabric was observed. Filter fabric on the downstream side of the inlet zones and upstream sides of the outlet zones was subsequently removed from Cells 1 and 4. Fabric removed from the inlet zones had a two-mm layer of fine-grained orange solids, which appeared to be predominantly iron colloids, on their upstream sides.

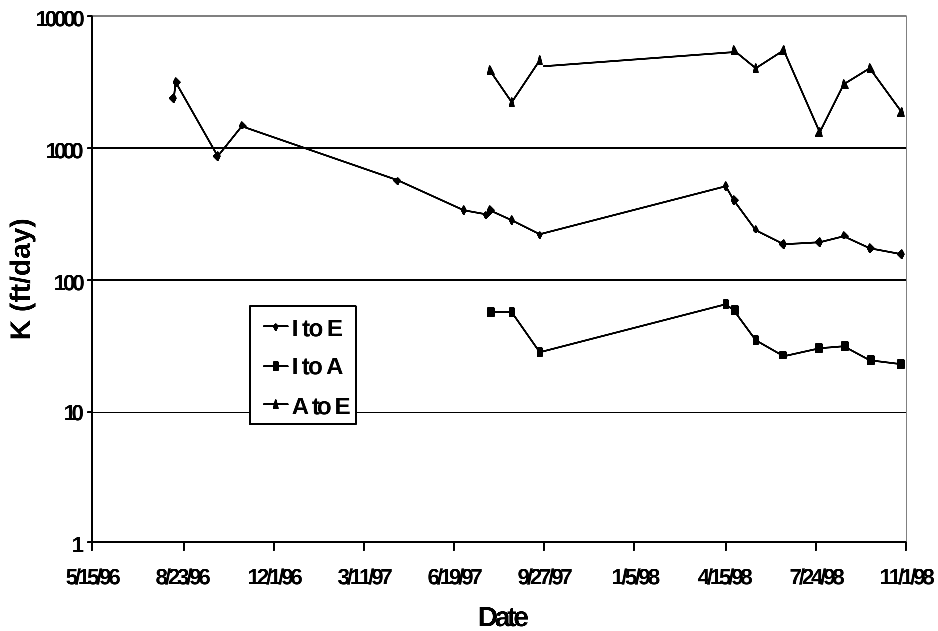

Figure 3. Hydraulic conductivity vs. date for Cell 2. "I" = influent manifold, "A" = piezometers immediately downstream from the influent manifold, and "E" = effluent manifold.

Hydraulic conductivity measurements to assess the effectiveness of filter fabric removal in Cells 1 and 4 could not be made immediately after this maintenance was done. Filter fabric removal in Cells 1 and 4 occurred in late October, 1997 after 17 months of operation. Wells from whom water elevations were measured froze within a week after this work, and *K* measurements could not be made until the spring of 1998.

Filter fabric removal caused a temporary improvement in *K* in Cell 1 and Cell 4. *K* values dropped to where they were before the filter fabrics were removed within a year (Figures 1 to 3).

Hydraulic conductivity of Cell 3 was low compared to the horizontal flow SSF wetlands. Measurements showed nearly all the head loss to occur between the inlet manifold piping and the lowest level of sampling piezometers, located one ft above the gravel pack around the inlet manifold. Between the inlet manifold and the lowest piezometers was a filter fabric separating the gravel pack around the inlet manifold and the wetland substrate. It could not be determined if the cause of the head loss was filter fabric clogging or a loss of porosity due to substrate settling

Cell 3 flow rates became too low for the flow meters to measure after about one year of operation. Periodic water pulses did move through Cell 3. The highly variable flow rate during this period may have been due to periodic substrate fracturing. Pressure would build until the substrate grains were displaced, letting water through quickly and relieving the high pressure. Darcy's Law does not describe transient flow and displacement of the granular medium, so no attempt at *K* measurements were made under such conditions.

Effective porosities were calculated from tracer data in the three horizontal flow SSF wetlands (Table 2). Effective porosity decreased, on the average, 11% over approximately one year. The pore volume decreases possibly attributable to metal sulfide accumulation between the two tracer tests, as a percentage of overall pore volume decrease, were 0.099%, 0.024%, and 0.032% for Cells 1, 2, and 4, respectively. This calculation assumes that the volumetric accumulation of all metals besides Zn was negligible, all Zn precipitated as ZnS (Gammons and Drury, 2000) and the amorphous ZnS solid had a specific gravity of 1. It can be seen that the majority of the porosity loss was due to reasons besides metal precipitates. Organic matter accumulation in SSF wetlands is an important reason for porosity loss in SSF wetlands used for BOD destruction (Tanner and Sukias, 1995), and could be a significant cause of porosity loss in SSF wetlands used for metals removal as well.

Vessel dispersion numbers (*D/uL*), a measurement of the amount of mixing in the SSF wetlands, were also calculated from the tracer test data (Table 2; Mainzhausen, 1998). The vessel dispersion numbers measured in these SSF wetlands fall between an intermediate amount of dispersion and a large amount of dispersion (Levenspiel, 1972). The results are consistent with the conclusion of Kadlec and Knight (1996) that SSF wetlands are fairly well mixed systems.

Table 2. Effective porosities and vessel dispersion numbers of three SSF wetlands.

Cell	1		2		4	
Time after start-up (mo)	12	23	10	26	11	24
Porosity (%)	34	33	37	31	32	28
D/uL	0.10	0.13	0.12	0.061	0.16	0.10

CONCLUSIONS

Hydraulic characteristics of four subsurface flow treatment wetlands were measured in a 2.5 year field-scale experiment. Wetland substrates consisted of river gravel, crushed limestone, and compost. Hydraulic conductivity was inversely proportional to the quantity of compost. Hydraulic conductivities decreased over the 2.5 year experiment by over 90%. Inlet zone clogging was observed, particularly clogging of filter fabric used to separate the wetland substrates from gravel packs around manifold pipes. Clogging was most likely caused by filtration of colloidal iron particles. Effective porosites were about 0.3 and decreased 11% from year 1 to year 2. The SSF wetlands behaved as well mixed systems.

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REFERENCES

Gammons, C.H. and W.J. Drury. 2000. Seasonal Influences on Heavy Metal Attenuation in an Anaerobic Treatment Wetland, Butte, Montana. 3rd International Conf. On Acid Rock Drainage, Denver. CO. SME, Littleton, CO 80162-5002.

Jones, S.A. 1997. Hydraulics of Field-Scale Subsurface Flow Constructed Wetlands. M.S. Thesis, Montana Tech of the University of Montana, Butte, MT.

Kadlec, R.H. and R.L. Knight. 1996. *Treatment Wetlands.* CRC Lewis Publishers, Boca Raton. FL.

Levenspiel, O. 1972. *Chemical Reaction Engineering (2nd ed.)*. John Wiley & Sons, New York.

Mainzhausen, K. 1998. Effects of Flow Patterns on Mean Hydraulic Residence Times and on Zinc removal in Subsurface Flow Constructed Wetlands. M.S. Thesis, Montana Tech of the University of Montana, Butte, MT.

Patterson, J.W. 1985. *Industrial Wastewater Treatment Technology*. Butterworth, Boston, MA.

Tanner and Sukias (1995) Accumulation of Organic Solids in Gravel-Bed Constructed Wetlands. *Wat. Sci.Tech.* 32:229-239.

Wildeman, T., G. Brodie and J. Gusek. 1993. *Wetland Design for Mining Operations.* BiTech Publishers, Ltd., Richmond, B.C.

2000 Billings Land Reclamation Symposium

A Bioengineering Approach to Upgrading Sediment Ponds for Retention as Permanent Structures

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ABSTRACT

Sediment storage ponds, required to capture sediment and protect watersheds during mining and reclamation, may be incorporated into post-mining land use strategies—for example, enhancing wildlife habitat or providing a watering source for livestock. Supporting post-mining land use can be an incentive to maintain ponds, while the costs associated with upgrading structures to meet regulatory requirements can be a disincentive to keeping ponds. Reclamation supervisors are particularly interested in finding ways to reduce the cost of upgrading permanent structures, because upgrading usually involves creating or enlarging open channel spillways. An alternative to enlarging the spillway is to use the entire embankment surface as the spillway. In the event of a discharge, the entire dam would be overtopped with a shallow flow, rather than the flow being concentrated into a spillway. Previous attempts to model over-topping flows have predicted dam failure as the flow velocity and depth exceeded the soil's resistance to friction. However, recent developments in synthetic geotextile technology make reinforcing soil a plausible option. By calculating stresses that would result from a 100-year flow, and comparing these to manufacturers' documented material thresholds, it is possible to demonstrate that a permanent turf reinforcement mat, combined with vegetation, will be able to withstand high flow events. In 1999, we designed and implemented this approach on a surface coal mine in eastern Montana.

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INTRODUCTION

Pursuant to regulations promulgated under Surface Mining Control and Reclamation Act of 1977 (SMCRA) and Montana Surface and Underground Mining Reclamation Act (MSUMRA), final bond release requires engineered structures to be constructed of permanent materials, or supported by maintenance in perpetuity. Any hydraulic structure must be able to withstand the stresses associated with a 100-year storm event. Sediment storage ponds, required to capture sediment and protect watersheds during mining and reclamation, may be incorporated into post-mining land use strategies—enhancing wildlife habitat or providing a watering source for livestock. Therefore, supporting post-mining land use is an incentive to keep ponds, while the costs associated with upgrading structures to meet regulatory requirements can be a disincentive for keeping ponds. Reclamation supervisors are particularly interested in finding ways to reduce the cost of upgrading permanent structures.

Sediment Pond 20, at Westmoreland Resources, Inc. Absaloka Mine, had been designed with a flow-through culvert spillway and rock armored energy dissipator designed to safely carry flows associated with a 25-year storm event. The pond is retained by an earth embankment dam with the following dimensions: 150 ft long, 20 ft high, 20 ft wide on the upper surface, and 2.5H:1V (40%) slope—resulting in approximately 10,000 ft^2 of surface area. In order to construct a spillway capable of handling the larger 100-year storm event, the natural coulee below the dam would need to be disturbed and partially filled with riprap.

As an alternative to reconstructing the spillway, we developed a design that uses the entire embankment surface as the spillway. In the event of a discharge, the entire dam would be overtopped with a shallow flow, rather than concentrating the flow into a spillway. By reinforcing the embankment surface with a permanent turf-reinforcement geotechnical fabric, we were able to ensure that any overtopping flow would be in the form of sheet flow—making the overtopping event easier to model, and providing a high safety factor for the embankment at the design flow.

While most regulations affecting small dams require an emergency, open channel spillway as part of the design, the idea of designing an embankment to withstand overtopping flows has been considered in the past. The Bureau of Reclamation used a 1:15 scale model to study the relative effectiveness of different embankment treatments for overtopping flows. As a rationale for the experiment, the BOR remarked, “some embankment dams have undergone moderate overtopping without failure…therefore it is surmised that some existing embankment dams, especially those less than 50 feet (15.24 m) high, could possibly be modified to safely permit overtopping.” (USDI Bureau of Reclamation 1988). The study was inconclusive based on the difficulty of modeling the hydraulics of failure (a transition from sheet flow to rill flow).

CONCEPTUAL DESIGN

Geotechnical Fabric Selection

Because soil by itself is subject to unpredictable erosion forces at some threshold, which is also difficult to predict, the problem can be simplified by introducing a turf-reinforcing geotextile. Manufacturers have documented material failure thresholds that have been quantified in terms of velocity and shear stress, and by duration of the stress. By calculating the velocity and shear stress given the drainage characteristics, it becomes possible to compare these values to manufacturer's specifications for turf-reinforcing geotextiles.

We selected a geotechnical fabric, of the class "Erosion Control/ Long Term Nondegradable" as defined in the Geotechnical Fabrics Report (GFR), as a turf-reinforcement mat, to provide long-term stability to the embankment upstream face, top surface, and downstream face. Permanent or long-term nondegradable geotechnical fabrics are designed to "…provide long-term reinforcement of vegetation. They are used in more challenging erosion-control applications where immediate, high-performance erosion protection is required. The materials extend the erosion resistance of soil, rock, and other materials by permanently reinforcing the vegetative root structure," (GFR Specifiers Guide 1999). We considered the following characteristics: 1) ability to withstand the forces of the design flow; 2) ability to support plant growth; and 3) longevity.

Several products have been documented to withstand the velocities and shear stresses that would result from the design flow. With respect to vegetation, non-woven, needle-punch materials were excluded because they might inhibit root growth. Similar materials are used in grow-bags, whose main purpose is to restrict root growth outside of a specified zone. Even if grass roots can grow through a needle-punch, non-woven geotextile, any root constriction caused by the geotextile would cause a shear plane at the surface of the geotextile. To meet our objective of longevity, only those products classified as permanent geotechnical fabrics were selected.

Based on careful evaluation of product data, and on discussions with technical staff employed by several manufacturers—including manufacturers who did not have any products that met our criteria—North American Green C350 was selected. In addition to having a strong, synthetic matrix, C350 has a layer of coir fibers, which retain soil moisture, aiding in seed germination and seedling establishment. Coir degrades slowly and mechanically, only minimally impacting soil nutrient availability. The coir—since it is loose, not woven— does not contribute to the product's strength, so the product would not be compromised after the coir degraded.

Flow Analysis

In order to meet the assumptions of a channel flow model, the embankment top and face must be uniform and level, so flowing water cannot concentrate on any part of the surface. An assumption of sheet flow is important. A spillway diffuses water's energy by providing a low gradient route for excess flow. However, shear stress increases with both gradient and depth (Shields 1936 as cited in Rosgen 1996). Because spillways concentrate flow into a channel, they increase the water depth, and therefore the energy affecting any given point in the spillway. Decreasing depth of flow is another way to reduce water's erosive energy.

Even though water flowing over an embankment will drop more steeply than water in a spillway, the volume is spread out over a large, uniform surface area, resulting in shear stress values within the limits of several permanent erosion fabrics that are currently available.

In order to be conservative, it was assumed that the sediment storage pond would be full at the time of the 24 hour, 100-year event, so that inflow approximately equals outflow, and the hydrograph is not altered by any storage influences in the pond. It was also assumed that the embankment top and face are uniform—any overtopping flow will be sheet flow.

To determine the duration of the peak flow, the top 10% of the hydrograph was approximated, and it was determined that the duration of this 90^{th} percentile would be approximately 35 minutes. From HydroCad output, 75.1 cfs would be the maximum runoff over the embankment. North American Green's Erosion Control Materials Design Software 4.1 was used to calculate forces on different areas of the embankment. The face can be split into four sections—A, B, C, and D (Figure 1). Table 1 provides a summary of the forces impacting different areas of the embankment. Because the embankment toe is staggered, and the coulee bottom slopes generally toward A, all of the flow on B could potentially concentrate on the bottom of A. Flow from C and D combine into the existing spillway. The spillway is not considered part of the embankment structure.

While Gray and Sotir (1996) recommend a Manning's n value of 0.02 for a grass-covered slope steeper than 3H:1V, USDA Agricultural Handbook #667 outlines a different approach. Here, vegetation height is compared to flow depth to estimate the roughness contribution of vegetation. To summarize the reasoning—shallow flow is less likely to bend over a tall plant because of a lack of leverage on the stem. Therefore, when vegetation is considerably taller than the flow depth, even high velocities result in significant friction because the plants remain mostly erect. Significant friction causes a slower, deeper flow. Because shear stress is a function of depth and gradient, shear stress increases as friction increases. Since the additional shear stress is caused by above-ground plant biomass, the above-ground portion of plants dispel the energy. In the process of dispelling energy, grass leaves may be sheared off. However, the soil and roots, which are reinforced by the turf reinforcement mat, are protected from significant shear by the above-ground biomass. Safety factors reported in Table 1 indicate that soil and roots will not be affected by the 100-year, 24 hour event.

Table 1. Forces on different areas of Pond 20 embankment face.

Area	CFS	Velocity (ft/sec)	Depth (ft)	n	Soil Shear Stress	Safety Factor
Top	75.1	0.57	0.84	0.22	0.003	302.64
A	42.4	2.65	0.32	0.16	0.127	7.89
B	18.4	1.69	0.28	0.23	0.054	18.41
C	7.7	1.46	0.29	0.26	0.044	22.49
D	25.0	1.74	0.28	0.22	0.056	17.75

Embankment Areas Used in Calculations

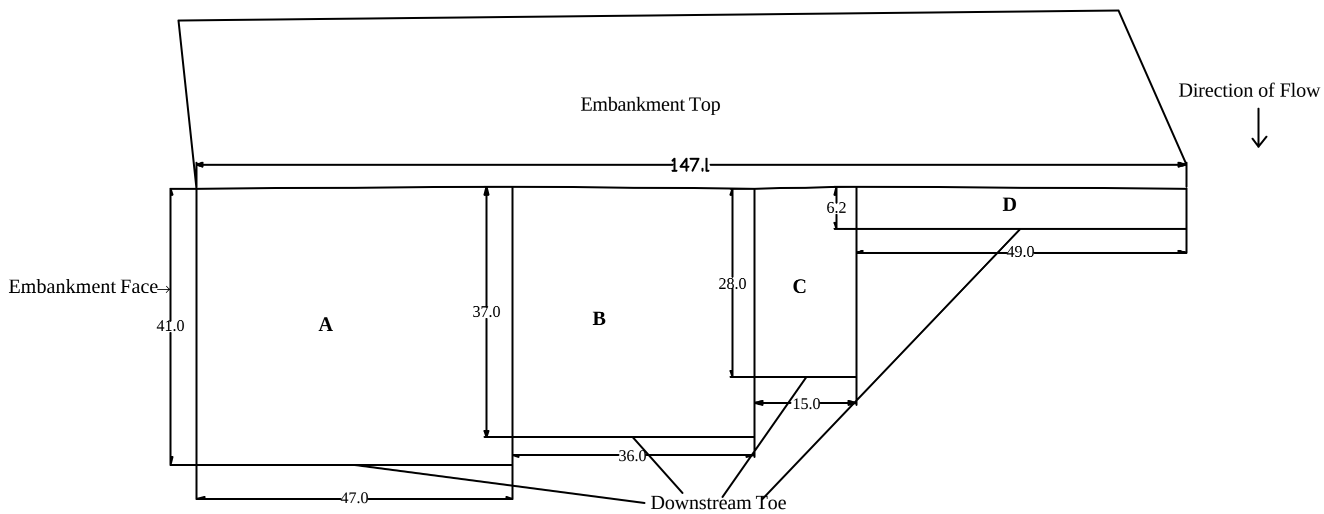

Figure 1. Areas of Pond 20 Embankment Face.

While the existing spillway remains in place after implementation, the spillway's capacity was not considered when calculating forces on the face of the embankment for the 100-year, 24 hour event. An overtopping event would partially utilize the spillway, and the spillway would be able to safely carry its portion of the total flow volume, thus increasing the safety factor for the structure.

Vegetation

Vegetation is part of the design, not only for its aesthetic and habitat values, but also for its documented engineering properties. In general, roots reinforce soil by transferring shear stress in the soil to tensile resistance in the plant roots. Specifically, in the case of shrub roots, minimum shear resistance values are approximately 10 lbs/ ft^2. Willow roots have a shear resistance between 13.8 lbs/ ft^2 and 34.7 lbs/ ft^2. (Gray and Sotir 1996). Shrubs, in addition to providing extremely high values of shear resistance, are appropriate on engineered structures like levies and embankments because they are not as likely as trees to grow large and fall over, taking part of the structure with them. Grass roots, while not as strong as shrub roots, provide up to 8 lbs/ ft^2 of shear resistance.

IMPLEMENTATION

Approximately 10,000 ft^2 of geotechnical fabric was installed on a uniform embankment surface scraped clear of vegetation, appropriately de-compacted, and seeded with native grasses. The fabric was installed from the downstream toe, over the embankment, and to the high water mark of the sediment pond. Seed was hand broadcast underneath and on top of the installed fabric. Shrubs were planted at the embankment toes and around the pond perimeter (Figure 2).

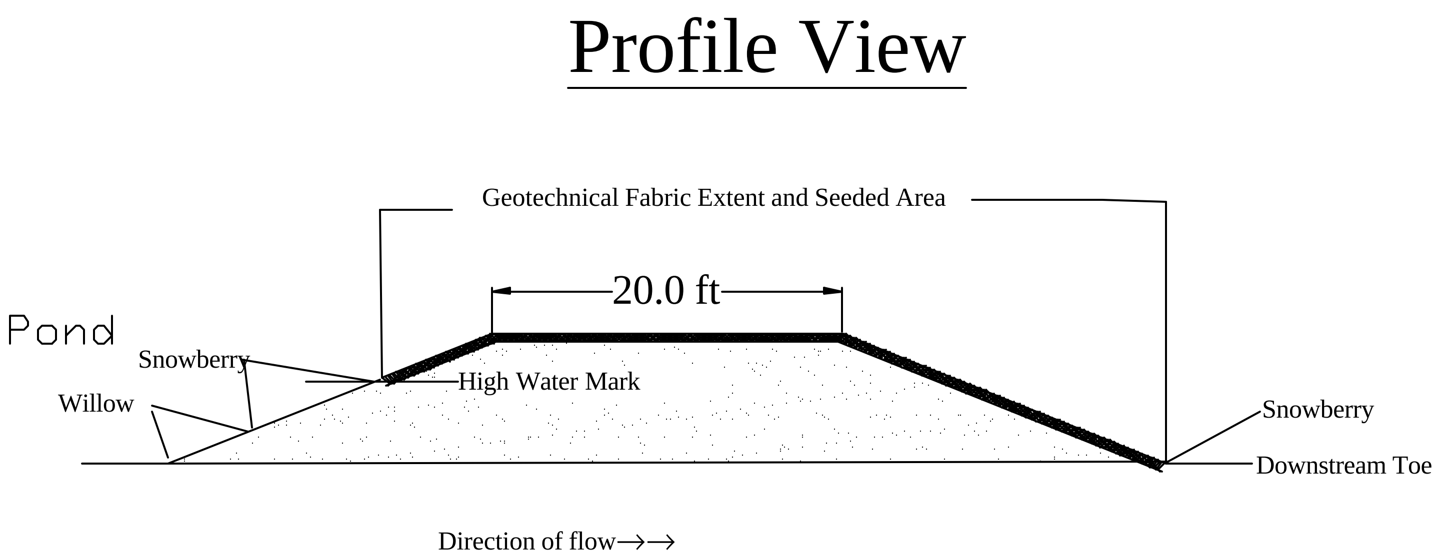

Figure 2. Profile view of Sediment Pond 20 implementation.

Prior to site preparation, the site was staked to identify excavation areas necessary to obtain a level grade. Levelness was determined using a laser level and receiver. A D-6 Caterpillar was used to level the embankment top and to scarify and flatten the embankment faces. A backhoe was used to scarify embankment areas inaccessible to the D-6. Once the embankment surface had been leveled, the surface was ripped to a depth of 12 inches to reduce compaction from prior use as a haul road. The entire embankment surface was then hand raked to ensure uniform contact between soil and the geotextile, and to prepare a seed bed for native grass seed (Table 2).

Table 2. Seeding rates by species for Pond 20.

Species	% of mix	PLS lbs/acre	Total lbs
Phlaris arundinacea (reed canarygrass)	15	2.20	0.55
Bouteloua gracilis (blue grama)	20	1.89	0.47
Agropyron smithii (western wheatgrass)	20	14.18	3.54
Elymus canadensis (Canada wildrye)	15	10.17	2.54
Agropyron dasystachyum (thickspike wheatgrass)	20	10.13	2.53
Achillea lanulosa (western white yarrow)	5	0.14	0.03
Artemisia ludoviciana (prairie sagewort)	5	0.09	0.02

After the fabric was installed, ten cubic inch containerized shrub seedlings were planted at two-foot spacing at both the upstream and downstream embankment toes with the goal of creating a continuous rhizomatous matrix of woody roots. At the upstream toe, 125 *Salix exigua* (streambank willow) were planted in two rows at the edge of a low water mark. Above this mark, 200 *Symphoricarpos occidentalis* (western snowberry) were planted at two foot spacing up to the high water mark as determined by the culvert level. At the downstream embankment toe, 150 *Symphoricarpos occidentalis* (western snowberry) were planted at two foot spacing in a six foot wide band on approximately the right half of the slope toe, and on a three foot wide band on approximately the left half of the slope, since the left half of the toe already supported a vigorous snowberry community.

As this project matures, it will be important to observe vegetation development on the embankment, because vegetation is an integral part of the design. Staff at the mine plans to monitor grass establishment and re-seed as necessary.

CONCLUSION

This method of reinforcing the entire embankment was a cost-effective alternative to increasing spillway capacity for this particular structure. Suitable rock rip-rap is rare in areas of eastern Montana and would be expensive to import. In addition, reconstructing the spillway would have required significant disturbance to the natural coulee below the sediment pond. Given the remote project location, any risk associated with attempting a new approach to upgrading a sediment pond was low.

While using a permanent turf-reinforcing geotechnical fabric was a cost-effective method for retrofitting the existing structure at Sediment Pond 20, it might prove even more cost-effective to include this type of surface-reinforcing technology in initial designs. Not only would this approach eliminate the cost of a second construction phase, but it would also eliminate the time required for obtaining new permits, as the permanent structure would be included in the initial permitting process.

REFERENCES

Gray, D.H. and R.B. Sotir. 1996. Biotechnical and soil bioengineering slope stabilization. John Wiley and Sons. New York. 378 p.

McCuen, Richard H. 1982. A guide to hydrologic analysis using SCS methods. Prentice-Hall. New Jersey. 145 p.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs, CO. 300 p.

Shields, A. 1936. Application of similarity principles and turbulence research to bedload movement. Mitt. Preuss. Verschsanst., Berlin. Wasserbau Schiffbau. In W.P. Ott and J.C. Uchelen (translators), California Institute of Technology, Pasadena, CA. Report No. 167. 43 p.

USDI Bureau of Reclamation. 1987. Design of Small Dams. United States Government Printing Office. Denver, CO. 860 p.

USDI Bureau of Reclamation. 1988. Overtopping flow on low embankment dams—summary report of model tests. REC-ERC-88-3. Denver Office. 29 p.

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ENGINEERING METHODS FOR ASSURING SUFFICIENT RECLAMATION BOND AMOUNTS

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ABSTRACT

Successful reclamation is the cornerstone of the Surface Mining Control and Reclamation Act of 1977 (SMCRA.) Mine permittees are required to complete reclamation in accordance with SMCRA, their approved mining permits, and the regulations. To accomplish this, reclamation plans must be well designed and detailed enough that they could be used as a "scope of work" under a contract should a regulatory authority be faced with completing the reclamation.

Coal mine permittees consider each facet of the mining and reclamation process when they estimate reclamation costs. A cost for everything from structure demolition to seeding a reclaimed area must be determined. The regulatory authority sets a bond amount based on the permittee=s cost estimate and the regulatory authority=s independent cost estimate that includes the costs of having a third party, under contract to the regulatory authority, complete the reclamation plan. The regulatory authority adds third-party costs as an allowance for contractor profit and overhead.

In 1987, OSM developed a cost-estimating handbook utilizing standard engineering principles, equipment productivity guidebooks, and construction cost references. To keep current, OSM revised the handbook in 1993 and 1999.

OSM's handbook utilizes industry-standard resources such as cost reference guides, building construction cost data, and other widely-used resources. To facilitate cost-estimating, the handbook includes detailed worksheets, examples, maps, and equipment selection guidance for earthmoving equipment.

The handbook expedites and standardizes the development of site-specific reclamation cost estimates in order to set sufficient bond amounts. OSM offers training to states and Indian Tribes on the use of the handbook. Other federal agencies, state agencies and industry representatives utilize the handbook as well. The ultimate goal is to assure that sufficient funds are available to guarantee successful reclamation in the event that the permittee defaults on reclamation obligations under the reclamation plan in the approved permit.

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