Dynamic Segmentation for Monitoring Underground Mining Effects on Pennsylvania Streams

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Abstract

A rigorous ecological monitoring program has been implemented to evaluate potential effects of underground coal mining on the aquatic environment. The program has been designed to collect pre-mining data and to provide a means to monitor and predict ecological impacts to surface waters. A custom ArcGIS/ArcInfo application has been developed for this purpose that utilizes dynamic segmentation to map stream habitat types throughout extensive mining areas. The application utilizes a custom designed interface for data entry, GPS data, biological data, and digital video for production of the project database. Geoprocessing is utilized to determine which features have been mined. This paper will present the application process and describe the cost benefit of process automation through use of ArcGIS/ArcInfo and dynamic segmentation. It will also illustrate the powerful data analysis tools that have been made available through the development of the custom GIS application.

1.0 INTRODUCTION

In the year 2003 Pennsylvania coal mines produced approximately 6% of the nation's bituminous coal. The study area for this project includes portions of four western underground coal mines in southwestern Pennsylvania. The location of the southwestern Pennsylvania coalfields can be seen in Figure 1.1.

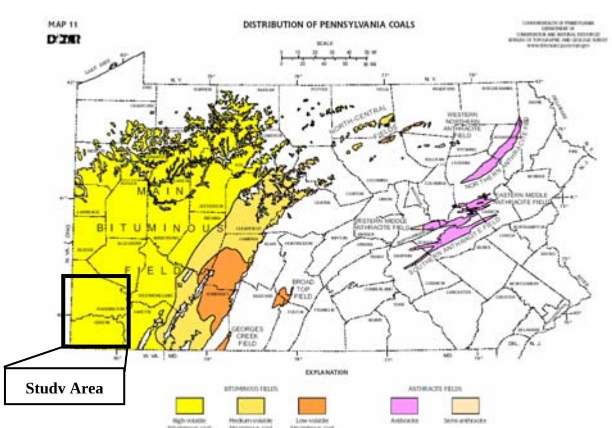

Figure 1.1 Bituminous Coal Fields of Pennsylvania

These mines utilize a full extraction method of mining called longwall mining. Longwall extraction methods use a series of shields and a cutting head to remove the entire coal seam within a panel. Panels can be up to 1000' wide by 10,000' long and designed in a sequential pattern. Figure 1.2 illustrates a typical longwall mine configuration.

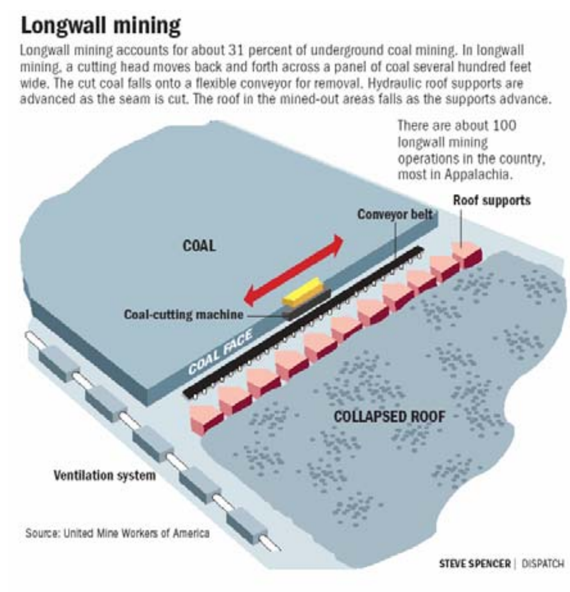

Figure 1.2 Longwall Mining Operation

Areas called gates, mains and bleeders are located between the mining panels and serve as support for the longwall operation. These areas contain ventilation, power and coal handling infrastructure and are critical to the operation of the mining operation.

State and federal regulations apply to the land surface above the longwall panels. The Pennsylvania Department of Environmental Protection (PADEP) regulates the longwall mining areas and surface support facilities such as mine portals and vents, coal cleaning and handling facilities, and coal conveyors. The PADEP also is required to acknowledge the concerns of the United States Fish and Wildlife Service (USFWS), Pennsylvania Fish and Boat Commission (PAFBC), the Pennsylvania Game Commission (PAGC) as well as local citizens.

The regulations require that companies involved in longwall mining monitor water supplies and ecological resources to document pre-mining baseline conditions and to assess potential post mining impacts to these resources. A team of mapping, geological, ecological and hydrogeological professionals collects and analyzes this extensive data sets. The Geographic Information System (GIS) technology presented in this paper has been utilized to compile and analyze the large amount of ecological stream data collected during the scope of this investigation.

2.0 SCOPE OF ECOLOGICAL INVESTIGATION

One of the mine operator's consultants, Civil & Environmental Consultants, Inc. (CEC) assists in monitoring streams, wetlands and ponds at the various study sites.

The monitoring approach has been developed and customized specifically for this project. The stream assessment activities include biomonitoring and stream habitat mapping. Currently, approximately 24,000 acres of land and 70 miles of stream are being monitored.

The biomonitoring component consists of sampling of fish, benthic macroinvertebrates and water quality. The habitat mapping component is performed to assess potential morphological changes in the streams and the resulting changes in the aquatic communities. Although GIS is used to compile data in all aspects of the ecological study, this paper will focus on the methods associated with the habitat mapping component.

Biomonitoring events and habitat mapping are performed at least two times prior to the longwall operation passing under a stream and two times after the longwall face has passed under a stream. The monitoring is also performed to provide information for permit applications which are submitted prior to the longwall mining operation.

2.1 Data Collection Protocol

The habitat mapping protocol has been designed to collect geospatial data that represents habitat types and other geomorphologic characteristics for study streams. Videotaping is also performed to provide documentation of field conditions and for storage and archiving in digital format. The field crews comprised of a two biologists and are outfitted with standard data collection gear. Stream habitat types are predefined in the standard habitat mapping protocol and include:

- Riffle
- Run
- Riffle/Run Complex
- Pool
- Glide
- Pool/Glide Complex
- Step Pool Complex
- Waterfall/Plungepool
- Beaver Dam Pool
- Braided Channel
- Dry Stream Channel
- Artificial

Other descriptive attributes are collected on paper field forms by the field teams. These include:

- Habitat unit length
- Channel dimensions
- Substrate type
- Channel slope
- Bank angle

Video recording of each habitat unit is performed using MiniDV format camcorders. Global Positioning Systems (GPS) data is collected in autonomous mode with a Trimble GeoXT unit. A point is collected at each of the vertices of the streams. The GPS points are used to define stream geometry, and the points must correspond to the locations of the length measurements. The length measurements for each habitat unit are obtained using consumer grade rangefinders.

2.2 Data Processing

A team of GIS analysts and ecologists accomplishes the various data processing tasks. The multi-disciplined team performs the data manipulation and mapping required for the presentation and analysis of the habitat data.

2.2.1 GPS Data

GPS Data for the stream habitat mapping is used to supplement planimetric mapping stream coverage supplied by CONSOL. The autonomous data collected with the GoeXT units is post processed using Trimble Pathfinder software and a local base station on the Continuously Operating Reference Station (CORS) network. The GPS points are plotted and compared to the planimetric stream data layer. Figure 2.2 provides an illustration of field collected stream GPS data as it relates to the existing stream coverage.

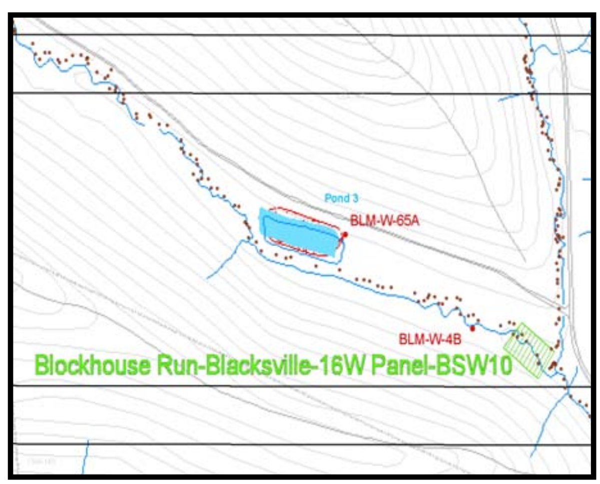

Figure 2.2 Post Processed Stream GPS Data

2.2.2 Attribute Data

The habitat and stream characteristic attributes are entered into a relational Microsoft Access database using a custom web-based interface (Figure 2.3). This database is used to create the event tables for the dynamic segmentation procedure that is described in the following section.

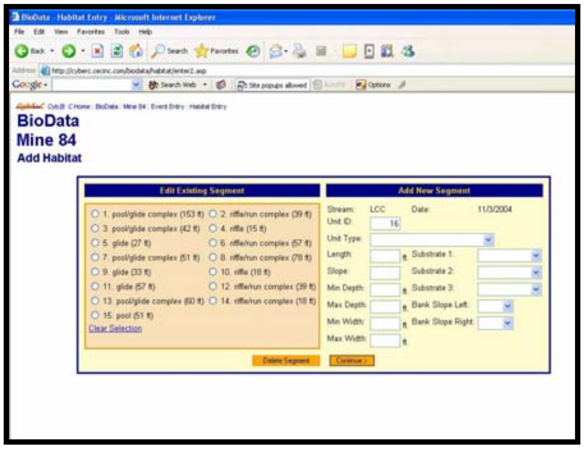

Figure 2.3 Custom Web-based Interface

2.2.3 Dynamic Segmentation

The dynamic segmentation procedure has been developed to streamline the task of creating feature datasets from the field collected data. The dynamic segmentation function of ArcGIS is contained within the ArcInfo Desktop application. To begin the procedure, the data is exported from the Microsoft Access database discussed in Section 2.2.2 using a predefined export function. Event tables, including "To" and "From" fields, are then compiled using this data and checked against field data forms. The "To" and "From" fields are used later to perform the dynamic segmentation. The event tables are created in a simple delimited text file format and contain all the habitat unit attributes as well as the "To" and "From" fields.

The ArcGIS dynamic segmentation application utilizes a linear feature that ESRI refers to as a route. The route is a polyline feature that will form the basis of the linear referencing process and can be described as the linear container in which the events will be placed.

The linear routes are generated using polylines created from the field collected GPS points. The critical step in the process is performed using ArcInfo desktop. Using the dynamic segmentation tool, the event tables are linked to the routes. Here, the analyst must define a unique identifying field for the route identification, and also define the "To" and "From" fields in the event table.

The dynamic segmentation process is run for each stream and the habitat segments checked against GPS data. A tolerance of 3% of the entire stream length is the goal for the process. If the segmentation quality is unacceptable, the analyst will refer to the field data notes to ensure that the data was entered into the Microsoft Access database correctly. The GPS points are also utilized to determine if the routes and corresponding events are intelligible. The routes with the events are then exported to a shapefile and then imported into the project geodatabase.

2.2.4 Video Processing

Field teams may produce up to 20 hours of video per seasonal sampling event. A system was developed which makes this media accessible to the client and other project stakeholders.

The digital video tapes are captured to a hard drive using Pinnacle and Canopus brand hardware and software products. The tapes are captured to large volume hard drives via a removable hard drive bay. Subsequently, the video is captured to Audio Video Interleave (AVI) format at full 720 x 480 resolution at 30 frames per second.

The video clips are edited on non-linear digital editing system (Figure 2.4) and titles and dates are added to video. The video clips are then compressed to MPEG1 files for storage and delivery on DVD. The MPEG1 data files can be viewed with readily available media viewers such as Windows Media Player or Real Player.

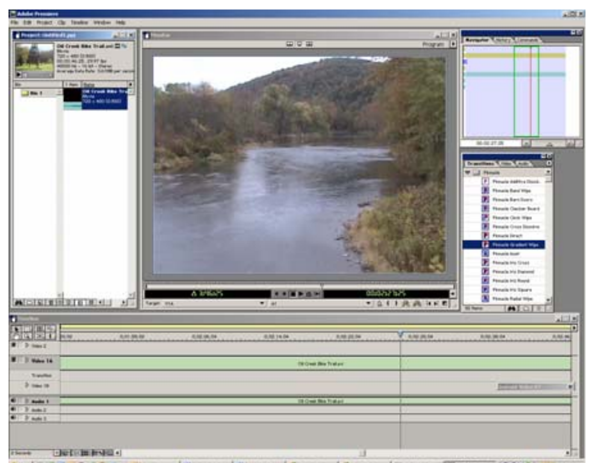

Figure 2.4 Non-linear Video Editing Software

Using a viewer such as this, the video file can be quickly loaded and browsed. Navigation of the video file can be accomplished using the slider bar at the bottom of the media player window. This allows a user to shuttle the video easily to any point of interest.

3.0 DATA ANALYSIS

The objective of the habitat mapping component of the biomonitoring is to assist in the determination of effects of the mining on stream ecology and morphology. Stream impacts observed during the investigation that may be attributable to longwall mining include flow loss and diminution, pooling, substrate alteration and bank sloughing.

3.1 Mine Panel Data

To assist in the determination of potential mining related impacts, it is critical to determine exactly which stream segments have been undermined. Because the longwall face location moves continuously, a routine has been developed to determine the mined status of stream segments. This routine utilizes the panel geometry and dates associated with the longwall face location.

The longwall face position is updated weekly in the GIS database. Figure 3.1 illustrates a typical panel section with the longwall face location and associated date.

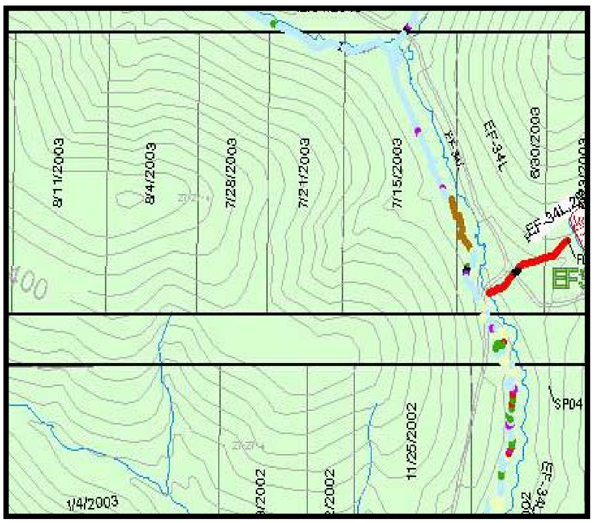

Figure 3.1 Mine Panel with Working Face Updates and Stream Habitat Layer

The panel geometry is subjected to topology verification using Arcview's topology tools. The topology verification is performed to ensure that results of subsequent geoprocessing are accurate.

3.2 Stream Habitat Data

Upon verification of the topology of the mine panel and working face geometry, an intersect routine is run on the stream feature datasets during which the date and longwall working face segment identifier is assigned to each stream habitat segment. A structure query language (SQL) statement is then applied to the geodatabase to compare the dates of the habitat mapping event with the date that the panel was mined.

Habitat units that span more than one mine panel unit are clipped in the geodatabase and divided into segments based on which panel section that they bisect. Once the mined status is determined for each stream segment, summaries are generated for each panel based on the mined status of the habitat units. Summaries are also generated for entire stream lengths within the mine study areas. The following Figure 3.2 presents a typical summary table that is created in MSExcel after the geoprocessing is performed in Arcview.

Panel/Gate	Brush Run (BrR)					
Sampling Season	Panel (unmined)		Gate		Entire Stream	
Habitat Type	(feet)	(%)	(feet)	(%)	(feet)	(%)
Riffle	60	2	54	7	114	3
Run	0	0	0	0	0	0
Riffle/Run Complex	1,442	49	392	48	1,834	49
Pool	114	4	0	0	114	3
Glide	457	16	200	25	657	18
Pool/Glide Complex	851	29	171	21	1,022	27
Step Pool Complex	0	0	0	0	0	0
Waterfall/Plunge Pool	0	0	0	0	0	0
Beaver Dam Pool	0	0	0	0	0	0
Braided Channel	0	0	0	0	0	0
Dry Stream	0	0	0	0	0	0
Artificial	0	0	0	0	0	0
Total (feet)	2,923	100	817	100	3,741	100
Substrate Type						
Bedrock %		0		7		1
Boulder %		0		0		0
Cobble %		1		11		3
Gravel %		68		72		69
Sand %		8		0		6
Silt %		20		10		18
Clay %		3		0		3
Total		100		100		100
Other Characteristics						
Average Slope %		2		1		2
Maximum Depth (in)		33		17		33
Minimum Width (ft)		10		2		2
Maximum Width (ft)		15		12		15
Average Minimum Width (ft)		3		3		3
Average Maximum Width (ft)		6		6		6

Figure 3.2 Typical Habitat Summary Table After Geoprocessing

4.0 PROCESS BENEFITS

Implementation of the ESRI dynamic segmentation process has resulted in significant reduction of resources required to process the large amount of stream habitat data that is generated during each sampling season. Initially, the procedure consisted of clipping a polyline feature at each habitat type break. A different polyline was created for each sampling event. This initial process was very time consuming and did not facilitate quick visual comparison of the data. In addition, the possibility of implementing a change detection and geo-spatial analysis application would be virtually impossible. Although the scope of this investigation has grown significantly as the longwall operation continues, processing time for the data has remained fairly constant.

Using dynamic segmentation has laid the groundwork for the environmental managers to perform complex geo-spatial analysis on multiple events. This analysis will assist in the prediction of mining related stream impacts and promote prompt responses to the concerns of the regulatory community.

5.0 FUTURE DEVELOPMENT

The increasing number of stream sampling events associated with this monitoring program and mounting regulatory scrutiny experienced by longwall mine operators will provide impetus for the future development of additional functionality within this application. As mentioned previously, the dynamic segmentation process readily lends itself to change detection modeling. The change detection modeling will assist in determining the geomorphic character of study streams over consecutive sampling seasons.

Specifically, the model will utilize one geometric route for each study stream. Multiple event tables will be added to the route and the resulting processing will provide a detailed analysis of the geomorphologic character of the stream.

A process automation feature is also currently under development for the reporting function of the dynamic segmentation mapping application. An involved process is used to compile the summary tables in Microsoft Excel.

These summary tables are created form data that is exported from the personal geodatabase. The automation feature will use SQL to perform this analysis within the personal geodatabase. Reporting could then be accomplished utilizing Crystal Reports with Arcview.

6.0 CREDITS

Figure 1.1 - PA Department of Conservation and Natural Resources, "Distribution of Pennsylvania Coals." (2000) www.dep.state.pa.us/dep/deputate/minres/bmr/annualreport/2000/map_coal.pdf

Figure 1.2 - The Columbus Dispatch – "Longwall Mining. (May 11, 2004). www.buckeyeforestcouncil.org/dysart/columbdisp511.html