USING A GIS TO DOCUMENT RELATIONSHIPS BETWEEN DISTURBANCE AND SEDIMENTATION FOLLOWING SALVAGE LOGGING[1]

Wade G. Wells II, Eileen J. Napoleon, and Peter M. Wohlgemuth[2]

ABSTRACT: Following the Stanislaus Complex Fires of 1987 in California's central Sierra Nevada, we initiated a study to investigate the effects of salvage logging on sediment production. We are using ARC/INFO, a GIS, to perform spatial analyses to relate natural features and logging impacts to sedimentation. This also provides an opportunity to evaluate the utility of GIS as an analytical tool. Sedimentation was measured behind debris dams, constructed of logs, on 22 small (2-15 acre) headwater catchments subjected to salvage logging treatments. A topographic basemap was photogrammetrically produced, and aerial photographs of each basin were taken in order to map site and disturbance features. The basemap, site and disturbance features, and the sedimentation data were all entered into a GIS database for analysis. We contracted for aerial photography and basemap compilation and received data files in AutoCAD for conversion to ARC/INFO. The contracting process, limitations imposed by the contractor, and problems with data translation caused a great deal of frustration and additional cost in terms of both time and money. We hope that relating our experiences will help others to avoid some of the pitfalls we encountered.
KEYWORDS: GIS, spatial analysis, sedimentation, erosion, salvage logging

INTRODUCTION

Following the Stanislaus Complex Fires of 1987, the Pacific Southwest Research Station and the Stanislaus National Forest jointly initiated a study of the impact of salvage logging on erosion and sedimentation. Earlier work has established that both fire and logging result in increased erosion and sediment production (Rice et al. 1979, Rice and Datzman 1981, Wells 1981, 1984). The purpose of this project is to determine if logging aggravates the sedimentation problem associated with fire. This paper addresses the incorporation of explanatory variables derived from spatial analysis.

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[2]Wade G. Wells II, Eileen J. Napoleon, and Peter M. Wohlgemuth, USDA Forest Service, PSW Research Station, Forest Fire Laboratory, 4955 Canyon Crest Drive, Riverside, CA 92507.

The study employs a series of small dams made of logs and silt-filtering cloth located in 22 small (2-15 acres) watersheds to trap sediment moving down their channels (Wells 1989). These small debris basins are periodically surveyed and the surveys are used to calculate sediment production for statistical analysis. Differences in basin sedimentation presumably reflect differences in watershed characteristics and, logging practices.

STUDY DESIGN

The study was designed to investigate the effects of both cable and tractor logging operations on sedimentation. Furthermore, the cable-logged basins were steeper than the tractor-logged basins, so each logging treatment required a separate set of controls. Dam construction and basin surveying were slow and expensive, limiting the number of replications. The statistical design selected is a four-cell 2x2 matrix, with two treatments and two controls, replicated five times. The data will be analyzed using t-tests and analysis of variance. Although the statistical design only required 20 basins, a last minute change in timber sale boundaries forced us to build two additional dams to maintain five replications in each cell, bringing the total number to 22.

Sedimentation data from small areas often exhibits very high variances (Wells, 1982), requiring large sample sizes for useful statistical comparisons. Because logistical constraints forced us to keep our sample size small, we decided to augment the statistical design by adding a spatial analysis component to the study. Spatial analysis might help explain what attributes of the logging operation, if any, were correlated with sediment production. Such attributes could include the extent of disturbance, the types of disturbance features, and the location of the disturbance relative to the stream channel. Furthermore, spatial analysis might help identify which site variables, if any, were correlated with sediment production, in isolation or in combination with logging disturbance.

The statistical design tacitly assumes that the areas disturbed will be similar in extent and location for all basins. This is not the case. The extent to which each logged basin was treated varies greatly regardless of the logging method used. This additional variation can be examined and described using spatial analysis, and then incorporated into the statistical analysis.

After the study had begun, we decided that using a GIS would enable us to facilitate the spatial analysis and, perhaps, expand it. For this analysis, we designed a GIS database consisting of natural watershed attributes and logging disturbance features. We will use a combination of spatial and statistical methods to determine important relationships between watershed and disturbance variables and sediment production.

WHY GIS

Our aims in using a GIS in this project were to handle large amounts of spatial and attribute data; to perform analytical operations such as overlay and buffer analyses; to derive morphometric data using 3-D surface analysis; and finally to evaluate the utility of GIS as an analytical tool for future studies.

We selected ARC/INFO for our GIS because we had access to both the mainframe ARC/INFO on a VAX8820 CLUSTER and the workstation ARC/INFO on a SUN SPARCstation. Furthermore, we had received specific training in the use of ARC/INFO. After making inquiries and trying some other systems, we decided that ARC/INFO was the most appropriate system available to us for this project. (Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.)

DATA REQUIREMENTS

The study area spans approximately 12 square miles. Within this area, we wanted to map individual skid trails and tractor tracks and, perhaps, even tree stumps resulting from the logging operation. We also wanted to perform slope analysis within the study basins and required a contour interval of 3 meters or 10 feet. The available data, 1:6000 scale air photos and a 7 1/2 minute USGS quadrangle with 50-foot contours, were insufficient.

Large-scale air photos and basemap were needed to match our data requirements. Color, 1:3000 scale air photos were selected for detailed mapping of individual study basins. A 1:6000 scale, with 10-foot contour intervals, was chosen for the basemap. Digital output would be in a format compatible with ARC/INFO.

BASEMAP

A set of 1:12000 scale air photos covering the entire study area provided the data for creating the basemap. We selected eight layers to be entered into the GIS database (Table 1).

Twelve-foot targets were constructed and placed at pre-selected locations, as ground control for the basemap. We contracted for basemap construction, including aerial photography, photogrammetry, and ground control survey through a third party and requested that digital map output be in the form of ARC/INFO export files and hard copy mylar plots.

Table 1. Basemap Layers.

Layer name	Contents
GRIDa	Map boundary
GRIDb	Map grid (cross-hairs); target (control) points with elevations
INDEX	Index contours (50-foot intervals) with elevations
INTER	Intermediate contours (10-foot intervals) with elevations
ROAD1	Paved roads
ROAD2	Gravel roads
SPOT	Spot (uncontrolled) points with elevations
STRM	Major streams

PITFALLS

After the contract was let, we learned that the contractor for photogrammetry, who used AutoCAD for basemap compilation, could not provide the ARC/INFO files specified in the contract. About this time, however, the 5.0.1 version of ARC/INFO became available, which included software to convert AutoCAD DXF files to ARC/INFO files. This conversion process appeared to involve two straightforward operations (commands). Based on this information, we decided to convert the data ourselves and therefore accepted the basemap data from the contractor in AutoCAD DXF file format. For compatibility with ARC/INFO, we requested specific limits on file size and the need for uninterrupted (continuous) contours in the AutoCAD data files.

We later discovered that "z" or elevation values are lost in the DXF-to-ARC/INFO conversion process. Much effort went into dealing with this problem. The solution chosen initially, to tag each contour line with a point that had an associated elevation text value, proved unsuccessful. Other unforeseen problems arose. Labeling of contour lines with annotation to describe elevation values in AutoCAD resulted in interrupted contour lines. This in turn presented a barrier to using TIN, a sub-program of ARC/INFO, which uses continuous spatially distributed data (in this case elevation) to create a 3-D surface map.

Architecture-specific problems with files were also encountered. To download the AutoCAD DXF files on the VAX mainframe, a certain architecture was required, and this requirement could not be met by the mapping contractor. Furthermore, carriage returns and line feeds which appeared in the DXF data blocked the conversion to ARC/INFO. Identifying and solving these problems was a major task involving many people.

To complete the project, it was necessary to seek a second contractor with expertise in converting (translating) data from AutoCAD to ARC/INFO. We requested that ARC/INFO export files be placed on a 150 megabyte cassette for downloading on the SUN SPARCstation, which we were now using instead of the VAX mainframe. The second contractor was quite successful in meeting our objectives, but at considerable additional cost. The foregoing process took approximately one year.

DATABASE DESIGN

Additional map layers were designed to represent logging disturbance features and basin properties. A list of possible features to be quantified and represented in the database is given in Table 2 (the drainage basin is the basic study unit). Fire intensity, rainfall, soils, and geology will be treated as constants, and therefore were not mapped. So far we have developed six map layers (Table 3) based on features that could be mapped from 1:3000 scale air photos.

The line disturbance layer includes logging roads, skid trails, and tracks made by tractors. Line width was determined by field measurements. This formed the basis for a classification scheme designed to generalize the data, allowing for easier data manipulation when performing overlay and buffer analyses. The polygon disturbance layer includes different types of areal disturbance such as landings, tractor networks, and terraced slopes.

Vegetation mapping involved identification of polygons according to both type and relative cover. Vegetation types were determined in the field and include trees, shrubs, and herbaceous vegetation. Relative cover ranges from very dense to

Table 2. Basin Features.

Site Variables	Disturbance Variables
Drainage. density	Logging treatment (type and year)
Drainage basin mean slope	
Basin aspect	Logging roads
Stream order	Road drainage
Drainage basin area	Trees removed by logging
Elevation of drainage basin	
Vegetation cover	Logs downed
Basin shape	Skid trails
Relief ratio	Gullies
Rock outcrops	Landings
Stream channel gradient	Tractor scars
Mass movements	

Table 3. Data layers.

Layer name	Data definition
Basin boundary	Polygon
Drainage network	Line
Dam site	Point
Disturbance.L	Line
Disturbance.P	Polygon
Vegetation	Polygon

bare ground and was determined using a combination of interpretation and ground truthing. Vegetation classification was based primarily on erosional considerations.

SPATIAL ANALYSIS

Spatial analysis will be performed using standard GIS operations: spatial (topologic) overlay, to combine features from more than one layer in specific ways; proximity analysis (zone or buffer), to determine what lies within a certain distance of a feature using uniform or differential buffer distance based on the value of feature attributes; and proximity analysis (search), to determine the distance from a target feature to the nearest feature or all other features (Gottsegen and Radke 1990).

In addition to standard methods of spatial analysis, we will perform the following more sophisticated analyses, both within the framework of the original four-cell study design and beyond it:

* ANOVA (Analysis of Variance) and Cluster Analysis, based on both individual and combined factors, to identify critical attributes, reduce the number of variables, and determine specifications for regression analysis;

* Regression Modeling, based on specifications from ANOVA and Cluster Analyses (above), to identify relative weights of attributes and their significance levels;

* Surface Topographic Analysis, using slope-line or gravity flow techniques, to identify potential sediment sources.

We recognize that we can produce an unlimited number of variables from our GIS database. Cluster analysis will assist us in selecting the most appropriate ones. Even so, spurious correlations may become a major problem. It may be necessary to formulate new hypotheses for subsequent studies addressing these correlations.

FUTURE APPLICATIONS AND RECOMMENDATIONS

Our main objective in applying spatial analysis to this study is to identify significant relationships between watershed and disturbance variables and sediment production. We expect, however, that in the process of analyzing the data new research questions will arise leading to further querying of the database, refinement of the data, and designing of new studies. If resources allow, this database could be employed to study the impacts of future reforestation on sedimentation and erosion.

Finally, we offer the following recommendations for others planning to initiate GIS projects:

* Do your own contracting whenever possible. Meet face-to-face with potential contractors. Examine similar projects they have done. Consider the contractor's level of enthusiasm for the job. Write very detailed specifications. Release only a small portion of the project with the stipulation that it be approved before the entire job is released.

* Make your first GIS project a small one, preferably a small scale pilot project.

* Acquire only data that are formatted specifically for the hardware and software you will be using, and include these requirements in your specifications. Be sure you understand the limitations of the software you are using. If AutoCAD is used for automation, for example, then elevation must be coded as an attribute of each contour rather than as an annotation label. When annotation is used, it should not interrupt graphic features such as contour lines.

* If you do decide to translate data from one system to another, perform the translation on a small subset of the data first, and consider consulting with a data translation specialist who is familiar with both systems.

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