Geographic information systems applied to rock slope stability analysis in Yellowstone County, Montana

by Edwin Jay DeYoung

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
There are over 200 mapped slope failures in Yellowstone County, Montana. This study uses Geographic Information Systems (GIS) analysis to predict slope-failure hazard. Most regional slope stability analyses do not address discontinuity factors although such discontinuities are widely recognized as important. This analysis tests the importance of bedding-plane discontinuities in Yellowstone County.

Data layers consist of ARC/INFO grids with values of slope gradient, material type, slope type and the distance to the nearest lithologic contact for each 30 meter cell of the study area. Average slope gradient was calculated from U.S. Geologic Survey 30m Digital Elevation Models. Material type was categorized as the dominate lithologic material (sandstone, shale or mixed) in each cell area. A surface was created from near surface structure to represent bedding layers parallel to lithologic units. Slope type was determined from the relative structure gradient (dip) and slope gradient, identifying key areas having similar structure orientation and slope aspect. A stepwise discriminant analysis was used to determine the combination of slope, material, slope type and contact distance factors to determine the combination of variables to maximize the difference between mapped landslide locations and a set of stable slope cells.

Slope gradient is the strongest discriminating factor, and accounts for nearly 80% of the variance in the discriminant function. Material type has minimal significance and slope type is insignificant in discriminating between failed and stable slopes in this study. The distance to contacts with relatively hard lithologic units overlying relatively soft lithologic units is significant in discriminating between failed and stable slopes, accounting for nearly 20% of the discriminant variance. The origin of these relationships is probably related to mass movement.

Bedding discontinuity is a relevant factor although bedding is not a significant factor as determined for this study area. Overdip slope types are likely misclassified because the cell size (±250 m) approaches the size of mass-movement features. Site analysis shows discontinuities are a part of overall instability analysis, however, further work is needed to successfully incorporate bedding discontinuities in a regional stability analysis.

The probability of rock slope failure was determined for southern Yellowstone County, Montana from slope gradient, material type and the distance to the nearest hard over soft contact. This study does not give any site-specific information because input data was averaged to 30m grid cells and the resolution of combined analysis of multiple data sources is ~250m. The results indicate slope-failure probability for general areas. The maps can be used for regional assessment and emphasize where site-specific analysis is strongly recommended before development.

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MONTANA STATE UNIVERSITY - BOZEMAN
Bozeman, Montana

March 1996

APPROVAL

of a thesis submitted by

Edwin Jay DeYoung

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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CHAPTER 1

INTRODUCTION

Statement of Problem

Slope failure is a widespread natural hazard that poses a threat to life and property. Such failures are a problem in Yellowstone County, Montana (Yellowstone County Department of Planning, 1990). Assessment of where slopes are unstable is necessary for planning future development. Such planning would enhance opportunities to avoid building on unstable sites or encourage special design where building does occur in such cases (National Research Council, 1985). One approach to locating potentially unstable slopes is through analysis of slope instability factors through Geographic Information Systems (GIS) technology in Yellowstone County.

Figure 1.1 outlines the components addressed in this thesis on slope stability analysis. The pyramid structure represents stability prediction as the culminating goal. Identification of factors critical to slope stability is fundamental to the analysis. After the factors are identified, sources of information about the factors are collected. Collected data is imported into a GIS format. GIS is used to calculate derived layers which give additional information specific for slope stability analysis. Statistical analysis of data representing the determined factors allows prediction of potential slope instability for the study area.

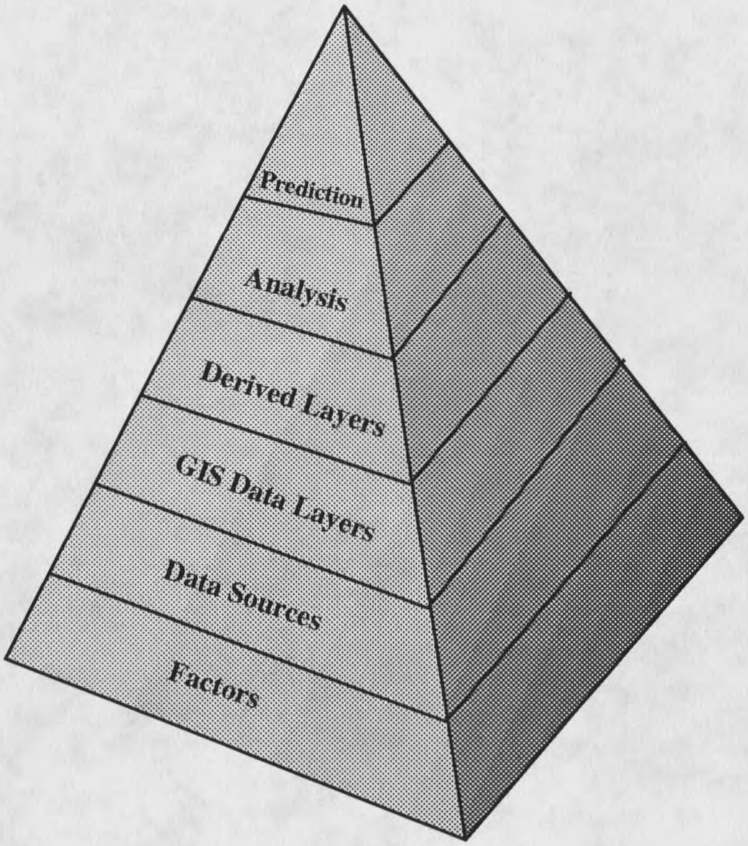

Figure 1.1. GIS model for prediction. Pyramid diagram shows order of model process from factor basis to final prediction.

GIS enables the processing of input data and the spatial analysis to evaluate locations of potential slope failure. Representation and analysis of multiple factors through space is feasible in GIS. Identification of appropriate land stability factors is fundamental for analysis and accurate predictions. Past GIS models have used factors of slope and material type but have generally left out geologic discontinuities. A model that incorporates such discontinuities is expected to better predict the location of unstable slopes than a model using slope and material alone. GIS technology enables rigorous instability analysis for large data sets for county sized regions, and is cost effective.

Study Area

The study area is the southern two-thirds of Yellowstone County, Montana (Fig. 1.2), where detailed elevation data are available. Billings, the most populous urban center of Montana, Laurel, several smaller towns and part of the Crow Indian Reservation are in the study area. The Yellowstone County Comprehensive Plan (Yellowstone County Planning Department, 1990) identifies slope stability as an important environmental geologic factor for planning and development. Three stated goals of the plan are to encourage designs which respect existing topographic features, take natural physical constraints into consideration, and promote safety in existing and new residential development. The aim of the county plan appears to be to inform residents of the existing natural hazards and to promote informed rational decisions about suitability for development.

This study will not provide the detailed information that is needed on a site-specific basis to make an informed decision about slope instability hazard. Rather, the intent of this study is to promote slope stability as a necessary consideration for development evaluation potential and indicate where site evaluations are critical for responsible development at a county-scale. More detailed site evaluations will be necessary because slope gradient, material type and all other slope characteristics vary at scales finer than 30 m x 30 m (the grid scale of the largest-scale GIS data layer).

Difference in topographic elevation is one of the bases for potential slope instability (Fig. 1.3). Overall relief in the area is 650 meters. The Pryor Mountains form a high area (1,518 m) at the southern edge of the study area. The lowest point (867 m) is in the northeast corner of the study area along the Yellowstone River. Elevation differences in Yellowstone

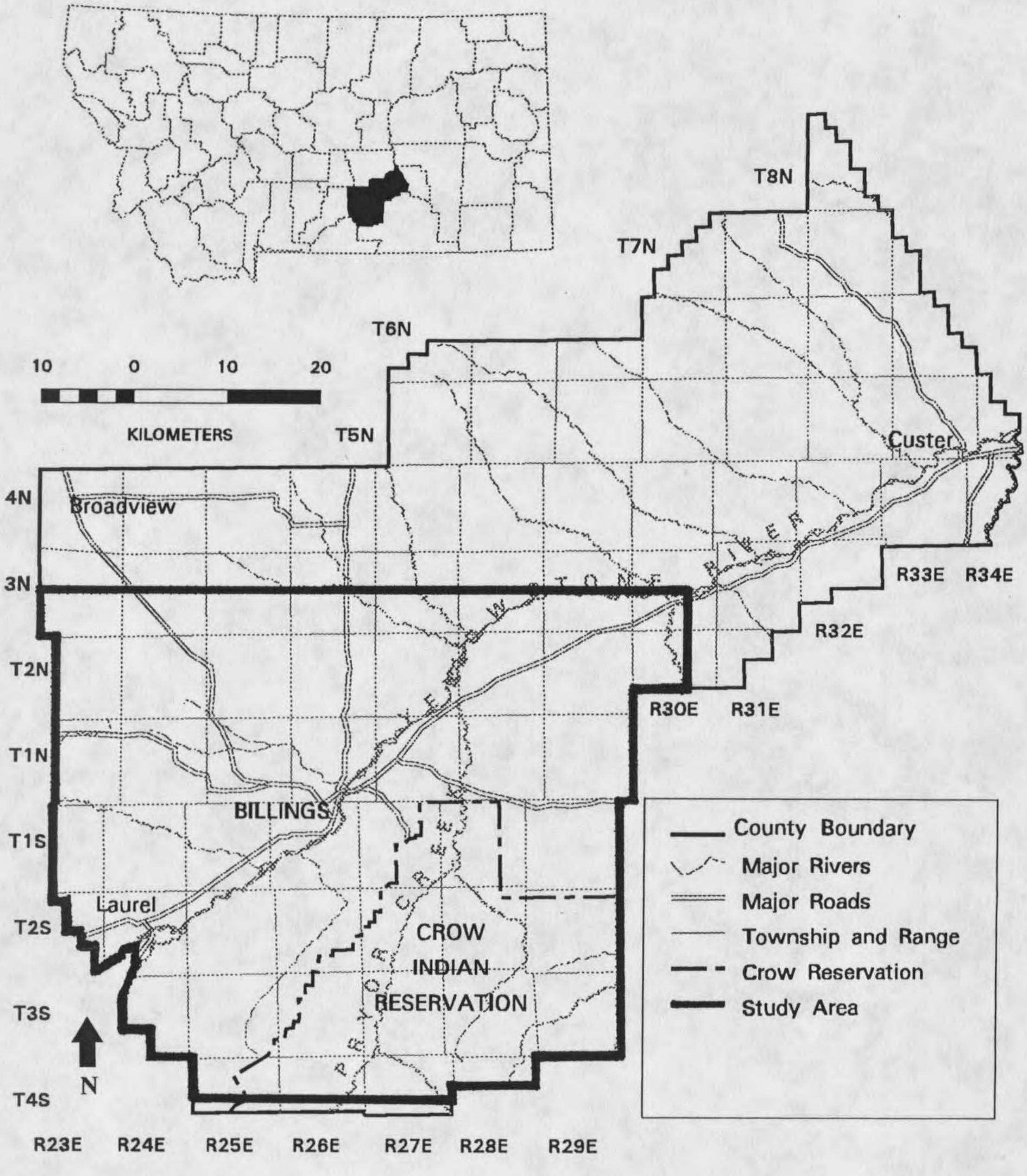

Figure 1.2. Location of study area within Yellowstone County, Montana.