Application of GIS To Modeling Fire For Vegetative Restoration in Northern Arizona

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I. INTRODUCTION

Ecological restoration has gained increasing recognition for several decades and use of fire to manage and restore native vegetation is gaining popularity for this purpose. Consequently, the Kaibab Paiute tribal council, in conjunction with the Bureau of Land Management, Bureau of Indian Affairs, and the Ecological Restoration Institute at Northern Arizona University, have joined forces with the intention of using prescribed burns on the Kaibab Paiute reservation in northern Arizona. Primarily this use of fire will be a means for vegetative restoration, specifically short-grass prairies which have been encroached upon by other native and non-native species of plants. Since this area is federally managed and no burning has been allowed, an excess of the natural fuel-load for fires has put villages located on the reservation in increased danger of catastrophic fire events. These substantial reasons support the need to accurately predict and model fire behavior using site-specific criteria. The objective of this research is to create a fire model using ESRI's Spatial Analyst tool in ArcGIS and hypothesize to accurately load that model with the appropriate data so fires on the Kaibab Paiute reservation may be simulated and thereby managed.

To meet this critical need, it is important to understand and include all of the operational components and geographic variables in the model, which can be broken down into subcategories of the main issue. The literature review section of this paper will discuss the history of fire modeling. In the methods section, the GIS fire model will be described, along with the digital data layers available to run the model. Finally, the problems associated with running the model and the accuracy assessment of the model itself will be addressed.

Specifically, I propose to do the following:

?? Collect digital geographic data for the Kaibab Paiute Reservation

?? Construct a GIS model that can replicate the fire pattern of the accidental fire on the reservation in the summer of 2000. This will serve as a test of the model's validity.

?? Model patterns of potential impact from fires under a variety of scenarios

This model will provide information on the potential for impact on villages and the reservation with the intended outcome being that fires (accidental or purposeful) can be controlled and managed to reduce danger to people and property.

II. STUDY AREA

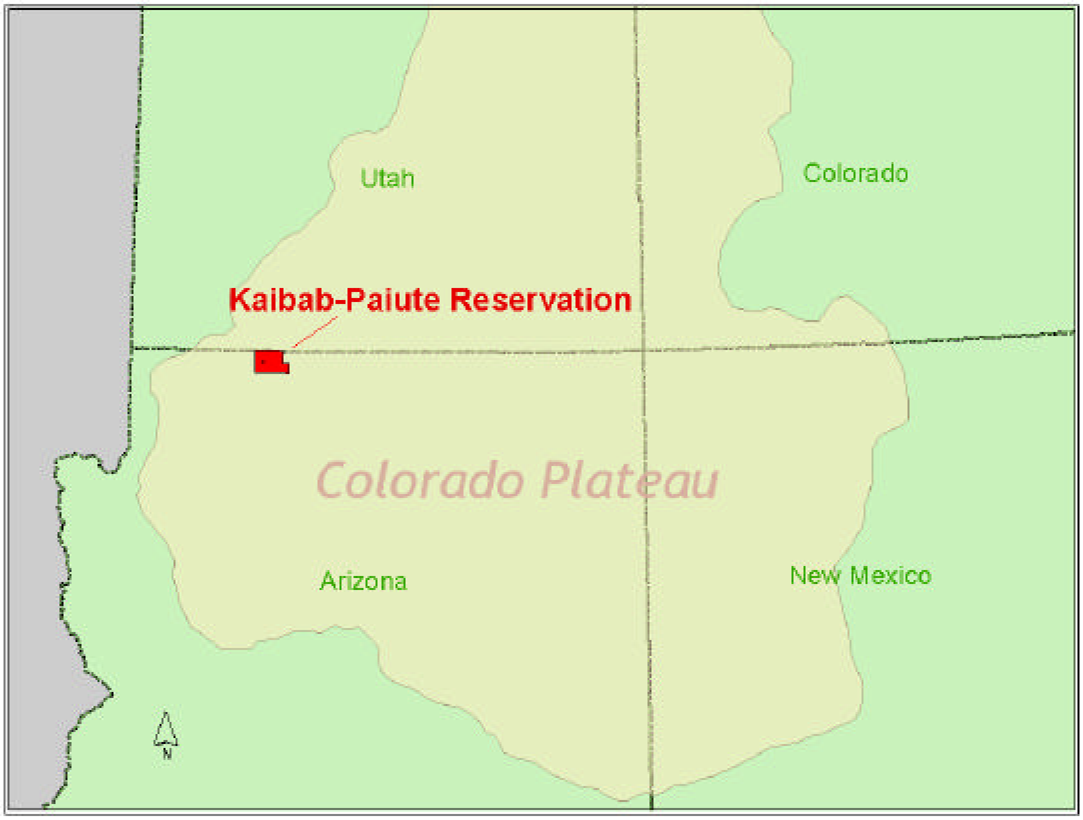
My study area is the Kaibab Paiute Reservation in northern Arizona (Fig.1). Over 120,000 acres in size and unique in its combination of history, geology and vegetation, this region serves as an excellent site for analysis of this type. Much of the land on the reservation today is undeveloped (Kaibab, 2001). Rich history of multi-cultural colonization (Holt, 1992) combined with the unique geology and vegetation types endemic to the Colorado Plateau (Baars, 2000) serve to make this project a truly novel case study for prediction of fire impacts.

III. LITERATURE REVIEW

GIS Fire Model

Fire management begins with describing how the characteristics of an area's ecosystem might be affected by fire (Fischer, 1985). A model is necessary to predict or simulate those affectations (Miller and Urban, 1999; Miller and Urban, 2000; Kilgore, 1985; Kushla and Ripple,1997; Ross, 1999; Green, et al., 1995; Albini, 1976). Over time, the concept of this model has changed along with the advancements of technology. The latest models for fire use GIS-based

Figure 1: Study area



data and produce a three-dimensional simulation (Ross, 1999; Green, et al., 1995). This simulation makes it possible to safely employ prescribed fire techniques and easily communicate results to managing agencies (Ross, 1999).

Historically, models that predict fire behavior have differed greatly throughout the decades of use. Albini (1976) lists the first documented fire model as being published in 1946. Older models from this time and even some algorithms being published today are completely mathematical with a calculator as the main processing tool. Unfortunately, a low level of accuracy is inherent with most of these mathematical models, and each model was designed for a specific fuel type without variation, or in some cases, even heterogeneity of vegetation. Earlier models also went under the name of "fire spread" models, giving little attention to the intensity aspect of fire. Later computer-based models, such as FYRCYCL (van Wagtendonk, 1985) added more parameters for input, which in turn increased accuracy in the output. However, these simulations were still specific to only certain types of fuel loads.

GIS has clearly stepped into the lead for simulating prescribed fires. FARSITE and FIRE! are both stand alone GIS software with capabilities of being linked to ESRI's ARC/INFO for more enhanced functions (Green, et al., 1995; Ross, 1999). These two software have identical input parameters but completely different output displays and user interfaces. Upon further research it was discovered that FARSITE is actually the engine of the FIRE! application.

FARSITE, a C++ program developed by Systems for Environmental Management, is a raster model versus other GIS models such as BEHAVE and FARSIGHT which use vectors (Green, et al., 1995). Raster models utilize a neighborhood function to create the fire shape and spread (Jensen, 2000). In other words, each cell (pixel) uses the constant spatial arrangement of neighboring cells to determine its reaction to the spread of fire.

This concept will be used in the fire model for this project using the tools available in ArcGIS Spatial Analyst. Variables for input will be determined by looking at earlier models, specifically FARSITE. Those variables will be shown in the next section of this paper and discussed in the methods section. Finally, the resultant grids for models run using specific parameters will be viewed in ArcGIS using 3D Analyst.

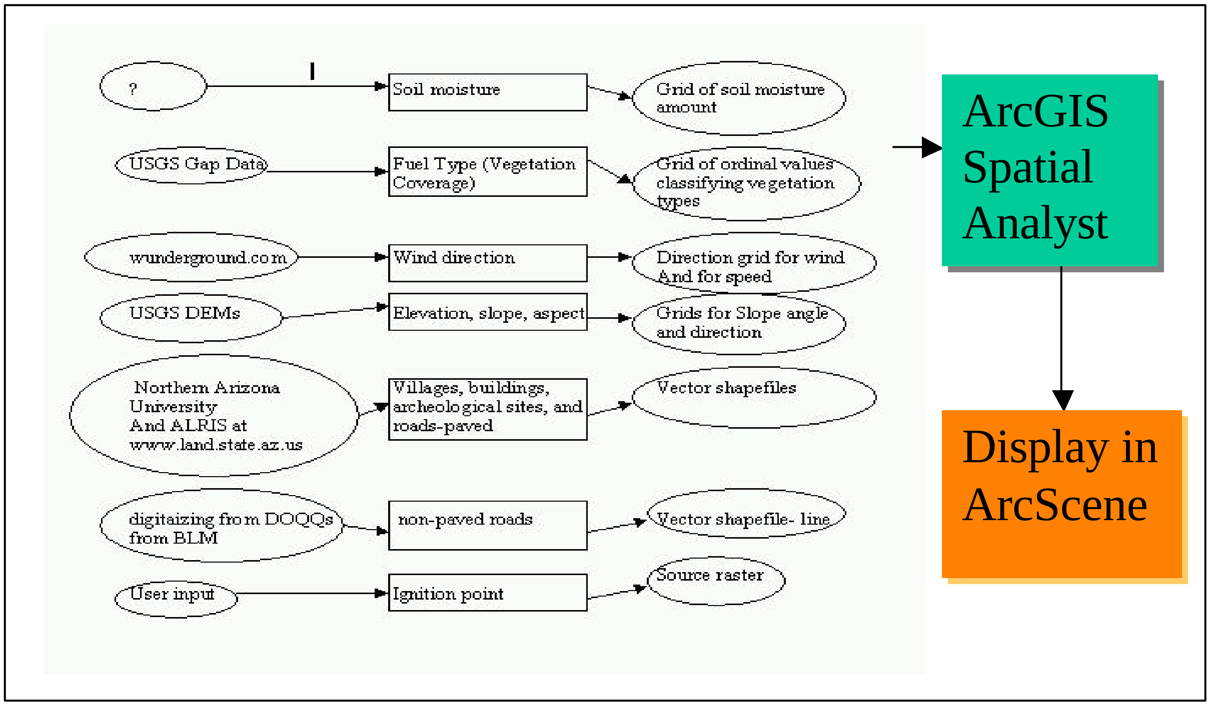
IV. METHODS

Figure 1 illustrates the effective movement of data through the proposed GIS model. Sources of digital data are shown on the left followed by the name of the variable as well as the format of the input type. The processing stage is shown in green and finally the presentation of information is shown on orange.

Data Collection and Preparation

As stated in the introduction there are three objectives designed to meet the main goal of creating a reliable and accurate fire model for the Kaibab Paiute reservation. The first objective is to gather digital data on the study area in order to load the fire model. Consultation to FARSITE's input parameters was important in determining the selection of variables for the model for this project. Data necessary for the model includes vegetation (or fuel), terrain and locational data for villages, roads, and places of archeological significance. Other variables such as meteorological conditions and soil moisture are also input as raster variables.

Figure 2: Organizational Chart of variables and processes



As a preliminary statement, I find it necessary to affirm that all data, once received, was projected to UTM, zone 12, WGS 1984 datum. After being appropriately transformed if necessary, data was clipped (or masked, if raster) to a shapefile of the boundary of the Kaibab-Paiute reservation. This boundary file was obtained from Geo Communities, an online GIS data source.

Much of the data necessary to the model is pre-existing GIS data; figure 1 lists the sources. Gap data from the USGS was obtained for vegetative cover and is at 30m resolution. As determined from the literature review, this level of precision is frequently used, as it is also the same resolution for Landsat imagery, another common source for vegetation cover. Unfortunately, it was discovered late in the course of this project, that Gap data has essentially been recalled due to what ALRIS calls “inaccuracies.”

USGS is also the resource for all elevation-based data. DEM’s were downloaded, converted to Grid files, merged, clipped, and finally slope and aspect were derived from this dataset. These derivations were processed in ArcGIS Spatial Analyst.

Meteorological conditions are still in the process of being located. While there are many websites that offer historic climate data, it would appear that finding both wind speed and direction for this area will be a more difficult task than earlier supposed. Wunderground.com is the quickest and simplest provider found to date for this data, however the important factor of wind direction is missing from their collection. The National Weather Service online provides a number of conditions for stations all across the US since 1943, but, perhaps due to the reservation's remoteness, there is no wind data. More time and research will be necessary for the important variable. Likewise, soil moisture was not found.

Vector data is also an important component for the fire model. Vector data such as roads can be an existing barrier to fire while a village would be an existing feature in need of a barrier for fire protection. There is a wealth of data available from Arizona Land Resource Information System. Data is available free of charge, however it must be ordered and sent on CD. It has not yet arrived at the time of this report. Unpaved roads prove to be another problem due to the lengthy process of digitization. Twenty DOQQs cover the reservation and each file takes considerable time for processing, a time that was not accessible within the frame of the project.

The last parameter listed in Figure 1 is the source of the fire or the ignition point. This remains variable for the user to input to test different scenarios. For the trial run of the model however, the ignition point of the fire on June 22, 2000 will be input. This was a GPS point taken and converted first to a shapefile then a raster *source* file.

Finally, to conclude this section regarding data collection and preparation, the final obligatory dataset is the perimeter of the fire in 2000. A Landsat image of the study area after the fire was purchased and the burned area digitized. This shapefile would be used to check the trial model for accuracy.

Creating the Model

Referring to the second objective outlined in the introduction, the next step after data collection is to create the fire model. As previously stated, I proposed to accomplish this objective using ArcGIS Spatial Analyst tools which encompass most of the functionality of ArcGrid. ArcGrid has the capability of processing an operation called "pathdistance." The pathdistance command calculates the least accumulative-cost distance over a cost surface from a source cell while accounting for surface distance and horizontal and vertical cost factors. As with most functions that ESRI provides, this is a general operation with an array of applications, one of which could be the modeling of fire.

In other words, theoretically, one should be able to input a number of raster datasets into the algorithm provided in the pathdistance function and output a grid of values quantifying the likelihood of being burnt. Problems with applying this to fire are inherent and abundant. First and foremost, fire "accumulation" which may presumably be the growth of the intensity, is a complicated calculation, in and of itself: one for which this command may not necessarily be well suited. A second area of uncertainty is the use of "least" cost. It makes more sense to want to know the "most" desirable cells for the fire. While this may cause some confusion, a possible fix may be to reclassify data to making more desirable circumstances into a lower discrete value. Finally, the most complicated aspect of this using this method may be the weights of the actually variables themselves. For instance, how does elevation effect the movement of fire? What if the wind is pushing it uphill? It is mainly for these reasons that the second objective for this project could not be met at this time.

It was this author's intent to attempt to reconstruct the fire that occurred in the summer of 2000 using this method of modeling. However, the level of understanding necessary to completing such a task was underestimated and the resolution and accuracy of the data (especially vegetation) was somewhat inappropriate to the task. As the scope of this project demands some sort of analysis, here I include Table 1 depicting a possible analysis scenario.

Table 1.

Pathdistance arguments and possible variables for fire

ARGUMENT	*MY INPUT*	*WHAT IS IT*
Source Grid	Ignit_grid	cell defining source of movement of fire
Cost Grid	Gapveg	vegetation grid
Surface Grid	res_dem	elevation grid
HorizFactor Grid	winddir	wind direction (constant 90)
HorizFactorParm	"forward"	
VertFactorGrid	res_dem	elevation grid
VertFactorParm	?	
O_backlink_grid o_allocate_grid		N/A
max_distance		N/A
value_grid		N/A

Surprisingly when this command and arguments were entered the output, when put into classes, was not too far from the actual fire perimeter. (See included map files.) This occurred in spite of the many issues that were thought to exist with the model. Upon reviewing the analysis, there are some striking problems that were not heretofore addressed. An example of such a problem can be seen in that the fire seemingly does not stop. While the actual fire had a perimeter, this one appears to have only direction and distance from ignition. Another that might be raised could be that there was no reclassification of the input data. One would think that with elevation with a range in the thousands and vegetation nominally ranging from one to fourteen, that the algorithm would not produce results with any accuracy. Perhaps the answers to these problems lie hidden within the weights of the algorithm itself, to be understood by this author at a later date.

Running subsequent scenarios

With so many unanswered questions, it may be imprudent to continue to model any other scenarios at this time. Consequently the third objective remains, at this time, unmet.

V. CONCLUDING REMARKS

While I conclude that there were no substantial results from this project methodology, it certainly was an immense learning process. A great deal more research is needed to increase my understanding of the weights of the variables and the data.

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