Using GIS and MCDA to Determine

Suitable Sites for Prescribed Burning

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Introduction

Prescribed burning has for many years been considered a tool for ecological restoration. In Arizona, the Kaibab tribe of Paiute Indians would like use fire to restore much of their reservation to its previous short-grassland state. Overgrazing has decimated the grasses and allowed native shrub and tree species such as *pinus edulis* (pinyon), *juniperus monosperma* (juniper), *atriplex canescens* (saltbush) and *artemisia tridentata* (big-sage) to take over. Exotic grasses such as *bromus tectorum* (cheat grass) have also invaded, out-competing the native grasses while the exotic canyon-dweller *tamarix ramosissima* (salt cedar) has invaded the ephemeral (at best) creek beds.

As part of a larger ongoing project, a fire modeling software, FARSITE, has been loaded with current GIS data representing the reservation. The objective of that project is to accurately predict the behavior of fire on the reservation. Deliverables, besides the fire model, should include one to three scenarios to run in the model as test plots. It is the selection of these test plots that is the objective of this paper. I propose to use ArcGIS Spatial Analyst and the simple additive weighting (SAW) method of multi-criteria decision analysis (MCDA) to determine the location of sites best suited for the purpose of simple experimental burn plots. The final product will be a shapefile of these prioritized plots and a map showing their location and ranked class.

Kaibab-Paiute Reservation

Located in Northern Arizona, the Kaibab-Paiute reservation actually lies in the ecological region of the Colorado Plateau (see Figure 2). The

reservation shares the geology, vegetation and climate of the rest of the plateau yet the area itself has its own specific history. In the late 1800's, Mormon pioneers settled this wild and harsh environment and brought cattle through this the reservation region, which is also called the Arizona strip. At one time it was noted that the area held a million cattle. From this, it is easy to see how the area could quickly degrade from overgrazing.

Figure 1. This picture shows the results of harsh droughts of the last four years and overgrazing.

In the 1930's the land was given to the Paiute Indians by the federal government yet it is still used primarily for grazing. There are over 120,000 acres (48,000 hectares) within the reservation boundary, over 90% of which is undeveloped grazing land or higher up in the mesas, used for deer hunting. There are populated areas: five Paiute villages, and one Mormon town in the

center, Moccasin. Another point of interest is Pipe Springs National Monument which displays an old Mormon settlement home and one of the area's natural springs. Locations of these areas must be carefully noted, as they must be excluded from the prescribed fire plots.
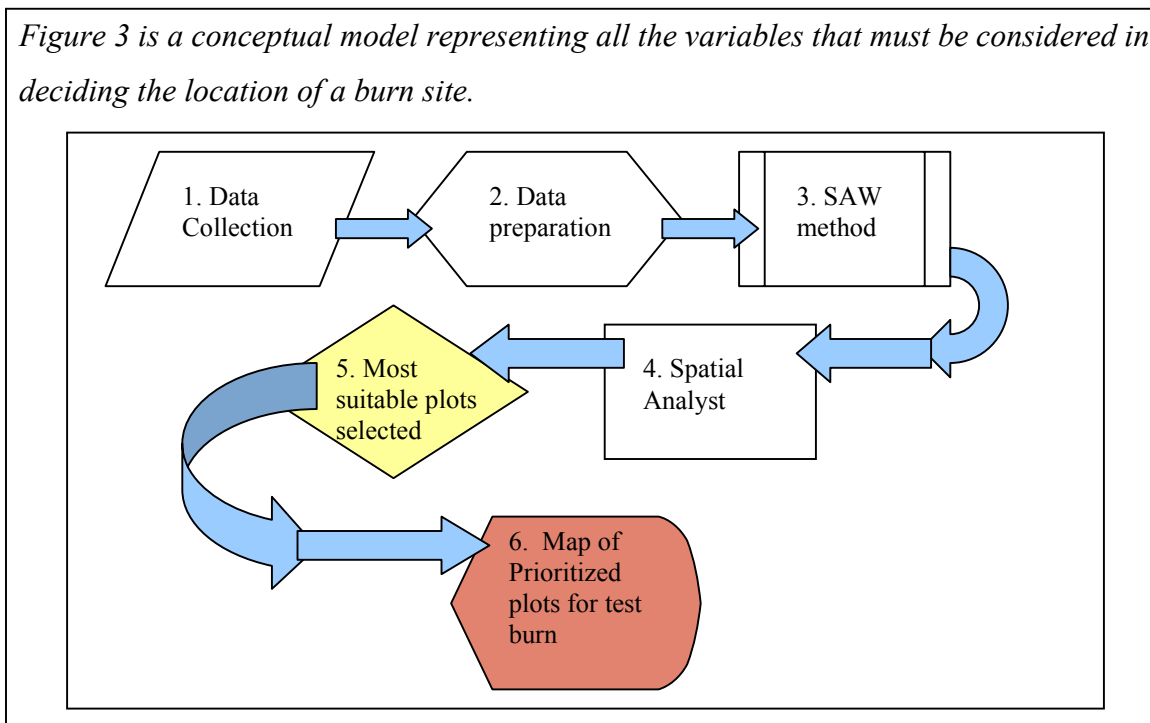

Figure2. Location Map
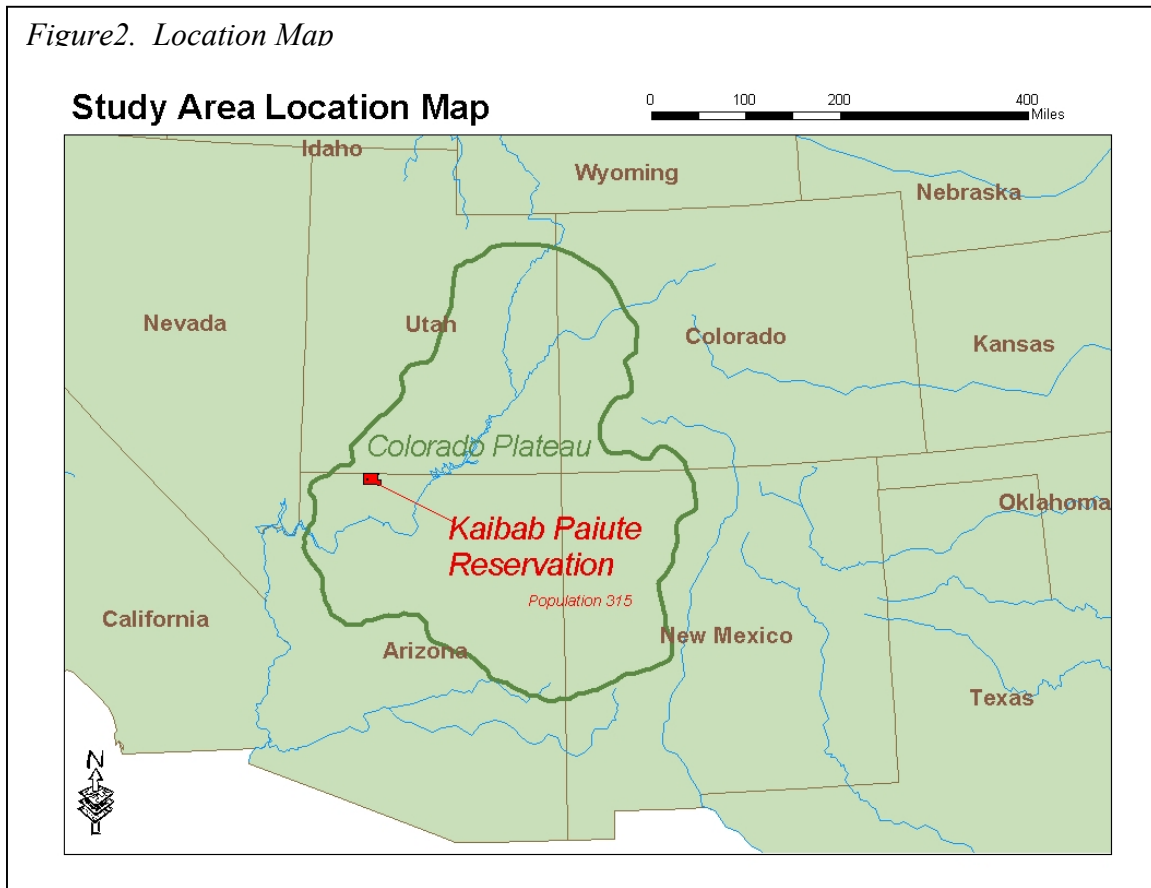
Methodology

In order to meet the objective of finding an appropriate site to burn on the reservation I elected to use Multi-Criteria Decision Analysis combined with raster analysis in ArcGIS Spatial Analyst to aid in the decision making process. The simple additive weighting (SAW) method was chosen from Malczewski's 1999 book on the incorporation of GIS and MCDA. After the data was obtained from multiple sources, the SAW procedure was

followed by manipulating the data using the raster calculator function of Spatial Analyst. Figure 3 gives a general overview of the project plan.

Figure 3 is a conceptual model representing all the variables that must be considered in deciding the location of a burn site.

1. Data Collection

2. Data preparation

3. SAW method

5. Most suitable plots selected

4. Spatial Analyst

6. Map of Prioritized plots for test burn

Data Collection:

Data collection for this project was mainly borrowed from the fire-modeling project. Determining which data was derived from various reading of prescribed fire literature referenced in the prescribed fire portion of the Reference section. Much of the data was created from field survey and remotely sensed imagery. Online data clearinghouses supplied the remainder. A list of all data sources is shown in Table 1.

Originally, I intended to use elevation belts to prescribe which vegetation community the areas should have. However, upon classifying the elevation grid, I learned that this was not discernable, and that there appeared to be no species encroachment from other elevation ranges.

Table 1. Data sources.

Data	GIS Data type	Source
Vegetation cover	Grid	Classified from Landsat 7-TM
Digital Elevation Model	DEM converted to grid, and analyzed for slope	USGS Online
Points of Interest	Point shapefile	GPS in field
Burned area from 2000	Polygon shapefile	Digitized from Landsat 7-TM
Reservation Boundary	Polygon shapefile	GIS Data Depot online
Highway and roads	Line shapefile	Digitized from DOQQs

I did still incorporate both the vegetation coverage and the elevation grid into the model, though for different purposes. The next section explains reasoning behind choices in criteria and, therefore, GIS data.

Since vegetation is homogeneous in that no type is preferable over another for burning, I simply classified it for coverage or bare. Common sense dictates that it is not beneficial to try to burn an area that is empty of fuel. Elevation was used for the slope characteristic. Fire literature maintains that fire management may be simpler on flatter land, so I determined that a first burn would be better with lesser slope. Access to the burn site would be necessary so a roads coverage would be needed. Previously burned areas were included, as they would not benefit from being burned a second time. Also, exclusion zones from the fire would need to be known. These areas include villages, the National Monument, the Mormon town of Moccasin and the boundaries of the reservation; all to be avoided for obvious reasons.

Data preparation:

Preparation of this data could not begin until the plots were determined. As stated earlier, most of the land is undeveloped, leaving no true boundaries within the reservation that could be used as plots for this spatial determination. In other words, there are no smaller parcels that

could be compared. Therefore, I determined that the land would have to be measured off in grid cells; the question became what size?

For this project it was helpful to have had a fire on the reservation in the year 2000. Burning for four days, the fire consumed almost seven million square meters (according to the digitized polygon). Since prescribed burns are managed easiest in a one-day period, I decided to simply divide that area by four and take the square root of the quotient to obtain an appropriate cell size for the plots. Thus, 1300x1300m were the lengths of the sides of each cell.   Working out to be 330 plots, this was considered to be a manageable number of plots to analyze.

After the grid size was determined resampling, and, in some cases, constructing the grids was the next phase of the plan. Some grids simply needed to be resampled to change the cell size. Other layers, however, needed reclassification or even more complex functions performed on them so they would be helpful to this analysis. Following is a list of all layers and the steps that were taken to make them ready to be used in the SAW process. (See also Figure 4. for a detailed diagram of the SAW procedure.)

- ✓ Vegetation – reclassified to either vegetated or bare (0 or 1), then resampled to 1300m cell size
- ✓ Slope – simply resampled to match vegetation
- ✓ Burned area – Feature to raster function invoked, masked to slope and reclassified to 0 or 1 (not-burned, burned)
- ✓ Points to not burn – Point feature to raster, masked to slope and reclassified to 0 or 1
- ✓ Boundary – line feature to raster, masked to slope and reclassified to 0 or 1 (cell contains boundary or not)

- ✓ Highway – separated from roads shapefile and line feature to raster, masked to slope and reclassified to 0 or 1

- ✓ Distance from highway – Costdistance function run in raster calculator (temporary grid with fixed value of one created for cost grid, and highway grid was source) Equation reads: "costdistance (highway, tempgrid, #, #, #, #)

- ✓ Distance from roads – roads shapefile (without the highway) was converted from feature to raster and masked to slope and reclassified to 0 or 1. Costdistance function was run (same process as for Distance to highway)
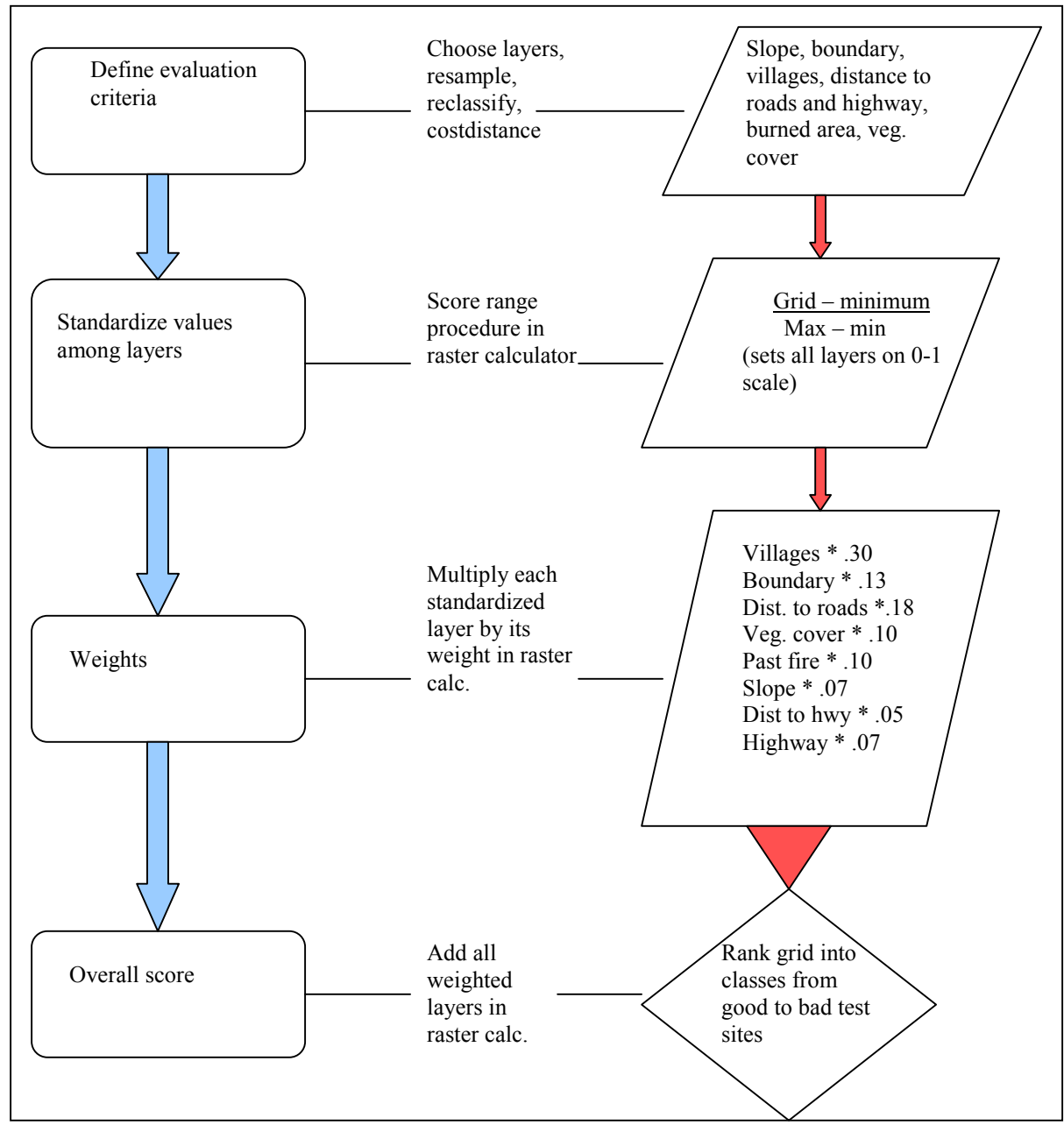
SAW in Spatial Analyst:

After the data was prepped and ready to analyze, it was time to implement the steps of the SAW method in Spatial Analyst. This process was almost entirely carried out using the raster calculator. Once the layers were resampled, the next step was to standardize the values. The process I chose to use was the score range method. This method is particularly appropriate to determining the lowest cost alternative. Equation A, below, was interpreted to equation B for implementation in the raster calculator.

A.

$$x_{ij} = \frac{x_{ij} - x_i^{min}}{x_i^{max} - x_i^{min}}$$

B.

(<grid_layer> - minimum value) / (Maximum value – minimum value)

Using this equation sets all the data layers on a scale of 0 to 1, or in some cases 0 or 1. In all instances, 0 would be considered beneficial, as it is the least cost plot for that particular criterion.

Figure 4. SAW implementation in ArcGIS Spatial Analyst

Define evaluation criteria	Choose layers, resample, reclassify, costdistance	Slope, boundary, villages, distance to roads and highway, burned area, veg. cover
Standardize values among layers	Score range procedure in raster calculator	<u>Grid – minimum</u> Max – min (sets all layers on 0-1 scale)
Weights	Multiply each standardized layer by its weight in raster calc.	Villages * .30 Boundary * .13 Dist. to roads *.18 Veg. cover * .10 Past fire * .10 Slope * .07 Dist to hwy * .05 Highway * .07
Overall score	Add all weighted layers in raster calc.	Rank grid into classes from good to bad test sites

Once the data layers are standardized, weights can be determined and applied. These weights, detailed in figure 4, are subjectively chosen by the decision maker, which for all practical purposes is myself. Obviously, the villages would be the most costly alternatives to burn, and so were given the highest weight. Access to the plot also ranked high in the weights, while

slope and distance to the highway ranked relatively low. Multiplication of the standardized grid layers and their assigned weights was carried out one at a time in the raster calculator.
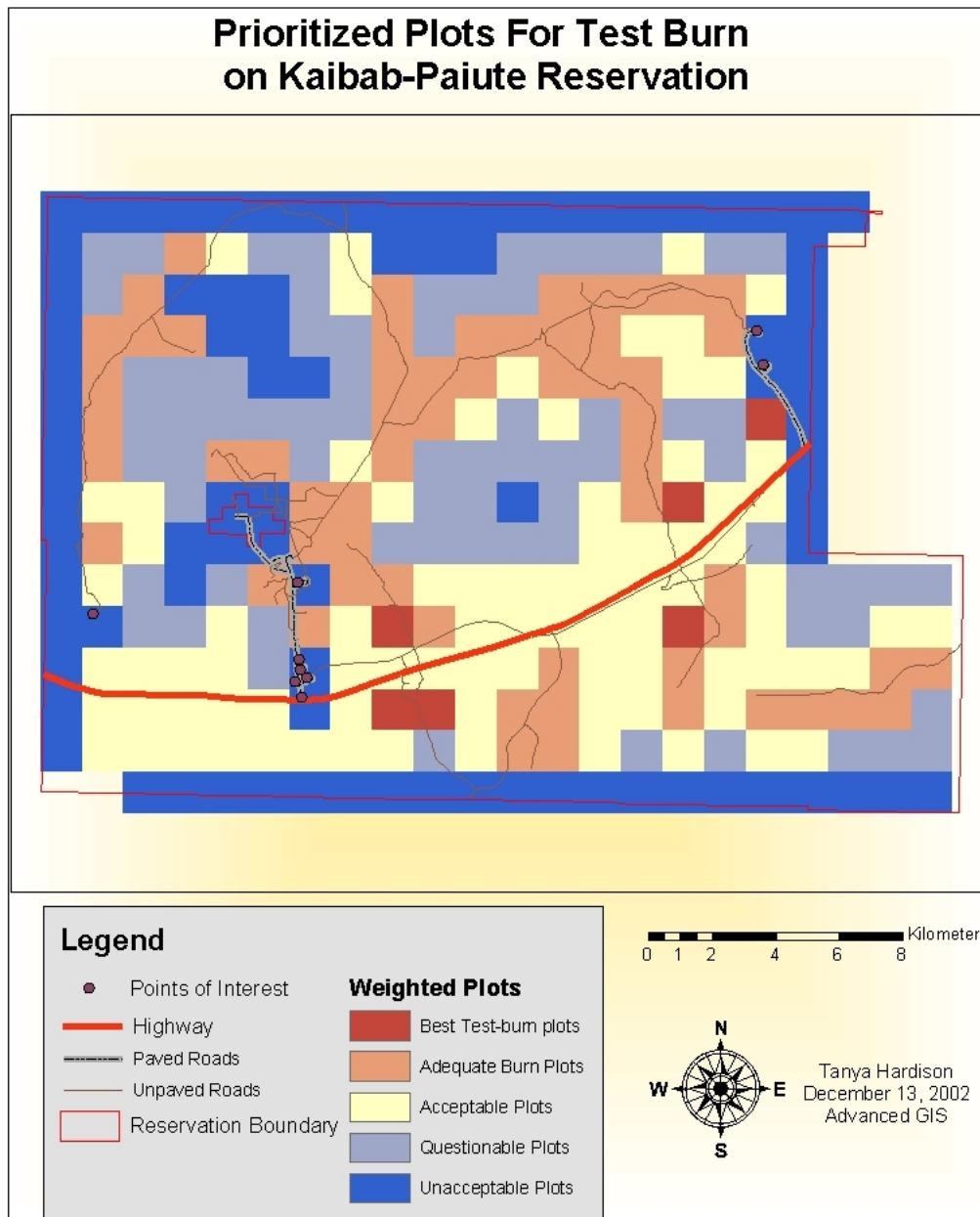
Finally, all the weighted layers were added together in the raster calculator to achieve the objective. Output from this calculation was a grid that had values from 0 to 1, representing the cost of burning that plot. The closer the value was to zero, the most suitable that plot would be for an initial test burn on the reservation. Upon studying the data, it was determined that ranking the 330 cells would be confusing to the observer. Therefore, a classification of those values was made. Five classes were named: Best plots, Adequate plots, Acceptable plots, Questionable plots and Unacceptable plots. The classification method was natural breaks, then I manually widened the last class to encompass the entire lower half of the ranked values. Also, the upper class was restricted to just a few of the highest ranking plots. Figure 5 shows the results.

Discussion of Results

The output map from this project does meet the objective set out in the introduction. However, it does not escape criticism. Admittedly, this resulting grid was a second attempt. After the first attempt weights were altered and it was then that the highway itself was added as a cost criteria. Upon making these alterations, I realized how completely subjective in nature this process was and there is low probability that someone else could repeat this project and get the same results.

Another issue that merits discussion is the grid cell size selection process. From the literature, it can be learned that a fire does not grow at

Figure 5. Final map of output grid.

Prioritized Plots For Test Burn
on Kaibab-Paiute Reservation

Legend

Points of Interest
Highway
Paved Roads
Unpaved Roads
Reservation Boundary

Weighted Plots

Best Test-burn plots
Adequate Burn Plots
Acceptable Plots
Questionable Plots
Unacceptable Plots

Kilometers
0 1 2 4 6 8

N
W E
S

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a steady rate, but almost exponentially. Therefore, simply dividing the original burned area by four would yield a much larger area than would probably burn in one day. This problem is of minimal importance, however, since the majority of planning and managing a prescribed burn is done *in situ* and such issues as plot size could be easily changed in the decision making process of the fire planning.

Somewhat more important of a problem, would be the generalization that occurs when the cell size of all grids is resampled to 1300 meters. This would imply to an observer that there is homogeneity and continuity within that cell when, in fact, that may not be the case. Using a method other than simply resampling (perhaps fuzzy logic) may solve this problem if the project were to be repeated. Perhaps, even analyzing the grid (SAW) at the original higher resolution would be beneficial. Then one could run a neighborhood function to ascertain contiguous areas large enough to burn.

Other minor issues worth mentioning are the shift in the grid during resampling. This problem was noted and quickly disregarded since burning near the boundaries is not wise (in case of escaped fire). Also, the map itself may not be very explicative to someone not familiar with the reservation. This lowers the repeatability of this project yet again, but is not necessarily a problem considering the only users of this information will be myself and others who are already familiar with the area.

Aside from these tribulations, overall the resulting grid and map appear to be a success. Based on my knowledge of the reservation, which goes beyond my ability to document in this report, the sites chosen as best appear to be correct, as do the sites deemed unacceptable. In all, with

certainty, this will be a valuable addition to the fire modeling project and a practical aid in the actual fire planning on the reservation.

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