ESTIMATING ANIMAL UNIT MONTHS USING GIS AND REMOTE SENSING,

A WYOMING CASE STUDY

THESIS

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TABLE CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

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Ranchers and range managers use a tool called an Animal Unit Month or AUM to estimate the number of animals a range can support for one month without over grazing. Currently, range managers have to go out in the field and cut, dry, and weigh the grasses to determine how much forage is on the range. Then they determine how many animals the range can support based on this field work. This research attempts to eliminate the field work by automating the AUM tool using remote sensed imagery and the NRCS SSURGO polygon data. A threshold of SAVI values will be implemented in the remote sensed imagery. The

SSURGO data will be converted to a raster data set and categorized based on the forage amounts the NRCS gives for each type of Soil. Finally the imagery and the SSURGO data will be fed into ArcGIS 9's Model Builder and a model will be built that will automatically calculate the total AUMs for the study area.

CHAPTER 1

INTRODUCTION

Grazing areas occupy roughly 55% of the United States land mass (Curtain, 2002). Thus, they are a very important resource for us to manage and keep as healthy as possible. Good grazing practices are one way in which to maintain these healthy grazing lands. A tool that helps ranchers and range managers promote good grazing without overgrazing the land is the Animal Unit Month (AUM). An AUM is a number, which represents the amount of livestock one can graze for one month on a grazing property. Currently, AUMs are determined by going out in the field and physically clipping the forage in certain points to determine the overall pounds of forage in a pasture. This is put into the AUM equation to determine AUMs. This research attempts to automate the process by building a GIS model, which will calculate AUMs for ranch and range managers automatically. Forage data will be taken from the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic Database (SSURGO), which are 1:24,000 scale soil polygons. These soil polygons contain range sites which give an estimated forage production for good, normal, and poor years of precipitation. Areas of good, normal, and poor grazing for the study area will be derived from remote sensed data which contain Soil Adjusted Vegetation Index

(SAVI) values. These values give details of how green or healthy the vegetation is. From the forage data and the SAVI values a model will be built in ArcGIS 9's Model Builder. The model will calculate the total AUMs for the study site in this research, and can be used by the NRCS and other government agencies to calculate AUMs for other ranches as well.

CHAPTER 2

BACKGROUND

Natural Resource Management

In the United States natural resource conservation and management began during the Progressive Era. Congress in 1891 and 1897 passed laws that established forest preserves. These laws were put under the Division of Forestry in the Department of Agriculture by President Theodore Roosevelt in 1905. Under Roosevelt, the Division of Forestry became the Forest Service and added millions of acres to the national forests, controlled their use, and regulated their harvest. Now with the idea of conservation and our growing knowledge of natural resource management, we can manage our resources for multiple uses and leave them as good or better for the next generation. For example, national forests support many uses for the public such as camping, fishing, hunting, and hiking and the production of timber. Also, forests are an excellent place for livestock operators to graze their cattle and sheep in the summer months. This is important because many forests use cattle and sheep as tool to reach desired range conditions through grazing. However, these uses of the resource must be monitored and controlled to limit the over use of the resource. With more research and more environmental laws, society is becoming more aware of our environmental surroundings and how best to use them and sustain them. The discipline of range management has evolved to incorporate these innovations.

Range Management

Range management is an important part of resource management, especially in the American West. It is important in terms of the economy of western states and lifestyles of the population. It is therefore in our best interest to try and manage, and keep our rangelands as healthy as possible. The goal of range management is to maintain or restore the health, sustainability, and biological diversity of range ecosystems while supporting sustainable economies and communities (Weltz et al. 2003). The best way to promote, healthy rangelands is through the use of best management practices (BMPs).

Rangelands are like the lawn of a residential house that needs to be cut. A lawn is mowed every couple of weeks which in turn promotes growth and sustainability of the lawn. However, if the lawn is cut to short it becomes brown and takes time for the grass to return to its healthy state. The same goes for grazing our western ranges as it promotes the continued health of the range. Grazing a plant shocks it into producing more biomass, and as the soil is somewhat disturbed from the livestock, this allows the seed to be taken into the soil. This in turn promotes a healthier rangeland as more plants are added to the landscape and they grow back faster. However, too much grazing can impact rangeland in negative a way as well. Grazing pastures for too long can lead to over grazing and trampling the pasture to barren ground which leads to soil erosion.

A form of rotational grazing is one of the best ways to graze livestock and at the same time promote healthy, sustainable rangelands (Stelljes 1995). Rotational grazing is the practice of grazing livestock for intense short period of times and then rotating off of the pasture to another. Returning to the first pasture in time when the forage has been given a chance to grow back again. This grazing practice allows the range to heal itself after the grazing has occurred and the livestock receives the benefit of good forage. However, you simply cannot put as many animals as you want in a pasture even if you are incorporating a type of rotational grazing. If you are grazing on public lands, agencies such as the Bureau of Land Management (BLM) or the U.S. Forest Service hire range managers to regulate the numbers of animals a rancher can place on the pubic land. Private lands are not as regulated, but if a rancher over grazes, non desired plants invade and soil erosion accelerates. Ranchers and range managers need a system to determine the number of animals that can be safely placed on a pasture without over grazing it. A critical tool for effective range management is the Animal Unit Month (AUM).

The Calculation of AUMs

Animal Unit Months (AUMs) is a number that explains the amount of forage required for one animal unit (AU) to survive on a piece of rangeland for one month. An AU is defined by a 1,000 lb. beef cow, which has a daily requirement of 26 lbs. of dry forage (Ruyle and Ogden 1993). Thus, one AUM is equal to 780 lbs. of forage. The calculation for an AUM is given below.

AUM = 26 lbs. x 30 days (1 month) = 780 lbs of forage.

From the definition above, an AUM is standardized using a weight of a 1000 lb cow. However, equivalents are available for various kinds and sizes of animals. These are known as animal unit equivalents (AUE). Table 1 below illustrates this.

Table 1 AUE values and corresponding monthly forage requirements (Ruyle and Ogden, 1993).

Animal Body Wt. lbs.	AUE (AU/Animal)	Monthly Forage Requirements lbs.
100	0 69	464
600	0.68	532
700	0.77	597
800	0.85	660
900	0.92	721
1000	1	780
1100	1.07	838
1200	1 15	894
1300	1.22	950

With the standard calculation of an AUM given, pastures need to be properly utilized given the available forage. Over grazing can cause a decrease in the amount of AUMs and an increase in the amount of invasive species. A general rule of thumb is to use half of the available AUM and leave half. Half of the available forage for consumption is not consumed by the animal; some is lost due to trampling, droppage, excrement contamination, and insect damage (Tanner 1999). A second rule of thumb is that consumption is half of the total amount of utilization. Therefore, total AUMs = lbs of consumable forage / 780lbs/AUM. Here is an example.

Suppose you have a 150-acre pasture. Through forage clipping it is estimated that there are 4000 lbs. of dry forage per acre. Thus you have 600,000 lbs. of total forage. (150 * 4000). Next you need to come up with the total consumable forage. Remember our rule of thumbs: 1. Use half and leave half. 2. Half of the consumable forage is actually used in consumption. Therefore you multiply the total lbs of forage in the pasture by 25%. 600,000 * .25 = 150,000 lbs of consumable forage. Then divide that number by our standard AUM of 780 and you get 192 AUMs of forage that can be consumed by animals. In conclusion 192 - 1000 lb. animals could graze this pasture for one month.

Current Method of Calculating AUMs

Currently range managers such as those with the NRCS, the BLM and other agencies must physically go out in the field and take measurements of the vegetation on site. They do this by using hoops or square frames that measure 2ft x 2ft in diameter and placing the frames at random points in the pasture (Tanner 1999). In order to eliminate over and underestimating biomass many points are taken with the frames in the pasture. The more randomly selected points the more accurate will the estimate of biomass. After the frame is placed the forage is cut inside the frame and then dried and weighed. Once all the forage is dried and weighed and the acreages are calculated for each vegetation type, you can then multiply the pounds of forage per acre by the total number of acres for each vegetation type and sum those products to get the total estimated forage amount for the pasture in question. (Tanner 1999).

Alternative Method for Calculating AUMs

The method used in this research to calculate AUMs is an ArcGIS 9 Model where parameters where input into the model. The parameters being: 1. An SAVI value classified remote sensed image. 2. The SSURGO polygons downloaded from the NRCS. Once these parameters were obtained a model was created using ArcGIS 9's Model Builder where the final output was a raster showing the total AUMs for the study area.

CHAPTER 3

LITERATURE REVIEW

What is GIScience?

The University Consortium for Geographic Information Science (UCGIS) was an organization formed in 1995 that contained representatives from national laboratories and research universities to look at and promote key issues in the field of GIScience. Defined by UCGIS, GIScience looks at the capture, interpretation, storage, analysis and communication of geographic information (UCGIS 2004). The focus of the UCGIS and GIScience is centered on the science surrounding spatial or geographic information. This focus is unique to GIScience. What makes geographic information science unique is the spatial component which other disciplines do not often consider. For example, in using geographic information one can see the spatial and attributes relationships shared among characteristics. The UCGIS has come up with 10 research priorities for GIScience. These 10 areas emphasize the complexity of GIScience and geographic information. They are:

Spatial Data Acquisition and Integration
Distributed Computing
Extensions to Geographic Representations
Cognition to Geographic Information
Interoperability of Geographic Information
Scale

Spatial Analysis in GIS Environment
The Future of the Spatial Information Infrastructure
The Uncertainty in Geographic Data and GIS-Based Analyses
GIS and Society

These research areas show the importance of GIScience in addressing geographical information in research, and in fact, this research paper falls into the spatial data acquisition and integration in to predictive models. Furthermore, these research areas form the scientific backbone of the three topics discussed below in this literature review

GIS in Natural Resources

GIS has been widely used in natural resources as a tool for sustainable resource management. Through the use of mapping and visual aids which are easily produced using a GIS, many natural resource problems can be brought to people's attention visually and a solution can be rendered much more easily than without the GIS (Chuenpagdee et al. 2004). A good example of this is research done using GIS in the San Felipe, Yucatan, Mexico. The town of San Felipe has an economy based largely on fishing and thus over fishing has become a problem in the area. A marine reserve was set up to help control the over fishing in the area, which some abided by and others did not. Through the use of mapping and GPS equipment areas were shown to the fisherman where the different types of fish were, thus showing them alternative areas to fish other than the marine reserve. GIS helped bring about co management of the natural resources in the area, in this case fishing. It also encouraged public participation in working out an agreement between the fishers and the marine reserve (Chuenpagdee et al. 2004).

Other examples can also be found of how GIS/Remote Sensing can be used to come to management consensus for natural resources. IKONOS satellite imagery combined with GIS layers is used to help decision making along watersheds. These two technologies when combined can help target areas for natural resource conservations and improvements (Tyson et al. 2004). This type of relationship gave rise to the use of Remote Sensing and GIS to help improve rangeland conditions.

GIS in Analyzing Range Conditions

GIS can be used to provide data for range managers in determining the condition of the range and how many animals a piece of rangeland can support. Remote sensing is one aspect of GIScience that can provide classifications of land type of the rangeland in question. One way in which this is done is to use profiling and scanning airborne laser altimeter systems which measure land surface, vegetation types, and properties for large land areas (Ritchie et al. 2001). Measurements on these properties of the rangeland provide a valuable insight into how the land can change over time in terms of types of vegetation, and how this change effects water movement through a large scale area which in turn changes the quality of the rangeland. Therefore, once a range manager knows the quality of the rangeland, a better understanding of how to stock the range with the correct number of livestock animals can be determined. Assigning each pixel in remotely sensed data a value based on the quality and type of rangeland is another beneficial use of technology. Then the different images can be overlaid on each other and multiplied together to get areas of suitability for grazing. This type of location analysis is often beneficial to range managers trying to allocate where and how many animals can be placed on the range (Tueller 2000). One GIS program that does this most effectively is the Idrisi GIS/Analysis system. This system uses 3 types of maps to perform the location analysis: A slope map (raster), a water resources coverage (vector), and perimeter or boundaries of the certain pastures being analyzed (vector). The three datasets were combined in the GIS to give a combined suitability, or expected-use, for cattle grazing in the pasture (Guenther et al. 2000). One of the most important features of this GIS package is the ability to help the range manager define the AUM capacity in the pasture in question. This package can identify areas of high potential grazing impacts and identify areas where salt or other supplements can be placed to draw the livestock away from the high impacted sites (Guenther et al. 2000).

These examples show how a GIS can aid in determining the quality of the rangeland, thereby helping range managers determine the carrying capacity that can be safely placed on the range without over grazing. I will now describe some GIS Tools that are in place today that automatically determine the quality of the rangeland but still do not calculate AUMs.

GIS Tools Available Today

There are many tools available today in the field of range management, most deal with the issue of water in range management. These tools model water in a certain watershed to ascertain watershed conservation prioritization in range management (Biswas et al. 2002). Also there are GIS tools that model underground aquifer flow which is also important in range management. As it is water that helps the forage grow and regenerate itself after grazing, modeling water is an important facet of range management. However, GIS tools have had limited expansion in the area of estimating forage amounts on the range or in estimating range carrying capacity.

One such GIS tool was developed to help Mongolian herders determine where to graze their herds to help eliminate over grazing practices. Through the combination of meetings with the herdsman, the availability of GIS data in the area, and the use of an effective GIS to analyze the data, this tool provided an efficient means to evaluate and propose alternative strategies for the exploitation of rangeland resources (Rasmussen et al. 1999). However, the Rasmussen tool still required that AUMs be calculated through more traditional means. His method requires interviews with the herdsman asking them how many animals they grazed in a certain pasture, or through traditional field work of collecting forage data. If the tool were enhanced in order to show the AUMs the pasture can handle it would be a great benefit to the researchers and the livestock owners. The model produced from this research shows the user how many AUMs are in a pasture both visually through maps and in tabular form.

CHAPTER 4

METHODOLOGY

Study Area

The ranch study area for this research is located 60 miles west of Casper, Wyoming (Figure 1). It is approximately 21,240 acres and consists of a semi arid

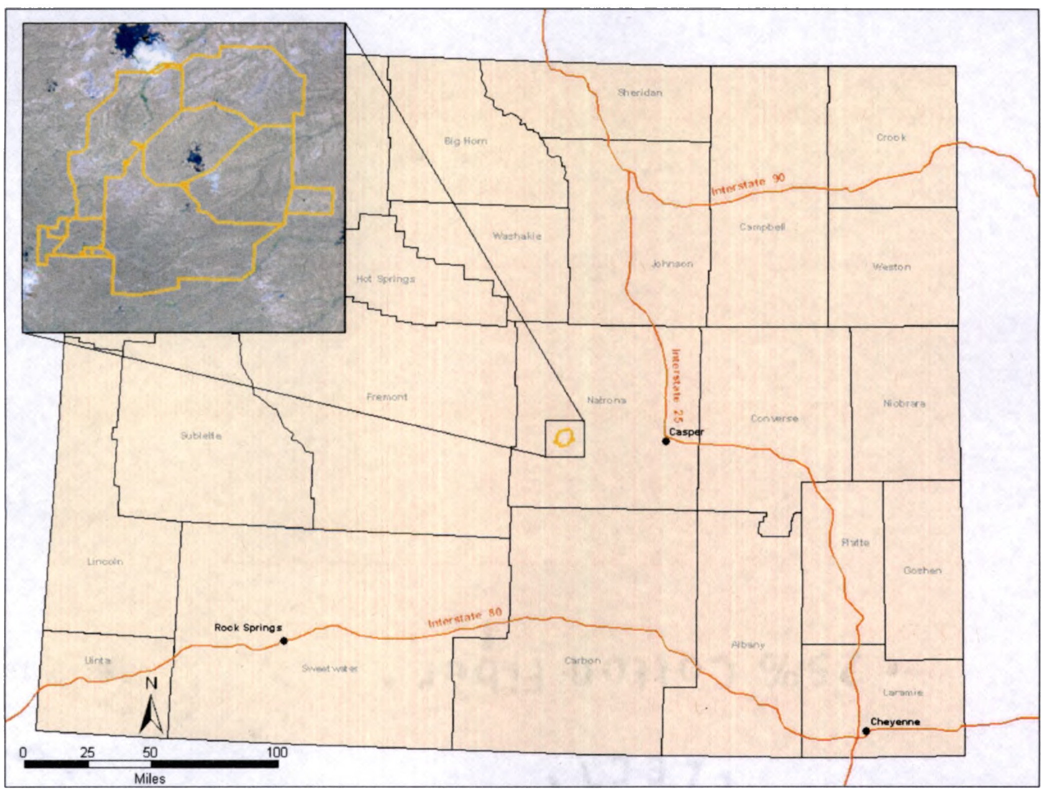

Figure 1. Study area map of ranch in central Wyoming.

steppe climate (BSk, Koppen Climate Classification) with grasses and small shrubs dominating the landscape. The main tributary that drains the ranch is The Middle Fork of

Casper Creek which feeds into the North Platte River which, in turn, flows into the Missouri River. Elevation ranges from approximately 5,500 feet to 5,800 feet above sea level with an average precipitation of 10 – 14 inches a year. The ranch grazes about 450 cattle from the beginning of May till the end of September.

Data Sources

The original data sources used for the research were a GPS unit, remote sensed satellite imagery, and the NRCS Soil Survey Geographic Database or SSURGO polygons. Following is a description of each of these three raw data sources.

The GPS unit was used to locate points on the ranch during the month of June 2004. These points served as quality control points (Figure 2) that marked areas of good, normal and poor grazing areas.

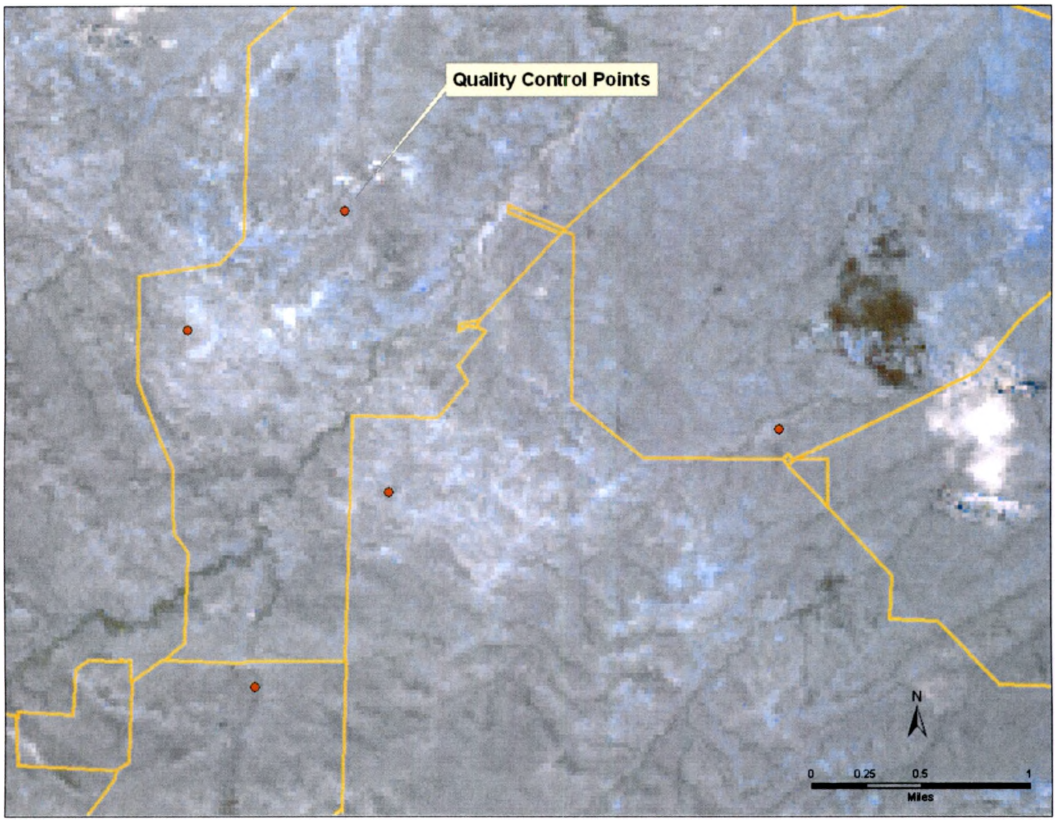

Figure 2. Map with quality control points and ranch boundary.

The Garmin eTrex Legend GPS unit performed this task. It is a relatively inexpensive unit which costs approximately 100 to 300 dollars and has an accuracy of approximately 30 meters. This type of unit was ideal in terms of cost and the 30 meter accuracy for this research was appropriate in that the quality control points were representing large grazing areas.

The remote sensed imagery was used to calculate the Soil Adjusted Vegetation Index (SAVI) on the ranch (Figure 3.)

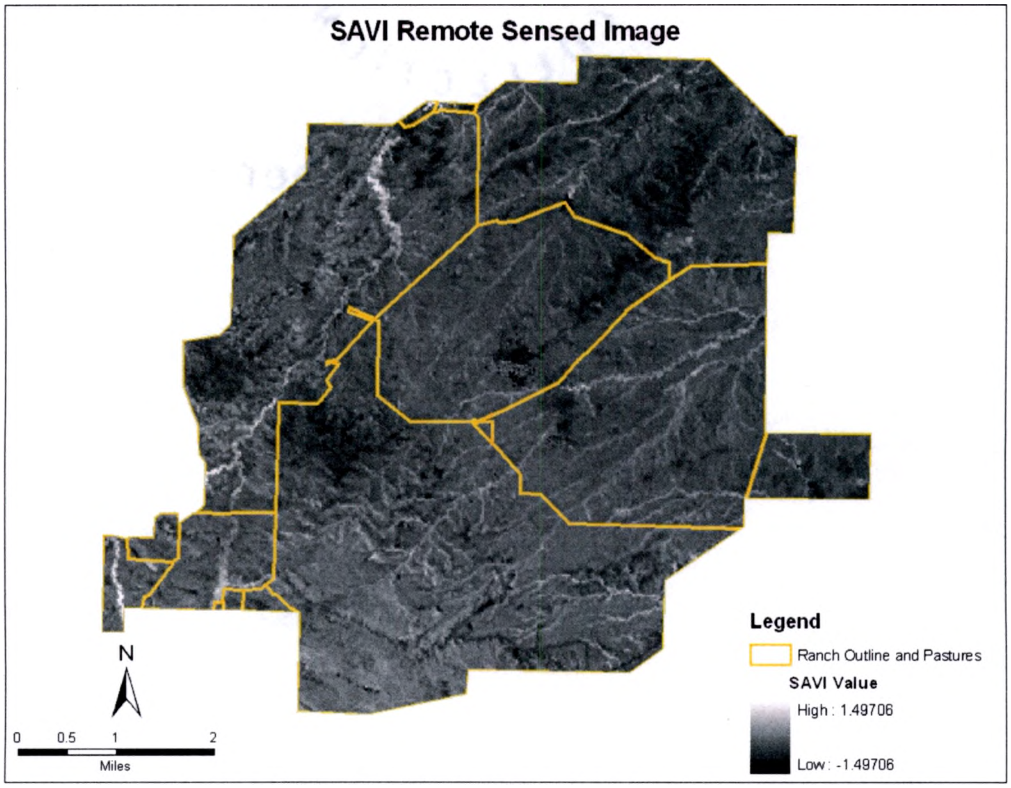

Figure 3. SAVI remote sensed image.

The imagery is the Landsat 7 Enhanced Thematic Mapper + remote sensed imagery. The path and row are 035 and 030 respectively, and the date of acquisition was June 3, 2004. The imagery was bought from the United States Geological Survey (USGS) and delivered on CD in the Fast-L7A format.

The final piece of data needed to begin the research was the NRCS SSURGO polygons (Figure 4).

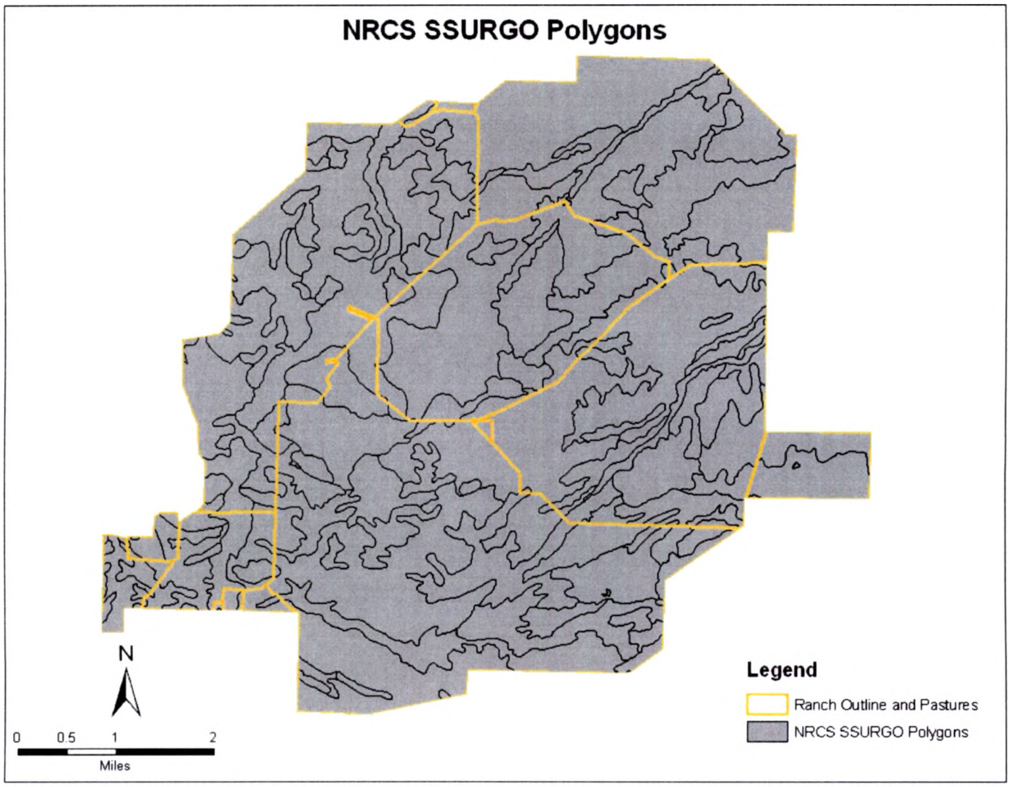

Figure 4. NRCS SSURGO polygons.

These are vector based 1:24,000 scale soil polygons which were downloaded by county from the NRCS's Soil Data Mart (NRCS, 2004). These polygons are known as range sites and are separated by what type of soil each range site contains. Each range site also has three fields in the attribute table listing the pounds per acre of forage for each polygon range site for a good years, normal years, and poor years. These categories are based on the amount of precipitation that the range has received in a year. The three fields were used in the calculations of the AUMs per range site which will be explained in greater detail in the data processing section.

Data Processing

After the raw data of the quality control points, the SAVI image, and the SSURGO polygons were gathered the processing of these data sets begins. From this processing four parameter datasets were created. They were an SAVI raster file showing the good, normal, and poor areas of grazing; and finally three SSURGO polygon datasets, these being a good soils shapefile, a normal soils shapefile, and a poor soils shapefile. Each of these three soil shapefiles pertains to the amount of AUMs per soil polygon based on the pounds of forage per range site field in the attribute table mentioned above. Instructions follow below of the processing steps to attain the four parameter datasets.

First, SAVI was calculated for every pixel in the imagery (Figure 3). This was done using the red and near infra-red bands, bands 3 and 4 respectively, where SAVI = (band 3 – band 4) / (band 3 + band 4 + L) * (1 + L). The L factor seen in the equation accounts for the reflectance of the soil as the study area is a clumpy grassland and bare soil is numerous (Guo et al. 1995). In this case the L factor used was 0.5 which is known to be a normal reflectance for bare soil. Finally the image was clipped to the ranch boundary with every 30 meter pixel in the image having a SAVI value between -1.47 which is poor vegetation, to 1.47 which is green healthy vegetation. A threshold was then developed based on the quality control points of the study area (Figure 2) where the points represented good, normal, or poor areas of grazing. Ten pixels were picked in a good, normal, and poor area of the ranch. The standard deviations of the SAVI values were found for each of the three categories. The good grazing category was between the highest SAVI value of 1.47 to one standard deviation above the mean of all SAVI values. The poor grazing category was between the lowest SAVI values of -1.47 to one standard deviation below the mean of all the SAVI values. Thus, the good grazing threshold ranged from 1.47 to 0.0182 SAVI values. The Poor threshold ranged from -1.47 to -0.8792. The normal threshold was all the other SAVI values in between the good and the bad grazing area thresholds. Finally the image was reclassified where good SAVI values = 3, normal SAVI values = 2, and poor SAVI values = 1.

The NRCS SSURGO data (Figure 4) provided the soil classifications used in the AUM model. Three copies of the SSURGO shapefile were made to represent the three categories of production mentioned above in the data sources sections. A Good_Soil shapefile, a Norm_Soil Shapefile, and a Poor_Soil Shapefile. Each of the attribute tables in the three shapefiles were manipulated to find out how much forage per pixel there was in each soil polygon with in the study area. This was done by adding fields to the attribute table and making simple calculations to get the forage per pounds per soil polygon down to AUMs per pixel per soil polygon.

There were several steps involved in preparing the SSURGO data to be used in the model. First, an acre field was added to the attribute tables and the acres per soil polygon were calculated using the area field in the shapefile that was in meters squared. Areas in acres were determined by multiplying the area in square meters by 0.0002471. Next a field was added called lbs_unit to store the available forage amounts per soil polygon unit. This was calculated by multiplying the acres by the original forage pounds per soil polygon that we started with in the data processing section. The next step was to figure out how many 30 x 30 meter pixels were in each soil polygon. There are 4.4965 pixels in one acre. With the acres per polygon calculated, a field was added to the attribute table called pixels and multiplying the acres by 4.4965 the pixels per polygon was calculated for each soil. Now that we know how many pixels per soil polygon there are a field was made called lbs_pixel which tells us how many pounds of forage per 30 meter pixel there are. This field was calculated by dividing the lbs_unit field by the number of pixels. Finally a field called AUM_pixel was created and calculated by dividing the lbs_pixel field by 780 which is how many pounds of forage equals 1 AUM. Figure 5, an example of the Good_Soils shapefile attribute table, shows the fields that were added to the three attribute tables

Attributes of Soils_Good

PRODFAV_I	F_AREA	Acres	lbs_unit	Pixels	lbs_pixel	AUM_pixel
2500	1036013.409	255.998913	639997.28375	1151.126011	555.975000	0.712788
700	1248.981579	0.308623	216.036344	1.387757	155.673000	0.199581
1400	6711861.545	1658.500988	2321901.38307	7457.623940	311.346000	0.399162
700	5011061.006	1238.233175	866763.222355	5567.845563	155.673000	0.199581
700	4176563.148	1032.028754	722420.127836	4640.625721	155.673000	0.199581
700	344846.8323	85.211652	59648.156596	383.163147	155.673000	0.199581
1400	1857774.106	459.055982	642678.374351	2064.193452	311.346000	0.399162
700	213848.3862	52.841936	36989.355367	237.609318	155.673000	0.199581
700	136608.3999	33.755936	23629.154940	151.787111	155.673000	0.199581
700	3719943.084	919.197936	643438.555302	4133.270094	155.673000	0.199581
700	1049311.526	259.284878	181499.414671	1165.901696	155.673000	0.199581
700	608519.2971	150.365118	105255.582822	676.132552	155.673000	0.199581
700	131670.3505	32.535744	22775.020532	146.300389	155.673000	0.199581
700	67702.04491	16.729175	11710.422709	75.224494	155.673000	0.199581
700	83622.93625	20.663228	14464.259285	92.914374	155.673000	0.199581
1400	250352.4421	61.862088	86606.923833	278.169380	311.346000	0.399162
700	284858.0945	70.388435	49271.904608	316.508994	155.673000	0.199581
1400	4963653.534	1226.518788	1717126.30389	5515.170594	311.346000	0.399162
1400	309300.5324	76.428162	106999.426183	343.667258	311.346000	0.399162
1400	4318071.795	1066.995541	1493793.7571	4797.857551	311.346000	0.399162
1400	9893.414348	2.444663	3422.527759	10.992683	311.346000	0.399162
1400	313027.9941	77.349217	108288.904305	347.808882	311.346000	0.399162
700	207977.5775	51.391259	35973.881583	231.086197	155.673000	0.199581
1400	1598284.440	394.936085	552910.519257	1775.871600	311.346000	0.399162
1400	201945.9938	49.900855	69861.197096	224.384438	311.346000	0.399162
1400	1318531.473	325.809127	456132.778039	1465.034971	311.346000	0.399162
1400	207844.3924	51.358349	71901.68912	230.938214	311.346000	0.399162
1400	1184607.526	292.716520	409803.127683	1316.230585	311.346000	0.399162

Record: 0 Show: All Selected Records (0 out of 95 Selected.) Options

Figure 5. Attribute table of soils_good polygon shapefile.

Once the remote sensed SAVI image was manipulate into a classified image of Good SAVI = 3, Norm SAVI = 2, and Poor SAVI = 1, and the NRCS SSURGO data obtained and separated into three shapefiles and the required fields calculated as stated above, the model was ready to be implemented. The model was built in ArcGIS 9's Model Builder which provides an easy to use platform that behaves and looks like a flow chart. The user builds the model by adding the parameter layers which in this case is the reclassified SAVI layer and the three SSURGO soil layers of Good, Norm, and Poor soils. Then it is simply a matter of using the appropriate tools to manipulate the parameter layers to get to the final raster of total AUMs.

The first step is to use the reclassify tool to reclassify the SAVI Raster into 3 dichotomous rasters. Where the first raster is classified with a 1 being equal to the Good SAVI values and all other SAVI values are equal to 0, the second SAVI Raster has a 1 being equal to the Normal SAVI values and all other SAVI values are equal to 0, and the final SAVI Raster has a 1 being equal to the Poor SAVI values and all other SAVI values being equal to 0. Thus after this first reclassifying step you have 3 SAVI rasters of Good_SAVI, Norm_SAVI, and Poor_SAVI respectively. Also in this step the three soil shapefiles need to be converted from features to raster using the feature to raster tool. Thus the Soil_Good shapefile is converted to the Good_Soil raster, the Soil_Norm shapefile is converted to the Norm_Soil raster, and the Soil_Poor shapefile converted to the Poor_Soil raster. Each of these shapefiles are converted based on the AUM_pixel field that was mentioned above in the DATA section. The second step is to multiply the respective rasters together using the single output map algebra tool. The Good_SAVI raster is multiplied by the Good_Soil raster, the Norm_SAVI raster is multiplied by the Norm_Soil raster, and the Poor_SAVI is multiplied by the Poor_Soil raster. Now there are three rasters called Good_AUM, Norm_AUM, and Poor_AUM. Each of these rasters shows the AUMs per pixel in each of the three SAVI thresholds that were developed earlier in the DATA section of this paper. The final step in the model is to sum these three rasters up to get the total AUMs for the entire study area. The single map algebra tool is used to sum the Good_AUM raster, the Norm_AUM raster, and the Poor_AUM raster to make a final 30 meter raster called Total_AUM which displays the AUMs per pixel for the entire study area. The AUM Tool process is diagrammed from the beginning to the end in Figure 6.

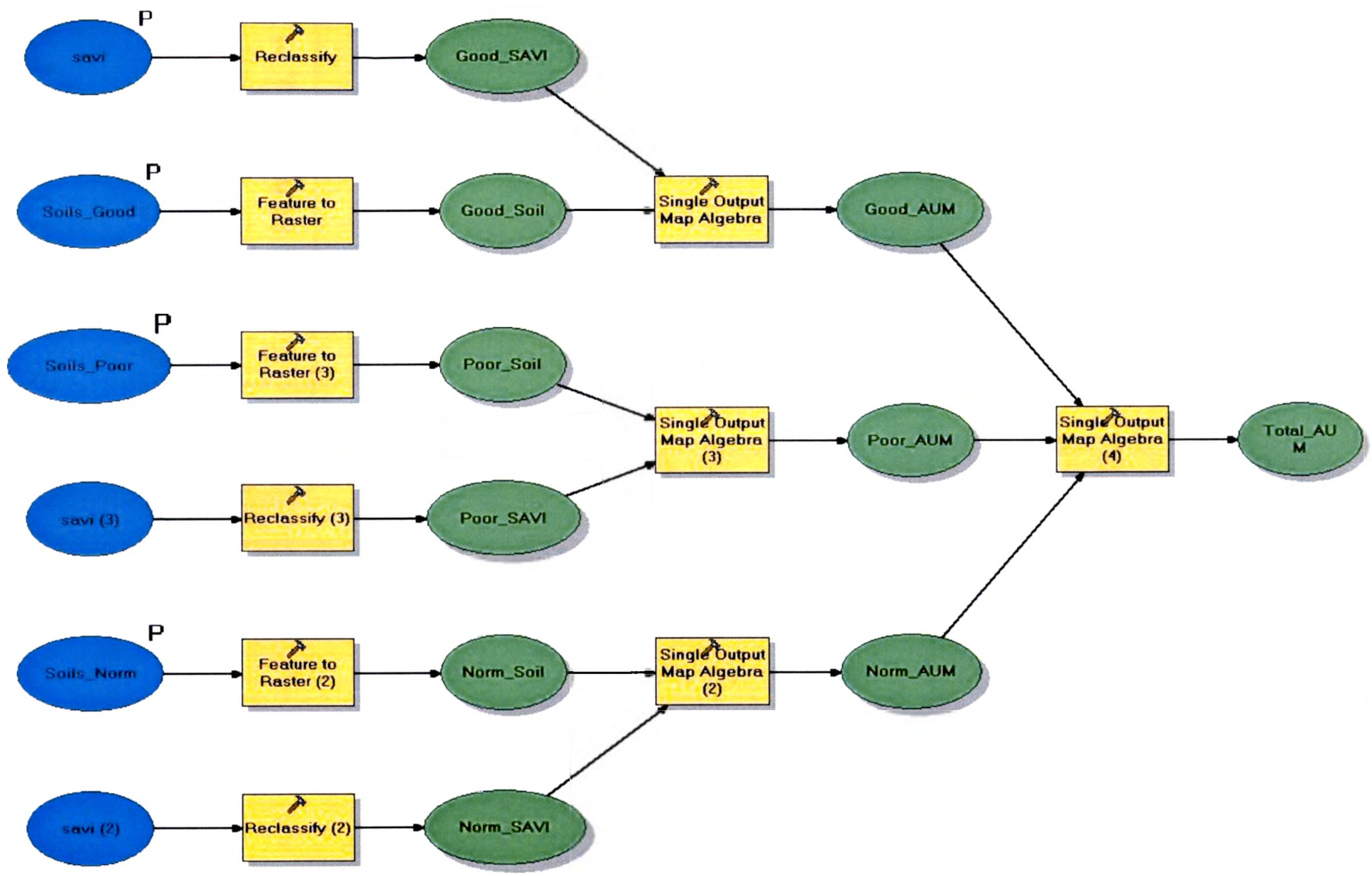

Figure 6. AUM model in ArcGIS 9 model builder

CHAPTER 5

RESULTS

The results of the model are a raster dataset that shows the AUMs per pixel for the entire ranch (Figure 7).

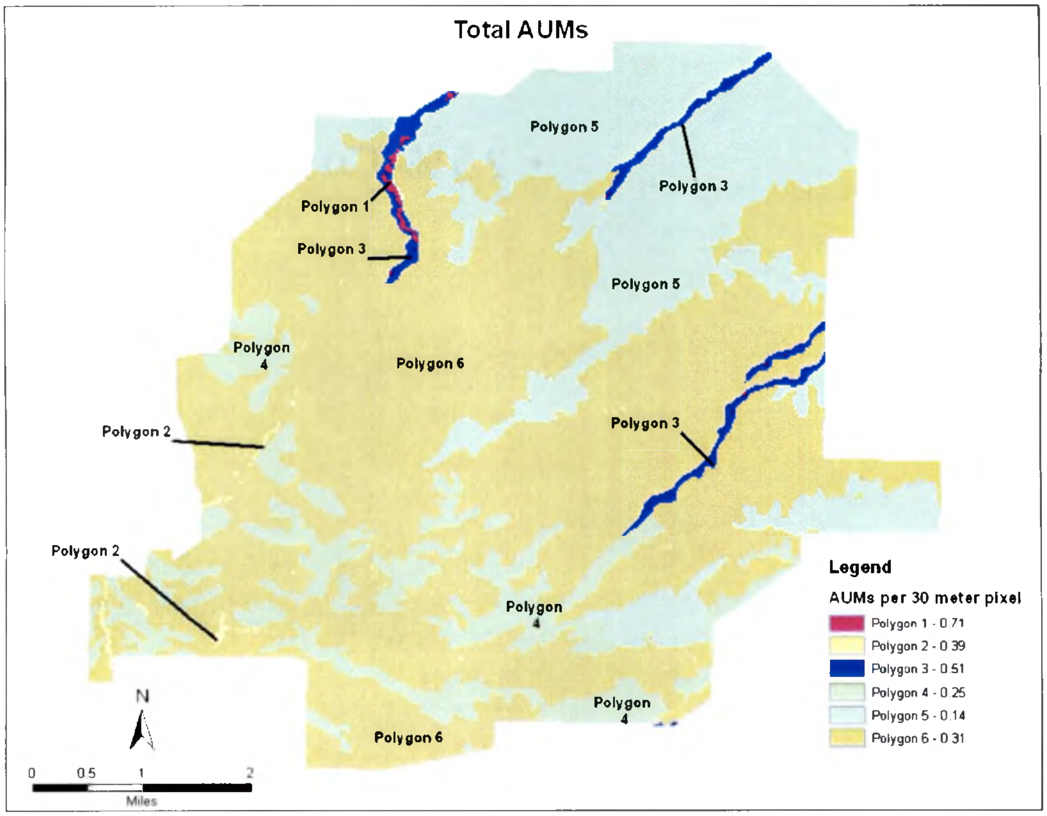

Figure 7. Total AUMs per pixel.

As seen in figure 7, the highest AUMs on the ranch occur along the streams and in the drainages where the highest amounts of moisture run off and accumulate. The AUMs decrease on the higher, windy plains of the ranch where moisture is scarce. Also the high AUMs correspond to the soils on the ranch as well. The high AUMs along the riparian areas correspond to the rich saline soil that are in those areas. The AUMs go down as the soil turns from saline, to loamy soils, and the AUMs are at their lowest where the soils are characterized as impervious clay soils. Table 2 lists the polygons shown in Figure 7 and their corresponding acres for each polygon, the AUMs per acre for each polygon, and finally the total AUMs that can be grazed in each polygon. The AUM/Acres field was calculated by multiplying the number of pixels in each polygon, which was listed in the attribute table of the Total_AUM raster, by the AUMs that the model calculated in Figure 7. As seen in Table 2, the model calculated that 21,820.2 AUMs per acre could be grazed on the ranch for the entire grazing year. That number can be broken further into how many AUMs) the ranch can graze per month on the entire ranch by dividing this number by 12. Thus the ranch can graze 1,818.35 AUMs per month based on June 2004 data.

Table 2 Summary of ranch carrying capacity

Polygon	Area in Acres	AUM/Acres	Total AUMs
1	35	3 1	108 5
2	68	1 2	81 6
3	375	2	750
4	2,367	1	2,367
5	4,932	0.5	2,466
6	13,463	1.2	16,155 60
		Total AUMs (Year)	**21,820.20**
		Total AUMs (Month)	**1,818.35**

Intermediate results of this model are the various raster datasets that are created during the process of executing the model. These raster datasets can be seen in Figure 6 colored in green ovals. Along with the final raster of Total_AUMs the model will also create raster datasets of Good_Soil, Good_SAVI, Normal_Soil, Normal_SAVI, and Poor_Soil, Poor_SAVI. These raster datasets are created in the process of running the model and can serve as useful datasets in other spatial analysis projects that may come up with the study site, such as examining more closely the soils and SAVI in their respective precipitation conditions of good, normal, and poor.

CHAPTER 6

DISCUSSION

Testing and Comparing the Model

This AUM model can be tested on other study sites by anyone who has access to the model parameters, the remote sensed imagery, the SSURGO data, and has ArcGIS 9 for their mapping software. Agencies such as the BLM, the NRCS, and the Forest Service, who have easy access to the parameters and use of ArcGIS 9 software, will be able to easily test and compare this model to the current methods and implement it if so desired.

When one compares the AUMs the model calculated, 1,818.35 AUMs per acre (Table 2.), with the number of AUMs the BLM allows the ranch to graze there is a discrepancy. The BLM allows for 354 AUMs to be grazed for the entire year on the ranch. This discrepancy may be explained in two ways.

One, the thresholding method that was used in this research is a qualitative approach. It was based on sound knowledge of good, normal, and poor grazing areas of the ranch, however it is not as accurate as a more quantitative approach might be. The thresholds of good, normal and poor were based on SAVI values in the remote sensed imagery as well as the good, normal, and poor forage amounts in the NRCS SSURGO dataset. These forage amounts were estimated using annual precipitation values the landscape receives. This value is not updated on a year to year basis. Thus since this research was conducted in the summer month of June 2004 the AUMs could be estimated either higher or lower depending on the SAVI values in the remote sensed imagery.

Two, as mentioned above this study was conducted in June 2004. The remote sensed imagery was taken during that month, and also the quality control points (Figure 2) were taken in June 2004. Precipitation during the months of April, May, and June tend to be the highest precipitation months of the year for the study area. Therefore, the SAVI values in the remote sensed imagery are higher than they would be for the other months of the year as the forage is healthier and greener. The time of year also affected the quality control points that were taken to come up with the threshold values mentioned in the methods section. Good areas of grazing that were observed in June may be normal areas of grazing in the months of August or September when precipitation amounts are much less. Also normal areas of grazing may be poor areas due to the same reason just mentioned. Therefore, it can be expected that higher AUMs would be calculated in the months that receive more precipitation and lower AUMs would be observed in the months of lower precipitation.

The agencies that calculate AUMs for ranchers calculate AUMs on a yearly basis and do not provide information on a month to month basis. This is one reason why this model can be useful as an efficient way of estimating AUMs for livestock producers. Range managers working for these agencies can help ranchers by simply running the model and have a quick estimate of how many animals the rancher can graze, either for one month or, if the data is available, for the entire year. This, as opposed to the old method where livestock operators may have to wait before agencies can send a range manager out in the field, cut the forage, dry it, weigh it, and estimate the AUMs. It is simple, easy to use, and easy to understand the output datasets. The final AUM raster, which is split up into categories of high to low AUMs, is a straight forward method of conveying information to non-GIS users. This is especially important as some livestock operators who may not have the background or GIS experience needed to decipher some complicated GIS datasets.

Thresholding Method of the Model

The research provides an accurate method for determining the total AUMs of a ranch while eliminating the process of having to acquire data through field work. This study however, hinges on the knowledge of the land owners and range managers in knowing the type of range and grazing areas of the ranch in question. This is where the thresholding has its role in the research. Knowledge of the ranch was needed to come up with sample sites of good grazing, normal grazing, and poor grazing areas (Figure 2). From these areas a mean and standard deviation was calculated and three thresholds were formed of good, normal, and poor grazing. The thresholds held true as the high AUMs were along the riparian zones and areas of low AUMs were along the uplands and bare areas of the ranch. This technique is a qualitative approach rather than a quantitative one in determining total AUMs. However, as long as good specific knowledge of the land can be obtained, thresholding is a very accurate method of statistical analysis. Saksa et. al. (2002) pointed out in their remote sensing study that thresholding and other unsupervised classification techniques give relatively good accuracy and give a very straightforward interpretation of the data. This holds true in this research as well, as the thresholding techniques gave very simple, straight forward categories of the SAVI values that were able to be used in the ArcGIS Model Builder to perform the raster analysis.

Alternative Method

A method that was explored in estimating AUMs on the ranch was to use a linear regression method. This involved retrieving forage data from the NRCS that had been collected through field work by cutting, drying, and weighing the grass clippings at certain points. The data came in the form of three polygon areas. Two of the polygons were calculated out to be 2,150 pounds of forage and the other 5,450 pounds of forage (Figure 8).

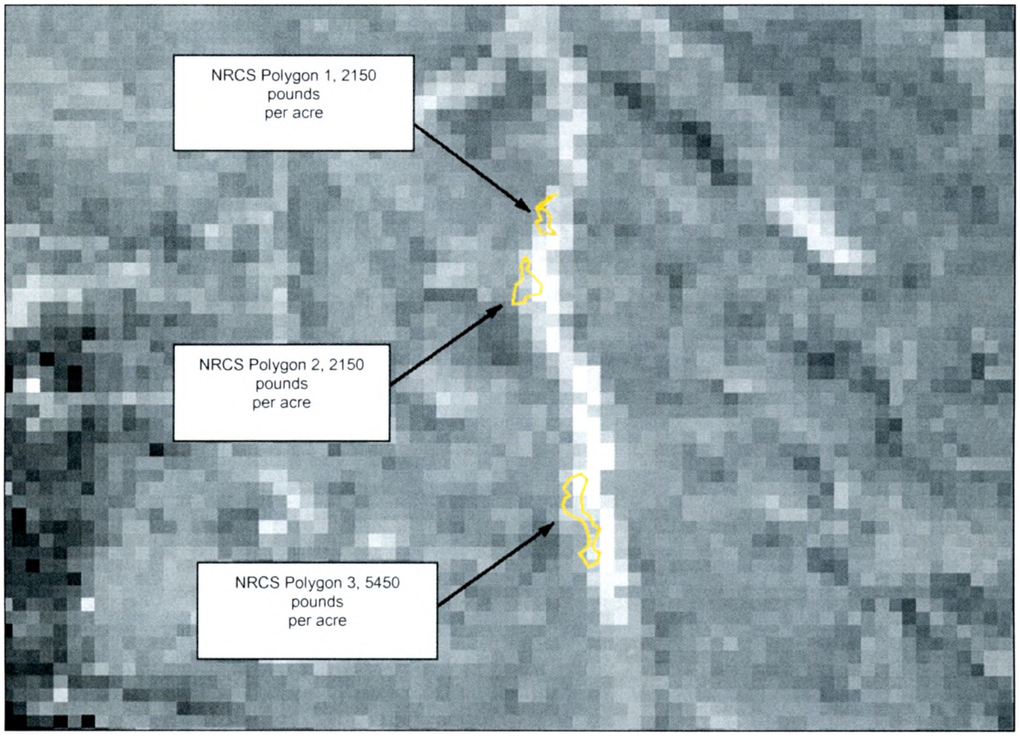

Figure 8. NRCS forage polygon data.

Once the three polygons were obtained they were over layed on top of the SAVI remote sensed image and the numbers of pixels that either fell completely within or intersected the polygons were counted. Then the forage per acre was calculated down to the forage per pixel level. A regression was then run between the SAVI values in the remote sensed image and the forage per pixel values inside the polygons to find any relationship between SAVI values and forage amounts per pixel.

There were several problems with this. First, as you notice from Figure 8 above, the three NRCS polygons were taken along a riparian stream area. This does not represent the entire ranch or a random sample. All of the SAVI values were on the higher end of the spectrum because the forage is greener and healthier along the streams banks. Another problem was the polygons were very small in size. Polygon 3 measured 1.5 acres and polygons 1 and 2 both measured approximately 0.5 acres. Consequently the number of pixels in each polygon was very low. Therefore there was little data to perform the linear regression between the SAVI values and the forage per pixel data with in the three polygons. Combine this with the fact the sample sights were not random through out the ranch and you have a relationship that was not significant. This type of spatial data collection proved to be the downside of this AUM calculation method.

CHAPTER 7

CONCLUSION

This research found the thresholding technique used in classifying the remote sensed imagery SAVI values were very reliable for the study area. The ArcGIS 9 model builder used the classified SAVI values and the NRCS SSURGO polygons to produce a final AUM raster which showed that approximately 1818.35 AUMs could be grazed on the ranch based on June 2004 data. This in comparison with the BLM estimation of 354 AUMs that can be grazed for the entire year on the ranch. This discrepancy exists, in part because the model used remote sensed imagery that was taken in a relatively wet time of the year in June 2004. Also the quality control points used in the research to help develop the areas of good, normal, and poor grazing were taken during the month of June 2004 as well. Thus, the model in this research looks only at a one month time on the ranch. Through field work of cutting, drying, and weighing the grass in the 2ft x 2ft diameter hoops that were mentioned in the background section, federal agencies estimate the carrying capacity of ranch for an entire grazing year. This may or may not be accurate as precipitation changes from month to month and the AUMs estimated in June, for example, are probably very different from the AUMs that would be estimated in the month of August. Therefore the model developed in this research may prove to be more accurate as it can be implemented whenever the user chooses based on the availability of data.

One advantage of this model is that one can implement an averaging process to estimate AUMs. The possibility being that a user could take AUM estimates of the wettest month and the driest month and average those together to come up with a long term AUM estimate of a ranch or pasture. The possibilities of the model are endless as they provide a more short range outlook at estimating AUMs, but data can still be averaged together to look at a long term estimation. The model also reduces the time and cost in sending range managers from federal agencies such to go out and complete field work. Ranchers do not have to wait for range managers to visit the study site, cut, dry and weigh the grass in order to determine the number of AUMs allowed to graze. Agencies can implement the model and quickly tell the livestock producers an estimate of the AUMs that can be safely grazed on the ranch without damage to the range itself. Users of the model are only hampered by how fast they can obtain the remote sensed imagery and the NRCS SSURGO polygons. As remote sensed imagery becomes more available, and various data becomes available on the internet, the ability to acquire and purchase the needed datasets will not be the issue as it once was.

REFERENCES

Biswas, Sujata, S. Sudhakar, and V.R. Desal. 2002. Remote sensing and geographic information system based approach for watershed conservation. *Journal of Surveying Engineering 17* (Aug): 108-124.

Center for GIS Towson University. 2004. Geospatial Data. Available from: http://chesapeake.towson.edu/remotesensing/ndvi.htm. Accessed Nov. 13, 2004.

Curtin, Charles. 2002. Livestock grazing, rest, and restoration in arid landscapes. *Journal of Conservation Biology* 16 (June): 840-842.

Chuenpagdee, Ratana, Julia Fraga, and Jorge Euan-Avila. 2004. Progressing toward co- management through participatory research. *Society and Natural Resources* 17 (Feb) 147-161.

Gaile, Gary L., and Cory J. Willmott. 2003. Geography in America at the dawn of the 21st century. Oxford University Press, New York.

Goodchild, Michael F. 1991. Keynote address at The Fourth International Symposium on Spatial Data Handling, Zurich, July 1990.

Guenther, Keith S., Glen E. Guenther, and Peggy S. Redick. 2000. Expected-use GIS maps. *Society for Range Management* 22 (April): 18-20.

Guo, Xulin., Kevin P. Price, and James M. Stiles. 2000. Modeling biophysical factors for grasslands in eastern Kansas using landsat TM data. Available from: http://www.kars.ku.edu/projects/epscor/Publications/Proceedings/ERIM00_Xulin.htm. Accessed Feb. 10, 2005

De Oliveira, Juliano Lopez, Fatima Pires, and Claudia Bauzer Medeiros. 1996. An environment for modeling and design of geographic applications. *Geoinformatica* 1 (1997): 29-58.

Meine, Curt. 2001. Roosevelt, conservation, and the revival of democracy *Conservation Biology* 15 (2001): 829.

Rasmussen, M. S., R. James, T. Adiyasuren, P. Khishgsuren, B. Naranchimeg, R. Gankhuyag, and B. Baasanjargal. 1999. Supporting Mongolian pastoralists by using GIS to identify grazing limitations and opportunities from livestock census and remote sensing data. *GeoJournal* 47 (1999): 563-571.

Reeves, Mathew C., Jerome C. Winslow, and Steven R. Running. 2000. Mapping weekly rangeland vegetation productivity using MODIS algorithms. *Journal of Range Management 54* (March): A90-A105.

Ritchie, Jerry C., Mark S. Seyfried, Mark, J. Chopping, and Yakov Pachepsky. 2000. Airborne laser technology for measuring rangeland conditions. *Journal of Range Management* 54 (March): A8-A21.

Royal, Kevin. 2000. Decision support systems for precision ranching. Journal on-line. Available from: http://www.microimages.com. Accessed March 7, 2004.

Ruyle, George, Phil Ogden. 1993. What is an A.U.M.? *Journal of Range Management* 26 (May): A1-A4.

Stelljes, Kathryn B. 1995. Rangeland can improve with grazing. *Agricultural Research* 43 (9): 15.

Tanner, George W. 1999. Determining grazing capacity for native range. University of Florida Cooperative Extension Service. Available from: http://edis.ifas.ufl.edu. Accessed March 7, 2004.

Timo Saksa, Janne Uuttera, Taneli Kolstro, Mikko Lehikoinen, Anssi Pekkarinein, and Vesa Sarvi. 2002. Clear-cut detection in boreal forest aided by remote sensing. *Scandinavian Journal of Forest Research* 18: 2003.

Tyson, Ben, Tom Worthley, Kim Danley. 2004. Layering natural resource and human resource data for planning watershed conservation strategies. *Society & Natural resources*, 17 (Feb) 2: 163-170

Tueller, Paul T. 2000. Remote sensing of range production and utilization. *Journal of Range Management 54* (March) A77-A89.

University Consortium for Geographic Information Science. 2004. Accessed from: http://www.ucgis.org. Accessed December 4, 2004.

Weltz, Mark A., Jean Reeder, Gary Frasier. 2003. Ecological sustainability of rangelands. *Arid Land Research and Management* 17 (4): 369-388.

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