FORAGE ANALYSIS TARGETING:

A PRACTICAL TECHNIQUE FOR FORAGE SURVEY SAMPLE SITE SELECTION

THESIS

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CHAPTER 1

INTRODUCTION

Overview

In 1963, Shoop and McIlvain (1963, 172) wrote, "Of all the measurements used in range research and range administration, none has been so difficult and expensive to obtain and none so sorely needed for correct decision-making as *weight* of forage per acre." In 1990, Vallentine (1990, 330) noted, "Determining the grazing capacity of grazing lands is one of the most difficult tasks in grazing management." And still, in 2004, Holechek, Pieper and Herbel (2004, 194) maintain, "Determination of grazing capacity remains one of the biggest problems in managing rangelands." There are a number of reasons why this is so difficult; annual and monthly precipitation variability, vegetation variability both spatially and temporally, the widely varying survey techniques used to evaluate forage supply and demand and the time, cost and expertise required to execute scientific vegetation and utilization surveys (Holechek et al. 2004). Establishing grazing capacity, the amount of forage available to livestock for a given area and time, is key in establishing stocking rate. Overly conservative stocking rates fail to achieve optimal productive use of the range, but stocking rates that are too high can degrade the range, thus limiting future productivity of the resource.

There are a number of contemporary, quantitative techniques for establishing stocking rate, but a measure of current forage standing crop is central to all (Holecheck 1988, Lyons and Machen 2001). Forage survey techniques and vegetation mapping methods are the subject of extensive scientific research, particularly in ecology, and the literature places the primary emphasis on producing accurate, statistically unbiased measures of vegetation often with a corresponding measure of uncertainty (Tueller 1988, Bonham 1989, Stein and Ettema 2003). Forage survey techniques in the range management literature draw from ecology and vegetation mapping but attempt to address the time and cost associated with measuring forage inventory primarily through increasing the time efficiency for *in situ* procedures (Shoop and McIlvain 1963, Anderson and Currier 1973, White and Richardson 1995). The most common techniques in range science involve double sampling with ocular and clipped observations. These techniques are reported to be fairly accurate and are employed in range science research, but they fail to address the real problem facing operational graziers. It is not the time required for a single measurement that is important, it is the number of sites required for an unbiased survey and the associated travel time to reach sample sites. Although procedures exist for statistically determining the number of samples required (Bonham 1989, Stein and Ettema 2003, White and Richardson 1995), these techniques are more commonly used in range research than in practice. In a very large range environment, the operator requires a timely estimate of current forage supply for planning. It is implicit that actual grazing will be continuously monitored and adjusted as required. Simply put, the cost to execute a scientifically valid forage survey is more than most operations are willing to bear.

Statement of Problem

Although an unbiased measure of vegetation is important, there are also practical constraints that limit how a forage survey is executed. Given limited resources, where should samples be taken? Management can decide which pastures should be included, but where in each pasture should a sample be taken? It is intuitive to try to measure in the most representative area of the pasture, but where is that area? How is the pasture utilized by grazing animals? Where are the various regions of homogenous forage? How does each area contribute to the total available forage in the pasture? How should these areas be prioritized? Once sample locations are selected, how long will it take to execute the survey? Are there some locations that should not be included because of cost? Are there others that should be included no matter the cost? These are all very important, yet complicated questions, but questions that can be addressed using spatial analysis.

Geographic Information Systems (GIS) are well suited to model these types of constraints and factors and to provide information that can allow management to make planning decisions. This project assembles a systematic, justifiable, repeatable and optimized process for determining where to sample forage for use in rangeland management that accommodates the requirements of the grazing capacity decision process but also management constraints. By assemble it is implied that the techniques and procedures used are drawn or adapted from the literature. Systematic, justifiable and repeatable mean the process has a formal structure that can be substantiated from accepted techniques and can be implemented or executed to produce the same results given the same inputs. Optimized connotes that the process includes a degree of parameterization that allows the user to choose the relative importance of one or more constraints so that the output reflects these management preferences. The process output informs the grazing management function by providing a prioritized list of forage sample points along with an estimate of cost to execute the survey. This technique is different from traditional vegetation mapping in that it changes the question from "where must be sampled" to "where are you willing to sample" and "at what cost."

From a practical perspective, where to sample is a very important question because it has a profound impact on the amount of effort required to perform the survey. A substantial amount of range management literature addresses the effort required to take each sample, but when large areas are involved, the real time is not consumed taking the sample, rather it is spent moving from sample location to sample location. It matters little whether sample collection takes four minutes or thirty seconds if it takes thirty-five minutes to get to the location. In fact, some might argue that a thirty-second sample is less justified than a four minute one as a ratio of sample time to travel time.

If one is willing to accept that there are certain practical constraints on where samples can be taken, then allocating locations based on these constraints can be systematic, justifiable, and repeatable. It also facilitates planning to the extent that the total cost of the survey can be limited by selecting fewer sample locations or only the most important locations. Perhaps the most important aspect of this technique is that it provides an explicit way to select sample locations but also a means for recording the decision and decision criteria for selecting locations, a critical step in any business decision.

In practice, many forage surveys are performed by driving or riding around and observing the range. The technique described here helps guide that process by setting priorities and providing a structure for selecting sites. It uses spatial considerations as well as management discretion in deciding where to sample. This research demonstrates how GIS can be useful in providing a platform to facilitate quantitative decision-making. It should be noted that this technique produces a highly biased forage survey result, but an unbiased result is not the intention. The goal of this technique is to assist in the difficult process of planning and managing forage surveys. It should be mentioned that this technique does not address the actual sampling field method but only the location for sampling.

Document Structure

This project employed an iterative approach where processes were refined through each iteration. Each trial builds on the previous results and issues discovered in each trial were resolved to the extent possible prior to the next trial. Because each iteration builds on information from the previous, the work is presented chronologically.

First, the general methods of data collection and preparation are presented so that the stage is set for each iteration. Next, the first trial is presented along with results. The second trial, along with results, is presented next, followed by the third trial. The third trial marks a shift from requirements determination and problem analysis to actual model construction. It is in trial three where the full-blown raster GIS model is assembled. The third trial includes more specific information about the model, how it works, and limitations along with the information products it produces and how they can be interpreted. The final section includes model performance evaluation and conclusions.

CHAPTER 2

METHODS

Study Area

This study was executed in cooperation with a commercial ranching operation. The requirements reflect the priorities and concerns of the management of that operation. The study area for Trials 1 and 2 included two non-contiguous range extents located in west Texas. The western extent of more than thirty thousand acres is located in the Davis Mountains and includes a single ranch characterized by primarily Igneous Hill & Mountain, Deep Upland, and Gravelly range sites. The eastern extent of more than 100 thousand acres includes slightly more diversity in range sites including approximately 37% Igneous Hill & Mountain, 21% Clay Flat, 12% Loamy, 10% Foothill Slope, 9% Limestone Hill & Mountain, 6% Draw, 4% Gravelly and1% Deep Upland range sites. Combined, there are approximately 105 grazing units, also called pastures, about thirty of which are comparatively small in size and are considered temporary holding areas or traps.

Trial 3 was conducted on a much smaller ranch of more than two thousand acres located in central Texas. Although the ranch is smaller in size, it exhibits more than a dozen range site types and substantial diversity of range site types within each pasture.

Obviously the types of forages and forage capacity are very different from those in Trials 1 and 2, but the way in which the forage survey is executed is very similar.
The term "Forage Analysis Targeting," or simply FAT, is coined to describe the processes used in this study. It serves the role of a traditional, seasonal forage inventory, but uses spatial data and analysis. FAT consists of a repository of spatial data, a number of constraints and parameter values, the processing steps representing the analysis and the output that provides the information to be used in decision-making. During the first trial, emphasis was placed on identifying areas, termed FAT Areas, in which to sample. Preliminary evaluation looked at the ratio of FAT Area to total area as an indicator of effectiveness. In Trial 1, the area allocated to FAT Areas remained quite high relative to the total area. From a practical perspective, area is not as important as identifying navigable destinations, so FAT Points were used to mark destinations within an area to be sampled for the subsequent two trials. A path over connected road segments that connects FAT Points is called a FAT Route.

Units of measure used in this document are consistent with source data, the pertinent literature, or projected coordinate system units. For example, pounds forage per acre is a commonly used measure of forage and distances are often stated in statute miles or feet.

Development Cycle

Just as no great work of literature is created without revision, no project is complete without some fine-tuning. With this concept in mind, the study follows the cycle identified below.

Gather Requirements and Constraints

The first step in the FAT process includes enumerating management requirements, rules and constraints that define where sampling should or should not occur. During each trial, requirements changed slightly and constraints were adjusted. Examination of these constraints revealed the spatial data requirements, which changed only slightly from trial to trial.

Data Collection

Based on requirements and constraints, spatial and non-spatial datasets are identified that can be used to satisfy requirements. Many of the datasets were already contained in the ranch spatial data repository. Datasets used include:

- Roads (a combination of 2000 Census roads along with GPS collected roads)
- Grazing Unit Boundaries or *Pastures* (collected from GPS coordinates and digitized from digital orthoimagery)
- Water Features (primarily collected from GPS or imagery) The important features include sources of water for livestock, specifically water troughs
- Soils and Range sites (Soil Conservation Service – digital datasets derived from vegetation mapping published around 1970)
- Digital Elevation Model (DEM) – Digital data provided by the USGS from digitized topographic maps

Geographic Information Processing

Some of the source datasets require preliminary processing to provide derived information. A good example is that of percent slope derived from the DEM. These datasets are created from standardized procedures that are common in most GISs.

Derived datasets include:

- Percent Slope
- Water Buffers -- created by computing buffers around water features and constraining the buffers to pasture boundaries, a second buffer operation is used to remove areas near the source of water creating a donut shaped buffer

- Usable Acres -- created from the intersection of the water buffers and areas with percent slope less than 20%
- Routes -- selected manually from the roads layer based on expert knowledge of the area
- Range sites -- the geometric intersection of the range sites and pastures layers

In this step, datasets representing various constraints, like the intersection of usable area, pastures and range sites are overlain and the result provides feasible areas in which measurements can be made.

Point Selection

Point selection involves identifying specific points within the feasible areas that best match the criteria to be used as targets during the survey. For the initial two iterations, these points were selected manually based on certain rules. These rules are implemented in an automated way in Trial three.

Test the results

The results of the analysis are tested in the field to determine their usefulness. Any issues or problems or additional constraints are documented.

Revise

Notes from each trial are analyzed and used to adjust requirements and constraints. The process iterates.

The first two trials, completed at the end of 2003 and the beginning of 2004, were primarily concerned with defining requirements and how to present the results, whereas the third trial used the refined requirements and focused on automation and the modeling process.

CHAPTER 3

FAT SURVEY RESULTS AND ANALYSIS

FAT Survey Trial 1

Requirements

The objective of FAT (Forage Analysis Targeting) is to identify regions, subsequently points, and finally routes that serve as a starting point for selecting forage analysis sampling locations. Forage survey and vegetation mapping protocols determine "what and how" to measure, while FAT uses spatial analysis to help identify "where" to measure and "how to get to where" to measure. FAT Trial 1 was intended to support Forage Analysis by constraining the total area that could be sampled during forage analysis to accessible regions that are most representative of usable grazing areas and the shortest path route among the points. Initially, FAT was a constraint-based process but by trial 3 had evolved into a weighted surface process.

The initial constraints for this prototype were derived from McGinty and White (1998). These constraints are indicated by an "a." The document outlines how and where to implement a range condition repeat photography program. Although the article is intended for use in range condition and trend monitoring, many of the constraints are equally applicable under the forage assessment scenario. Additional constrains, particularly parameter values, were derived based on ranch management request, indicated by a "b." The constraints are listed below.

Within Usable Acres (a)

Usable acres means the extent of range that is actually able to be grazed by livestock. There are many factors involved in this, but in this model, it is assumed the information provided for this constraint is accurate. The determinants of usable acres includes areas with slope less than 20%, within 1 mile of water, but other criteria may also be included, like the exclusion of burned areas or other unsuitable extents.

NOT within a quarter mile (402m) of a water source (trough) (a,b)

Because of excessive livestock traffic near watering points, these regions should be excluded.

Within 300 yards (274m) of a ranch road (a,b)

This is a practical constraint that makes sampling more time efficient. While it is possible that better points exist, if they are not accessible, then the potential sample sites are, from a practical standpoint, irrelevant.

Within each significant range site in each pasture (a,b)

Target areas need to be defined within each major range site within the usable area of each pasture so that samples reflecting the pasture range site composition can be collected. In the prototype, any range site that makes up at least 15% of the total usable area of a pasture is included.

Including specific target areas (a)

Other target areas might include sensitive areas or areas of known concern. Since these may not be included within the spatial constraints, they should be addressed separately. In FAT Trial 1, there are no additional sites.

The intersection of the constraint set provided FAT Areas. In the prototype, any location within a FAT Area was considered equally important as any other location with the area. The process of allocating FAT Points for sampling in this prototype was manual but generally guided by the following rules:

- Points must fall within FAT Areas.
- FAT Routes should follow "established" ranch routes and entry and exit points.
- At least one point should be allocated to each primary range site within each pasture.
- Larger pastures should have more points.
- More diverse pastures (greater number of range sites) should have more points.
- Larger extents of range site should have more points, but the points should be distributed across the range site extent.
- Points should be located near the road.
- Points should be co-located with range condition sampling sites if possible.

Figure 1 shows a sample of the results of FAT Trial 1. Red, dotted areas identify FAT Areas and FAT Points are marked with red "target" symbols. The FAT Route is shown in dark pink. Range sites are depicted only in usable areas. The map identifies a large number of FAT Points from which the user can choose to measure.

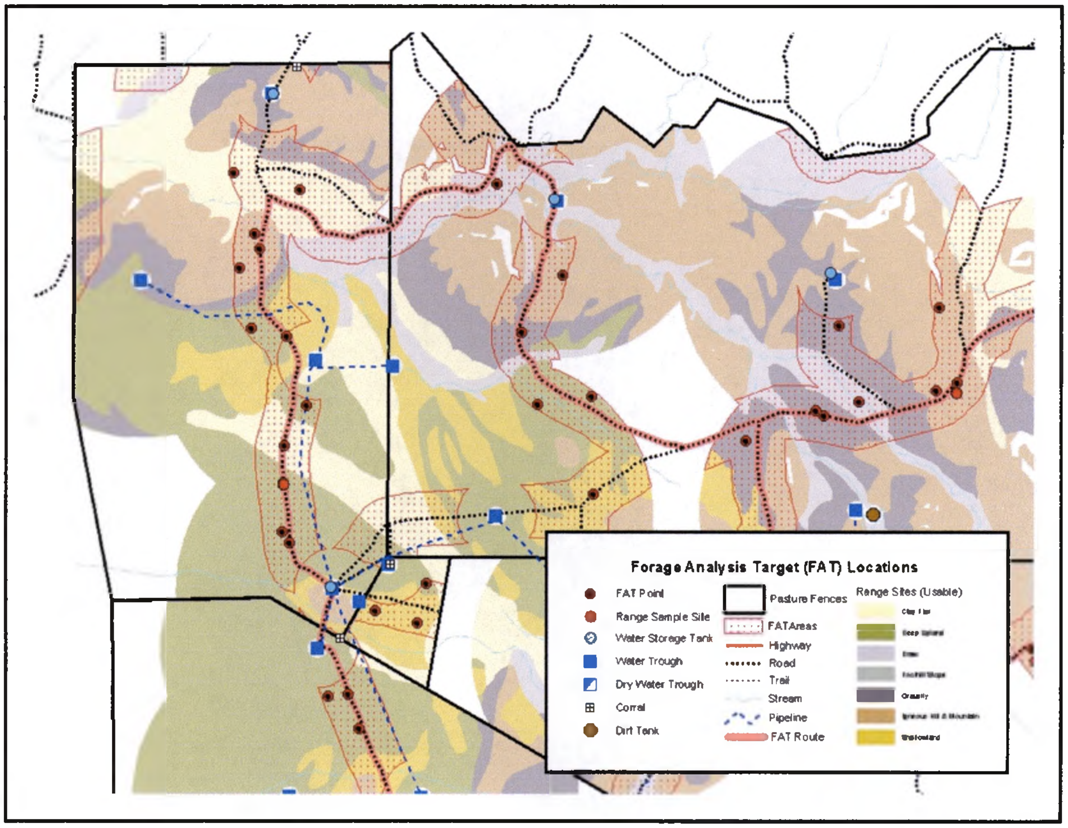

Figure 1: FAT Trial 1 Map

Results

A number of issues were discovered during FAT Trial 1. Although a range site may be a large component in terms of area, it may not make a large contribution in terms of forage production. For example, the forage production capacity of a 1,000-acre range site capable of 300 pounds per acre is the same as only 136 acres of a range site producing 2,200 pounds per acre. Following this line of reasoning, perhaps the proportion of production capacity, in terms of pounds per acre, should be used instead of area to determine the primary range sites.

Usable acres is yet another complex issue. There may be a number of reasons for an area to be considered unusable including the lack of a nearby source of water, excessive slope, brush coverage, recent burned areas and so on. Rather than explicitly considering each individual reason in the FAT process, the Usable Acres layer is considered to be a composite layer made available from an external source to be used in the FAT process.

Because of the inconsistency of soil and range site data across counties, there is a relatively high degree of uncertainty with respect to the actual forage capability of any given range site. This could cause a substantial amount of error in selecting priorities for sampling.

The boundaries in the range site layer may not be very accurate. In order to ensure that target points are within the appropriate range site, sample points should be allocated more towards the middle of the extent rather than near a boundary.

In general, location analysis techniques like spatial interaction modeling, and transportation techniques like network optimization may shed insight into this problem.

In Trial 1, only a limited number of spatial constraints were used to help define FAT Areas. The constraints were valid, but the parameter values and priorities needed to be adjusted, for example, restricting a measurement because of proximity to water is valid, but the specific distance from water may need to change. Perhaps the most important practical aspect is the ease with which points or target areas can be accessed. The suggested starting point for the subsequent trial was selecting common routes, routes that operators must use to check sources of water, fences and livestock. FAT Points could have been allocated along the route to the extent possible to facilitate easy sampling. Alternatively, many FAT Points could have been allocated and local expertise made to rate the points in terms of accessibility to provide a less biased approach. It would have allowed the person with local knowledge to "pick one" from a list of possible targets because it is easy to reach. However, too many extraneous points complicate the map and cause a great deal of ambiguity. Rather than marking all possible locations, a better strategy was to mark only the most important locations. The concept of usable acres remained the same. The number and priority of sample points based on pasture range site composition was possible, however, this had to be balanced with accessibility and practicality. Possibilities included an area threshold, for example, one point per 1,000 acres, or one point per square mile, or a graduated scheme like one point up to 700 acres, two points up to 2,000 acres, three points up to 4,500 acres, and so on. The production capability of each range site would remain an open issue for Trial 2.

FAT Survey Trial 2

Requirements

The objectives of Forage Analysis Targeting Trial 2 were largely the same as Trial 1 and many of the constraints remained the same in Trial 2. The changes to requirements are listed below.

Not within approximately 100 yards (100m) of a water source (water trough or tank)

This distance was relaxed for practical purposes. The area around a water source increases exponentially with the distance from the watering. This means a small increase in distance substantially increases the constraint area. In practice, 100 yards is probably enough area to minimize the effects of trampling on the forage near water sources. This parameter value was adjusted primarily due to management discretion.

Located on a FAT Route

In this trial, accessibility from the road was the primary constraint. Pre-defined routes that traverse each pasture were established based on expert knowledge of the site. These routes were modeled after the paths that are traveled for day-to-day ranch operations. FAT Points were located along these routes.

The results of this analysis yielded FAT Points along the selected route to identify where to start looking for a sample location. The points were manually allocated according to the following rules:

- Allocate number of points based on size of the usable range site extent.
- Allocate points relatively evenly over route segments through range sites.
- Allocate points near sample locations used for long-term range condition monitoring.

The points were loaded into a GPS for easy navigation. Printed maps were also produced depicting the containing range site type, percentage of total and usable area, range condition score and trend along with other information.

Figure 2, below, depicts a portion of a map produced for FAT trial 2. FAT symbology is consistent with Trial 1, but FAT Areas are not included. The range site composition of each pasture was shown to provide guidance in prioritizing FAT Points. Substantially fewer FAT Points were allocated to reduce confusion about where to measure. Only the best points were shown so that the user can more easily understand what was to be measured while in the vicinity of each point.

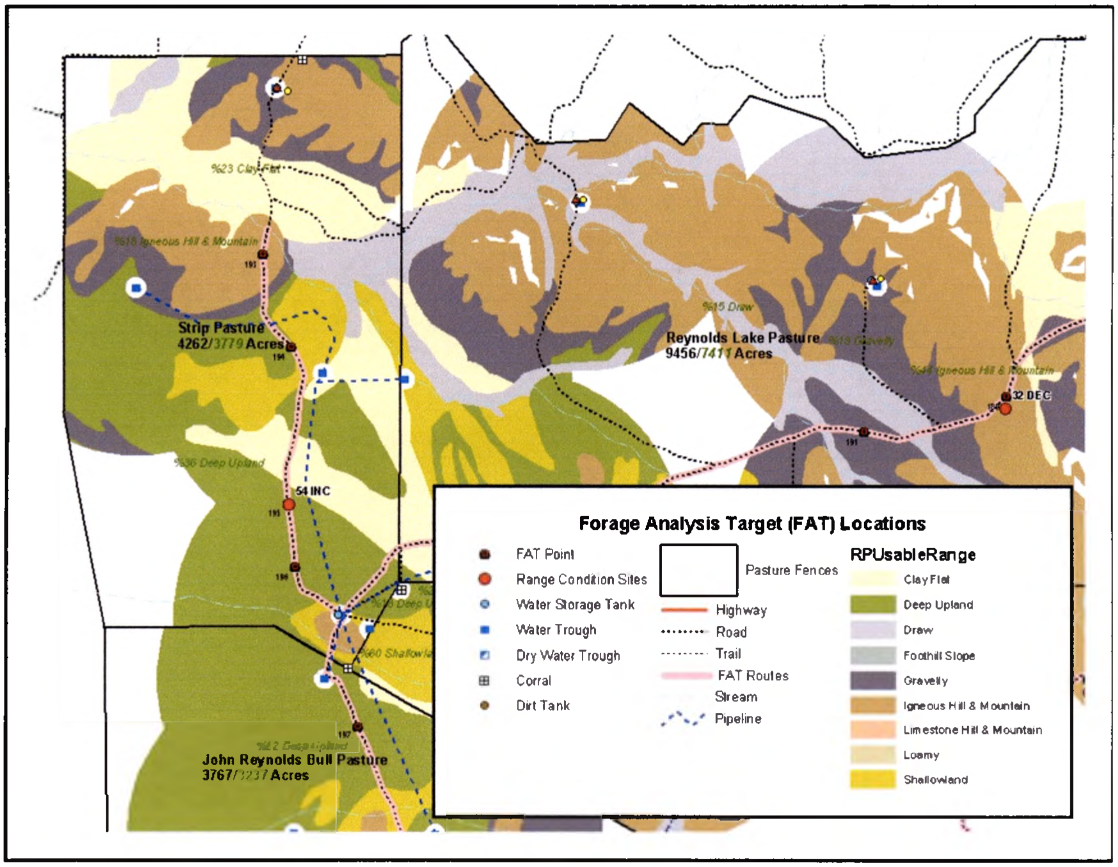

Figure 2: FAT Trial 2 Map

Results

FAT Points proved to be difficult to use, primarily because of the difficulty in finding exact points, but also because the points often conflicted with what was seen in the field.

For example, if a specific FAT Point was not representative of the area it is supposed to measure then it was ignored. The need to revert to FAT Areas but viewed in a different light seemed obvious. Once again, expert opinion and "trained eyes" played a very important role in the process supporting the idea that user discretion is required in the field. The route-based approach worked extremely well, but relied on high quality road data.

Trial 2 highlighted the need to identify regions of similarity in range, meaning areas that have or should have similar forage quality (plant mix) and quantity characteristics, and to provide an even better way to represent the location of the observer relative to each region. It was critical, particularly with respect to the regions, to be able to depict when a new region had been entered and how long the observer would be in that region. In the field, the observer is mentally integrating that which is seen in the region to develop a single estimate that is representative of the region. The number of individual samples that might need to be taken to achieve this level of integration may be so time consuming as to render the technique useless. Also, Trial 2 highlighted the need to be able to adjust observations based on factors in the field. Originally, areas of bare ground, brush or rock were to be included as constraints in the Usable Area layer. In practice, discretion for assigning a local percent usable in each region should be provided to the observer. This is good because most of the techniques that might be used to accommodate these constraints (that are economically feasible) would rely on remote sensing techniques that may not provide the required resolution .

Points are important, but identification of areas that represent homogenous forage regions is also important. Location awareness relative to these regions is critical and must be addressed. A field method quicker than sampling needs be found that can accommodate the benefits of "expert opinion." An estimation of the relative importance of each target needs to be established.

CHAPTER 4

FAT SURVEY TRIAL 3

Overview

The first two FAT Survey trials were geared towards refining practical requirements and how the results should be depicted. The third trial more deeply investigates the refined requirements and uses experience from the prior trials to refine and automate the process and output. Trial 3 moves from a vector overlay process to a raster GIS modeling process. The objective of the model is to produce an optimal set of points that identify where to take forage measurements and routes providing guidance on the most expedient way to get to those points. In so doing, the model also produced a number of products that are meaningful within the context of the forage survey process but also in other decision-making processes.

A number of high-level issues were revealed in the initial trials. First, there was some ambiguity about whether FAT Areas or FAT Points are the real result of the process. The process should identify important places to measure, but each point represents an area that is considered to be relatively homogenous. However, it is difficult, in practice, to navigate to a destination that is an area. A point is a good representation of a destination. In the third trial, specific emphasis is placed on the significance of the FAT Point as a navigable destination and the FAT Area as the entity to be measured. Second, it is important that the FAT technique be justifiable, so FAT Trial 3 pays greater attention to literature regarding specific constraint parameters. Third, the FAT process was initially developed to support an actual forage survey, so specific sampling methodologies are considered. In FAT Trial 3, field methods for sampling are ignored and the focus is on location selection. Sampling methodology is beyond the scope of FAT Trial 3. Fourth, the results of the process provide a degree of prioritization. The initial trials provided a binary result, for example in Trial 1, FAT Areas bounding regions suitable for measurement and in Trial 2, simply targets around which measurements might be taken. To be of greater use, the model developed for FAT Trial 3 explicitly includes prioritization. Fifth, and related to the first point, the results and how they should be depicted and interpreted are critical. This must be very clear for the process to be useful. Trial 3 produces standard products from the analysis for which techniques of interpretation can be established. Sixth, the process should be substantially automated. Automation serves two goals; 1) that the user can easily perform the analysis, and 2) that the user can repeat processing to consider different constraint parameters, using the system for scenario assessment. Finally, the results should be validated so that some sort of measure of effectiveness can be determined. A few measures of effectiveness have been mentioned, but a specific validation technique must be defined. With these principles in mind, the next sections define the revised requirements and the model components.

Spatial Data Representation

It is important to address the issue of spatial data representation particularly in light of the need to prioritize FAT targets. FAT Trials 1 and 2 use vector data and processing which is particularly well suited to spatial overlay functions and other geometric or topological operations. It is also the format of the majority of the original datasets in use for the project. Continuous field representations are useful when there is a relationship among data layers that is consistent over space or a concept whose value varies continuously over space (Burrough and McDonnell 1998). The need to prioritize where to sample is manifested in two ways; in selecting the importance of regions within pastures or pastures within the ranch, but also where within each region to sample. Two possible techniques could be used to implement the later form of prioritization. The first technique, spatial interaction modeling, is a way of assigning interaction functions between objects in such a way as to predict the location of some phenomenon. These techniques are heavily used in transportation and location analysis to help determine optimum locations for stores, services, transit stations, advertising, roads and so on. The down side to many of these techniques is that they often seek to optimize a location but provide less information about sub-optimal locations. Another major problem is that of aggregation, assigning to a representative point the information over an area. Picking the correct point is quite difficult. The second technique, a surface-based approach, assumes that some variable exists throughout space, but the value may be different everywhere. Temperature is a good example. Temperature exists everywhere, but the value of temperature may vary from location to location. If it is assumed that the concept of measurement priority exists everywhere and the value of this variable can be modeled, then the result is a very useful map, a FAT Surface, that not only depicts areas with the highest priority but also the priority at less than optimal locations. The benefit of this is that even if process-generated points are not actually used, the user can use the surface to aid in the decision making process.

The Model

FAT Trial 3 employs a raster GIS model. The model actually consists of a number of sub-models, each of which is controlled by the user. Based on user input, the sub-models interact to produce a number of work products. The two primary outputs are the location of FAT Points and FAT Routes. Other outputs include various views of the target area that might be helpful in making decisions about where to sample. In addition, these products may also inform a number of other decisions.

The general model consists of a slope usability model, a water usability model, a forage capacity model, a network travel cost model and a point allocation scheme. Additional user constraints, like percent usability range and range site boundary distance influence the model results. Each sub-model is described below along with how the requirements are met through various sub-models.

Slope Usability Sub-Model

In general, cattle prefer to graze on flat landscape but will use areas of steeper slope. The slope usability sub-model provides a continuous usability surface based on slope. The default slope usability sub-model uses a linear function of percent slope for usability that reflects guidelines presented by Holechek (1988), although, the user may choose to define an alternate function.

Water Usability Sub-Model

Cattle generally tend to stay close to a source of water. The water usability sub-model provides a continuous usability surface based on distance to water. Like the slope usability sub-model, the default water usability sub-model uses a linear function of distance from water for usability that reflects guidelines presented by Holechek (1988). Again, the user may choose to define an alternate function.

Composite Usability Product

The combination of slope and water usability provides a composite usability surface that is used in point allocation. Given the two surfaces, the surface with the minimum usability value defines composite usability at any point, in other words, the composite surface consists of the minimum of either surface. For example, if, at a given location, slope usability is 78% but water usability is 53%, composite usability at that location would be 53%. This surface satisfies the requirement "Within Usable Area" from FAT Trials 1 and 2, but rather than being a fixed geometry where a point is either inside usable or outside usable, usable exists everywhere and a specific location meets usability criteria or not. The user may specify a maximum and minimum usability to be used in point allocation. The maximum usability value prevents point allocation very near water (not within the user defined distance of water) or other potentially highly usable areas. The minimum usability value prevents points from being allocated in areas where livestock would tend not to be.

Figure 3 shows water usability. Usability is symbolized from dark blue, 100% to white, 0% usable. Figure 4 shows composite usability from black, 100% to white, 0%.

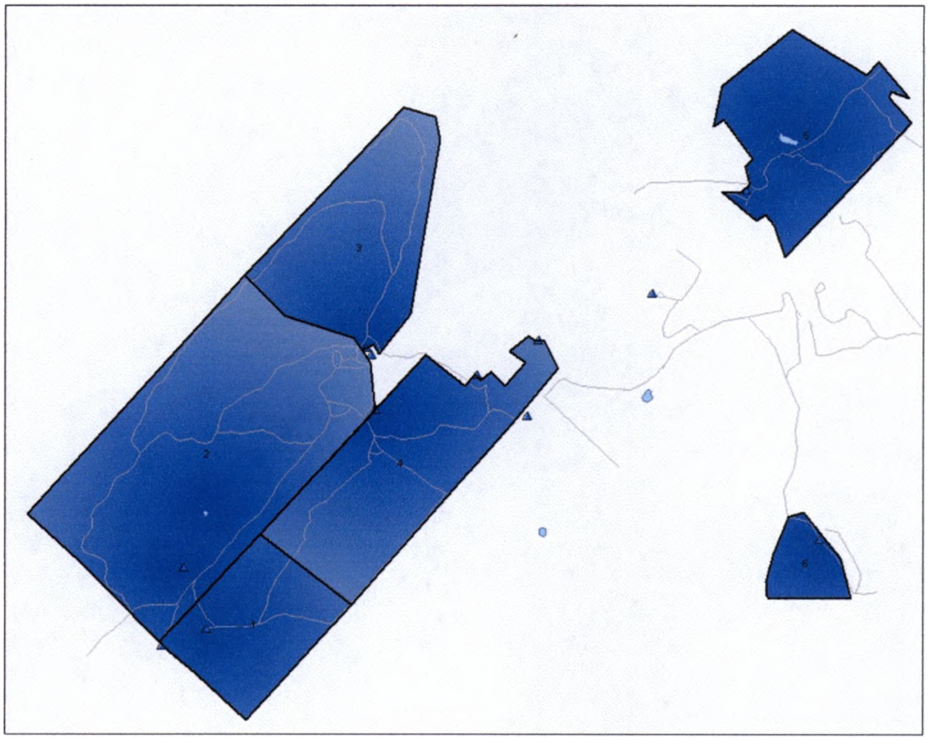

Figure 3: Usability based on water

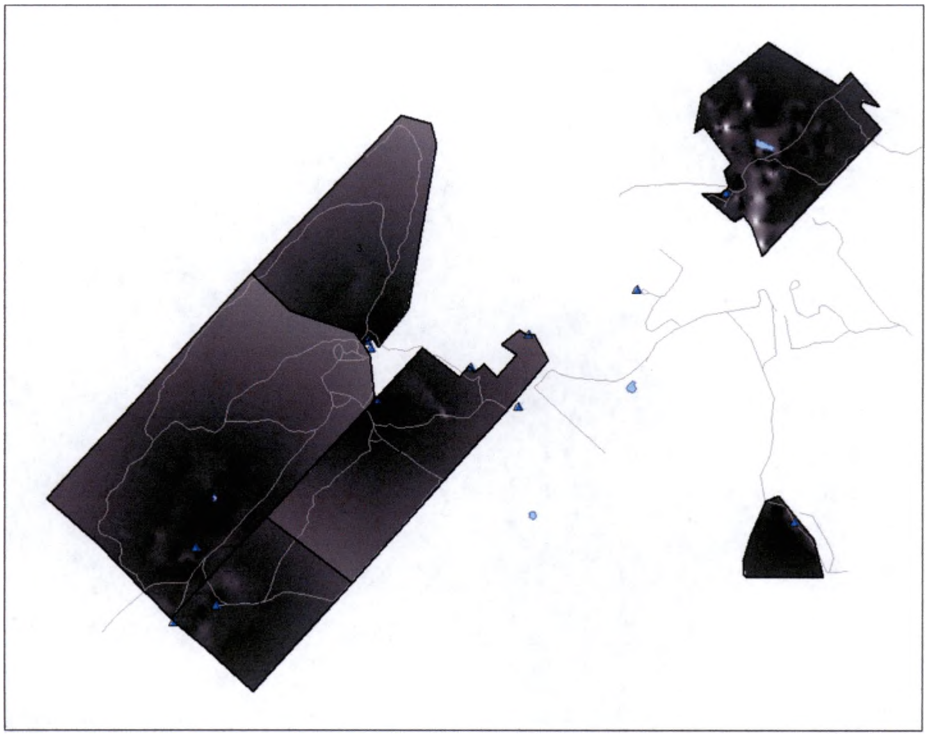

Figure 4: Composite Usability (slope and water)

While being useful in the forage survey process, these views are also helpful for other decisions such as where to install water improvements or fences.

Forage Capacity Sub-Model

The forage capacity sub-model allows for the creation of a forage capacity surface, a surface that represents the amount of forage available for each range site within each pasture. This value, for example, might represent the expected standing crop or the probable standing crop based on projected precipitation. In addition, the user may specify a forage threshold to be deducted from each range site in each pasture providing a net forage capacity. For example, an operator may expect a certain range site in a pasture to have a standing crop of approximately 2,200 pounds per acre. However, she may also recognize that a residual standing crop of 1,000 pounds per acre is required to maintain existing range condition. In this case, the range site can only contribute a net 1,200 pounds per acre. This net value is an important consideration because it helps define the relative importance of each range site within a pasture. The forage capacity sub-model also produces a layer called the priority surface, which provides a per unit area measure of usable forage capacity. At each point, the priority surface value is the forage capacity value normalized to a per unit area value. The forage capacity sub-model provides meaningful information about the contribution of forage for any given location. The third product of the forage capacity sub-model, the range site contribution surface, provides a depiction of the contribution of each range site to the total forage available in each pasture. This product provides prioritization of each range site within each pasture.

Forage Capacity, Priority Surface and Range Site Contribution Products

Figure 5 shows range site production, an input into the forage capacity sub-model.

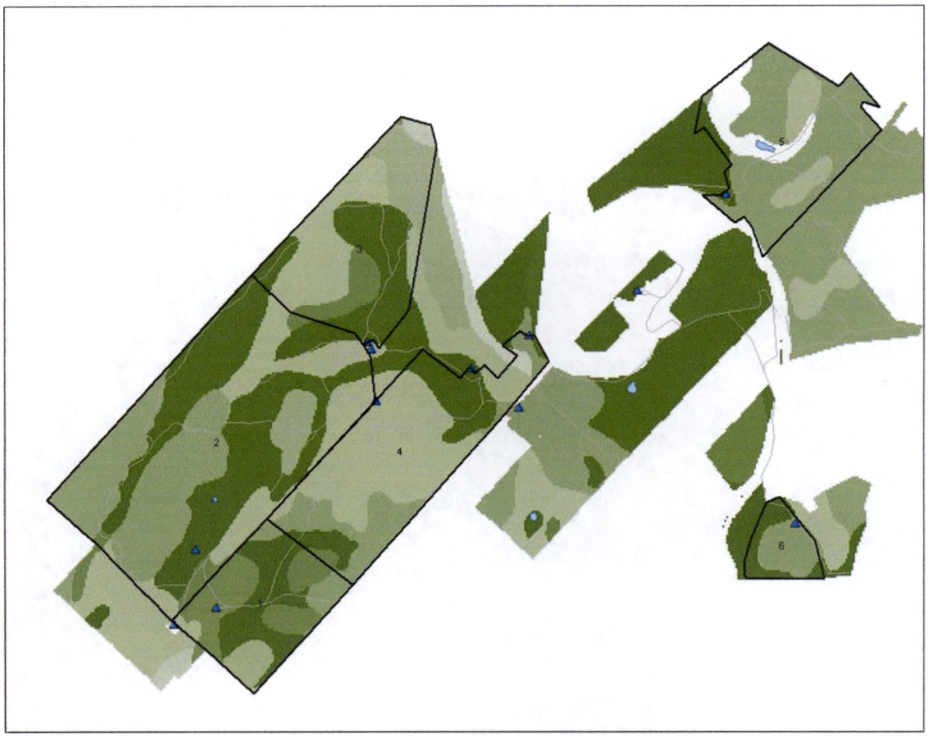

Figure 5: Range Site Production

Expected forage production values are categorized into shades of green. Darker green areas represent range sites that are highly productive while lighter areas depict less productive range sites.

Forage capacity is depicted in Figure 6. Darker green represents greater forage capacity while lighter green represents smaller forage capacity. The forage capacity product visually presents the combination of range site production and threshold, if specified, and composite usability. It allows the user to see an indication of the level of usable forage available over space. The value of the surface represents an estimate of the available forage at any given point.

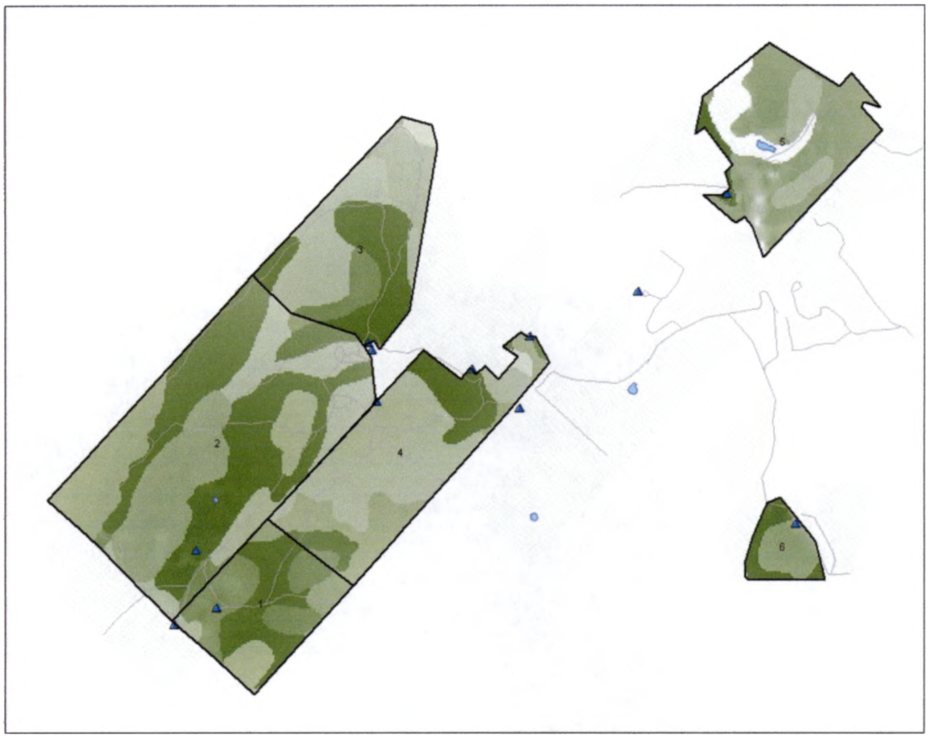

Figure 6: Forage Capacity

The priority surface is a similar representation, but the values have been normalized per unit area. This surface is appropriate for examining the amount of usable forage available over a given area. Forage capacity and priority surface would look identical, as the latter is an area-normalized version of the former. These two products help prioritize areas across the spatial extent.

Figure 7 illustrates range site contribution. Darker areas represent greater contribution.

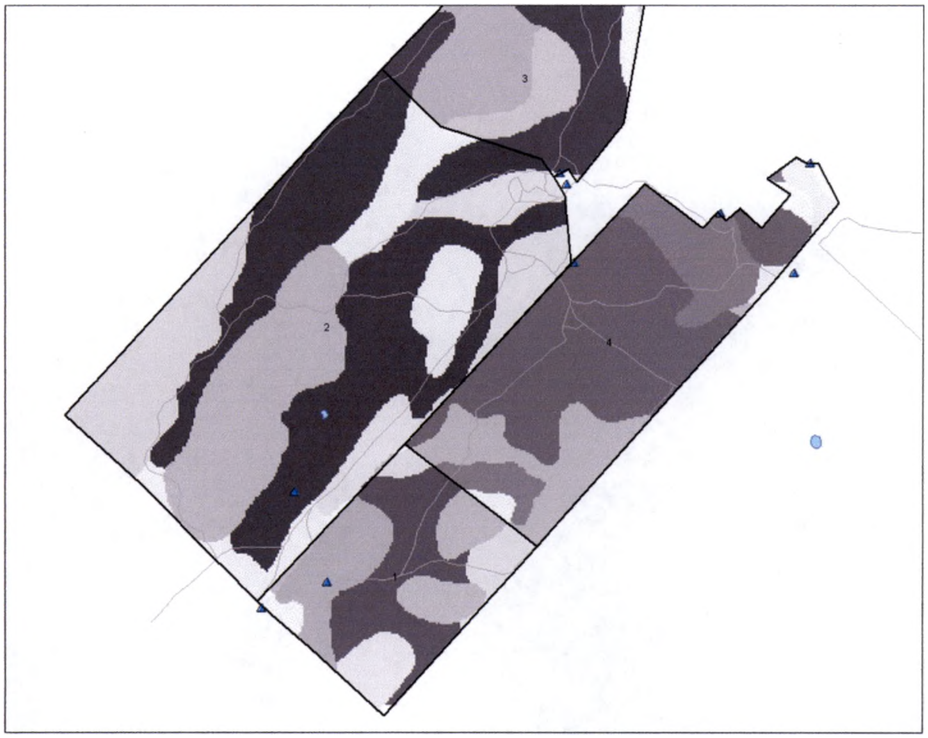

Figure 7: Range Site Contribution

The range site contribution product depicts the percent contribution of each range site to the total available forage in the pasture. A value of 60 in a specific range site would indicate that 60% of the total available forage in the pasture would be a contributed by that range site. This product provides prioritization of range site within each pasture.

Network Travel Cost Sub-Model

The network travel cost sub-model allows roads and associated travel cost to be included in the composite model. Roads are used to constrain point allocation satisfying the requirement that FAT Points are allocated on a road. If the road layer has an associated speed attribute, then the travel cost, in terms of time, is used to calculate the FAT Routes. If no speed attribute is present, then the speed for all roads is considered constant.

Point Allocation Scheme

There are a number of ways an operation may choose to allocate FAT Points. The point allocation scheme component facilitates selection from at least two strategies, "Best Points" or "Cheapest Points." Best Points reflects the location within each range site in each pasture that has the greatest per unit area net forage contribution subject to range site boundary and composite usability constraints. The "Cheapest Points" scheme provides one point per range site per pasture that is closest to the route starting point subject to range site boundary and composite usability constraints. Other schemes are certainly possible, but are not included for simplicity. Under both schemes, one FAT Point per range site per pasture is selected but only if the usability and range site buffer constraints are met.

The difference in allocation schemes is shown below. Figure 8 depicts Best Points and figure 9 shows Cheap Points.

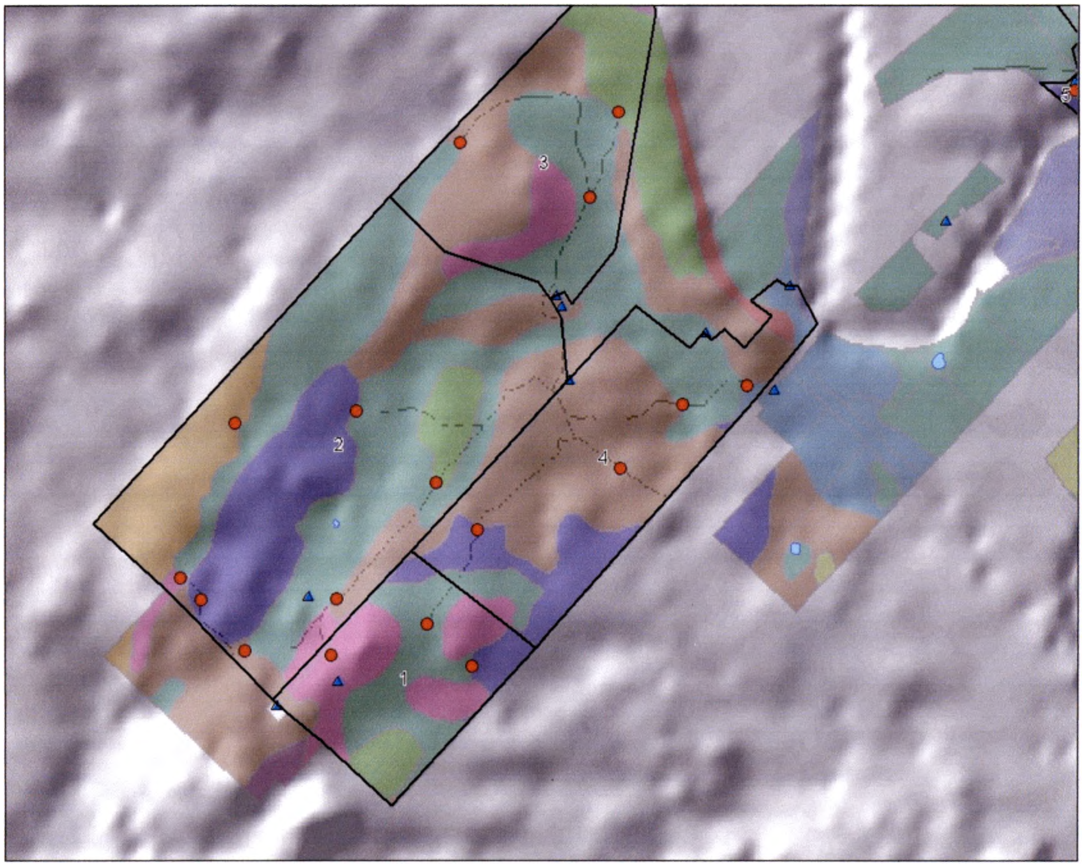

Figure 8: Best Points Allocation

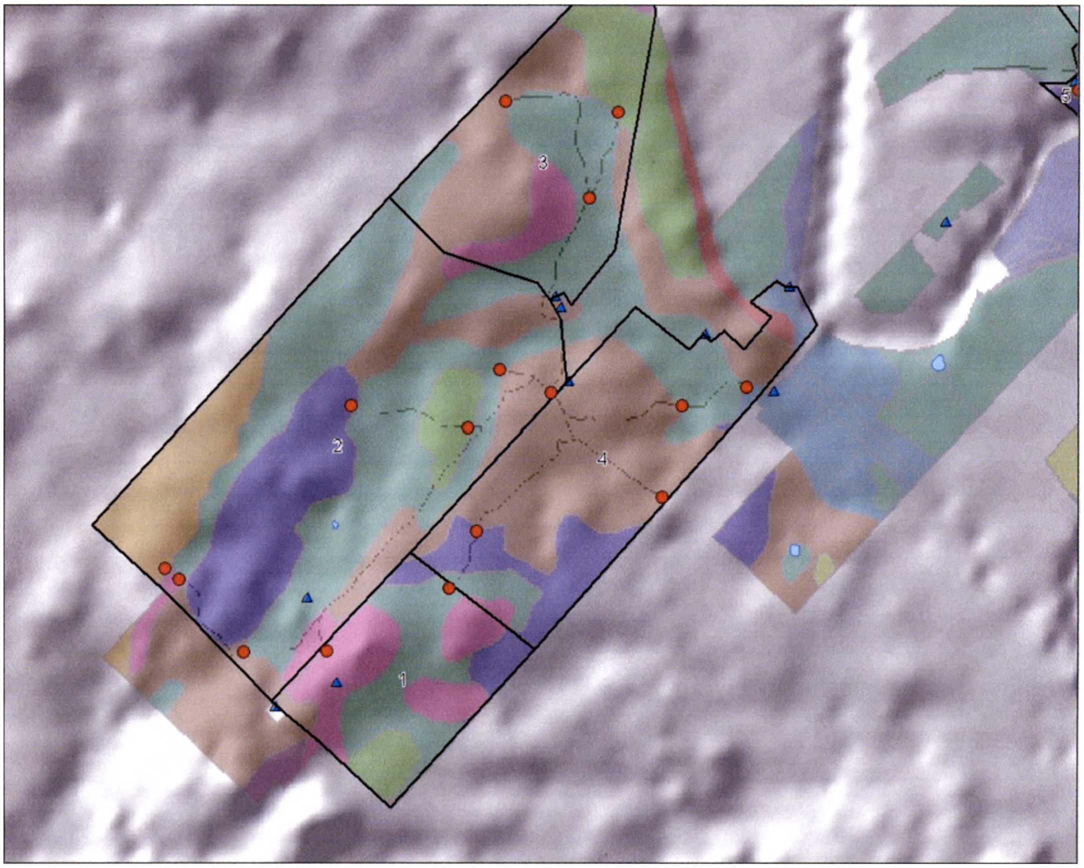

Figure 9: Cheapest Points Allocation

The Modeling Environment

The FAT model was developed using the Visual Basic for Applications environment within ESRI® ArcView® 8.3 with Spatial Analyst extension. ArcView® is a desktop GIS software package and Spatial Analyst is an add-on product that adds additional raster analysis capabilities. Access to the software components of both ArcView® and Spatial Analyst is provided through the Microsoft® Visual Basic® for Applications environment built into ArcView®. The model is constructed as a set of VBA procedures and a user interface. One limitation of the environment is that ArcView® can only have up to 50 raster datasets opened at a time. As a result, only about a dozen pastures can be considered in a model run.

The Model Template

A template document, figure 10, is used to structure input data, to contain output products and to provide an interface through which the user may interact. The required data sets are discussed below.

Pastures -- a vector polygon dataset that defines grazing unit boundaries. This dataset should include only the pastures under consideration for the model run, usually a sub-set of all pastures in the operation.

Range Sites -- a vector polygon dataset that represents areas of homogenous forage. Just as in FAT Trials 1 and 2, this dataset should be the intersection of range sites and pastures so that each polygon represents one range site within one pasture. This dataset must have an attribute that specifies the productive capacity of each range site in terms of pounds of forage per acre. This dataset may have an attribute that reflects a measure of threshold, also in pounds of forge per acre, which may be used in the forage capacity sub-model to provide a net rather than gross measure of forage capacity.

Roads -- a vector dataset representing roads. If this dataset contains a speed attribute, it can be considered by the network cost sub-model for determining least cost paths. If this attribute is not present, then a constant average speed for all roads will be assumed.

Waterings -- a collection or group of datasets that represent sources of water. Datasets typically included in this collection are water troughs, tanks and streams.

Starting Points -- a set of points that mark the start of potential routes through pastures. These points are used in the network cost model from which cost distance is computed over the network.

Digital Elevation Model (DEM) -- a raster dataset that represents elevation over the study area. This dataset is used to establish the raster modeling environment. The spatial reference, extent, and grid cell size for all model products are all inherited from this dataset, so it is important that this dataset match the requirements for the model.

Work Products -- a group layer that serves as a repository for products produced during the model run. It is empty to start.

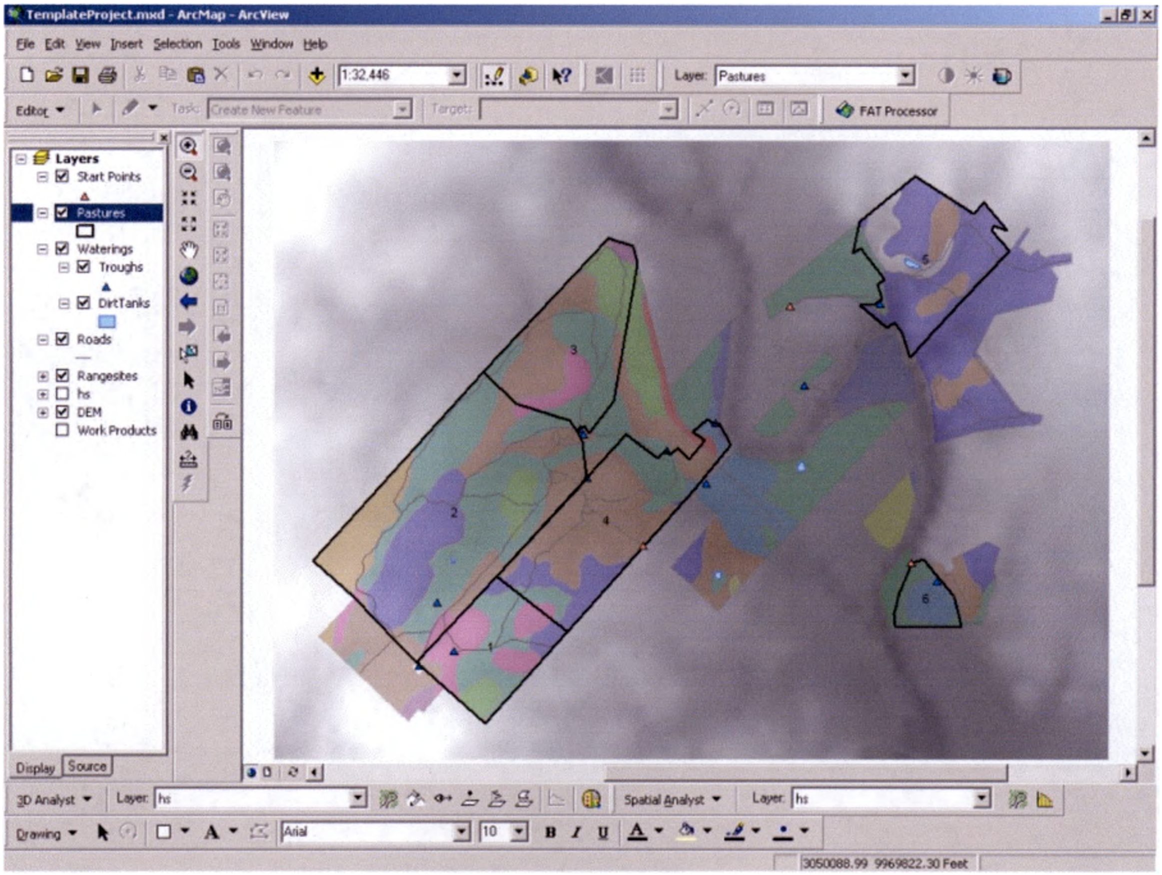

Figure 10: ArcView FAT Template Document

The user starts the modeling process by clicking the "FAT Processor" button. When the model has run, the output products can be viewed from the Work Products group layer. The next section discusses the modeling process and user interaction.

Running the Model

When the user clicks the "FAT Processor" button, the model begins processing. The first step in the model is to establish the spatial reference, extent and grid cell size used for processing. These characteristics are inherited from the DEM dataset. A higher resolution DEM provides greater resolution in output, but at the cost of increased processing time. In addition, it is wise to clip the DEM to an extent that matches that of the pastures, otherwise, a fair amount of processing time is wasted in areas outside of pastures. Step two is collection of user-supplied constraints, shown in figure 11.

Figure 11: Model User Input Screen

The user may choose one of two Point Allocation schemes. "Best Points" provides points that have the greatest per unit area net forage contribution subject to usability, road, and range site buffer constraints. "Cheapest Points" allocates points within range sites as close as possible to starting points subject to usability, roads and range site buffer constraints. Range site edge buffer distance allows the user to specify in map units the distance from a range site boundary that should be omitted in considering where to allocate points. This input prevents points from being allocated at range site boundaries that may lack accuracy. Maximum usable and minimum usable allow the user to specify a range of composite usability to consider in modeling. The workspace parameter allows the user to select where intermediate products are to be stored during processing. The consider threshold checkbox allows threshold to be included in the forage capacity sub-model. If no threshold attribute exists in the range site dataset, this should not be checked. The slope model list and water model list allow the user to select how usability is modeled relative to percent slope and distance from water.

Once all user input is collected, the modeling process is starting by pressing the start button. The following presents the general flow of the model to completion.

Slope and Usable Slope Calculation

First, percent slope is computed from the DEM dataset. Next, the slope usability model is applied to the slope surface producing a slope usability surface. Values greater than 100 are assigned 100 and values less than 0 are assigned 0.

Pastures

Next, vector pastures are converted to raster using the grid cell size, extent, and spatial reference of the DEM layer. An identity attribute is used as the value for the pasture raster so that individual pastures can be used later in a number of filtering steps.

Network Cost (Roads and Speed)

Roads and speed are converted to raster next. Two datasets are produced. The Roads layer uses a binary representation of the roads, 1 means road, otherwise 0. The Speed layer includes the rate of travel computed from the speed attribute. If no speed attribute is present in the vector roads dataset, a constant speed of 10 miles per hour is assumed throughout the network.

Range Site Buffers

So that the model can avoid picking points on potentially imprecise range site boundaries, the boundaries are first buffered in a vector operation the distance specified by the user then converted to raster where the buffer gets a value of 1 and outside the buffer gets a value of 0. One side effect of this process is that since the range site layer has already been intersected with pastures, buffers are also created at pasture boundaries. The implication of this is that points may not be allocated along roads very near fences because the roads would fall within the buffered area.

Composite Water and Usable Water

The next step produces the water usability layer. First, each dataset included in the Waterings group is converted to raster. These layers are combined using an OR operation into a composite water layer that has the value of 1 for water present or 0 for no water. Values of 0 are removed from the layer so that only 1 values remain. Next, for each pasture, a pasture filter is created containing 1 values within the pasture and no data elsewhere. This filter is multiplied by the composite water surface to produce the subset of water present in this particular pasture. Next, a cost distance surface is created over the pasture area using pasture water as a source. Essentially this surface provides for each cell within the pasture, the distance to the closest source of water. The distance surface is fed into the supplied water usability model to compute the water usability surface for this pasture. Values greater than 100 are assigned 100 and values less than 0 are assigned 0. After processing each pasture, each of the pasture water usability layers is finally combined into a composite water usability layer.

Composite Usability

With both slope and water usability layers, the composite usability layer can be created taking the minimum usability of the two layers at each location.

Range Production

The next step is gathering data for the forage capacity sub-model. Range sites are converted to raster using the forage production value. The forage production value used could be a mean estimate of forage standing crop for the particular range site, an estimate based on probable precipitation or an estimate produced from historic site-specific data. The role of the production value in the model is to represent the amount of forage expected in each range site.

Forage Capacity

The forage capacity sub-model integrates the Range Production layer, threshold if specified, and usability. The surface reflects an estimate of the usable net forage available at any location. If the user has indicated that threshold should be considered, a threshold surface is created from the range site data using the threshold value. The threshold surface is subtracted from the production surface to produce a net forage surface. The net forage surface is then multiplied by the usability surface (divided by 100) producing forage capacity. For example, at a given location, the production value is 3,000 pounds forage per acre and the threshold is 600 pounds forage per acre. If composite usability at that point is 80%, then the forage capacity would be calculated:

$$(3{,}000 \text{ lbs/ac} - 600 \text{ lbs/ac}) * (80/100) = 2{,}400 \text{ lbs/ac} * 0.8 = 1{,}920 \text{ lbs/ac}$$

Prioritizing Range Sites by Pasture

Although it is not explicitly used elsewhere in the model, a depiction of the contribution of each range site in terms of usable forage by pasture is helpful in the decision about which range sites to sample. Because this particular view is beneficial, it is created. For each pasture, a pasture filter is created by setting values within the pasture to 1 and other values to no data. This filter is multiplied by forage capacity normalized to a per unit area value. The sum of the values of cells in the resultant layer represents the total number of pounds of usable forage available in the pasture. Next, the product of the pasture filter and the range production layer is sliced into distinct zones, one per range site within the pasture. For each zone, normalized forage capacity is summed over the zone to produce a zonal sum, which is then divided by the pasture total, producing the percentage contribution of this range site to the pasture. The collection of layers of percentage contribution of range sites by pasture are combined into a composite layer and added to the work products group for user review.

Priority Surface

The priority surface is simply forage capacity normalized per unit area. Displayed cartographically, it looks identical to the forage capacity surface, however, the priority surface allows for calculating usable net forage in terms of pounds over an area, a very handy thing to be able to do.

Point Allocation Schemes

There are two built-in point allocation schemes, "Best Points" and "Cheapest Points." The selection of scheme is left to the user with Best Points being the default. Both schemes allocate a single point per range site within each pasture subject to constraints leaving the user to decide which of the points, if any, need to be visited. Both are created by first calculating a layer that represents the constraints. The usability range provided by the user is selected from composite usability and assigned a value of 1, elsewhere 0. Next, the constraints are combined by multiplying the inverse of range site buffers, the selected usability and roads producing a binary layer where 1 represents feasible areas, 0 represents non-feasible areas. In the case of Best Points, this feasibility layer is multiplied by priority giving priority values for each feasible location. For Cheapest Points, the feasible layer is multiplied by a cost distance layer over roads from the starting points using the speed layer to provide the cost (in terms of time) to access each feasible location from the closest starting point. Next, for each pasture, the feasible layer is filtered for each pasture. The result is sliced according to range site and either a zonal maximum for Best Points or zonal minimum for Cheapest Points is computed. The points that produced either the maximum or minimum are the desired points. These points are selected by value and used to produce a vector point dataset reflecting the selected points. Finally, routes are calculated using a cost path function from each selected point to the closest starting point.

Evaluation

How to evaluate the results of this project is a complex question. Perhaps the most simple question is, "does the process work or not?" This could be demonstrated through examining fulfillment of the requirements or more subjectively by user feedback. But, if the process works, it is important to establish, through some objective criteria, the performance of the process. A number of measures could be evaluated, for example, how well does the process predict the actual cost of a survey or how well does the process allocate sample locations in terms of representing the actual forage inventory or how faithfully does the process represent management decisions regarding where to sample? These are all extremely difficult questions to quantify and answer, so the model will be evaluated using DeMers' (2002) criteria. The model can be verified by ensuring that the algorithms implemented work as they are supposed to. This can be accomplished through hand checking certain cells. The model can be validated for reasonableness by comparing the results with those of experts. For evaluation for parsimony, a simple review of the cartographic model should provide a subjective determination of the elegance of the solution. Finally, and perhaps most important, the user can provide subjective feedback to establish user acceptance of the model for suitability and reliability. Although the user might choose not to use the produced points, the points and other process outputs may influence the user's selection of points, contributing to the process indirectly.

To begin, it is important to consider the limitations of the model. Perhaps the biggest limitation is the network cost component. Network travel times are always considered from a starting point to each allocated point with no consideration of more expedient routing. This kind of modeling would require more complex software than was available so was not attempted. Another limitation is that only one point is allocated per range site per pasture. This limitation could be overcome by making the point allocation scheme iterative, selecting a point then removing the representative area from consideration, then selecting another point and so on. Another limitation is that range site priority within each pasture is not explicitly included in point allocation. The model allocates a point for each range site in each pasture, if possible, no matter the productivity of the range site. In practice, a user may wish to restrict allocation to only significant pastures. A word of caution rather than a limitation, it is possible that features, particularly polygon features, may be dropped from the model if the feature dimension is not as large as the cell size used. For example, when the model was run with a 30 m DEM rather than the 20 foot DEM, very small dirt tanks (polygons) less than 30 m in a dimension were dropped from the composite water layer. The same could happen with very small traps, pastures or range sites causing unusual results. The model only supports two point allocation schemes. It would be better if the user had a greater selection in point allocation, perhaps more like slope and water usability functions. To a certain extent, it is important to remind the user that the model is a *simplification* of the real world, so a value depicted on the forage capacity layer may not exactly match what is really in the field. Many of the values are represented to whole percent, pounds, seconds and so on, but the model cannot predict this level of accuracy. The model leaves out a number of factors that contribute to grazing distribution, like brush or shade or climate. Finally, the model does not handle complex pasture configurations such as open gates which have a profound impact on water distribution.

Verification

Throughout model construction, individual steps were tested to ensure the algorithms were working as desired. A number of errors were identified and corrected, particularly in the water modeling section. One of the more critical problems had to do with distance from water calculations. At first, a straight-line distance function was used to describe distance from water, however, this method fails to represent the true distance to water as can been seen in figure 12.

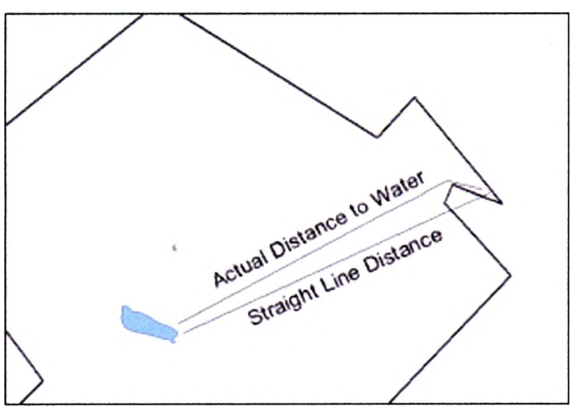

Figure 12: Straight line distance and cost distance

The function was replaced with a cost distance function to capture the shortest cost path to water from any cell. Another discrepancy that has not been fixed deals with range site data that have already been intersected with pastures. The new layer contains edges both where range sites meet but also at pasture boundaries. When this range site layer is buffered, pasture boundaries are buffered as well.

Validation

For model validation, an individual with considerable knowledge of the ranch was asked to identify locations where he would take forage samples given his knowledge of the ranch. The only supplemental information provided was the general productivity of each range site and a map showing range site boundaries, roads and known sources of water. The points selected by the individual are shown in yellow in figures 13 and 14. Next, the model was run to select FAT Points using the Best Points allocation scheme, 50 foot range site boundaries and 85% – 60% usability criteria. These points are shown in red in figures 13 and 14. Figure 13 shows both manually selected points and FAT Points.

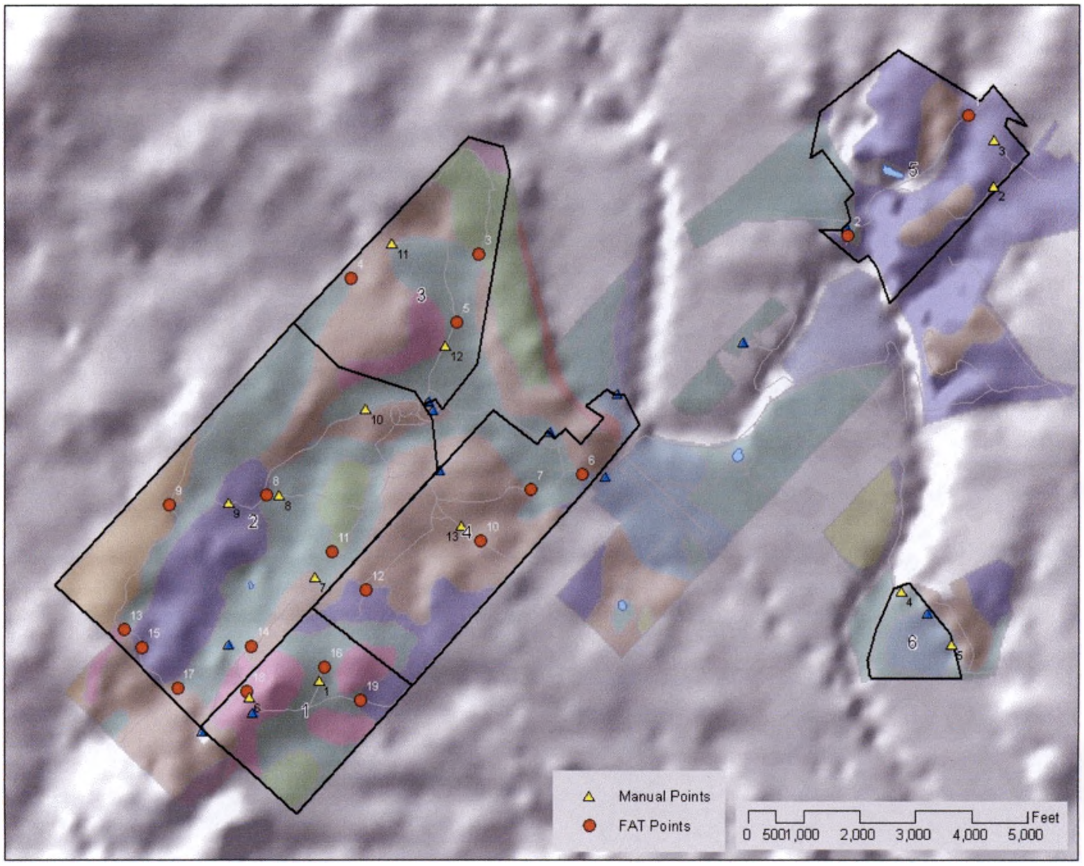

Figure 13: Map of validation results, points

During the manual selection process, points were selected only in certain range sites, the range sites known to contain substantial usable forage. In some cases, more than one point was selected per range site in a pasture reflecting the importance of the range site within the pasture. For model evaluation purposes, correspondence between FAT Points and manual points was established by selecting for each FAT Point, the closest manual point in the same pasture and range site. In figure 13, using pasture 1 as an example, FAT Point 16 corresponds with manual point 1 because they both are in the same pasture and range site. They share a common target.

Starting in pasture 1, figure 13, the model did an extremely good job at selecting points near where manual points were selected. The model selected FAT Point 19 in a range site that does not contribute much forage and so was skipped in the manual process. In pasture 2, FAT Point 8 corresponds quite well with manual point 8 in the most productive range site shown in light green but deviates substantially from the manual point 9 at FAT Point 15 in the second most productive range site shown in purple. Because the model does not currently support multiple point allocation, manual point 10 has no peer from the model. The other FAT Points in pasture 2 mark range sites that were considered less important in the pasture. Pasture 3 demonstrates that once again, the model is again in step with the manual selection process. In the manual process, two sites, points 12 and 11 were selected in the most productive range site and others were ignored. Pasture 4 also reflects good agreement between FAT Point 10 and manual point 13. As in pasture 3, only one range site was selected in the manual process. Pasture 5 shows less correspondence between the model and manual processes, although FAT Point 1 is in the same general region of the pasture as manually selected points 3 and 2, they are on a different road. In pasture 6, the model allocated no points because the road falls under the range site buffer. This is an artifact of the range site buffers limitation that probably could be addressed simply by changing the data requirements for the model.

Table 1: Validation results, RMS error

FAT Point	EASTING	NORTHING	Manual Point	EASTING	NORTHING	Distance
18	3053919	9957815	6	3053970	9957712	115
16	3055299	9958255	1	3055220	9958017	251
8	3054279	9961315	8	3054510	9961311	231
15	3052039	9958595	9	3053604	9961179	3021
10	3058099	9960495	13	3057771	9960767	426
5	3057659	9964395	12	3057481	9963984	448
1	3066799	9968075	3	3067266	9967636	641
RMS error	**640**	**1013**				**1198**
18	3053919	9957815	6	3053970	9957712	115
16	3055299	9958255	1	3055220	9958017	251
8	3054279	9961315	8	3054510	9961311	231
15			9			
10	3058099	9960495	13	3057771	9960767	426
5	3057659	9964395	12	3057481	9963984	448
1	3066799	9968075	3	3067266	9967636	641
RMS error	**245**	**290**				**392**

Examining the RMS error between corresponding manual points and FAT Points, Table 1, provides quantitative evaluation of model performance. Coordinates are in feet. In general, the points are relatively close to each other with the notable exception of FAT Point 15 in pasture 2. The key model predictors, composite usability and priority surface value, for FAT Point 15 are 84.99% and 21.07 lbs/400ft^2 respectively. Manual point 9 had values of 85.14% and 21.11 lbs/400ft^2 indicating that the points are quite similar, but manual point 9 was slightly beyond the usability range used for the model run. If this pair is excluded as an outlier, RMS error for distance decreases to less than 400 ft.

Route selection did not work very well. The model takes a very simplistic view of route selection, simply finding a suitable point the shortest distance from a starting point. In reality, an operator would chain together sample points into a more complex route, but modeling this behavior can be quite complicated and requires sophisticated route selection algorithms. Model route selection and manual route selection is shown in figure 14.

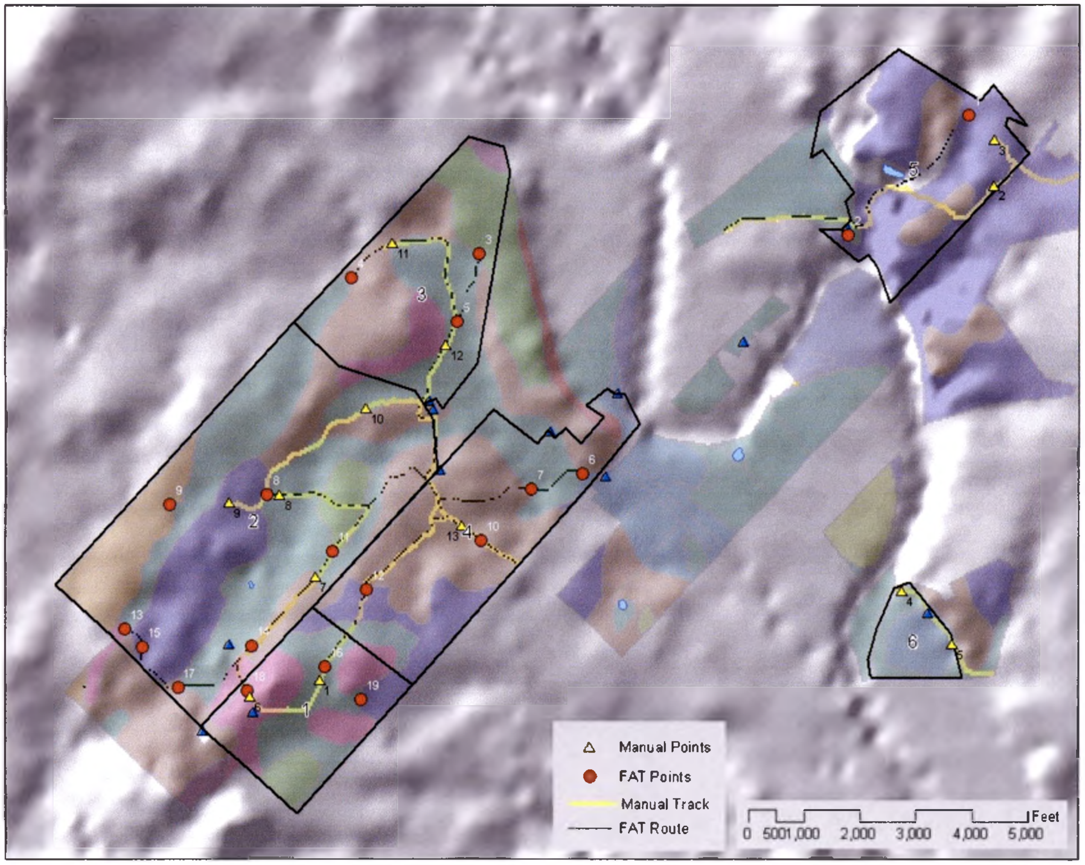

Figure 14: Map of validation results, routes

As an example, from the starting in pasture 4, figure 14, the FAT route to pasture 1 ends at FAT Point 16 rather than continuing on to FAT Point 18 and then pasture 2. The model demonstrates that it would take less time from the starting point in pasture 4 to go directly to FAT Point 18 in pasture 1 via the road in pasture 2, but this would not be very practical. The manual track connects points much more elegantly than the model, reflecting local knowledge, but also the simplicity of the network cost sub-model. In the absence of thorough knowledge of the ranch, the routes may provide guidance in choosing which roads to take.

Parsimony

DeMers (2002) describes a parsimonious model, in part, as one that can be easily explained or understood, and that involves few steps or very simple steps. In general, this model is limited to 5 simple sub-models that are each relatively easy to conceptualize. At the same time, the model accommodates substantial user tuning of many of the sub-models for specific purposes increasing the power of the model. There are relatively few inputs but a number of outputs that aid in the decision, even if the primary outputs are not used.

User Acceptance

In general, the user was quite pleased with the results. The model seems to allocate FAT Points where cattle tend to be, so in that regard the results are reasonable, however, the model does not do a good job at selecting reasonable routes, as was illustrated in figure 14. FAT Point 15 is as good a point as manual point 9, but manual point 9 is much more convenient. The user quickly suggested that many of the products like range production, forage capacity, range site contribution and composite usability are applicable to other decisions. These depictions inform decisions about how to address grazing distribution problems by adding or moving water or fences or cultivating certain areas as improved pastures. The user suggested that a modified range site contribution product without adjustment for composite usability would also be helpful. Although these uses were not planned, they are a helpful side effect. Another insightful observation was that the model used range production data based on soil types and expected plant communities for the range production input. In one case, a pasture had been cultivated to grow hay so the actual amount of forage was probably not correct. This discrepancy demonstrates that it is important to consider improved or cultivated pastures in input datasets and to make corrections as needed. Finally, the user acknowledged that using cost distance is much more realistic that straight-line distance, but there are other factors that might hinder accessibility to water, like dense brush or rocky patches. In fact, some other factors have been investigated in the literature (Ganskopp et al. 2000). Adding these additional constraints to this model is simply a mater of adding the additional datasets and creating a new user-defined water usability model.

CHAPTER 5

CONCLUSION

The model constructed for FAT Trial 3 is relatively simple and includes the most important factors associated with forage surveys; pasture boundaries, range sites and forage productivity information and usability based on distance from water and percent slope. The model typically does a good job of selecting forage survey sample sites, or FAT Points, but because of the simplistic view of network cost, does not perform well at selecting FAT Routes. The model allows for substantial user control through water and slope usability sub-models, and user specified usability range and point allocation scheme. The model relies on relatively little data and facilitates rapid evaluation based on various input through automation. Perhaps most important, the model provides some views of the ranch, particularly with respect to water and forage distribution that may be beneficial beyond the forage survey scenario, for planning improvements or grazing schedules. For range management, there is no substitute for a thorough knowledge of the range, but the model can provide insight that might otherwise be difficult to obtain. In the absence of any knowledge at all, it provides a good place to start.

APPENDIX: METADATA

Data for Trials 1 and 2

All data UTM NAD 83 Zone 13N, meters.

Pastures – Proprietary, GPS data collection and digitized from Texas Orthoimagery Program 1-meter digital orthoimagery at a scale of 1:3000
Water features (water troughs, tanks) – Proprietary, GPS data collection and digitized from orthoimagery at a scale of 1:3000
Roads – US Census 2000 TIGER Line files amended with GPS collected data
Range Sites – SSURGO Soil Data accessed on-line at:
http://www.ncgc.nrcs.usda.gov/branch/ssb/products/ssurgo/
Digital Elevation Model (DEM) – USGS 30-meter DEM produced from 1:24000 topographic map series
Slope – 30-meter resolution percent slope derived from DEM

Data for Trial 3

All data NAD 83 State Plane Texas Central (FIPS 4302), feet.

Pastures – Proprietary, GPS data collection and digitized from Texas Orthoimagery Program 1-meter digital orthoimagery at a scale of 1:3000
Water features (water troughs, tanks) – Proprietary, GPS data collection and digitized from orthoimagery at a scale of 1:3000
Roads – US Census 2000 TIGER Line files amended with GPS collected data
Range Sites – SSURGO Soil Data accessed on-line at:
http://www.ncgc.nrcs.usda.gov/branch/ssb/products/ssurgo/
Digital Elevation Model (DEM) - Capital Area Planning Coucil (CAPCO) mass points DTM dataset accessed on-line:
http://www.capco.state.tx.us/GIS/GIS_DEMs.htm
The dataset was used in an interpolation procedure to produce a 2-foot resolution raster DEM for the study area
Slope - Percent slope was computed at 2-foot resolution from the DEM
Starting Points – Digitized from Pasture and Roads datasets

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VITA

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