POTENTIAL USES OF SPATIAL TECHNOLOGIES IN RANGELAND MANAGEMENT

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ABSTRACT

Rangeland management uses spatial information on nearly a daily basis to define boundaries of ownership, document range improvements, locate monitoring sites, and identify areas of management concern. Traditionally, these activities have been accomplished with paper maps, aerial photographs, and a compass. Spatial technologies are becoming more widely available that may aide rangeland managers in the accomplishing these tasks. These technologies include: Global Positioning System (GPS), Geographic Information Systems (GIS), and remote sensing.

A case study was conducted to evaluate the use of GPS and GIS in rangeland management on a working ranch near Payette, Idaho. Locations of range resources and improvements and their attributes were gathered with GPS units, GIS was used to approximate forage production and erosion risk from the Natural Resource Conservation Service (NRCS) Payette County soil survey, estimate carrying capacity with reductions based on slope and distance from water, and document the potential value of GIS for tracking herd movements in a yearly grazing plan.

The case study was an effective review of opportunities though analyses were calculated with many assumptions, and were based on the potential rather than the current plant community. I concluded that although adopting GPS and GIS in a working ranch situation may be feasible, it would take hundreds of hours of training and data collection and manipulation for a rancher to conduct the analyses presented here. It is clear, however, that GPS and GIS allow for a precise and detailed level of record keeping of spatial data.

The final chapter defines the terms a land manager might need to know to purchase a GPS unit. A discussion of inherent problems with GPS is presented and a decision tree that helps a land manager determine what type of GPS unit may be most useful in their application.

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CHAPTER 1

IMPORTANCE OF SPATIAL INFORMATION IN RANGELANDS

INTRODUCTION

Spatial information is extremely important to natural resource management. The very roots of exploration, conservation, and utilization of natural resources begin with knowledge of the spatial characteristics of the resources; where resources are located, the area they cover, their elevation, and aspect. For example, two centuries ago when President Thomas Jefferson hired Meriwether Lewis and William Clark to explore the Louisiana Purchase, one of the primary goals of the expedition was to map the land and its resources (Hessburg and Agee 2003). When rangeland management emerged as a recognized discipline, maps were critical to establish boundaries, maintain resource inventories, and establish management plans (Hessburg and Agee 2003). Maps are the oldest, most basic, and well-known spatial tool (Vitek et al. 1996). Over time, maps became progressively more accurate and detailed (Weis et al. 2005). By the 1950's computer technology was emerging and being used to create maps (Vitek et al. 1996). Today, rangeland managers use maps on nearly a daily basis to locate monitoring plots, delineate property management boundaries, and extract taxonomic, cultural, and economic data (Salem 2003).

Maps are the most commonly used way of displaying spatial information (Lenz and Beuttler 2003), yet they are limited by their ability to depict a reality in only two dimension (Vitek et al. 1996; Buckley 2004). Maps are also limited by what themes or attributes a mapmaker chooses to display on the map (Buckley 2004). There are more recent spatial tools being developed and used in range management today that are capable of depicting reality in three dimensions, and displaying multiple attributes at once. Some of these tools include Geographic

Information Systems (GIS), Global Positioning System (GPS) and Remote Sensing (Foresman 1998; Hessburg and Agee 2003). A new era of range management will be ushered in by allowing greater accuracy in creating maps, geographic databases that can be updated and displayed spatially, and spatial technologies that can model ecological processes.

COMMON SPATIAL TECHNOLOGIES USED IN RANGE MANAGEMENT

Geographic Information Systems

A Geographic Information System (GIS) is a computer software program designed to capture, display, analyze, retrieve, and store spatial information. Although it is difficult to pinpoint a single origin of GIS, it is clear that techniques for geographic inquiry, such as overlaying maps, have existed for several centuries (Vitek et al. 1996). The modern adoption of GIS depended largely on the automation technology, and computer accessibility that occurred in the 1960's (Kennedy 1996). Early GIS programs were restricted by technical difficulties and cost and were often tailored to solve specific problems (Vitek et al. 1996). The earlier versions were also limited by lack of data storage capacity and slow central processing units the could handle only a few hundred thousand instructions per second (Foresman 1998). Another significant limitation of the early GIS programs was that they could only handle raster-based information (Faust 1998). Very few programs had even limited vector and cartographic referencing functions (Goran 1998). Raster data are grid data that are described by a grid cell (one value per cell) while vector data are stored as points, lines, and polygons rather than as a continuous grid. Raster to vector conversion was accomplished in the early 1980's (Greenlee and Guptill 1998) which greatly increased a GIS user's ability to integrate different data sources and types.

The National Environmental Policy Act (NEPA) of 1969 is regarded as the single most important factor encouraging the use of GIS in the federal land management agencies (Foresman 1998). Since early GIS programs were tailored to solve specific management needs, they were ideal for the federal agencies who needed to monitor land use and assess environmental impacts. These activities generated tremendous amounts of spatial and non-spatial data that could be efficiently managed with GIS programs. Today, GIS is commonly used by land management agencies including the United States Forest Service (USFS; Hessburg and Agee 2003), the Bureau of Land Management (BLM; Blaszczynski 2003), and the Natural Resource Conservation Service (NRCS 2005b).

GIS is a spatial technology that has revolutionized natural resource management. With environmental laws such NEPA, the National Forest Management Act (NFMA), Federal Land Policy and Management Act (FLPMA), and Endangered Species Act (ESA), the need for a system that could assign attributes to spatial data significantly increased (Foresman 1998). GIS fulfilled this niche, becoming the standard medium for managing geographic data and predicting landscape changes by incorporating spatial modeling approaches (Paniconim et al. 1999; Mati et al. 2000; Srivasta et al. 2001; Blaszczynski 2003; Ludwig et al. 2003; Perotto-Baldiviezo et al. 2003; Ming and Albrecht 2004).

ArcInfo, a GIS package developed by Environmental Systems Research Institute (ESRI), became available in 1981 (English and Feaster 2003). In the early 1990’s, ArcView, another ESRI product, and MapInfo, from MapInfo Corporation, were launched for desktop computers (Jardine and Teodorescu 2003). There are dozens of GIS programs in use today, including ArcGIS (ESRI 2005a); ERDAS Imagine (Leica Geosystems 2005); IDRISI (Clark Labs 2005);

MapInfo (MapInfo Corporation 2005); Global Mapper (Global Mapper Software, LLC 2005). ArcInfo is the most commonly used among federal land management agencies. Current GIS programs are driven by drop-down menus, buttons with on-screen display of results, and a “help” function to assist users. These GIS programs are still rather complex, but with a few days of training, most natural resource professionals can utilize spatial data on their own without relying on a GIS analyst.

Today’s GIS programs cost significantly less than their predecessors (Goran 1998). A GIS program in the late 1980's cost about $9,000 and could be installed on only one computer. Today, that same GIS program can be purchased for $25,000 with access by 500 computers ($50 per computer; E. Fish, personal communication, August 2005). GIS programs range in price from $19,000 (ESRI 2005a) to $249 (Global Mapper Software LLC 2005), depending on the capabilities of the program.

GIS is being used in many professions today, not just natural resource management. Examples include urban planning (Elwood and Leitner 2003), humanitarian emergency response (Kaiser et al. 2003), education (Broda and Baxter 2003), participatory GIS for land use planning (Talen 2000; Bojórquez-Tapia et al. 2001) and many other applications. Within natural resource science and management some of the uses of GIS include water balance and hydrologic modeling (Paniconim et al. 1999; Ludwig et al. 2003), non-point source pollution assessment (Srivastava et al. 2001), landslide hazard assessment (Perotto-Baldiviezo et al. 2003), rangeland vegetation monitoring (Al-Bakri and Taylor 2003; Geerken and Ilaiwi 2004), invasive species invasion modeling (Ming and Albrecht 2004), soil erosion assessment (Mati et al. 2000), creation and analysis of fire fuel maps (Yool et al. 1985; Miller et al. 2003), analysis of fire patterns (Pew and

Larson 2001), monitoring of biodiversity (Salem 2003), determination of endangered species' home ranges (Powell et al. 2005), prediction of forage use (Wade et al. 1998), and documentation of land ownership boundaries (Turner et al. 1996; Vitek et al. 1996).

Global Positioning System

A Global Positioning System (GPS) involves a constellation of satellites and receiving devices used to compute positions on the earth's surface. The predecessor of today's GPS system was known as the Navy Navigational Satellite System (NNSS) also called TRANSIT. The TRANSIT system had 6 satellites that orbited the earth and used Doppler radar to determine the distance between satellites and the earth's surface to estimate the position of a point on the earth's surface (Hofmann-Wellenhof et al. 1994). However, TRANSIT had two major shortcomings - low navigational accuracy and large time gaps in satellite coverage forcing users to interpolate their positions in these gaps. The TRANSIT system is still used in some marine applications (Hofmann-Wellenhof et al. 1994).

The primary system in use today is called Navigation System with Timing and Ranging (NAVSTAR). The first 4 satellites of this system were launched in 1978 (Lechner and Baumann 2000) and the current system includes 24 solar-powered satellites (Kennedy 1996). The NAVSTAR GPS system is much improved from the TRANSIT system because it involves minimal user interpolation.

GPS uses a process similar to triangulation, called trilateration, to accurately pinpoint locations on the earth's surface. Trilateration uses measurements from intersecting circles of distance from satellites (NOAA 2005b). For example, if a GPS receiver were 11,000 miles from one satellite, there are a finite number of places on the earth's surface (in the shape of a circle) where that location could be. If the GPS receiver were 12,000 miles from the second satellite, the receiver could narrow down the location by the overlap from the two circles. A third and fourth satellite would further narrow the site. In this manner, the more satellites a receiver can detect, the more accurate the position (Navidi et al. 1998). Most GPS receivers require at least three satellites to log data points, hence the term "trilateration."

Before May 2000, a process called "selective availability" was applied to satellite signals by the US Department of Defense to prevent foreign military powers from using our satellites to gain instantaneous information about secret operations and weapon locations (Florini 1998). With selective availability, satellite signals were deliberately distorted (Hulbert and French 2001). Under selective availability, only the military had access to precise and instantaneous GPS data (Kennedy 1996; Foresman 1998). One remedy for this situation was for a user to employ differential correction based on information from a stationary receiver, called a base station, located at a reference point with a precise known location. This allows for a post-processed correction for satellite signal distortion that could be matched and applied to a GPS signal from an imprecise location (Adrados et al. 2002).

In May of 2000, former President Clinton ordered selective availability disabled, allowing GPS units to calculate accurate locations without performing any post-collection processing. Most GPS units today are accurate within 15 meters, with some units allowing for sub-foot accuracy. However, GPS data are still subject to inaccuracies caused by the atmosphere, terrain, and the number and location of satellites. The practice of differential correction is still used in cases where high accuracy is needed, though not all GPS units allow for differential correction (Trimble 2005).

Advances in GPS technology have created GPS units that are widely available, affordable, and easily used. Ten years ago, a GPS unit that had a 2-5 meter accuracy weighed 9 pounds, was carried in a backpack with an overhead antenna, had no GIS capabilities (meaning the operator had to take detailed field notes) and cost about $15,000. Today, a unit that has a 2-5 meter accuracy weighs 24 ounces, is completely hand-held, can communicate with GIS application tools like TerraSync and Pathfinder Office, and costs $5,300 (Trimble 2005). GPS units that have accuracies of 10-15 meters but lack internal GIS capabilities are available for $100- $700 (Garmin 2005; Magellan 2005). These types of units are currently used for recreation and to navigate on highways.

Today, GPS is being used in many ways by natural resource managers. One common use is the logging of datapoint coordinates to be incorporated in a GIS program. For example, GPS can be used to determine property boundaries, map watersheds, and locate human-built features such as fences and roads. Additionally, GPS collars can be placed on both wildlife and domestic animals to track locations in relation to spatial and environmental attributes such as elevation, time, temperature, speed of movement, etc. (Ganskopp 2001; Adrados et al. 2002; Schlecht et al. 2004).

Remote Sensing

Remote sensing, in the simplest sense, is observation of an object or its properties from a distance. Remote sensing began in 1859 when the French photographer, Gaspard Felix Tournachon photographed the French country-side from a balloon with the goal of using the aerial photographs for land surveys. In 1903, the Bavarian Pigeon Corps used homing pigeons that had lightweight cameras strapped to them to take pictures from the air (NASA 1995) and in 1939, Wilbur Wright took photographs from his aircraft. During the next thirty years, the US and the Soviet Union spied on each other's military operations using aerial photographs taken from spy planes. Aerial photography has been used in range management to evaluate historic remediations of brush on rangelands (Rango et al. 2005) and determine the density of shrubs in a grassland (Whiteman and Brown 1998). Aerial photography is still used in remote sensing, but has largely been replaced by data acquired from satellites (Geerken and Ilaiwi 2004).

Satellite-based remote sensing evolved from the Apollo missions. The Apollo satellites photographed the moon with a multispectral lens allowing researchers to gather information about the lunar surface (NASA 1995). The techniques developed in processing these data were the foundation of the Landsat data used in current remote sensing. The first Earth Resources Technology Satellite (ERTS) which became known as Landsat 1, was launched in 1972. Landsat 1 carried a Multispectral Scanner (MSS) which is a land-scanning instrument capable of scanning in four bands of visible and near infrared with a resolution of 80 meters. Resolution is the smallest unit of surface detail detectable by a sensor (Yool et al. 1985). The latest satellite, Landsat 7, was launched in 1999 (USGS 2005b) and carries an instrument called Enhanced Thematic Mapper Plus (ETM+) which is a multispectral scanning radiometer that measures solar radiation reflected from the earth's surface. This instrument enables the capture of eight spectral bands with a resolution of 30 meters (USGS 2005b).

A series of remote sensing satellites called Système Probatoire d'Observation de la Terre (SPOT) satellites were developed in France. These satellites, first launched in 1986, have a much finer resolution than the Landsat satellites (NASA 1995). SPOT can produce color images in a 2.5 meter resolution while most of the Landsat bands are 30 meter resolution (the exception is the black and white panchromatic band 8, which can produce 15 meter resolution). As expected, there is a significant difference in costs between images from these two satellites. A Landsat image costs around $600, while a SPOT image is closer to $10,000 (SPOT Image 2005). Although SPOT imagery can have a much finer resolution than Landsat imagery, its cost can be prohibitive. Landsat images are commonly the basis for land cover or use classifications (Melesse and Shih 2002; Wang et al. 2004; Tang et al. 2005) and are often used in range management to determine cover class (Cingolani et al. 2004). SPOT imagery has been used to inventory range vegetation at the species level (Smith et al. 1995).

Another set of satellite sensors that are frequently used in comparison studies are collectively called Advanced Very High Resolution Radiometer (AVHRR) which have a resolution of 1 km (NOAA 2005a) and Moderate Resolution Imaging Spectroradiometer (MODIS) which have resolutions of 250 m, 500 m, and 1,000 m (NASA 2005). MODIS sensors have 36 spectral bands (NASA 2005) while most AVHRR sensors have 5 spectral bands (although the most recent has 6; NOAA 2005a).

MANAGEMENT ACTIVITIES ACCOMPLISHED WITH SPATIAL TECHNOLOGIES

Vegetation Classification and Monitoring

Rangeland vegetation plays an important role in protecting the soil from erosion, determining carrying capacity for livestock and wildlife, and affecting fire susceptibility and intensity. One of the most common uses of GIS and remotely sensed data in rangeland management is in vegetation monitoring (Senay and Elliot 2000; Al-Bakri and Taylor 2003; Geerken and Ilaiwi 2004). Many applications in soil or vegetation assessment involve the calculation of Normalized Difference Vegetation Index (NDVI) which is a ratio of measurements in the near infrared and the red regions. NDVIs are commonly used as a tool to compare how green the vegetation of a particular area is compared to previous years or seasons. NDVI can be used to determine the quantity of vegetation (Kawamura et al. 2005; Senay and Elliot 2000), identify areas of high human impact (Geerken and Ilaiwai 2004), monitor the length of the growing season (Groten and Ocatre 2002), determine greenness (Geerken and Ilaiwai 2004) and determine soil moisture (Mati el at 2000; Melesse and Shih 2002).

A recent study in Inner Mongolia compared AVHRR with MODIS to determine if the sensors were able to accurately discriminate vegetation type, phenology, and nutritional quality (Kawamura et al. 2005). NDVIs generated from sensors aboard the MODIS and AVHRR satellites were evaluated for accuracy over different types of grasslands. These data were compared to field measurements taken on the same day between April and October. The researchers found that although both NDVIs would discriminate among grassland types and phenology, neither could accurately determine nutritional quality of the forage.

In a similar study, Senay and Elliot (2000) used an AVHRR NDVI to classify and monitor temporal changes associated with vegetation in Oklahoma. The researchers used ArcInfo and ERDAS IMAGINE to calculate NDVI based on satellite data and classify the vegetation. Although AVHRR has only moderate spatial resolution (about 1 km), it has a high temporal resolution as the entire globe is imaged twice a day (Senay and Elliot 2000). The researchers used a resolution of 4 ha to accurately discriminate among cropland, rangeland, pastureland and forestland. They concluded that AVHRR NDVI was effective at detecting different classes of vegetation (i.e., low stature range which has sand sage and mesquite, medium stature range which is predominantly grasses, and high stature range that is an oak savanna) representing a wide variety of cover types (Senay and Elliot 2000).

Biomass is an important characteristic to monitor in rangelands as an indicator of climatic events, site potential, and use patterns (Barbour et al. 1999). Monitoring biomass over time can be an indication of the health of an area as it relates to the timing and amount of precipitation and temperature fluctuations. Al-Bakri and Taylor (2003), used AVHRR NDVI to determine its value for assessing the amount of above-ground vegetation in Jordan. Jordan has communal grazing lands that are severely overgrazed and the government sought a monitoring procedure that would enable them to quickly and easily compare the status of the grazing lands over years. AVHRR was used to create NDVIs and compare them to historic NDVIs (Al-Bakri and Taylor 2003). Because of the large amount of land area (89,500 km^2) and scarcity of rain gauges, the researchers were unable to conduct field verification, but felt that remote sensing had given them an accurate estimate of the above-ground vegetation in the field. The reason for this may be that severe overgrazing in Jordan has led to monocultures of *Salsola vermiculata* (Shrubby Russian thistle) and *Artemisia herba alba* (Desert wormwood) in many of the communal grazing areas and the biomass of these monocultures can be identified and estimated with relative ease (Al-Bakri and Taylor 2003).

Predicting the period in which the vegetation in an area is likely to become photosynthetically active and “green up” is important for understanding grazing pressures by livestockand wildlifeand for making grazing management decisions. This is especially true in countries that have a problem with severe overgrazing on communal rangelands. Geerken and Ilaiwi (2004) used AVHRR NDVI as a tool to assess the greenness of the standing biomass in

Syria. The researchers found that peaks in the AVHRR NDVI were negatively correlated with peaks in greenness observed by experts and local herders. The study focused on attempting to discern between human caused and natural fluctuations in the greenness of vegetation and showed the potential value for monitoring rangelands over a large land area using remotely sensed data (Geerken and Ilaiwi 2004).

In the US, the University of Arizona has created a website (http://rangeview.arizona.edu) for range professionals to use MODIS and AVHRR images to predict green up in theirregion (University of Arizona 2005). The site allows a user to compare different types of vegetation indices and different years and seasons. The site was created to utilize commercially available data to address real-world problems faced by managers and scientists (University of Arizona 2005).

Invasive Species Applications

Invasive species management is an important aspect of land management because in the United States, exotic plants invade about 700,000 ha of natural communities per year (Pimentel et al. 2002). There are several ways that spatial tools are being used in weed management. For example, GPS can be used to record location or perimeter of a weed infestation. These spatial attributes of weed infestations are used in weed management for monitoring (USFS 2005). After the GPS locations have been collected and downloaded into a database, this information can be used to track the rate of spread of an infestation. GIS databases can be used to record, inventory, and monitor the success of weed management activities (Yule et al. 1996).

The collection of field GPS data can be enhanced by a data dictionary that ties field observations to GPS location. The USDA Forest Service has created a data dictionary for observations of weeds that is used by a technician in field reconnaissance. The data dictionary includes fields such as: species, phenology, elevation, cover (habitat) type, aspect, slope, distance from water, other weeds present, location, percent cover class, and distribution. This information is recorded in a national database that allows the Forest Service to discern the acres infested by particular weed species, account for the resources being spent on weed treatment programs, track the success of those programs, and define appropriate management activities to reduce the incidence of further invasions (USFS 2005).

The use of models to predict potential distribution of a weed species may be important because weed management is most effective when weed infestations are detected and treated when they are small,. With some knowledge of how the plant grows and reproduces and georeferenced points from the native range of the species, ecological models can be created to predict where a plant will likely occur and how quickly it may spread (Peterson et al. 2003). Ming and Albrecht (2004) studied the use of GIS in a model simulating the invasion of lantana (*Lantana camara* L.) in New Zealand and found the model was fairly accurate, demonstrating the potential importance of spatial modeling in predicting and monitoring in weed infestations.

Similarly, a study in the Front Range of Colorado looked at tree invasions into grasslands using aerial photography, historical topographic maps, and GIS (Mast et al. 1997). Vegetation change was based on areas of tree invasion compared with maps from previous years. The GIS analysis revealed that the area has experienced a clear increase in woodland cover compared to historical conditions (approximately 60 years), apparently due to climatic and anthropogenic changes (Mast et al. 1997).

Parker Williams and Hunt (2002) used hyperspectral imagery to determine areas infested by leafy spurge (*Euphorbia esula* L.) in northeastern Wyoming. Leafy spurge has bright yellow-green brachts that give it a distinctive reflectance in the near infrared range. The researchers used extensive field reconnaissance to validate the findings of hyperspectral remote sensing from the Airborne Visible Infrared Imaging Spectrometer (AVIRIS). AVIRIS imagery was then analyzed using a specialized spectral analysis called mixture tuned matching filter and the researchers reported superior accuracy in the draws with the y-estimate (percent cover of leafy spurge) being lower than the upland y-estimate (Parker Williams and Hunt 2002). The mixture tuned matching filter was not quite as accurate in the woodland canopies because of the amount of canopy cover, but could still positively identify infested sites. The researchers concluded that hyperspectral imaging could potentially be used for leafy spurge detection on a regional scale if the did not contain dense canopies (Parker Williams and Hunt 2002).

Rangeland Soil Applications

Understanding soil resources is very important to rangeland management because plant growth and the type of vegetation present depends on the chemical and physical properties of the soil (Mati et al. 2000; Wang et al. 2004). Spatial technologies have been used to describe soil attributes such as erosion hazard (Mati et al. 2000), soil moisture (Wang et al. 2004), and runoff into water bodies (Melesse and Shih 2002). Additionally, if rangelands become degraded, soils are more subject to wind and water erosion making restoration more difficult (Wang et al. 2004). Mati et al. (2000) combined the universal soil loss equation (USLE) with the GIS program ArcInfo, to determine the erosion hazard in Upper Ewaso Ng'iro North basin of Kenya where recent land use changes have brought about increased erosion. The USLE predicts how susceptible to erosion a soil is based on characteristics of parent material. The area has traditionally been used for livestock grazing, wildlife habitat, and dryland crops such as wheat and barley. The USLE was incorporated into a spatial model that predicted erosion for different cover types. The model was accurate in predicting erosion in the higher elevation forested areas, but was only moderately accurate in predicting erosion for rangelands and croplands. The model tended to underestimate the maximum amounts of predicted eroded soil, but did reasonably well at predicting areas that had high erosion potential. It was concluded that the model could be used over larger areas to aid in making management decisions (Mati et al. 2000).

Plant growth is very dependent on the amount of soil moisture. Wang et al. (2004) used a combination of NDVI calculated from a Landsat image and field sampling that coincided with the days the images were taken, to calculate moisture in the soil in a semiarid rangeland in Arizona. The researchers used a supervised classification to determine land cover and masked (i.e., did not use) classes of vegetation that completely obscured the soil from the satellite (i.e., mesquite). A supervised classification uses areas of known cover types (training sites) and extracted these areas from the satellite image while an unsupervised classification uses clustering by a trained observer to classify a satellite image without using training sites. The researchers used a surface roughness reduction and vegetation parameters with a synergistic model to predict soil moisture. They concluded that the model was moderately effective at estimating soil moisture, but first needed to be validated under controlled conditions (Wang et al. 2004).

Melesse and Shih (2002) estimated storm runoff of the Kissimmee River in Florida using Landsat images (from 1980, 1990, and 2000), NRCS soils data, and a GIS. The NRCS soils data were integrated with the land use data and tabular attributes were added to the layer to evaluate runoff trends. The researchers found that land uses had changed in the basin over the two decades of study (Melesse and Shih 2002). The river had been channelized in the 1960's and 1970's, and the land was increasingly converted from wetlands to cropland. However, the 2000 image showed that the amount of wetland marsh had increased due to conservation measures. The increased wetland and marsh has reduced the amount of runoff (Melesse and Shih 2002). The researchers concluded that regardless of the varying spatial resolution of the images throughout the study, they were helpful in tracking land use changes

Natural Hydrologic Features

Landscape hydrologic features are extremely important in rangeland management especially where distribution of animals, both wild and domestic, is concerned (Cort 1996). Much of the focus for using GIS to capture natural hydrologic features is accomplished with a modeling approach (Kalin et al. 2003; Ludwig et al. 2003; Pandey et al. 2005).

To assess the effects of erosion on an agricultural watershed and determine priority areas for restoration, Pandey et al. (2005) combined a model that represents the hydrologic function of a watershed with raster-based GIS. The researchers used the model with imagery from the Indian Remote Sensing Satellite (IRS)1-D Linear Imaging Self Scanner (LISS)-III, soil data from the local soil conservation district, and digitized topographic maps to develop management options for the watershed under different scenarios (Pandey et al. 2005). The model was calibrated with measurements from field weather stations. This model accurately discriminated amongareas of traditional and conservation tillage. This could potentially be applied to rangeland scenarios in identifying areas of high impact by grazing livestock and underutilized areas. The researchers concluded that utilizing geodata had improved the original model’s accuracy tremendously and using a GIS was far more time efficient and cost less than traditional field surveys (Pandey et al. 2005). Models similar to this one are important to range management in predicting the nutrients and water lost from range sites as a result of different management practices.

Although the AVHRR satellites have a coarser resolution than IRS1-D LISS-III or aerial photography, the imagery has the advantage of having high temporal resolution (Ludwig et al. 2003). One of the biggest challenges to using AVHRR in hydrologic modeling is determining land use from an image with a resolution of 1 km. For this reason "fuzzy logic,"a logic system designed for situations that involve imprecise data, was used. Fuzzy logic divides data into vague categories (i.e., grass, shrub, tree). (For a more detailed discussion on fuzzy logic theory, see Zadeh 1965). In a study in the Upper Danube catchment, the area was characterized by highly variable relief that resulted in widely varying precipitation. The relief and precipitation layers were combined using a GIS to create a layer that would allow for boundaries marking the edges of catchment areas that are not always clear in nature. Catchment areas are physiologically different than other areas near them because they stay moister longer and have slightly different vegetation (Ludwig et al. 2003). Catchment areas are important in rangeland management because they have a different microclimate than surrounding areas and will likely stay green longer than their upland counterparts. Livestock and wildlife will tend to congregate in areas that stay green longer (Cook 1966).

As urbanization of rural lands continues, so does the threat of water sources becoming polluted (Tang et al. 2005). Rangelands are currently undergoing a tremendous changes in land use and are subject to subdivision and urban sprawl (Jensen 2001; Hansen et al. 2002). Tang et al. (2005) sought to understand how urbanization patterns would affect the runoff of a watershed of Lake Michigan. The researchers used aerial photography from 1978 to determine past land use for the area to ascertain the reliability of the model to accurately predict growth and sprawl at known (past and current) rates (Tang et al. 2005). The researchers predicted that with a normal growth pattern, water sources would experience a 5% increase in runoff volume by 2040 and with a sprawling growth pattern, up to a 12% increase in runoff volume (Tang et al. 2005).

Urban growth can lead to increased runoff (Tang et al. 2005). Sediment yield can also increase with urban growth and is further influenced by other conditions, such as poor management practices and catastrophic events (Kalin et al. 2003). Similar to the study by Pandey et al. (2005), Kalin et al. (2003) used GIS to combine spatio-temporal information with a hydrologic function model. The study area in Iowa used three rain gauges per watershed allowing for spatial and temporal measurements and comparisons across the same watershed (Kalin et al. 2003). The model was evaluated at different resolutions for predicting runoff and sediment discharge and could possibly be applied in more arid areas to predict areas prone to erosion from severe or prolonged precipitation events.

One way to track changes in waterway courses is to analyze historic data collected by United States Geological Survey (USGS) gauging stations as was accomplished on the lower Trinity River in Texas by Wellmeyer et al. (2005). The USGS gauging stations collect daily stage-discharge data about the river. Researchers used six sets of aerial photographs and digital orthophoto quarter quadrangles (DOQQs) to determine rates of channel activity (Wellmeyer et al. 2005). The study concluded that although there were no obvious changes in high flow conditions after the dam was closed in 1968, the low flow conditions, however, were elevated. The authors also stated that this type of study may be more useful in predicting or documenting change in arid climates where the flow of waterways is not as stable (Wellmeyer et al. 2005).

Wildland Fire Management

Wildfires are a significant concern for land managers and may result in the loss of ecosystem function, recreation, available forage, and saleable timber (Pew and Larsen 2001; Hessburg and Agee 2003). Significant resources are directed to fire prevention, suppression, and restoration (Wybo et al. 1995; Pew and Larsen 2001). Fires are influenced by the amount and distribution of fuels present, weather conditions, and terrain (Kushla and Ripple 1997; Pew and Larsen 2001). Wildfire managers have taken advantage of the tremendous technological advances of spatial tools and use GIS to create and analyze fuel maps (Miller et al. 2003), investigate the role of terrain in wildfire (Kushla and Ripple 1997), create vegetation databases (Welch et al. 2002), integrate GIS into decision support systems (Wybo et al. 1995), analyze fire patterns (Pew and Larsen 2001), and assess wildfire risk (Yool et al. 1985; Jaiswal et al. 2002; Hernandez-Leal et al. 2005).

A combination of remotely sensed data and GIS technologies are commonly applied to examine wildfires. Before these technologies were available, extensive field reconnaissance was required and predictive fire analyses were not generally conducted because of the tremendous time and manpower required (Miller et al. 2003). Many studies were aimed at better predicting where fires would occur and what variables affected occurrences (Yool et al. 1985; Kushla and Ripple 1997; Pew and Larsen 2001; Jaiswal et al. 2002; Miller et al. 2003; Hernandez-Leal et al. 2005).

Fuel models are an important aspect of wildland fire management and have benefitted from advances in both image resolution and analysis techniques. In one of the earliest fuel model studies to use GIS, Yool et al. (1985) used an early GIS to add layers such as fire history, precipitation events, and digital topographic data to a Landsat image that was classified into hazard categories. This enabled them to predict areas of urban interface that would be at high risk in a brushfire path in southern California. Similarly, Miller et al. (2003) used an ISODATA (an image classification clustering method) algorithm to classify fuel types into 16 different classes in southeastern Arizona. As spatial technologies have improved, so has the ability to classify fuels into finer categories enabling researchers and managers to more accurately predict fire behavior.

Sources of ignition and rates of spread are important variables in wildfire management. In a study conducted in India, Jaiswal et al. (2002) utilized data from the IRS-1D LISS-III remote sensing satellites to interpret which areas had burned and their vegetation types, slope, proximity to settlements, and distance from roads. They used this information to derive a model for their study area that predicted where fires had a high probability of igniting and spreading (Jaiswal et al. 2002). Similarly, a study conducted on Vancouver Island, Canada used a GIS to study spatial and temporal variables of human caused wildfires (Pew and Larsen 2001). Using information from a digital database of wildfires, the researchers were able to positively correlate fire ignition with industrial practices and recreation use (Pew and Larsen 2001). Rangelands support many forms of recreation including hunting, camping, hiking, and off-road vehicle use (Tueller 1987) and further studies may be able to predict where forest and rangeland managers should focus their fire prevention efforts (Pew and Larsen 2001).

The terrain in which a fire is burning plays an important role in its rate of spread, pattern and extent (Kushla and Ripple 1997). Using topographic variables and historic burn data, researchers have created a model supporting the hypothesis that local topography could have substantial effects on fire behavior (Kushla and Ripple 1997). Rangelands can have highly variable topography and could benefit from a wildfire model that takes terrain into account.

GIS databases can be extremely helpful in managing wildfires, predicting their spread and likelihood of occurrence, and integrating new information as it becomes available (Wybo et al. 1995). The use of GIS and remote sensing in managing rangeland wildfires could be further used to predict vegetation regrowth, plant abundance, and community composition (Guevara et al. 1999).

Wildlife, Endangered Species, and Biodiversity

The field of wildlife ecology has capitalized on the spatial revolution, using GPS collars to track herds and individual animals (Hulbert and French 2001; Johnson et al. 2002; Frair et al. 2004), GIS to monitor biodiversity (Salem 2003; Cunningham 2005), and the two technologies together for home range and habitat analysis (Selkirk and Bishop 2002).

One problem that has plagued wildlife scientists is not knowing if missing data from GPS collars affected the results of habitat selection studies. In a study conducted by Frair et al. (2004), the researchers dissected this problem by attempting to determine what kinds of errors were incurred in different cover and terrain types. The researchers determined that the brand of the GPS collar, cover type, and terrain all affected the likelihood of missing data (Frair et al. 2004). The more densely covered an area (e.g., closed deciduous and conifer forests) and the steeper an area, the less likely a GPS collar would pick up a satellite signal to log a data point. The likelihood of collecting a GPS location was further reduced in the summer months and certain times of the day because the satellites take different orbits during the year and different satellites are available at different times of the day. The researchers concluded that GPS collar studies should be interpreted carefully with consideration to terrain, cover type, and season of use (Frair et al. 2004).

Another study in northern British Columbia used GPS collars to examine movement patterns of caribou (*Rangifer tarandus caribou* L.; Johnson et al. 2002). Animal location data collected with GPS units supported the hypothesis that caribou use different areas at different times of the year (Johnson et al. 2002). This type of study could be used in rangelands to monitor movements of wildlife populations and to manage interactions among grazing ungulates.

Selkirk and Bishop (2002), used GIS to analyze home range and habitat for four eastern grey kangaroos (*Macropus giganteus*). The authors used of ArcView and vendor-developed extensions that allowed for further detailed analyses of spatial data. The study also examined human imposed features such as roads and fences to further extend the analysis of the habitat selection. Selkirk and Bishop (2002) found that kangaroo home ranges tended to overlap and were different depending on the time of day and the season. This may have been due to the particular type of analysis that was used and the authors concluded that GIS was a powerful tool to provide detailed information about home range and habitat analysis and should be included in similar studies (Selkirk and Bishop 2002).

Gap Analysis is an approach for species conservation utilizing GIS to create vegetation maps, and animal characteristics to predict animal distribution and potential habitat. Gap Analysis was developed by the USGS and identified areas that were rich in species diversity (Salem 2003).

Species-rich areas that did not fall in areas of government protection (i.e., parks, refuges, federal land) were considered “gaps” within the analysis (NOAA 2005b). There were three main assumptions on which Gap Analysis was based: 1) it is easier to conserve species while they are still common, 2) it is more economically effective to maintain natural populations than to intensely manage endangered ones; and, 3) it is possible to accurately model populations at different management levels (USGS 2005a).   Gap Analysis originated in Hawaii in the 1980's and today is a nationwide program with efforts to make it international. The Gap program has the cooperation of nearly 500 state and federal agencies and is used in research, business, development, and education (USGS 2005a).

GIS programs have been readily incorporated in the study of biodiversity because of their ability to project both spatial and non-spatial data (Salem 2003). In a study conducted in Egypt, ArcInfo was used to establish a database for monitoring the biodiversity of arboreal species. Non-spatial attributes such as degree of threat, life form, and economic uses were combined to create maps depicting the arboreal species’ risk of extinction (Salem 2003).The author developed an effective conservation tool and concluded that this study may pilot activities to eventually produce a worldwide database (Salem 2003).

In a study monitoring endangered species, Stoms et al. (1993) used GIS to validate California condor (*Gymnogyps californianus*) sighting data. The study used historic sighting data to reconstruct the condors’ range, and matched it with a land use/land cover map created from a Landsat TM image. The researchers used habitat requirements for the condor to correspond with the historic sighting data. The data were then used to study spatio-temporal changes in condor habitat and support for a model of suitable sites for condor releases. The authors concluded that the GIS program was useful for providing detailed information on factors that limit endangered species' home ranges, but the historic data did not provide the level of detail needed for an accurate analysis of condor habitat (Stoms et al. 1993). Similarly, the conservation of lemur species on the island of Madagascar has employed GIS. Smith et al. (1997) used GIS to map attributes of lemur habitat and models to predict where lemurs would be found. These were then translated into areas that are significant for lemur habitat conservation. The results were similar to Stoms et al. (1993) in that the models created with historic data were not accurate or reliable enough to name specific locations where lemurs would always be found (Smith et al. 1997).

The private and public grasslands of southern Minnesota harbor a tremendous diversity of songbirds and it has been debated which ownerships support a greater biodiversity. Cunningham (2005) used a GIS to quantify habitat use in relation to land use and ownership. The study compared the songbird diversity of public land comprised of natural areas, wildlife management areas, and other similar areas to private land enrolled in the Conservation Reserve Program (CRP). A program, known as FRAGSTATS, that uses spatial data to quantify landscape structures (McGarrigle and Marks 1995), was used to identify habitat patches important to grassland birds (Cunningham 2005). The author concluded that, surprisingly, CRP lands had greater bird diversity than public lands (Cunningham 2005). This study may lead to other studies that compare biodiversity on private and public lands.

Kerr and Deguise (2004) cite habitat loss as the main reason that species are at risk of becoming extinct and remotely sensed data can be used to quantify barriers to conserving endangered species. In Canada, researchers used data acquired from SPOT4 satellite imagery to conduct a geographic analyses of habitat loss with a GIS (Kerr and Deguise 2004). Of the 243 species considered, the authors found that 16 had no detectable habitat remaining, though some may be adapted to surviving in human-altered ecosystems (Kerr and Deguise 2004). The authors acknowledged that other threats (such as hunting or fire suppression) may not be accounted for in their geospatial analysis.

A combination of GIS with GPS was used to study an endangered shrub species, *Triunia robusta*, in Australia (Powell et al. 2005). The shrub's habitat was rapidly disappearing because of land clearing and until recently *T. robusta* was thought extinct. A GPS unit was used to mark recently discovered populations and GIS was used to interpolate spatial data such as location, slope, aspect, habitat type, and distance from water (Powell et al. 2005). The researchers then used the abiotic data with habitat requirements for *T. robusta* in a model to predict where the plant may occur. When this was checked against field observations, four new populations were found in areas the GIS model had predicted (Powell et al. 2005). Results of this study demonstrate the value of GIS and GPS as tools in endangered species management.

Decisions regarding areas to protect with conservation rules are often difficult and fraught with conflict. Land managers may find GIS-based analyses useful when deciding which tracts of land to conserve. Walker and Faith (1995) used GIS and phylogenetic diversity data to assess whether an area of land would be a suitable candidate for conservation. With GIS, geographic locations can be incorporated with social concepts such as: irreplaceablility, complementarity, representativeness, and substitutability (Walker and Faith 1995). The ability to weight decisions on social concepts makes this type of GIS software analysis important in setting conservation strategies and deciding whether or not to conserve a subspecies (Walker and Faith 1995).

Spatial technologies are important tools to the study of biodiversity and conservation of species. They are able to accurately re-create historical habitat ranges (Stoms et al. 1993; Smith et al. 1997), suggest land areas important to conservation (Walker and Faith 1995; Cunningham 2005; Powell et al. 2005), and predict areas highly susceptible to change (Kerr and Deguise 2004). Rangelands harbor a tremendous diversity of plants and animals and geospatial tools are becoming vital to the conservation of this diversity.

Range Improvements

Range improvements are human-constructed objects designed to improve the grazing capacity or utility of rangelands (Herbel 1983; DelCurto et al. 2005). Range improvements include water developments (Frasier 1975), salting locations (Martin and Ward 1972), vegetation manipulations (Svejcar and Vavra 1985), supplementation sites (Bailey and Welling 1999; Bailey et al. 2001; Bailey 2005), and fences (Walker et al. 1989). Although it has not been documented that spatial technologies have been used in the management of these features, it is clear that GPS and GIS are currently used for recording resource locations and how resources affect livestock distribution, but could be used more extensively in the management and record keeping. For example, GPS and GIS are used to determine if water and salt locations (Ganskopp 2001) and dehydrated molasses supplements (Bailey and Welling 1999; Bailey et al. 2001) change livestock distribution. Because it is possible to add attribute data to spatial locations (Hernandez-Leal et al. 2005), the condition of range improvements could be added to the locations of range improvements. For example, if a fence was repaired, the condition of the fence, the repair made, and the date it was made could all be stored in a geodatabase. Remotely sensed data could also be used to inventory locations of roads, water sources, and other range improvements.

Livestock Management

GIS programs have been used in combination with both GPS and remote sensing to quantify grazing patterns (Ganskopp et al. 2000), identify animal behavior (Beaver and Olson 1997), and predict forage use (Wade et al. 1998; Kawamura et al. 2004). Other studies used external motion sensors to quantify animal movement (Rutter et al. 1997; Schlecht et al. 2004; Ungar et al. 2005). GIS can be used to predict where livestock might graze. In an example from Oregon, Wade and colleagues (1998) defined criteria for where cattle would likely graze. The criterion were based on vegetation type (from the NRCS) and topographic data (from the USGS Digital Elevation Model; DEM; Wade et al. 1998). Cattle were unlikely to graze in places with steep relief and/or a dense canopy with little understory. The model proved to be fairly accurate in determining where cattle were unlikely to graze. Unfortunately, the study did not include other important information, such as water sources, which are particularly important in the arid areas of eastern, central, and southern Oregon.

Where cattle congregate, their activities, and how these activities affect pasture utilization have been the subject of many studies. Since the advent of GPS, GIS, and remote sensing, animal spatial activities have been much easier to monitor in natural settings (Wade et al. 1998; Ganskopp 2001; Ungar et al. 2005). In a study by Ganskopp et al. (2000), GPS units were used to document and traverse trails utilized by cattle and the least-effort pathway function of the GIS was used to compare trails taken by cattle to those predicted by a GIS. The authors concluded that the cattle take pathways that are shorter and require less effort than the GIS program predicted they would take. The reason for this is that the GIS program only looks "one step ahead" (or to the next pixel) and the cattle can see the landscape and take the path that is the straightest with the least effort expended (Ganskopp et al. 2000). Thus, GIS may be useful in predicting movements of cattle, but not at predicting the exact route they will follow.

In a similar study, Ganskopp (2001) outfitted cattle with GPS collars that tracked their movements and manipulated their distribution with salt and water. The salt location was then moved, but the water stayed in the same location. Then, the water was moved, and the salt remained in the same location. He found that moving water was more effective at redistributing cattle than moving salt (Ganskopp 2001). Discoveries of this nature are facilitated by the use of both GPS and GIS. Ungar et al. (2005) summarized that using this method in conjunction with GIS can relate animal distribution and movement to landscape features.

GIS may also be useful in predicting where cattle will be located in different seasons. For example, Beaver and Olson (1997) used a GIS to map areas of thermal protection relative to wind-speed and topography. Using visual observations as data points, the researchers determined that older cattle selected thermal shelter superior to younger cattle. This is important information for range livestock management because younger cattle will likely have higher nutritional requirements because of greater exposure to unfavorable abiotic conditions.

Remote sensing has been used to determine where grazing has occurred and the extent of grazing. In a study conducted by Kawamura et al. (2004), sheep were outfitted with GPS sensors and their locations were recorded for five days. These data were then correlated with a MODIS NDVI. Higher grazing intensities corresponded with areas of lower plant biomass (Kawamura et al. 2004). This type of study shows the potential of using remote sensing data to keep record and verify grazing practices.

Landscape Constructs Relevant to Human Use

Ownership. Within a landscape, there are features imposed by humans that are important to everyday land management. Land management decisions may be made very differently depending on the ownership of that land. For example, the USFS, a federal land management agency may not manage their land the same way that The Nature Conservancy, a private conservation group, would manage theirs. Land ownership designation was one of the first base layers used in most GIS projects (Vitek et al. 1996). Other ownership boundaries are drawn according to organizational affiliations (such as school districts, national forest boundaries, etc.; Vitek et al. 1996) and political boundaries (such as county, state, etc.). There are usually distinct differences in management objectives across these organizational and political boundaries (Turner et al. 1996; Cunningham 2005). Turner et al. (1996) conducted a study in two different parts of the country (North Carolina and Washington State) with very different ownership patterns to determine the differences among land managers resulting from different management objectives. For example, the owners of the properties in Washington State had a goal of timber sale while the owners of properties in North Carolina had a goal of tourism and natural resource conservation. Using Landsat MSS and TM imagery and the GIS program ERDAS (Leica Geosystems 2005) the researchers concluded that the landscape patterns differed very little between land owners in the North Carolina. However, the landscape patterns differed significantly among landowners in Washington State (Turner et al. 1996). Two basins within the area in Washington State were studied. The first basin was managed primarily by the United States Forest Service (USFS) and commercial entities and displayed low to moderate landscape change over time. The second basin was primarily privately owned by small-scale forest operators and had changed dramatically over time. There were far fewer patches of coniferous trees compared to USFS land because of different management objectives. This study clearly illustrates that land ownership influences landscape patterns (Turner et al. 1996).

Viewsheds. The land visible from a certain location is called a viewshed and is another feature that may influence how a land manager makes decisions about land management activities. Many of the GIS programs include viewshed calculators (Cooper *in press*). Viewsheds are commonly calculated to determine the optimal location for electronic equipment such as radio towers, and generally are located on higher points in the landscape (Kim et al. 2004). For example, Möller (2005) used ArcGIS (ESRI 2005a) to compute the viewshed for each wind turbine in one county in Denmark. Although viewsheds are regularly calculated in GIS programs, they are very time consuming because of the amount of data that must be run through an algorithm (Kim et al. 2004). A novel useof this analysis in the future may be in calculating viewsheds from property boundaries that could lead to a revised definition of "private" property.

Information Privacy. One of the biggest issues facing users of spatial technologies is that of privacy. Where does public information end and private information begin? There have been numerous discussions on this subject (Curry 1997; Haklay 2003). The issue of GIS and privacy really started with the advent of remote sensing (NASA 1995). In the case of the US and Russia, neither country was comfortable with the other country being able to perceive highly classified information (e.g., weaponry impacts on training sites) from satellites (Florini 1998). For civilians, the issue of privacy really came to light when GIS began to be used by marketing specialists to build geodemographic databases (Goss 1995). A geodemographic database is often used by marketers to collect spatially explicit information about a person including their potential marketability and then uses that information to attempt to sell products to the consumer. This information is traded, sold, and used by other marketing companies (Goss 1995). There is legislation to protect individuals from having incorrect information published about them, (i.e. Privacy Act of 1988, Freedom of Information Act of 1974 and 1996) however, it is up to the individual to investigate if the truth is being published about them. Most of the information to which corporations have access has a spatial component (e.g., zip codes and socioeconomic data; Goss 1995).

Some groups, particularly environmental advocates, would like to see more publicly accessible information about private property (Haklay 2003), while other groups would like to see less (Curry 1997). Haklay (2003) argues that more educated decisions will likely be made with public access to more kinds of spatial information about the environment. However, Curry (1997) argues that what an individual does on his or her private property should not be accessible by the general public. He does acknowledge that to make sound environmental decisions, access to the "big picture" information may be necessary (Curry 1997).

Although there have been many articles on the issue of privacy, there is no agreement on where the use of GIS and remotely sensed data cross the boundary into private information. Some authors are adamant that any remotely sensed data should be publicly accessible (Goss 1995; Haklay 2003), while others believe that private property and information have already been infringed upon (Curry 1997). Part of the difficulty in creatinga solution to the problem is in defining the concept of "privacy" (Goss 1995; Curry 1997). There is no easy answer to this question, and it will likely continue to be a contentious issue in land management.

Current Levels of Use and Barriers/Obstacles of Use of Spatial Technologies

After (about 40) discussions with ranchers in Washington, Oregon, and Idaho, I estimate only about one-third know what a GIS is. Most ranchers know that the state and federal land management agencies that oversee their public land allotments use GIS, but they have no idea for what it is used. Of those who knew what GIS is, only two have an active geographic database of their own land. About 15% of ranchers use aerial photographs as the basis for their ranch map and GPS units are carried by about 5% of ranchers in their daily operations.

One of the largest barriers to adoption of these spatial technologies is the lack of knowledge (Rogers 2003). First, there is a misconception that all GIS programs are extremely expensive hence not affordable by the average person. This may be true for ArcGIS which costs about $19,000 (ESRI 2005a), but a person can purchase a GIS program like Global Mapper for mapping purposes and simple analyses for about $250 (Global Mapper Software LLC 2005). The second perception that is apparently a large barrier is that GIS requires exceptional technical skills to use. While it is true that GIS does require some computer knowledge to operate, a user only has to be moderately proficient with a computer to learn the basic functions of most GIS programs (D. Johnson, personal communication, February 2005). However, to really become proficient at ArcView, one of the more complicated GIS programs, would require about 18-24 hours of instruction and additional practice (D. Johnson, personal communication, February 2005).

Another large obstacle is that there is no obvious or single “beginning point” to learning GIS. There are an infinite number of ways to approach learning GIS and no particular way is known as the “right” way. ESRI has tried to combat this obstacle by offering on-line training courses. However, these are only available to owners of ESRI's technology, and a rancher would have to purchase ArcView just to take the tutorials. If the rancher found that ArcView (ESRI 2005a) did not perform for his or her application, they would have spent money on expensive, useless software.

CONCLUSIONS

There are many ways that spatial technologies can be used in natural resource management and often, it is not a single spatial technology that has been used, but a combination, such as GPS and GIS. GIS was originally developed for use in natural resource management to organize the enormous amount of accumulating spatially relevant data. From there, GIS and the associated applications have branched out widely, and are used in a tremendous variety of disciplines.Ranching is an enterprise that requires many spatial decisions be made on a daily basis, such as where to move cattle, what kinds of forages populate a pasture, and how much forage is on an allotment. Based on the tremendous variety of uses in natural resources management, it would appear that spatial technologies could be readily incorporated into ranching.

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CHAPTER 2

POTENTIAL USES OF GPS AND GIS IN RANGELAND MANAGEMENT: A CASE STUDY FROM SANDHOLLOW RANCH

INTRODUCTION

Ranchers and range managers use spatial data nearly every day to accomplish ranching and range management activities. Most ranch managers use some type of paper map to maintain spatial information, but very few ranchers use electronic technologies such as Geographic Positioning System (GPS), Geographic Information Systems (GIS), or remote sensing. Many ranchers are not aware of the capabilities of these spatial technologies and are skeptical about investing time, labor, and money in them (Hancock unpublished data). To evaluate the potential value of these spatial technologies in ranching, I conducted a case study to:

1. Document the time and labor required to log the locations of ranch and range resources and edit and organize data into a geographic database for a working ranch.
2. Extend and explore opportunities for the use of the GPS and GIS in ranching operations.
3. Provide guidelines for ranchers interested in using spatial technologies.

RANCH AND STUDY AREA

This case study was conducted on an 8,023 ha (19,921 acres) ranch called Sandhollow Ranch which was purchased by the Hixon Corporation in 1988. Sandhollow Ranch is located near Payette, Idaho, (lat 44° 08'N, long 116°51'W) about 100 km (62 mi) north of Boise. The ranch contains 54 pastures and paddocks. Of these, 18 pastures that were larger than8 ha (20 acres) were used in this case study analyses (Fig. 2.1). Elevation of the ranch headquarters is 717 m (2,352 ft). The remainder of the ranch has highly variable relief from 669 m (2,195 ft) to 1,037 m (3,402 ft). Lands surrounding the ranch are primarily rangeland used for livestock grazing, with the lands to the west of the ranch currently in orchards, and irrigated alfalfa (*Medicago sativa* L.). Soils are unconsolidated lacustrine and fluviatile material from remnant high plains. Soils are of a Cashmere sandy loam series in the draws; Payette Haw loam series, Tindahay coarse sandy loam series, and Power silt loam series on moderate slopes; and Payette coarse sandy loam series, Saralegui coarse sandy loam series, and Lolalita-Saralegui coarse sandy loam association on the steepest slopes (Rasmussen 1976).

The climate is semiarid continental with a mean average precipitation of 26.5 cm (10.4 in) annually (Western Region Climate Center 2005). Mean average temperature is 10.7° C (51.3° F) with the average maximum of 18.7° C (66.6° F) and the average minimum of 3.2° C (37.8° F; Western Region Climate Center 2005). The summers are hot and dry with occasional thunderstorms. The winters are cool and wet with the majority of the precipitation falling from October to April, mostly as rain with little snowfall accumulation (Fig. 2.2).

The historic vegetation communities on the ranch were likely bunchgrasses with a shrub overstory (NRCS 2005a). The native bunchgrasses include Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass (*Pseudoroeneria spicata* [Pursh] A. Löve) and the shrub overstory included basin big sagebrush (*Artemesia tridentata* Nutt. ssp *tridentata*) and Wyoming big sagebrush (*Artemesia tridentata* Nutt. ssp *wyomingensis* Beetle & Young). Other grasses present historically were needle-and-thread (*Hesperostipa comata* [Trin. & Ruper] Barkworth), Indian ricegrass (*Achnatherum hymenoides* [Roemer & J.A. Schultes] Barkworth), Thurber's needlegrass (*Achnatherum thuberianum* [Piper] Barkworth), bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey) basin wildrye (*Leymus cinereus* [Scribn. & Merr.] A. Löve), and

Sandberg bluegrass (*Poa secunda* J. Presl). Other shrubs that are part of the potential natural community include antelope bitterbrush (*Purshia tridentata* [Pursh] DC) and rabbitbrush (*Ericameria nauseosa* [Pallas ex Pursh] Nesom and Baird), and *Chrysothamnus viscidiflorus* ([Hook.] Nutt.). Dominant forbs in the historic plant community included arrowleaf balsamroot (*Balsamorhiza sagittata* [Pursh] Nutt.), fleabane (*Erigeron* spp), tapertip hawksbeard (*Crepis acuminata* Nutt.), granite prickly phlox (*Leptodactylon pungens* [Torr.] Torr. ex Nutt.), common sunflower (*Helianthus annuus* L.), and western yarrow (*Achillea millefolium* L.; NRCS 2005a).

Frequent fire return intervals and historic grazing patterns have led to a dominance of annual grasses and weeds (Mack 1981; D'Antonio and Vitousek 1992) in lower elevation and southern pastures on the ranch. The annual grasses now present include cheatgrass (*Bromus tectorum* L.) and medusahead rye (*Taeniatherum caput-medusae* [L.] Nevski). Two plants on Idaho's noxious weed list, Rush skeletonweed (*Chondrilla juncea* L.) and puncturevine (*Tribulus terrestris* L.), also occur on the ranch. Other non-native plants include kochia (*Kochia scoparia* [L.] Schrad.), pineapple weed (*Matricaria discoidea* DC), tumbleweed (*Sisymbrium loeselii* L.), and Russian thistle (*Salsola kali* L.).

The ranch is currently used as wintering grounds by about 1,000 head of beef cattle from mid-November to early March. The rest of the year the herd is at the parent ranch about 153 km (95 mi) northnear Bear, Idaho. There is also a feedlot for finishing stock on the ranch. Water is distributed on the ranch by a pipeline system that begins at a spring near the center of the ranch and waters most of the pastures to the west. The pipeline system was installed by the current owners. There are also a few developed watering sites (e.g., wells, ponds, and springs) that are not connected to the pipeline and provide water for the ranch east of the pipeline.

METHODS

To understand the potential applications of spatial technologies in ranching, this case study was conducted in July and August of 2004. The first step was determining the labor requirements for locating range improvements on the ranch including fencelines, roads, buildings, and water developments. Although it has been documented that salt locations can influence the distribution of cattle and are considered a range improvement tool (Martin and Ward 1973; Ganskopp 2001), salt locations were not included in this analysis because of insufficient time during the study and because the locations of all salting areas were not known.

Two Trimble GeoExplorer II[1], one Trimble GeoExplorer III[1], one Trimble ProXRS[1], one Dell[1] PDA with TeleType[1] GPS attachment, one Garmin Map76[1], and one Garmin GPSIII+[1] GPS units were used to log locations of resources on Sandhollow Ranch. Locations were recorded by seven field technicians; three traveled on horseback and four were on foot with assistance from an all terrain vehicle (ATV), a four wheel drive pick-up, and a ranch employee. The technicians logged locations with the GPS units and used field logs to record major resource attributes and document specifications or difficulties encountered. Technicians were given a 30 minute individual instructional course on how to use their unit. These technicians spent 29 July and 30 July 2004 collecting GPS locations of ranch resources. Three technicians also collected data on 31 July 2004. Over these three days, 141 data collection hours were accumulated. Thirty three more data collection hours were accumulated in late July and August bringing the total GPS location collection hours to 174.

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[1] Use of trade names is for information only and does not constitute an endorsement by the University of Idaho of any product to the exclusion of others that may be suitable.

Satellites were available for data collection from dawn (about 0530) until about 1430. After satellite coverage ended each day, data were downloaded from GPS units and imported into ArcGIS v. 8.3 on a laptop computer. The Trimble GPS units could be downloaded into the software program GPS Pathfinder Office v. 2.90 and imported directly to ArcGIS. The Garmin and Teletype data were downloaded into ExpertGPS (ExpertGPS 2004) and imported into Microsoft Excel. Using Excel, the data points were saved as comma separated values (CSV) files. The CSV files were then displayed in ArcGIS. All data were checked for accuracy against the technicians' field notes. Data points were edited using the editor function in ArcGIS and separated into descriptive data layers or themes (e.g., primary road, natural spring, etc.). About 100 hours were spent editing, organizing, and manipulating raw GPS data into useful GIS layers.

Layers acquired from other sources were also used in this study. Soils data were downloaded from the NRCS Soils Data Mart (formerly SSURGO; NRCS 2005c). The digital elevation model, and land ownership layers both came from the Inside Idaho website (Inside Idaho 2004). Nearly 215 hours were spent on manipulations and analysis including these layers.

RESULTS AND DISCUSSION

Range Improvements

Range improvements are human-constructed objects designed to improve the grazing capacity of rangelands (Herbel 1983; DelCurto et al. 2005). The current studies of range improvements using spatial technologies generally either document how the placement of salt, water, and/or mineral supplements alters livestock distribution (Bailey and Welling 1999; Bailey et al. 2001; Ganskopp 2001; Bailey 2005) or attempt to quantify grazing utilization with remotely sensed data (Kawamura et al. 2004). This case study documents the resources, technology, and labor associated with locating range improvements.

Fences are generally the most effective way to alter livestock distribution (Walker et al. 1989) and constituted the largest proportion of data collection hours. Logged fence locations included boundary, internal, and corral fences. Gates and locations where fences needed repair were noted in the field notes and could be added to the map as an active layer by the ranch manager. The type (e.g., metal or wire) and condition of gates could also be added at a later time. A total of 189 km (117 mi) of fencelines were recorded in this GPS-based procedure.

Data points were also collected for roads, buildings, and developed water with a Trimble GeoExplorerII. Although some roads were available in a layer from Payette County (Inside Idaho 2004), not all roads were contained in that layer and some had changed course since the layer was created. All data were imported into ArcGIS from Pathfinder Office v. 2.90. Roads were then classified and edited into two categories: primary and secondary. Primary roads were those that could be accessed with a four wheel drive vehicle. Secondary roads were roads that required an ATV. A total of 87.5 km (54.3 mi) of roads were recorded by GPS, with 57.6 km (35.8 mi) classified as primary roads and 29.8 km (18.54 mi) classified as secondary roads.

A pipeline constructed in 1988 provides water for the majority of the ranch. Two springs converge in the central part of the ranch and their water is collected in a main cistern. The pipeline runs west for the length of the ranch, and tanks can be turned on or off depending where livestock are located. Tanks filled by electric wells or natural springs have also been installed to further distribute livestock in the larger pastures that cannot be fully watered by the central pipeline. The feedlot corrals are served by the pipeline system, but are on a separate sub-system. The watering locations along the pipeline included a set of 2-3 tanks that were recorded with a

GPS unit and other pipeline attributes such as stop and waste valves and overflow pipes. Locations of 31 sets of tanks along the pipeline were recorded, with 6 sets of tanks located in the feedlot system. Locations of developed water sources, such as ponds, springs, and wells were also recorded by GPS and added as a layer in the GIS database. A total of 16 developed water sources were located and recorded; 10 of which were ponds and springs and 6 wells.

Other ranch resources, including buildings, were also located and recorded. Although ranch buildings and structures may not be used on a daily basis, they are important resources. For example, Sandhollow Ranch has five pole barns for storing hay. If the land were being appraised, the value of the buildings could easily be attached to the database. Locations of each corner of important ranch buildings were acquired by GPS. Buildings that had metal roofs were more difficult to obtain accurate points for (Fig. 2.3) because of excessive satellite signal distortion. The locations of 14 structures were recorded.

Editing the data was a time-consuming process as each set of points was imported into ArcGIS separately. A set of points are all those points downloaded from a GPS unit and edited into a specific theme (e.g., fenceline, primary road, etc.). The theme of any data point was determined from technician's field notes. It is possible to import an entire batch of points at once, but it would have been very difficult to sort them into individual themes once they were imported into ArcGIS.

Another problem encountered when editing was that different types of GPS units have different accuracy levels (Frair et al. 2004). Low accuracy GPS units may yield coordinates as far as 50 meters from the actual location. For example, Figure 2.4 illustrates a fence location that was mapped with a Garmin GPSIII+, which has an accuracy rating of about 30 meters, crossing a road that was mapped with a Trimble GeoExplorerII, which has an accuracy rating of 5-10 meters. In actuality, the road parallels the fence.

Alternatively, when the same GPS unit (Trimble GeoExplorerII) was used for both the road and the fence, the two features did not intersect when imported into GIS because of higher GPS accuracy even though the data were collected on a different date and time than the road. Thus, using GPS units with the same margin of error for the entire ranch would have likely reduced accuracy errors or at least made them consistent.

The time required and mistakes made during data collection might have been reduced if the technicians had been more familiar with the layout of the ranch, resources, and terrain. Plus, several data collection activities could have been conducted by staff at Sandhollow Ranch if GPS units had been available and staff had been appropriately trained. For example, cowboys at Sandhollow Ranch inspected all fences for soundness before cattle were turned into any pasture; a GPS unit could have easily been utilized to log the location of fences while they were being inspected. Likewise, the location of stock tanks could have been logged when tanks were inspected during the grazing season.

Another way that time spent editing data may have been reduced is if technicians had gone through a training and testing period. Even though each technician was given individual instruction about the unit, they were not briefed on errors that are inherent with GPS units such as multipathing (satellite signal reflecting off of inanimate objects) or the accuracy difference when a GPS unit is in Differential mode (applying a correction factor in real-time) and when it is not. It would have likely taken a full day of training and testing for technicians to become proficient with individual units.

Attributes Based on Soil and Vegetation Characteristics

Although there is a great deal of soils data available, it is sometimes difficult to find and even more difficult to interpret. Many of the soil surveys conducted by the Natural Resource Conservation Service (NRCS) have been re-surveyed and most are now available as spatial GIS layers and tabular data that can be freely downloaded (NRCS 2005c). The entire package of soils data at Sandhollow Ranch was available as a Microsoft Access database. The soils data used in these anlyses were digitized from soil surveys conducted in 1976. The spatial data could be viewed with any GIS program, and the tabular data could be opened with Microsoft Excel. However, it was sometimes difficult to determine the meaning of values in specific tabular files.

One piece of information contained in the NRCS soil data from Sandhollow was the kfactor which is based on the Universal Soil Loss Equation (USLE) and predicts how prone a soil is to water erosion (Mati et al. 2000). The kffactor is similar to the kfactor, but with the added risk of wind erosion. Because of the steepness of the terrain and loss of native vegetation cover, the current risk of accelerated erosion may be increased on Sandhollow Ranch relative to the risk associated with historic vegetation types but that risk is unknown. An erosion risk assessment was generated for Sandhollow Ranch by extracting the kffactor from the soils data. The kffactor was joined to the soils polygon and this layer was then rasterized (made into a grid) using Arc Toolbox. The raster values were normalized by taking the grid and dividing by the maximum number in the raster (grid) data set according to Chang (2002). A 30-m United States Geological Survey (USGS) digital elevation model (DEM; Inside Idaho 2004) was added to this map and the percent slope was extracted from the DEM using the Spatial Analyst Extension (ESRI 2005b) and the "Surface Analysis" function. The percent slope was then normalized. An index model (Chang

2002) was created by adding the equally weighted normalized kffactor and normalized percent slope using the "Raster Calculator" function of the Spatial Analyst Extension to determine the erosion risk (Fig. 2.5).

The erosion risk analysis took about four hours to complete, and was completed without all six factors of the USLE. Only two factors were used, the erodibility factor (kffactor) and the steepness of slope; the other four factors were not taken into consideration because data were not available. An estimate of soil loss due to erosion is also very dependent on the current vegetation occupying the site. I was not able to take into account the role that current vegetation cover may play in erosion risk because these date were not available and it was beyond the scope of this study to determine current vegetation. In summary, this erosion risk is very simplified and rudimentary, but represents an example of a prediction done with limited data.

Another land attribute particularly useful to ranchers is vegetation biomass (called range site production in the soils data). Range site production was originally determined by clippings conducted by the NRCS over a number of years and was available as estimated values by range site in the NRCS electronic soils survey. These data were calculated in pounds/acre for favorable, normal, and unfavorable years. A "favorable" year was one that had higher than average rainfall with temperatures and timing of precipitation favorable to plant growth. An "unfavorable" year for biomass production was generally restricted by inadequate or ill-timed precipitation (D. Hoover personal communication, July 2005).

Determining herbage production for the ranch based on the range site data was rather complicated as the data were not available in a form that was easy to display spatially. Most of the soils in the Sandhollow survey were mapped as soil map units (SMU) which are complexes of different soil types that occur together spatially. Another file that is available in the NRCS soils data is the proportion of specific soil type in each SMU. The range site production for specific soil types was multiplied by the percentage of each soil type in each SMU represented on the range to determine productivity for each SMU. This combined file was then saved as a CSV file, displayed in ArcMap, and joined to the soils polygons. Sandhollow Ranch is mostly located in Payette County, but a small portion of land in the northern part of the ranch falls in Washington County, so this process was repeated for each county. The two soils layers were then merged using the “Merge Layers” function of the Geoprocessing Wizard (Fig. 2.6). From this, total annual herbage production per pasture or for the whole ranch was calculated.

Estimating the annual biomass production took nearly ten hours because of the significant amount of manipulation required to put the data from both counties into a usable and compatible form. My resulting biomass production figures are just estimates and may not be accurate for several reasons. First, the estimated biomass was based on the potential natural community (PNC) and the current community is a significant departure from the PNC. Second, there are several potential errors in the estimates of biomass in the soil survey data. I was not able to verify these estimates so I accepted them as reasonable and emphasize that they are simply estimates. My estimates of rangeland production probably overestimates how much biomass is actually on the ranch, and it is something that a land manager would have to be very careful to note.

Range restoration is expensive and risky, but has a high payoff if successful. Establishing restoration potential with spatial tools would be a useful application for ranchers. I further combined the information about site productivity and erosion potential to estimate a “restoration potential” with revegetation as a primary goal. The probability of a restoration activity succeeding depends on several site-specific attributes. First is climate, which is regarded as a stochastic event that humans cannot control. Although GIS has been used to model climatic patterns (Schmidt and Dikau 2004), it was not included in this analysis for lack of sufficient site-specific data. Second, the moisture retention capacity of a site is directly related to the likelihood that seeds will germinate (Whisenant 1999). Northern aspects generally retain soil moisture longer than other aspects, and can have a greater potential for seeds to germinate. Sites that are flat or gently sloping are often better able to hold soil moisture than sites with steep slopes and are also generally less prone to erosion. Leveler sites are also easier to access with the equipment needed for revegetation (e.g., tractors and rangeland drills). Finally, the type of soil on a site has a significant influence on its productivity; sites with more productive soils have greater restoration potential than those with less productive soils (Whisenant 1999).

To determine areas of land that had the greatest potential for restoration, aspect was reclassified into four classes (cardinal directions). North was given the highest value and south was given the lowest. Next, production was sorted into five classes based on jenks (natural breaks). I added the reclassified aspect and production together using the “Raster Calculator” function of the Spatial Analyst Extension, then divided this newly formed layer by the erosion risk layer to estimate restoration potential (Fig. 2.7). Restoration potential also depends on the composition and extent of the plant community currently occupying the site (such as persistent weed dominance), data that are currently unavailable without significant field reconnaissance or advanced remote sensing.

Predicting the potential of any site requires many assumptions. First, the DEM that was used had a 30 meter resolution which is relatively coarse, especially for Sandhollow which has highly variable and rapidly changing topography. This may give an inaccurate picture of the landscape. I also used layers in which I had made previous assumptions, such as the annual biomass production. All these assumptions were compounded in the prediction of the restoration potential, and this may overestimate the potential of the land for restoration purposes. It may also weight factors unevenly favoring one factor over another (such as slope or aspect). Restoration can be a very good way to improve the condition of the rangeland, but it is very difficult to predict where a restoration might succeed because there are assumptions made about the factors used and so many factors that were not (and could not be) accounted for.

Several soil attributes that may be utilized by rangeland managers were illustrated, but this list is certainly not all-inclusive. Each county soil survey includes different types and forms of data, which makes a general summary difficult. The NRCS is currently in the process of making their soils data available through a web-based GIS that users can query for information (NRCS 2005c). Although the NRCS data requires significant effort to use in a GIS, it is a widely available and extremely important source of information for natural resource management.

Estimated Carrying Capacity

Ranching is a diverse endeavor requiring knowledge of a wide range of spatial and temporal topics (e.g., animal health, marketing, ecological condition, animal movement, wildlife habitat, etc.). Although spatial technologies have been used to track animal movement (Rutter et al. 1997; Schlecht et al. 2004; Ungar et al. 2005), determine the extent to which range improvements influence animal distribution (Bailey and Welling 1999; Ganskopp 2001) and predict where animal grazing will occur (Wade et al. 1998), they have not been widely used to keep spatial records of grazing management. In this analysis, the potential to estimate stocking rate based on site productivity and animal behavior characteristics was assessed. Calculations were based on the estimated annual herbage production from the NRCS soils database, the digital elevation model (DEM) for the ranch, and distances from developed water sources.

Production varies widely on the ranch with the draws ranging from 440-1,100 kg/ha, the moderate slopes ranging from 440-1,210 kg/ha, and steep slopes ranging from 165-825 kg/ha (Rasmussen 1976). The total amount of available forage of each pasture on the ranch was calculated by the method described in the previous section (Attributes Based on Soil and Vegetation Characteristics). The NRCS site productivity may not accurately reflect the actual situation because the current vegetation composition is much different than the potential natural community in several areas of the ranch. Annual grasslands containing medusahead rye and cheatgrass currently dominate much of the ranch. NRCS site productivity data was used because a spatially explicit description of current vegetation composition was not available. The proportion of usable forage was estimated using a proper use factor. Works by Pechanec and Stewart (1949) and Laycock and Conrad (1981) and current NRCS guidelines (2003) suggest proper use of sagebrush grasslands generally varies between 30% and 40% utilization of current year's growth. In my example, I selected a 40% utilization level to accomplish proper use. The amount of forage production for each SMU was calculated and then multiplied by 0.4 to yield the available forage with a 40% utilization rate (Table 2.1).

Although the available biomass was determined from NRCS range site production data and a proper use factor of 40%, the amount of actual available biomass in a pasture can be affected by slope and distance from water (Mueggler 1965; Holechek 1988). Pastures with slopes exceeding 20% generally are not uniformly grazed by beef cattle (Gillen et al. 1984). The valley bottoms and gentle slopes often experience heavier utilization than steeper slopes (Cook 1966). Holechek (1988) recommends reducing the predicted grazing capacity to account for steep slopes in a pasture. To determine the necessary reductions, the slopes derived from the 30-meter DEM were reclassified into four classes; 0-10%, 11-30%, 31-60%, and greater than 60%. The number of pixels in each class was determined from the layer properties by pasture. These data were then exported to an Excel file where a reduction factor was applied for each pixel class. If the slope was 0-10% no reduction was applied, if the slope was 11-30% available biomass was reduced by 30%, if the slope was 31-60% a reduction of 70% was applied to biomass availability and if the slope was greater than 60% the forage was considered unavailable and a reduction of 100% was applied (following Holechek 1988).

Another factor that affects the utilization of a pasture is distance from water (Holechek 1988; Ganskopp 2001). Beef cattle generally do not graze more than 2 miles from water (Martin and Ward 1973). Vegetation surrounding watering areas is generally much more heavily utilized than upland vegetation because cattle tend to congregate near water (Cook 1966). Holechek (1988) recommends reducing the predicted grazing capacity by 50% for distances 1 to 2 miles from water and considering areas beyond 2 miles unusable. The Buffer Wizard was used to create a feature layer of concentric circles one mile in diameter around each water source. This feature layer was then rasterized to a 30-meter resolution, and the number of pixels in each concentric circle was determined from the layer properties. These data were then transferred to an Excel file where the reductions mentioned above were applied. The reductions for steepness of slope and distance from water were then multiplied together in Excel and the total reduction was then applied to the total herbage production at the 40% utilization rate to obtain the forage (kg/ha) that is available for grazing in each pasture.

In arid areas with rugged terrain such as Sandhollow, coarse adjustments, such as miles, may not accurately predict the grazing patterns. Currently, the NRCS (2003) recommends evaluating water sources using a 0.25 mile buffer in concentric circles from water sources to predict the pattern of utilized areas. The Buffer Wizard in ArcGIS was used to obtain values based on the NRCS recommendation of 0.25 mile concentric circles to evaluate grazing pressure predictions. This buffer layer was also rasterized. To display these two layers spatially, the reclassified slope was then multiplied by the 0.25 mile rasterized distance from water layer using the "Raster Calculator" function of the Spatial Analyst Extension and used to create a map of predicted grazing levels (Fig. 2.8).

Though general rules for forage reductions based on slope and distance for water were used, calculations could have been more detailed with access to more detailed knowledge of the ranch such as astute operators generally possess. For example, a 10 m DEM of the landscape and analyses that utilized a DEM would have been much smoother because of the smaller pixel size compared to the 30 m DEM. In the above example, I applied reductions as suggested by Holechek (1988). Actual reductions that should be applied will vary among individual ranches and herds. For example, the breed of cattle may result in different grazing practices (Bailey et al. 2001). Cattle breeds that originated in rugged country will often be more likely to use more rugged terrain than cattle breeds developed in areas of lower elevation and gentler terrain (Bailey et al. 2001). There have been studies of the influence of vegetation type affecting where cattle prefer to graze (Stevens 1966; Sheehy and Vavra 1996; Wade et al. 1998).

There are several factors that could not be accounted for, but should be noted. First, biomass changes with slope. Generally, biomass declines as slope increases. This may be confounded by the fact that cattle don't use steep slopes as heavily as they use gentle slopes where biomass is generally more abundant. A related factor is that some soil conditions or rockiness may further restrict the use of slopes beyond my estimates. Sandy soils or rocky surfaces that provide poor footing and traction, may be avoided by cattle compared to stable soils. Studies that specifically addressed how soil surface conditions affect the use of slopes were unavailable, to fine-tune reductions in forage use due to slope and footing were not possible. Secondly, it is likely that there is an interaction between distance from water and steepness of slope. Steep slopes that are in close proximity to water may see heavier utilization than steep slopes that are farther from water. Though this interaction seems logical and is likely, data to clarify this relationship are lacking so it was excluded from this analysis.

I also made several assumptions with the factors that I used. First, when cattle graze a sagebrush grassland, they do not graze all plant species equally; some are more desirable than others. When a 40% proper use factor is applied, it is general, so that some plants have 60% utilized while others have 20% (or less). Second, cattle graze differently during the year. In winter, the cattle will likely seek shelter from the elements. Therefore, areas that provide thermal cover (such as draws) will likely see higher utilization and this is not accounted for in this analysis. Cattle also have changing nutritional needs through-out a year of production, which was no accounted for. Sandhollow Ranch has a significant population of wild herbivores, including mule deer (*Odocoileus hemionus* Rafinesque) and jackrabbits (*Lepus* spp.). The biomass consumed by wild herbivores is not accounted for in this analysis. The ranch itself is well watered, so the reductions were probably disproportionately favoring steepness of slope. In all, because of the assumptions made, the amount of available forage has probably been overestimated.

An individual rancher may be able to look at a grazing prediction map of his or her ranch and point out areas in the landscape where cattle do graze even though they were not predicted to graze there. Maps predicting spatial grazing patterns could be verified by the rancher or changes could be made using on the ground observations. Another potential use of spatial technologies is facilitating discussion between ranchers and federal land management personnel and justifying a rancher's grazing management practices. Even though these analyses are preliminary, they are promising for the application of spatial data to estimating stocking rates. In this study, I have explored the potential integration of spatial technologies in ranching. With more detailed information, finer adjustments could be made, and the analyses would likely be more accurate. One potential drawback for using GIS, however, is the time needed for an analysis like this, especially if some of the assumptions were accounted for. This analysis took just over 33 hours to complete, not counting the time that it took to record the locations of the water sources with a GPS unit.

Based on the above calculations, the total amount of usable forage per pasture can be estimated. Assuming that an Animal Unit (1000 pounds of grazing animal) eats about 11.8 kg (26 lbs) of oven dried forage per day or 354 kg (786 lbs) per month (NRCS 2003), carrying capacity can be expressed in Animal Unit Days (AUDs; the number of days the pasture can support 1 Animal Unit), or Animal Unit Months (AUMs; the number of months a pasture can support 1 Animal Unit; Table 2.2). Sandhollow Ranch is currently stocked with about 1,000 cow/calf pairs for about 4 months or 4,000 AUMs. According to my calculations based on NRCS site production with rough reductions based on slope and distance to water, Sandhollow Ranch is capable of supporting 912 cow calf pairs for 4 months or 3,648 AUMs at a 40% utilization level. The AUMs calculated for this analysis were based on an average year. These calculations would be 40% higher for a favorable year and 40% lower for an unfavorable year.

An allowable utilization level other than 40%, may be appropriate as Sandhollow Ranch is currently grazed only in the winter when plants are dormant and are very tolerant of grazing impacts. It would be reasonable to apply a proper use factor of 50% or more for dormant season grazing. With this higher utilization rate of 50%, the ranch would be capable of supporting 1,140 cows for 4 months or 4,560 AUMs.

Documenting Herd Movement

One of the criticisms of spatial technologies, particularly GIS, is the relative inability to link spatial and temporal data (Turner et al. 2001). The MODIS and AVHRR satellites provide an opportunity to link spatial and temporal data by providing global images twice daily at a moderate to coarse resolution. It is, however, complicated to link spatial and temporal data with a GIS program because the attributes have to be displayed in categories that can be difficult to merge. To explore how GIS could be used to accomplish a ranching activity that deals with spatial and temporal data, I created a hypothetical herd based on the grazing capacity estimated above and documented their movements in time and space. In this exercise, I explored herd movements in a year-round grazing situation, even though Sandhollow Ranch is currently used only in the dormant season to explore the uses of GIS for year-round record keeping.

In this hypothetical herd, there are 250 cows (450 kg or 1,000 lb), and 25 bulls (635 kg or 1,400 lb) totaling 285 animal units (a 635 kg bull equals 1.4 animal units). The animals were put on a 4-pasture rotation schedule based on the calculated carrying capacity for each pasture (Table 2.3) and this was displayed spatially in ArcMap by joining the file containing the type of animals (e.g., cows or bulls) and the number of animals in that pasture with the shapefile that contained all the pastures (Figs. 2.9, 2.10, 2.11, and 2.12). By opening the attribute table for the layer, the number of animals in each pasture could also be revealed. This is a step towards the joining of spatial and temporal data. A rancher could use this to predict where he or she would move their animals, and to track the actual animal units of use on each pasture like the example in Table 2.3. This could facilitate grazing allotment discussions between federal land management agency personnel and ranchers. With GIS, a rancher could use this spatial information as a powerful tool for long-term record keeping to justify and quantify their grazing management practices. The information and tools could also be used for contingency planning such as deferrals for improvements. This level of record keeping is especially important as federal land management agencies often experience a high turnover of personnel and ranchers may need to explain grazing patterns to several agency personnel over the years.

The examples given here represent a first attempt to quantify spatial data into a usable form for ranchers. Some of the situations are simplified (such as the grazing rotations by the hypothetical herd) and some situations do not have enough information to make entirely accurate conclusions (such as biomass production on the ranch). However, the analyses performed here are exciting and promising. With more detailed information such as actual biomass production from the areas of the ranch that have been converted to annual grasses, the analyses could be much more accurate.

Additional Land Features

Landscape uses are rapidly changing in the west with open spaces giving way to rural subdivision. As urban development and fragmentation continue, larger ranches such as Sandhollow, will become less common. In the future, spatial tools will likely be used to understand the physical and social properties of ranches. For example, ArcGIS v. 8.3 has a "viewshed" calculator built into the program, and is able to take into account the earth's curvature when calculating a viewshed (Cooper *In press*). Already, viewsheds are calculated for optimal places to place radio towers (Kim et al. 2004). As the activities conducted on private lands adjoining public lands become more highly scrutinized, a rancher may want to know exactly what a person could see if they were standing at the rancher's property line. A viewshed was calculated for Sandhollow Ranch using the USGS 30 m DEM and the boundary of the property (Fig. 2.10).

Another concept that may become a topic of interest to ranchers in the future is the documentation of "special places." Special places are areas of land that have a social value as opposed to just a physical or utilitarian value. Examples of special places could include favorite fishing or hunting spots or a natural pond with exceptional wildlife viewing. GIS may be used to quantify and place a value on these places (ESRI 2005d).

In recent years, endangered and rare species have gained attention from environmental advocates, political leaders, and the general public. Already GIS is being used to determine suitable habitat and probable ranges for endangered and rare species (Powell et al. 2005). GIS is beginning to be used to add social values to such species (ESRI 2005d) and quantify conservation decisions. In the future, GIS may become a tool that is necessary to aid decisions regarding endangered and rare species conservation.

In the future, it is likely that aspects not traditionally a part of range management (such as viewsheds and special places) will receive greater attention. With the integration of GIS, these aspects may be managed and recorded over long periods of time. This may be critical as long-term management decisions are required for conservation areas.

Summary

To evaluate the potential of using GPS and GIS on a working ranch, a case study was conducted to document the time and resources required to assimilate a geographic database, extend and explore the potential of GPS and GIS in ranch management, and provide basic information about the use of GPS and GIS in ranch management. The major points are highlighted here:

- Inventory of ranch resources and range improvements such as fences, buildings, roads, and water sources and their conditions are an integral part of ranch management. This inventory was accomplished for Sandhollow Ranch with the use of GPS units and a GIS. Resources were located and the conditions were noted. These resources were the foundation of analyses completed later.
- Data collection by technicians unfamiliar with the ranch terrain or resources resulted in more time than was expected to collect field location data.
- Locations recorded with GPS units having different levels of accuracy required more time in editing to correct the differences in spatial placement.

- Soil surveys performed by the Natural Resource Conservation Service (NRCS) contain a wealth of important information, but accessing the data can be complicated. Because spatial soils data must be downloaded in a different form than the tabular soils data, a spreadsheet or database program must be employed to manipulate the tabular data into a form that can be joined with the spatial data.
- Keeping topsoil on a site is crucial to maintain health of the plant community and quality of water sources. The kffactor, a factor determined from the universal soil loss equation that predicts how prone to erosion a soil may be, is one significant piece of information contained in the soils data. Combining the kffactor with the slope of a landscape will give land managers a good indication of soils that may be particularly vulnerable to erosion.
- Biomass production on different soils is one type of information in the tabular part of the soils data. Land managers may use production data to estimate grazing capacities (i.e., Animal Unit Months of forage) for planning purposes.
- Combining the production and erosion data and incorporating it with aspect and slope could give land managers an idea of what areas may be suitable for restoration activities. Sites that have high production potential, low erosion risk, north facing aspects, and little slope will likely have the highest potential for restoration.
- A number of studies have examined the proper grazing utilization for sagebrush steppe. After estimating the total annual production using the NRCS soils data, I applied a 40% utilization level to determine the amount of forage available for grazing. The actual appropriate proper use factor would depend on a greater understanding of existing vegetation, management goals, and seasons of grazing.

- In rugged terrain such as Sandhollow Ranch, grazing distribution may not be even across the landscape. Where cattle will graze is influenced by a number of factors, but slope and distance from water are two of the more influential factors. Using several studies, I applied reductions in grazing capacity based on steepness of slope and distance from water. This example was only relevant to Sandhollow Ranch at the time of the analysis. The scale at which this case study was conducted may not be appropriate for all applications.
- GIS can be used to track herd movement spatially (through space) and temporally (through time). It can also be used to justify grazing management practices. Using the estimated production from the NRCS soils data, combined with the reductions for slope, distance from water, and 40% utilization level, forage availability was predicted for each pasture. A hypothetical herd was created and tracked through an annual grazing season based on predicted grazing capacity. Actual numbers of animal units in the hypothetical herd were then compared against grazing capacity. A GIS was used to display this rotation spatially.

GPS and GIS are powerful tools that have a potential to be extremely beneficial to ranch managers. These spatial technologies can be used in planning tasks such as inventory of range resources and improvements and estimation of erosion and restoration potential and in management tasks such as estimating annual production, approximating carrying capacity, and documenting animal movements spatially and temporally. These spatial technologies also allow for data stored as maps and files to be integrated and stored in the same location.

CONCLUSIONS

During the course of this case study, several important observations were noted that could affect the use of spatial technologies by land managers. First, the amount of time spent on data collection could be significantly reduced if it was coordinated with an activity that was already planned, such as checking fences or water sources. Since I acquired the NRCS soils data in July 2004, tremendous improvements have been made to that database. A web-based GIS has been incorporated and easily read reports can be generated from that GIS for most soil survey areas for attributes selected by the user (NRCS 2005d). The NRCS is currently working to organize the soils data into more user-friendly and easily understood files. It is now possible to acquire many types of data sets (e.g., roads, streams, soils, etc.) from a wide variety of sources such as state-hosted GIS web sites and federal government entities and make it applicable to an individual setting (ESRI 2005c).

As technology continues to improve, the costs will likely decrease making accurate systems more affordable to the public (Frair et al. 2004). With improvements in technology, it will likely become easier to facilitate links between spatial and temporal data enabling ranchers to predict and record their grazing and land management practices. Although the majority of ranchers do not currently use GPS or GIS, it is possible that with the decreasing costs, more ranchers will begin to adopt spatial technologies. It may also be that as ranches are being turned over to younger generations that are more computer competent, more of these technologies may begin to be used.

The analyses presented here are encouraging but preliminary and call for further exploration. GPS and GIS are complicated technologies that require knowledge and skill to operate. A land manager considering use of any spatial technology should take a course to learn its proper and efficient uses (Vitek et al. 1996). This is particularly true of GIS, which, like many software programs, has a number of technical problems that are still in the process of being fixed. Without proper training, GIS can be extremely frustrating for a beginning user (D. Johnson, personal communication, February 2005). However, with a little training and lots of time, analyses such as those presented in this paper are possible.

Use of GPS and GIS allows a new level of record keeping that was not previously possible. It allows all the resources and improvements and their attributes as they change over time to be kept in one database and be displayed spatially. GIS also allows for analyses to be tailored to a specific ranch or land management area and to evolve as the components of the analyses change. GPS and GIS have an important and promising future in ranch and range management.

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Table 2.1. Total available biomass on selected pastures on a ranch located near Payette, Idaho. Forage production values based on site potentials from the NRCS Payette County Soil Surveys. Available biomass after applying a 40% proper use factor and after applying reductions for steepness of slope and distance from water.

Pastures	Area (ha)	Total Annual Production (kg/ha)	Production with a 40% proper use factor (kg/ha)	Available Forage with Applied Reductions* (kg/ha)
Alfalfa field	14	5922	2369	1461
Biven's field	677	323719	129488	90344
Bull pasture	9	1805	722	415
Center canyon north	398	161205	64482	50958
Center canyon south	748	384517	153807	110828
Cherry gulch	333	250412	100165	74364
Curlew field	796	365142	146057	113563
Horse pasture	149	55128	22051	16140
Lower canyon north	162	65945	26378	18179
Lower canyon south	772	294870	117948	82732
Lower field	23	15132	6053	3874
Lower meadow	52	10624	4250	2618
Rye field	81	35066	14026	11221
Upper canyon north	867	490134	196054	149088
Upper canyon south	1330	794548	317819	221024
Upper meadow	53	9129	3651	2168
Wildlife area	25	4847	1939	1196
Woodbury field	1537	1125391	450156	341201
Sandhollow Ranch Total	8026	4393536	1757415	1291374

* Reductions were calculated as follows:

Distance from water:

0-1 miles = no reduction
1-2 miles = 50% reduction
>2 miles = 100 % reduction (completely unusable)

Steepness of slope:

0-10% = no reduction
11-30% = 30% redution
31-60% = 70% reduction
>61% = 100% reduction (completely unusable)

Table 2.2. Available forage biomass calculated in Animal Unit Days (AUDs) and Animal Unit Months (AUMs) for select pastures on Sandhollow Ranch near Payette, Idaho. An animal unit is defined as a 450 kg (1000 lb) beef animal that consumes 11.8 kg (26 lb) dry matter per day.

Pastures	Available Forage (kg/ha)	Animal Unit Days	Animal Unit Months
Alfalfa field	1461	124	4
Biven's field	90344	7656	258
Bull pasture	415	35	1
Center canyon north	50958	4318	146
Center canyon south	110828	9392	317
Cherry gulch	74364	6302	212
Curlew field	113563	9624	324
Horse pasture	16140	1368	46
Lower canyon north	18179	1541	52
Lower canyon south	82732	7011	236
Lower field	3874	328	11
Lower meadow	2618	222	7
Rye field	11221	951	32
Upper canyon north	149088	12635	426
Upper canyon south	221024	18731	631
Upper meadow	2168	184	6
Wildlife area	1196	101	3
Woodbury field	341201	28915	975
Sandhollow Ranch Total	1291374	109438	3690

Table 2.3. Available forage to predict Animal Unit Months (AUMs) for select pastures on Sandhollow Ranch near Payette, Idaho for three months. Predicted AUMs are then compared with actual AUMs from a hypothetical herd of 250 cows 25 bulls. An animal unit is defined as a 450 kg (1000 lb) beef animal that consumes 11.8 kg (26 lb) dry matter per day.

Pastures	Available Forage (kg/ha)	Predicted AUMs for 3 Months	Actual Animal Units for 3 Months
Alfalfa field	1461	1	
Biven's field	90344	90344	80
Bull pasture	415	0	0
Center canyon north	50958	48	48
Center canyon south	110828	104	98
Cherry gulch	74364	70	70
Curlew field	113563	107	110
Horse pasture	16140	15	17
Lower canyon north	18179	17	18
Lower canyon south	82732	78	72
Lower field	3874	4	0
Lower meadow	2618	2	0
Rye field	11221	11	0
Upper canyon north	149088	141	140
Upper canyon south	221024	208	202
Upper meadow	2168	2	0
Wildlife area	1196	1	0
Woodbury field	341201	322	285
Sandhollow Ranch Total	1291374	1217	1140

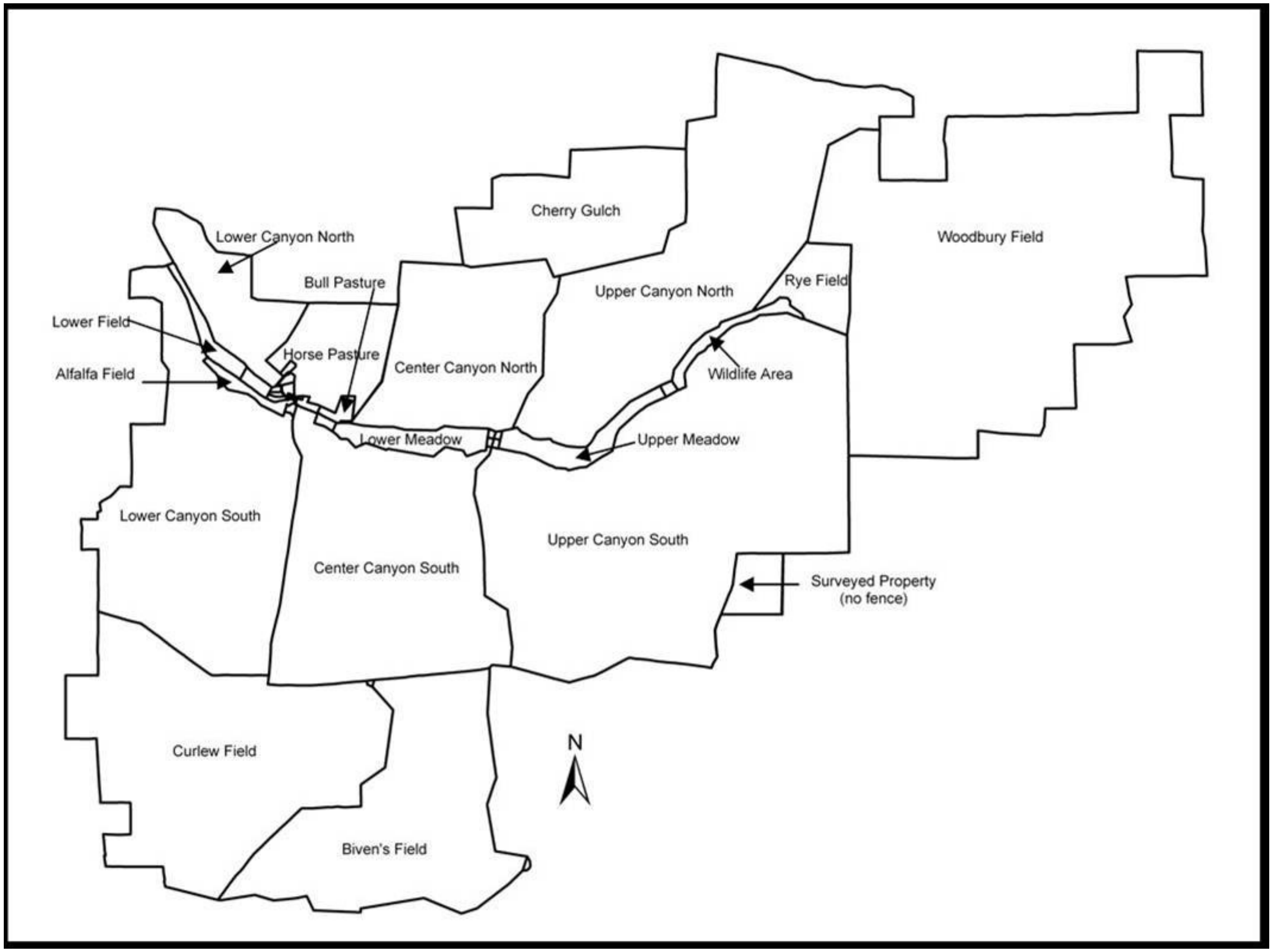


Figure 2.1. Names of pastures >8 ha in size in Sandhollow Ranch near Payette, Idaho.

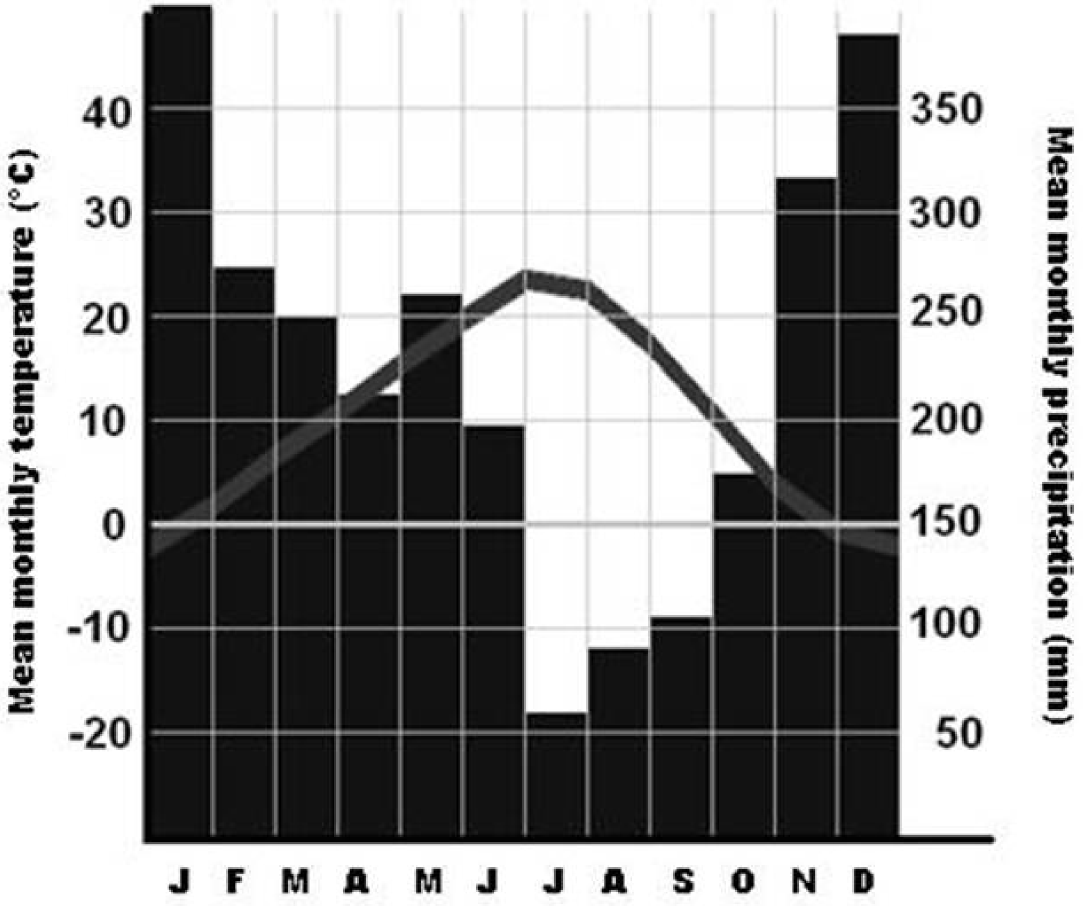


Figure 2.2. Climate diagram for Payette, Idaho, 655m , lat 44°05'N, long 116°56'W. Mean monthly temperatures (°C) are indicated by the gray line and the mean monthly precipitation (mm) is indicated by the black bars. Months are indicated by the first letter of the month on the bottom of the graph. This graph is representative of a 56 year (1948-2004) average of both temperature and precipitation (WRCC 2005).

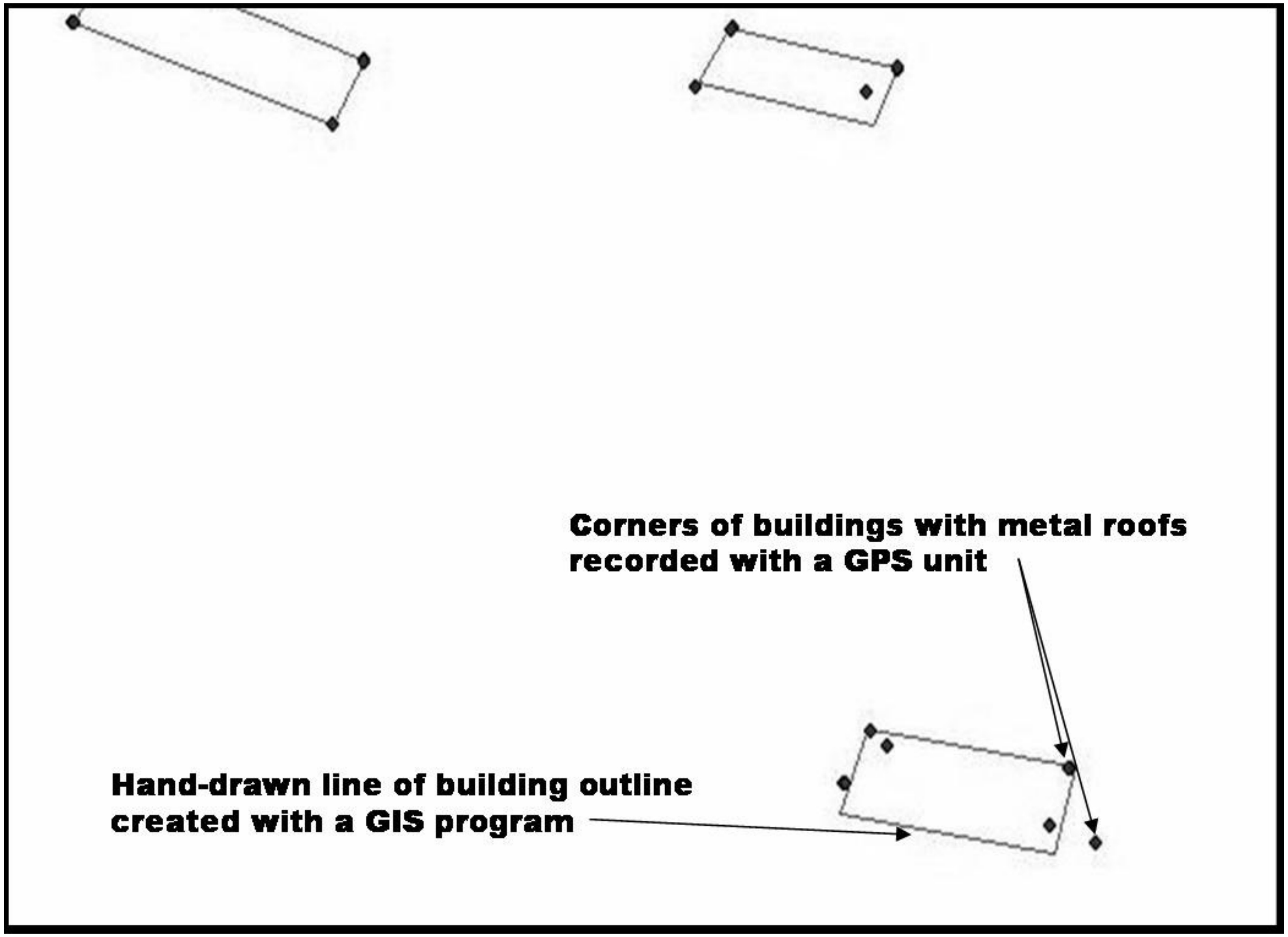


Figure 2.3. Satellite signal can become very distorted and yield inaccurate results under buildings with metal roofs. The original locations marked with a GPS unit were all taken from one of four corners of the building, but because of signal distortion, they all appear in different locations. The outline of the building was hand-drawn in a GIS program.

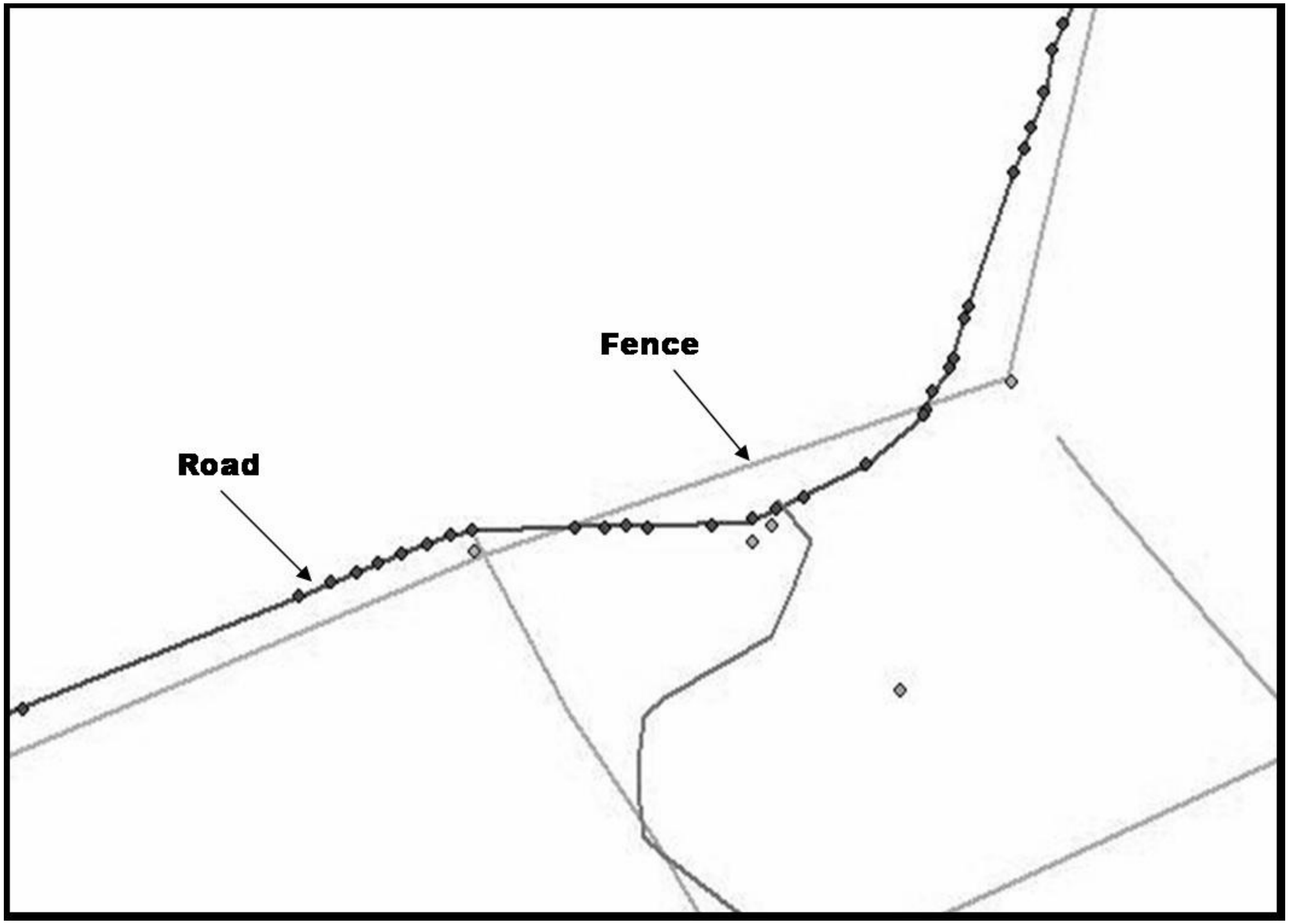


Figure 2.4. Because of different accuracy levels in the GPS units the data points were taken with, the fence appears to cross the road. The data points for the fence were taken with a Garmin GPSIII+ which accepts errors up to 30 meters and the data points for the road were taken with a Trimble GeoExplorerII which accepts errors up to 5-10 meters.

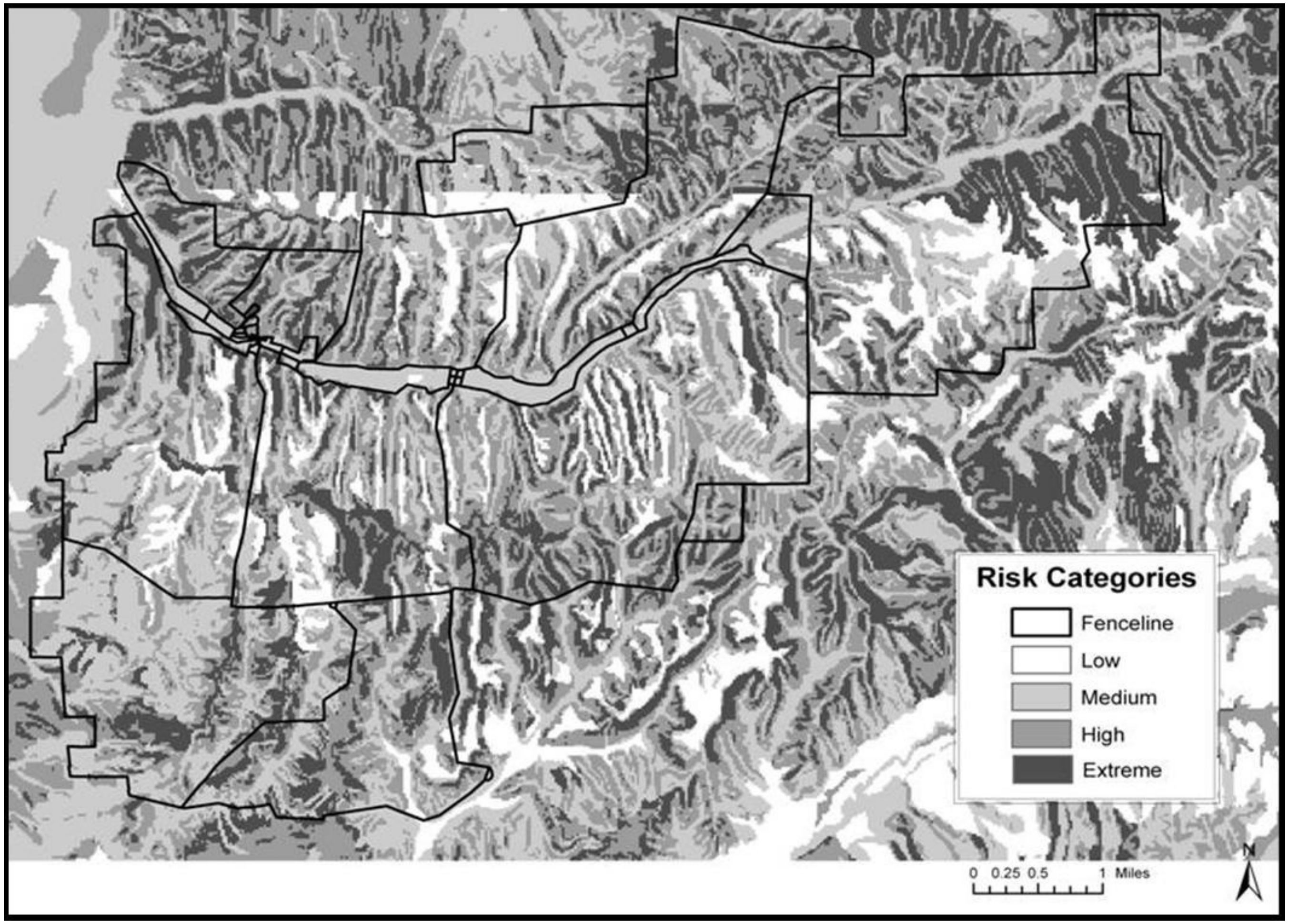


Figure 2.5. Risk of erosion from wind and water on Sandhollow Ranch near Payette, Idaho can be characterized in a GIS program. The risk of erosion is based on normalized kffactor values combined with percent slope. Kffactor values are assigned to soils based on the potential for wind and water erosion to occur on that soil.

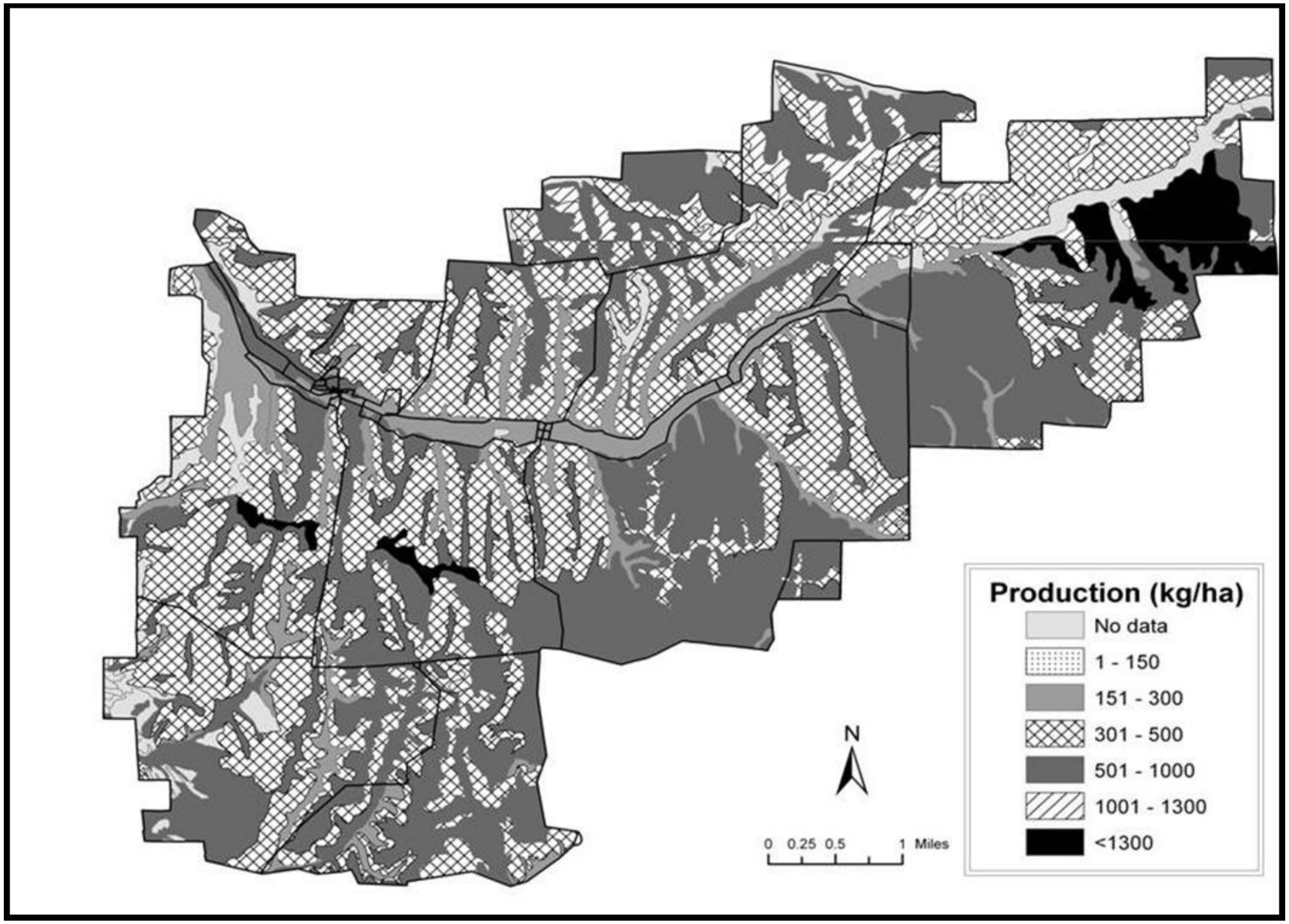


Figure 2.6. Total annual production of Soil Mapping Units (SMUs) approximated from NRCS soils data range site production from the Payette County soil survey in kgs/ha for a normal year for Sandhollow Ranch near Payette, Idaho. A normal year is one that has normal temperatures and normal precipitation amounts with normal timing.

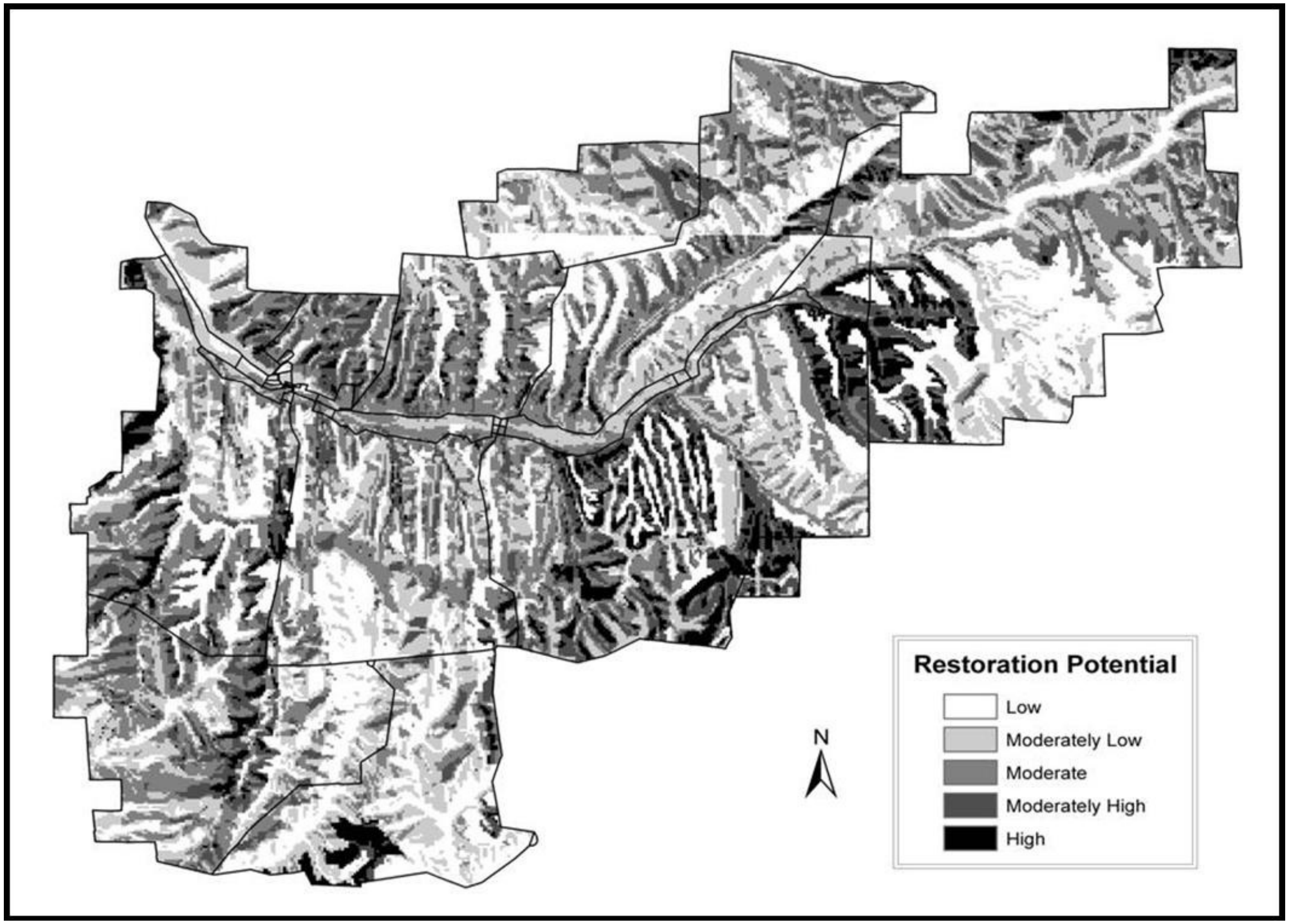


Figure 2.7. Restoration potential for Sandhollow Ranch near Payette, Idaho is based on slope, aspect, annual production, and kffactor of soils. Slope and aspect were derived from a 30-meter Digital Elevation Model (USGS 2005). Annual production and kffactor were derived from NRCS Payette County soil survey. Restoration would be favored on sites with low kffactors, high productivity, little slope, and northern aspects.

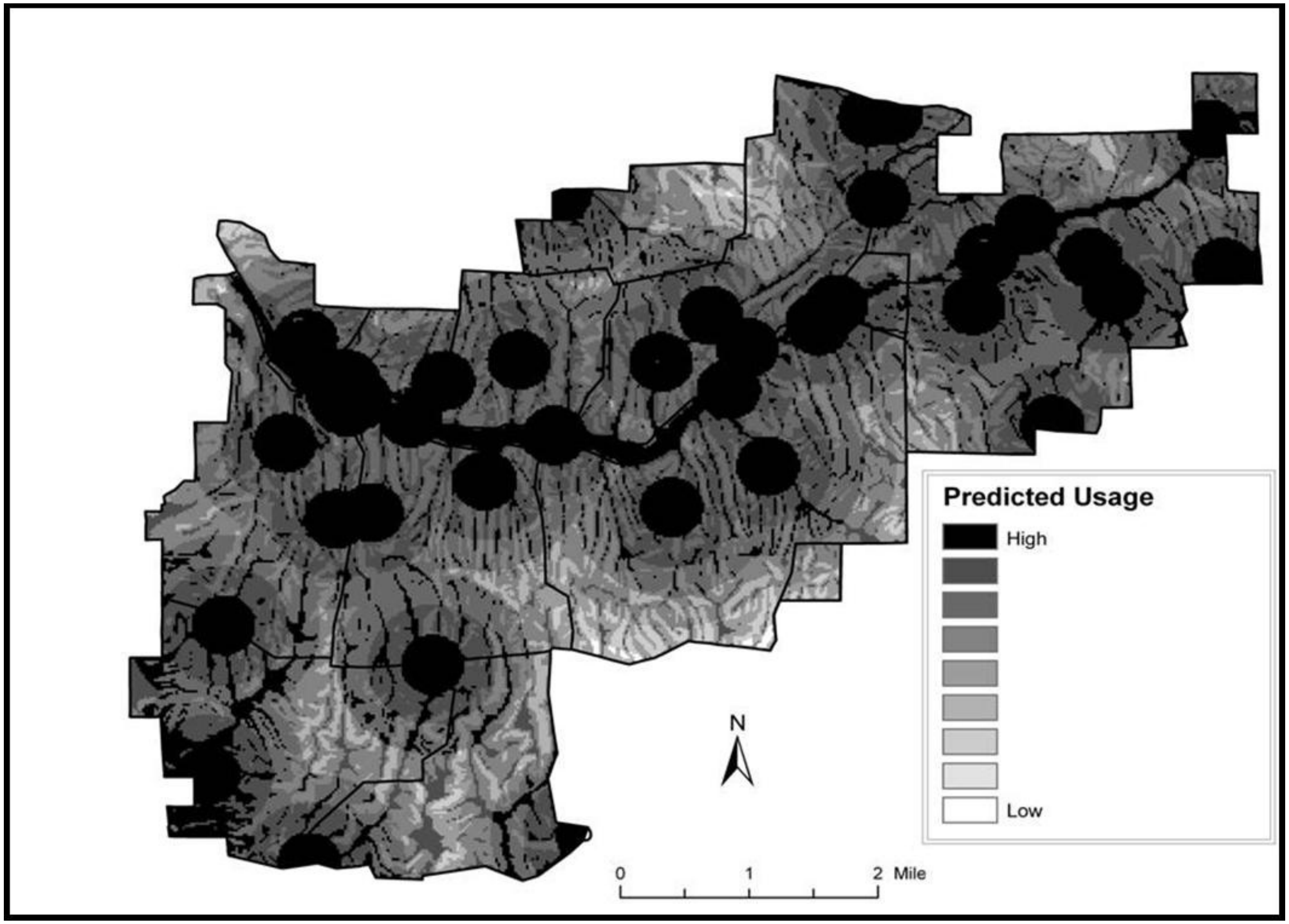
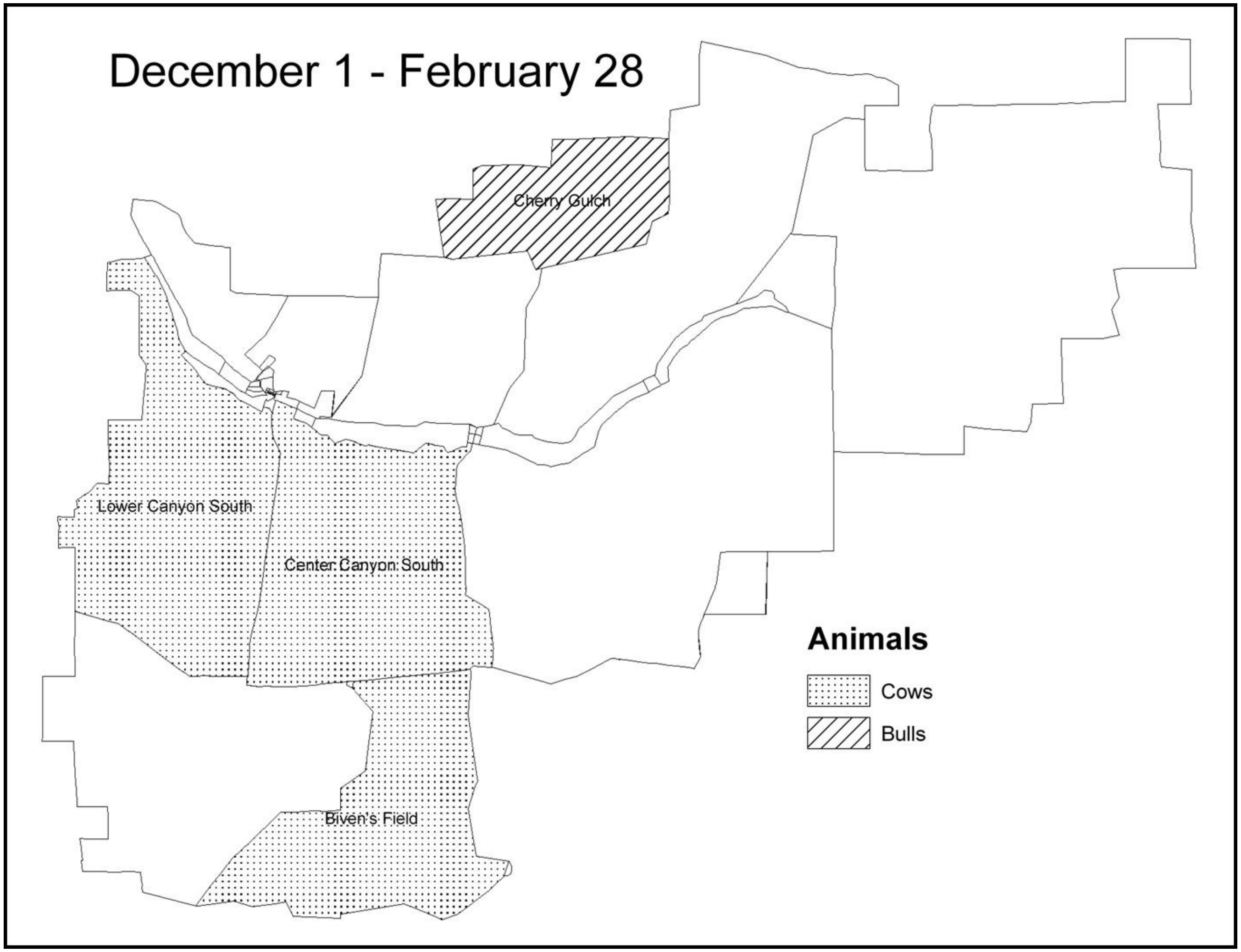


Figure 2.8. Areas of predicted grazing use on Sandhollow Ranch near Payette, Idaho based on a slope reclassification into classes of 0-10%, 11-30%, 31-60%, and >60% slope and 0.25 mile water buffer layers being combined using the "Raster Calculator" function of the Spatial Analyst Extension. Slope was derived from a 30-meter Digital Elevation Model (USGS 2005) and water sources were located by field technicians with GPS units.



Figures 2.9A-D. Rotation of a hypothetical herd of 250 cows and 25 bulls through select pastures on Sandhollow Ranch near Payette, Idaho on a 3-month rotation schedule. Carrying capacity for individual pastures was determined from NRCS Payette County soil survey range site production with applied reduction factors based on steepness of slope and distance from water. Rotation is from December 1 to February 28.

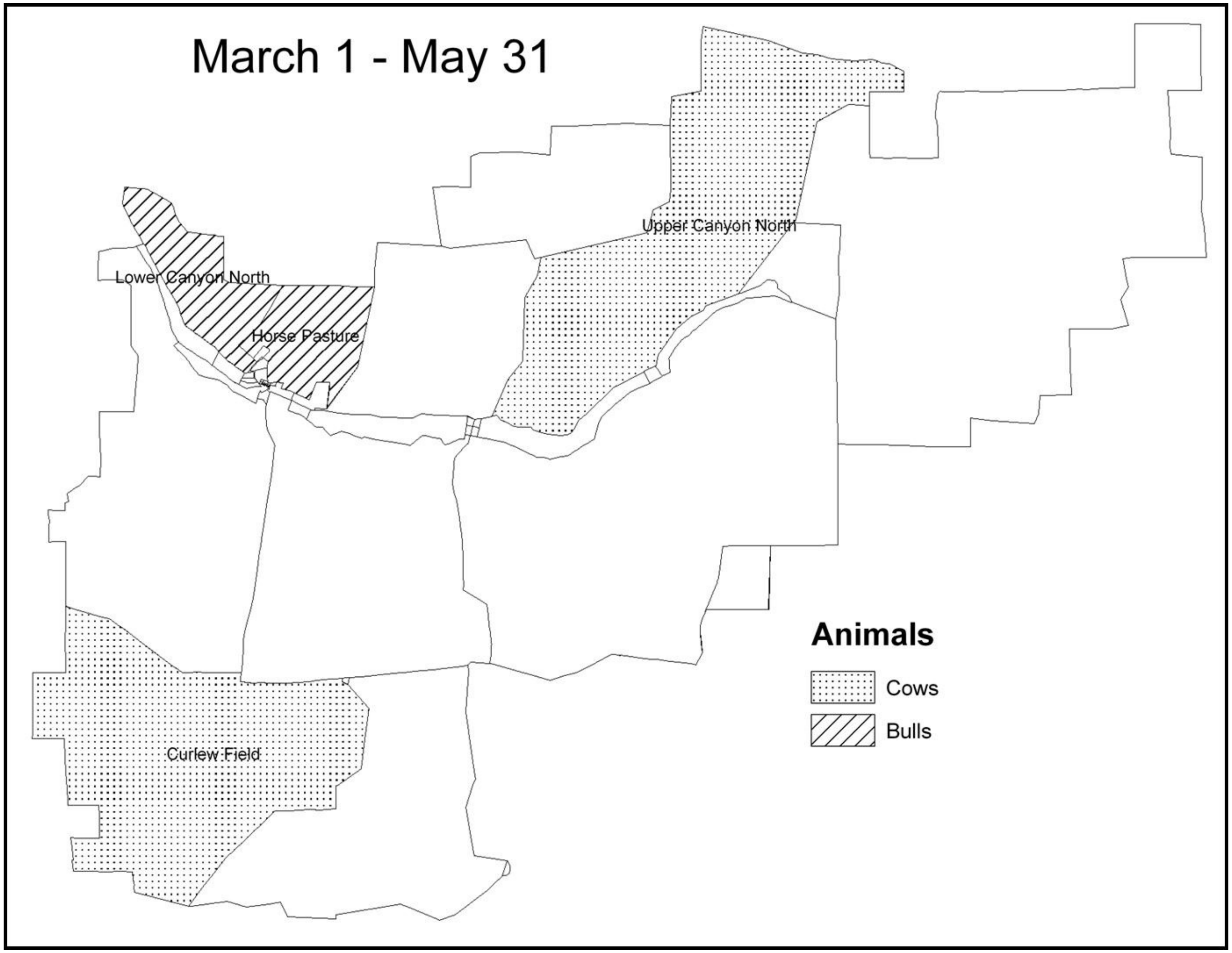


Figure 2.10. Rotation of a hypothetical herd of 250 cows and 25 bulls through select pastures on Sandhollow Ranch, near Payette, Idaho, on a 3 month rotation schedule. Carrying capacity for individual pastures was determined from NRCS Payette County soil survey range site production with applied reduction factors for steepness of slope and distance from water. Rotation is from March 1 to May 31.

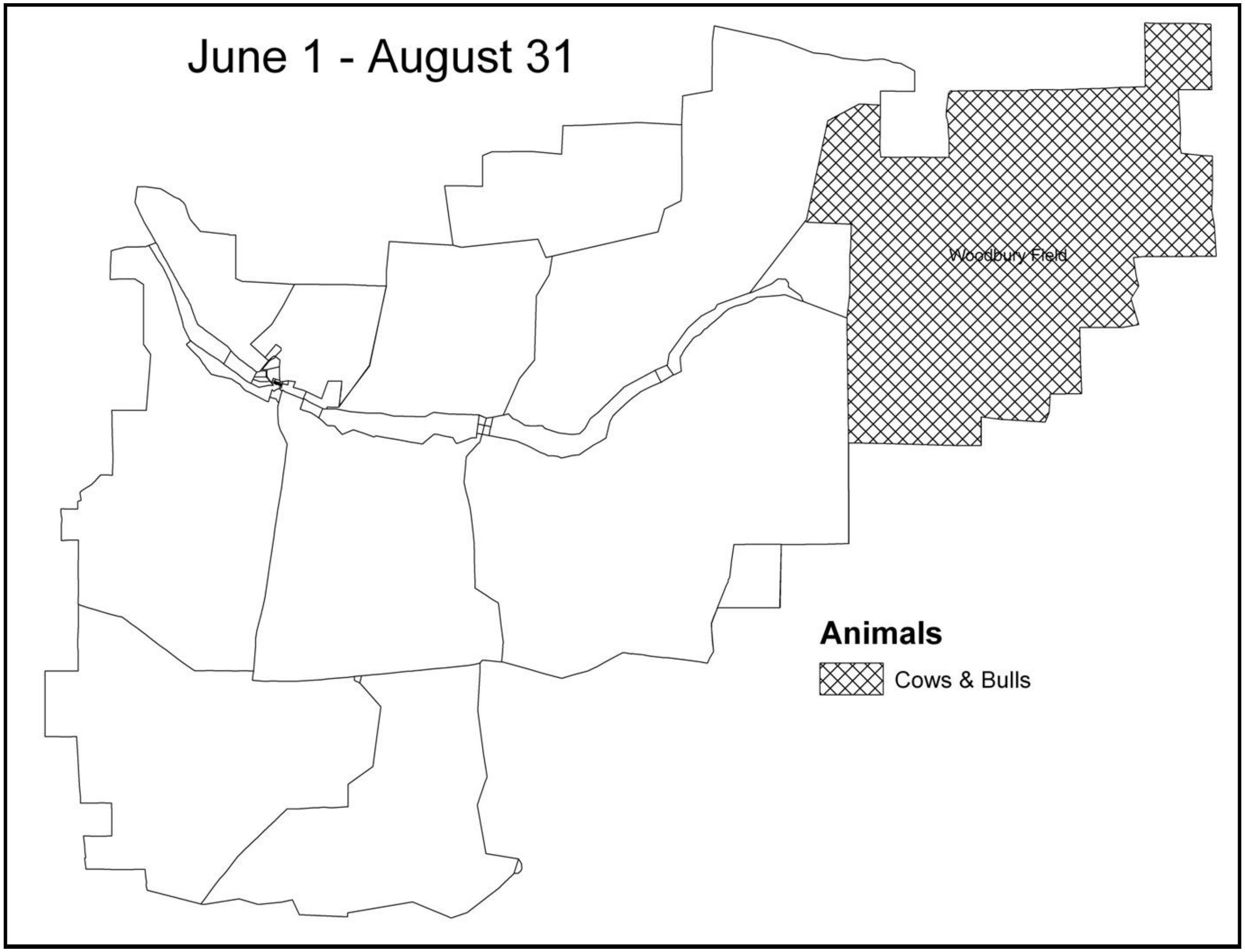


Figure 2.11. Rotation of a hypothetical herd of 250 cows and 25 bulls through select pastures on Sandhollow Ranch, near Payette, Idaho, on a 3 month rotation schedule. Carrying capacity for individual pastures was determined from NRCS Payette County soil survey range site production with applied reduction factors for steepness of slope and distance from water. Rotation is from June 1 to August 31.

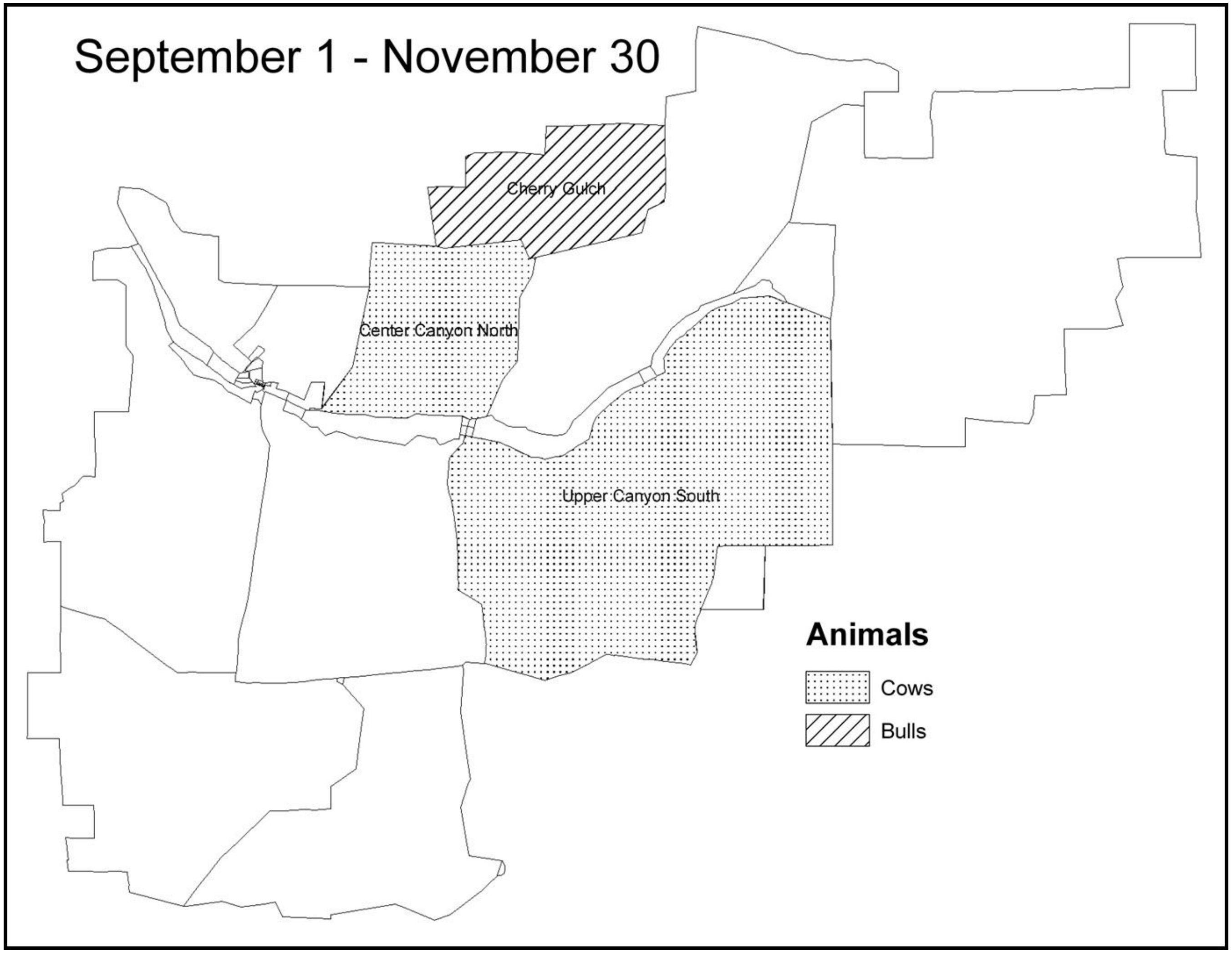


Figure 2.12. Rotation of a hypothetical herd of 250 cows and 25 bulls through select pastures on Sandhollow Ranch, near Payette, Idaho, on a 3 month rotation schedule. Carrying capacity for individual pastures was determined from NRCS Payette County soil survey range site production with applied reduction factors for steepness of slope and distance from water. Rotation is from September 1 to November 30.

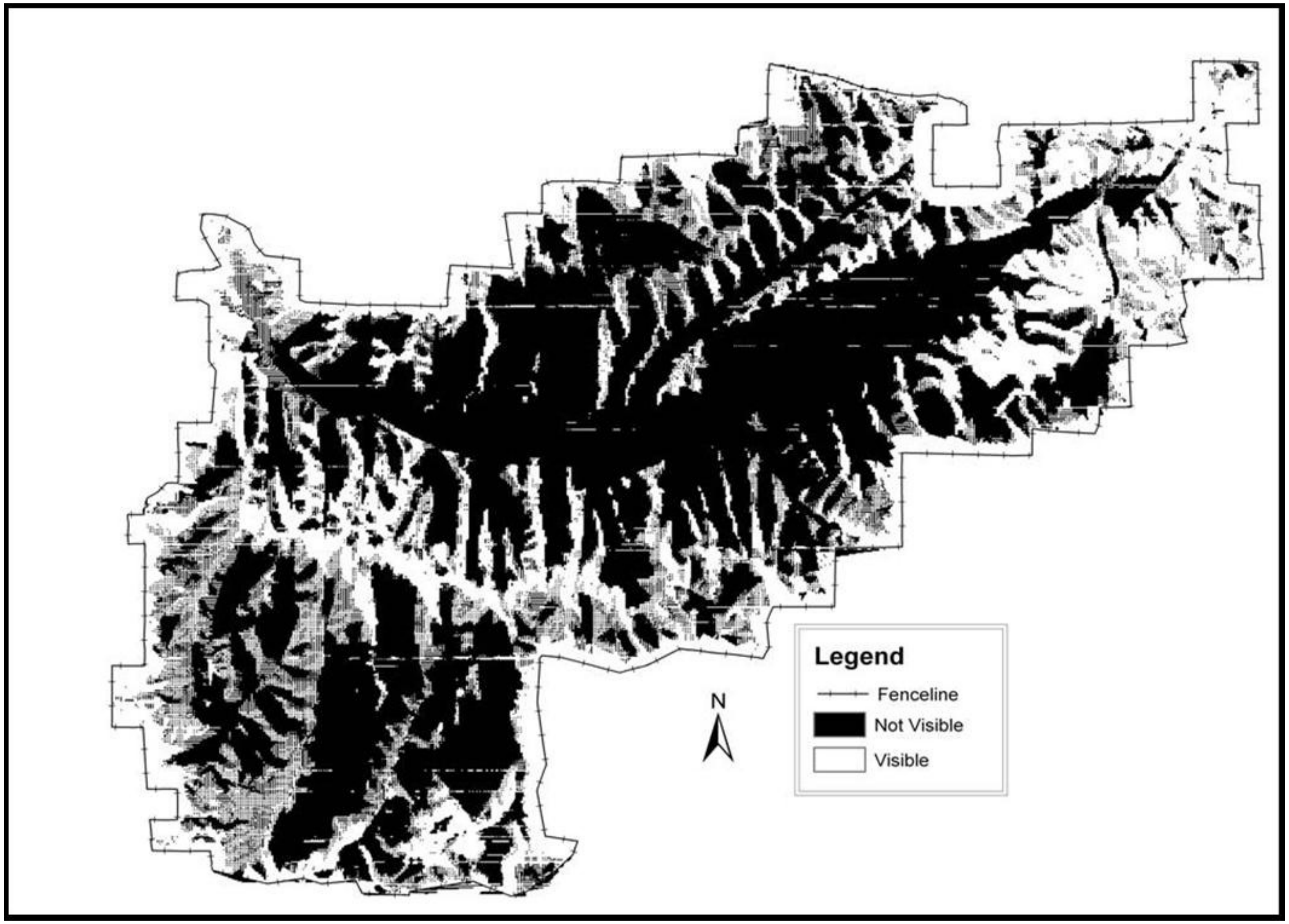


Figure 2.13. Viewshed of visible property from the boundary fenceline of Sandhollow Ranch near Payette, Idaho looking in towards the ranch

CHAPTER 3

WISH UPON A SATELLITE: APPLYING GPS TO RANGELAND MANAGEMENT

INTRODUCTION

Paper maps have long been used in range management and science to document the location of important natural and human-imposed features. It is hard to find a desk, wall, or dashboard of a working range professional that is not adorned with some sort of map. Maps have been used to depict ownership boundaries, pasture fences, stream courses and topographic features. The locations of monitoring plots, study sites, and range improvements are often stored on maps. With the introduction of the Global Positioning System (GPS), the locations and boundaries of rangeland features have reached a new level of precision and accuracy. However, GPS systems come with a plethora of features and limitations that can cause confusion and frustrations that can make one want to return to the old days of paper maps and compasses. In this manuscript we hope to dispel misconceptions and improve working knowledge of how GPS can be applied to rangeland management.

USES OF GPS IN RANGELAND MANAGEMENT

The technologies used in GPS are rapidly changing to improve both accuracy and usability. Aerial photographs and remotely sensed satellite images can also be validated with on-the-ground observations using GPS. Range scientists adopted GPS technology shortly after it became available to aid in locating field plots, tracking wildlife and domestic livestock, and in recording known locations of invasive or rare species populations. Rangeland managers and ranchers are now using GPS technology to accomplish many of their day-to-day tasks. Most of the federal land management agencies are required to conduct rangeland monitoring which can include trend plots, green line surveys, and repeat photopoints. Historically, these monitoring locations were often marked on maps with written directions or sketches on how to locate the plot. In most cases, legal coordinates (Township, Range, Section) were the only description of plot locations. The imprecise and sketchy locations led to thousands of hours simply trying to relocate monitoring plots. With GPS technology, a plot location can be more easily recorded and relocated with an error of only about 30 meters, even with a basic GPS unit.

An important part of land management is maintaining an inventory of resources. The location and condition of rangeland improvements, such as water tanks, fences, or creek crossings can be collected and documented with GPS technologies. As part of the monitoring, range improvements are often inspected for functionality and condition. Some GPS units include the ability to add a description of specific locations (called attributes), which could be useful for documenting the condition of range improvements.

Many invasive plants management programs include GPS tools to document the location of weeds, record the management applied, and the results achieved. Information gained by GPS can also be linked to a Geographic Information Systems (GIS) program which are computer software programs designed to capture, display, analyze, retrieve, and store spatial information. GIS can be used in conjunction with GPS data to perform simple to advanced analyses of spatial data collected by a GPS unit. GIS can also be used to store the location and attributes recorded by a GPS unit.

WHAT IS GPS AND HOW DOES IT WORK?

The Global Positioning System (GPS) is a constellation of satellites orbiting the earth sending signals of precise locations to receiver units on the surface. The GPS in use today is called Navigation System with Timing and Ranging (NAVSTAR) and includes 24 solar-powered satellites. GPS units use a process called trilateration to accurately pinpoint locations on the earth's surface. Simply put, trilateration involves making measurements from intersecting circles of distance from satellites (Figure 3.1). For example, if a GPS receiver were 11,000 miles from one satellite, there would be a finite number of places on the earth's surface (in the shape of a circle) where the location could be. If the same GPS receiver were 12,000 miles from a second satellite, the receiver could narrow down the location by the overlap from the two circles. The same would be true for a third and fourth satellite. In this manner, the more satellites a receiver can detect, the more accurate the position; GPS receivers require at least three to four satellites to log data points.

How accurate is GPS?

There are generally three grades of GPS units; **recreational**, **mapping**, and **surveying**. Most of the recreational grade units are marketed as being accurate to between 7-15 meters, but can incur inaccuracies as high as 50 meters. The mapping grade units are commonly accurate to 1-5 meters, and the survey grade units are usually accurate to 1-10 centimeters, called "sub-foot" accuracy. Generally, the more accurate the unit, the higher the cost. Most recreational grade units cost between \$100-\$900, while mapping grade units cost between \$1,500-\$7,000, and survey units generally cost upwards of \$45,000. The accuracy of a location displayed on a GPS unit depends on several features related to the type and hardware of the unit itself. Some important features of a GPS unit which affects its accuracy include the type of antenna, the number of channels the unit can receive, and the ability to post-process the data collected.

Antennas. A GPS unit can receive signals with either an internal or an external antenna. Most of the recreational grade units employ internal antennas. Internal antennas, though not as accurate, are much more convenient. The mapping grade units generally come equipped with internal antennas, but have the option of an external antenna. The survey grade units generally have an external antenna. The advantage of an external antenna is that it allows a user to place the antenna where it may best acquire a satellite signal. For example, if a user were driving down a road, an external antenna could be placed on the outside of the vehicle for better reception.

Channels. The number of channels a unit has can also affect a unit's accuracy. Most units of all grades currently have between 12-16 parallel channels. This means that these units can track 12-16 different satellites simultaneously. Although a unit only needs three or four satellites to locate a position, the more satellites it can acquire, the more accurately it can narrow down its precise location.

Satellite Locations. The relative position of the satellites on the horizon affects the accuracy of the signal. If a satellite being tracked by a GPS unit is lower than 10˚-15˚ on the horizon, it should be considered unusable. Satellites are in a continuous orbit, and are constantly changing location throughout the day. Because of this, satellite signal acquisition may be compromised or nearly impossible during certain times of the day. Some GPS units are capable of rejecting signals from satellites with poor position relative to their horizons. Mapping and survey grade units generally include software packages that calculate times on specific dates when an adequate number of satellites will be available which is useful in planning field activities that require GPS. One example is Trimble's Pathfinder Office. These tools are useful in planning GPS acquisition to assure that four or more satellites will be available at the desired place and time of GPS data collection.

PDOP. Position Dilution of Precision is the expression of the relationship between the error in satellite position and the error in user position. When satellites are clustered together in the GPS receiver's horizon, it makes acquiring a precise location more difficult because all the satellites are broadcasting similar location signals; the circles of signal will overlap each other considerably. When the satellites are spread out over the horizon, the precise location will be much easier to acquire. In general, the lower the PDOP, the better the location accuracy. Commonly a threshold of PDOP = 6 is used; data collected when the PDOP is lower than 6 is considered acceptable and usable for most situations, while locations collected at a PDOP higher than 6 are of limited use because of the large inaccuracies incurred. Mapping and survey grade units report PDOP explicitly on the data logger display, while recreational units usually do not.

WAAS and Other Differential Corrections. The process of applying corrections to data locations is called differential correction or DGPS. Differential correction can be done in "real-time," simultaneously with data collection, or "post-processed," after the data has been downloaded to the computer. Most units of all grades allow for real-time correction by applying corrections broadcast from base stations. One of the most common systems is the Wide Area Augmentation System (WAAS). Sometimes, however, a unit will be too far away from a base station to receive a correction signal. In this case, the data must be post-processed to obtain better accuracy. Most mapping and survey grade units allow for this process, but recreational units generally do not. The ability to post-process data is one of the major price differences between recreational grade and mapping and survey grade units.

How do Environmental Conditions Affect GPS Accuracy?

The signal quality that reaches a GPS unit is affected by atmospheric conditions. Atmospheric gases, particularly water vapor, slow the speed of the signal resulting in inaccurate estimations of position. The topography and surrounding vegetation have a dramatic effect on the accuracy of the estimated location as well. The steeper the relief, the more difficult it is for GPS receivers of all grades to acquire adequate satellite signals. Canyons, draws, or steep basins can inhibit the unit's ability to detect satellites that are lower on the horizon. Dense canopy covers in forests also distort the satellite signal and will cause some recreational grade units to produce errors over 50 meters. The errors in accuracy resulting from terrain are called "multipath signals." That is, the satellite signal can be reflected off of inanimate objects such as trees, rocks, buildings, water bodies, the ground, etc. and then be picked up by a GPS unit which results in significant distortion of the original signal. Some of the advanced mapping and all survey grade units use a technology that is capable of filtering multipath signals and are more accurate under adverse conditions. Multipath filtering technology largely contributes to the accuracy and price differences between recreational grade units and mapping and survey grade units.

What Kind of Display and Memory is Needed?

Information on GPS units can be displayed either in color or in grayscale (i.e., black-and-white or monochrome). The recreational grade hand-held units tend to come in grayscale, although a few have the option of a color screen, but at an increased cost and lessened battery life. The automotive GPS units (generally of recreational grade) generally come with large, easily read color screens, but may have no ability to record locations; although most are pre-programmed with maps and points of interest. Most of the mapping and survey grade units come with full color screens that can easily be read in any light. The use of GPS units in rangeland settings generally requires screens that can be easily read in full sunlight. Some GPS units can even display full maps of the area; thus screen readability is important. Smaller screens and color displays can often be more difficult to read. However, screen readability varies greatly from unit to unit, so make sure to try a unit in full sunlight before it is purchased.

The amount of memory with which a GPS unit comes equipped determines how much data (including maps) a user can upload to that unit. Most of the basic recreational units do not come with any capabilities to upload maps. These units have a predetermined amount of memory based on the number of waypoints and tracks they are programmed to handle. Some of the intermediate and most of the advanced recreational grade units include limited memory for uploading maps. Mapping and survey grade units have a virtually unlimited memory capacity because they can accept memory cards, so a user is only limited by the number of memory cards they have. The more memory that is included with a unit, the more complicated the data that can be uploaded and stored. For example, aerial photographs, which are extremely large files, are commonly uploaded on mapping units, but are too big for most recreational grade units. The memory capacity of a unit will affect its price but not the accuracy.

Field GPS Settings and Dealing with Data

Data logging. Most units of all grades are currently sold with data logging capabilities. This means that they are able to record positions and tracks or routes. These routes can then be stored in the unit or downloaded into a computer. There are only a few of the basic recreational grade units that don't allow a user to download the data to a computer. An individual position that is recorded is called a waypoint, while a route is a collection of waypoints that define an intended path of travel. A track log is a collection of waypoints taken while the user is moving. Units vary considerably in the number of waypoints, routes, and track logs they can store. Most recreational grade units can store up to 500 waypoints, and between 20-50 routes. The survey and mapping grade units have a capacity that is only limited by their memory storage. Survey, mapping, and some of the advanced recreational grade units are equipped with the ability to handle memory cards and the capability to accept uploaded maps.

Data Dictionaries. Data dictionaries are catalogs of information that describe locations in a database. Data dictionaries can be very useful in the field when a user wants to add descriptive information or attributes to object locations. For example, if a user were mapping locations of weed infestations, a data dictionary would include information such as species, phenology, infestation size, date, previous treatments, terrain, surrounding vegetation community, etc. The information recorded in the data dictionary can be directly downloaded to the computer and the arduous task of entering field data into the computer can be avoided. Recreational grade GPS units generally do not have data dictionary capabilities unless they are connected to a personal digital assistant (PDA) unit.

Grids and datums. A complicated concept that a GPS user must master is the idea of grids and datums. A grid is a set of horizontal and vertical lines on a map that help determine absolute location; for example, latitude and longitude represent a grid system. There are several different types of grids or coordinate systems in use, and most GPS units can be set to report locations in a specified grid. The two most commonly used grids are Latitude and Longitude (lat/long) and Universal Transverse Mercator (UTM). Lat/long is a grid that is based on the measurement of angles from a reference line; the equator is the reference line for latitude and the Greenwich Meridian is the referent for longitude. UTM is a metric grid that divides the earth into sixty 6-degree-wide zones. Although it is possible to convert data to different grids, you must know which grid the data were collected in.

A datum is a geographic reference system that defines the three-dimensional shape of the earth. There are many different datums in use today, but the most common in North America are North American Datum 1927 (NAD 27), North American Datum 1983 (NAD83), and World Geodetic System 1984 (WGS 84). Most of the older topographic maps produced by the United States Geological Survey (USGS) and the United States Forest Service (USFS) used NAD 27. It is important to know and correctly set the coordinate system and datum of the GPS unit. Differences in datum can result in errors of up to a mile depending on the location on earth and the datum specified in the setup of the GPS unit. The default setting for most GPS units is to use the lat/long grid and the WGS84 datum. If you plan to incorporate GPS data in a Geographic Information System (GIS), it is advantageous to set the GPS unit to collect data in the same grid and datum that are used in the GIS. At minimum, it is important to note the datum in which you collected location data so that points can be relocated and data can be shared.

Relationship Between GPS and GIS.

GPS can be used by itself, but many times it is helpful to use the data within a GIS program. GIS programs are capable of storing the spatial data collected by a GPS unit and displaying it as a map. The map can be tailored to an individual's preference, adding or removing layers of data. Layers are a group of data that are categorized and displayed together. For example, a group of waypoints that make up a route, such as a road, would all be displayed together in a layer. Another layer might be all the individual stock tanks on a ranch.

Field GIS. There are many different types of GIS programs, and some have field-ready versions that can be incorporated into the GPS unit. This allows for manipulation of spatial data in the field. Most mapping and survey grade units are able to handle a variety of field GIS programs. Some of the recreational grade units that are available as a personal digital assistant (PDA), are also capable of supporting field GIS programs. The use of a field GIS program reduces the need for significant data manipulation after the user has returned from the field because the field GIS can be used in conjunction with the collection of GPS data. In other words, the user can see exactly how the field data they are collecting fit with the other files used in a GIS.

Desktop GIS. GIS programs allow data from different sources to be combined. For example, data taken in the field with a GPS unit can be combined with topographic features, soils, and watershed characteristics. Many organizations, such as federal land management agencies, states, and others host websites that have spatial data available for download. One well-known example is the Natural Resource Conservation Service, which has soil surveys online and available for download free of cost (http://soildatamart.nrcs.usda.gov/). A land manager could download a soil map of his or her land, and use a GPS unit to record the location of fence-lines, then combine the two layers with a GIS program to determine what kinds of soils are in each pasture. Aerial photographs can also utilized within a GIS and incorporated with GPS data. There are many ways in which GPS data can be utilized within a GIS program, and it is important to recognize that although the two technologies can be used separate of one another, they can be used in combination to produce powerful analyses.

WHAT GPS UNIT IS BEST FOR ME?

There are many different types and brands GPS units available. Which ones work best for land managers? Which ones are most cost-effective? The answer to those questions is that it depends on what kinds of activities need to be accomplished with the unit. It also depends heavily on the terrain and canopy cover that the unit will be used in, and how accurate the data need to be. The decision tree in Figure 3.2 is designed to help rangeland managers decide what kind of unit may suit their needs best.

SUMMARY

The future is bright for the use of GPS in land management. As technology progresses, the cost of GPS units will undoubtedly come down and accuracy will increase. Currently,basic recreational grade unit can be purchased for about $100, making GPS technology very affordable. It would not be difficult to carry a GPS unit while out checking range resources, such as water sources, salt locations, fences, etc. and record the location of the resource. The potential uses of GPS in land management are limited only by the user’s imagination and the satellites in the sky!

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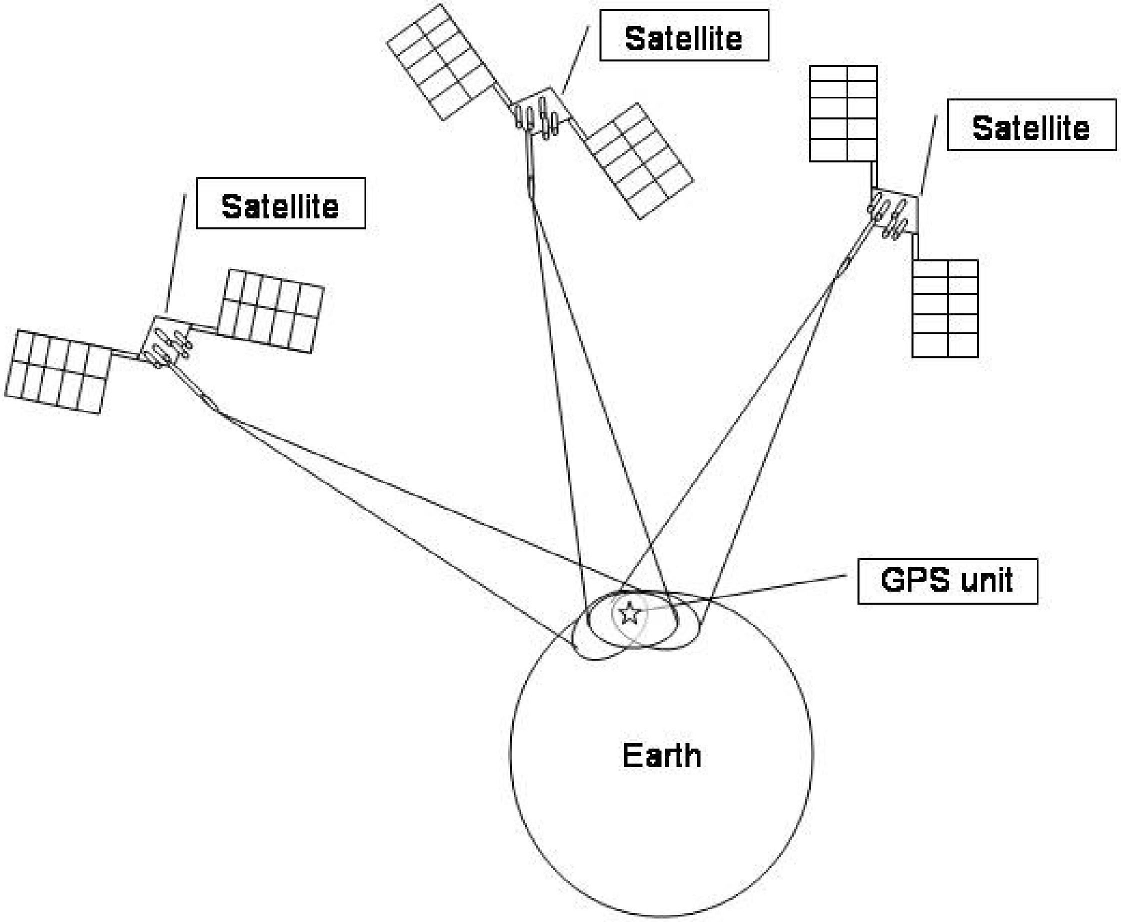

Figure 3.1. GPS units use intersecting circles of satellite coverage to narrow down a precise location on the surface of the earth in a process called trilateration.

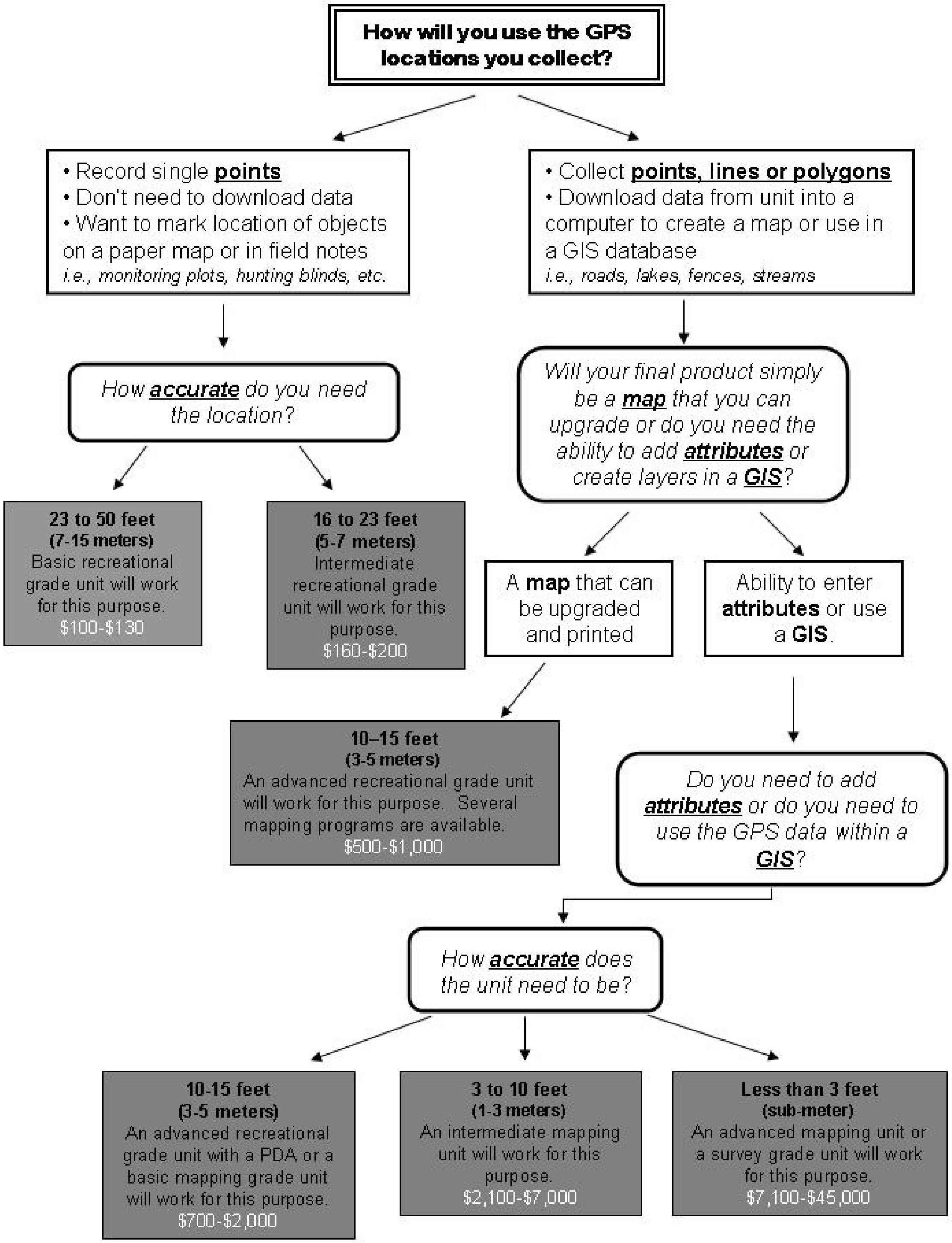

Figure 3.2. A decision tree can be a useful tool when deciding what type of GPS unit is needed.