USING THE RANGELAND HYDROLOGY AND EROSION MODEL TO ASSESS RANGELAND MANAGEMENT PRACTICES ON THE KALER RANCH

By

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ABSTRACT

It is difficult to assess rangeland management practices at a hillslope scale because of the spatial and temporal variability of ecohydrological processes across a landscape. The Conservation Effects Assessment Project (CEAP) aims to provide a cost-effective method for quantifying benefits of conservation practices on rangelands. This study uses the Rangeland Hydrology and Erosion Model (RHEM) to develop a framework to assess rangeland management practices by quantifying sediment yield and runoff. Kaler Ranch, located in Eastern Arizona, was used as a study site because of their recently implemented rangeland conservation practices. Vegetation parameters were developed based on field data collected across the ranch and used to represent various rangeland management scenarios in RHEM. Peak flow and sediment yield rates were determined for each scenario using RHEM and were used as metrics to evaluate rangeland condition. RHEM provided an adequate method to evaluate the relative differences between upland rangeland management scenarios; however, it was less effective at evaluating changes in management practices within a riparian area.

CHAPTER 1: INTRODUCTION

PROBLEM STATEMENT

Rangelands make up over 80% of the lands in the western United States, providing important wildlife habitat and economic value as grazing lands (Weltz et al. 2008). Rangeland degradation occurs because of a combination of factors, including overgrazing, drought, fire and invasive species. Precipitation and vegetation vary spatially and temporally across rangelands. Rangeland assessments from a hillslope to watershed scale are challenging because of the ecohydrological complexities that exist across a landscape as well as the patchwork nature of land ownership in the western United States. The environmental benefits of conservation practices implemented on rangelands over large scales have not been well documented (Weltz et al. 2008). While studies have evaluated the effects of conservation at the field level, few studies are designed to measure conservation effects at the watershed scale (Weltz et al. 2008).

The Conservation Effects Assessment Project (CEAP) was initiated by the USDA Natural Resources Conservation Service (NRCS), Agricultural Research Service (ARS) and the Cooperative State Research, Education and Extension Service (CSREES) to assess the benefits of conservation practices and provide land managers with science-based guidance in a cost-effective manner. Natural resources managers often cannot find scientific data that is presented in an accessible and applicable manner. They often do not have time for lengthy investigations and as a result, decisions either disregard future needs, or the decisions may have unintended ecological consequences (Kepner et al., 2012). One of the goals within CEAP is to develop cost-efficient methods to assess conservation practices at a landscape and regional scale. CEAP aims to quantify the cumulative effects of conservation practices and develop a framework for conducting rangeland assessments at a landscape and national scale (Briske et al. 2011). This study will contribute to CEAP by developing a framework for assessing rangeland health and evaluating alternative management practices using the Rangeland Hydrology and Erosion Model (RHEM), a publicly available hydrologic and erosion model.

Soil loss rate is one of the few quantitative indicators used for assessing rangeland health. Rangeland topsoil is shallow and can take hundreds to thousands of years to accumulate in arid and semi-arid climates. Even seemingly minimal soil loss in these climates can render land unusable for the foreseeable future. Soil conservation on rangelands is of utmost importance to maintain a functioning ecosystem and the ability to effectively evaluate soil erosion on rangelands is critical for the assessment of rangeland health (Nearing et al. 2011). Sedimentation of waterways due to erosion is one of the leading water quality issues in the west United States. Runoff transports sediment and pollutants from upland areas into streams, affecting the downstream water quality. Estimates of sediment yield are used to address water quality issues within resource planning and land management (Nichols, 2006).

Geographic information systems (GIS) are becoming increasingly used by land managers to display and synthesize spatial data sets. Incorporating hydrological and erosion models into GIS enables land managers to simulate conservation measures and visually communicate results. Advances in spatial analysis and visualization tools allow for the integration of landscape information with hydrologic models to better forecast, detect and monitor long term ecological change (Pierson et al. 2001). Rangeland-specific erosion models can serve as a powerful decision making support tool and help land managers identify areas of concern and predict changes in ecohydrological processes occurring on rangelands.

This study will use the Rangeland Hydrology and Erosion Model (RHEM) to perform a rangeland assessment and evaluate alternative management plans. RHEM is erosion predictor tool recently developed by the USDA-Agricultural Research Station in Tucson, Arizona. It was designed specifically for estimating runoff and erosion rates on rangelands and fills a need for a process based rangeland erosion model (Nearing et al. 2011). RHEM provides an integrative method for performing a quantitative assessment of rangelands by modeling erosion and runoff from a hillslope. RHEM provides a cost-effective method that can be used by land managers to assess rangelands and supports the analysis of alternative management options. RHEM has been incorporated into the Automated Geospatial Watershed Assessment Tool (AGWA), a decision making support tool developed by the USDA-ARS (Miller et al. 2007). AGWA is operated with publicly available GIS data to evaluate watersheds on a spatial and temporal scale using reproducible methods (Miller et al. 2007). AGWA facilitates data organization, parameterization and visualization for RHEM.

OBJECTIVES

This study used runoff and sediment yield rates as an indicator of rangeland condition to evaluate conservation practices. A framework was developed to quantitatively assess the benefits of rangeland conservation practices using RHEM. Kaler Ranch, located near Clifton, Arizona, was selected as a case study site for the application of RHEM because of recently implementation of rangeland best management practices. Multiple agencies awarded grants to the Kaler Ranch to address the water quality issues on the San Francisco River. There has not been a comprehensive study to assess the total impact of all management practices implemented on the Kaler Ranch. This study used RHEM within the AGWA tool and the KINTEROS model, to determine the sediment load reduction as a result of removing cattle from the riparian zone on the Kaler Ranch and simulated possible management alternatives. This watershed assessment demonstrated the ability of RHEM to assess rangeland conditions and compare alternative management plans.

The objectives of this study were to:

1. Apply RHEM on the Kaler Ranch to quantify the current runoff rates and sediment yields.
2. Simulate alternative rangeland management practices within RHEM and determine the effect on resulting sediment yields.
3. Analyze the sensitivity of RHEM to different parameterization options available, including channel widths and slope geometry options.

4. Contribute to the CEAP effort by developing a framework for assessing runoff and erosion on a ranch to watershed scale.

OUTLINE OF APPROACH

An analysis of the Kaler Ranch using RHEM required a combination of field methods and GIS analysis. A spatial database for the Kaler Ranch was created within ArcGIS using publicly available land cover, soils and elevation data and observed vegetation data. Vegetation cover values were measured on the upland and riparian areas of Kaler Ranch and used to create a vegetation data set in GIS representing the spatial variability of vegetation across the ranch. AGWA automates the conversion of required data layers to parameter input files for different models (Miller et al. 2007). Once the area of interest was identified and parameters were assigned to the watershed, RHEM was executed to determine runoff and sediment yield values.

Multiple management scenarios were run within RHEM. The vegetation parameters applied to the watershed were increased or decreased to reflect the location and intensities of cattle grazing. Higher vegetation cover values indicated less impact from cattle grazing. Vegetation values were also adjusted along channels to indicate the presence or absence of a riparian buffer zone. For each simulation, the sediment yield and runoff was estimated.

The relative change in sediment yield between different simulations was analyzed to determine the possible benefits of implementing conservation practices. Analyzing relative change illustrated the impact riparian buffer zones may have on reducing sediment loads entering the waterways. This method of analysis allows land managers to evaluate and assess alternate conservation practices in a manner that is widely understood by the public.

EXPECTED RESULTS

The simulation results from AGWA/KINEROS/RHEM model (referred to as RHEM for the remainder of this document) were expected to demonstrate a decrease in sediment yield as vegetation cover increased as a result of the implementation of conservation practices. The primary conservation practice evaluated on the Kaler Ranch was the implementation of a riparian buffer zone that was expected to cause a decrease in sediment yield. The effect on soil loss rates due to changes in vegetation cover was expected to be non-linear; small decreases in vegetation cover values should lead to significant increases in erosion. The creation of riparian buffer zones along the main channel and along upland regions was expected to reduce sediment loads entering the waterways. Running RHEM in GIS allows the user to visually identify areas of concern, enabling land managers to adjust management plans across a landscape.

CHAPTER 2: LITERATURE REVIEW

Rangeland assessments require an integrative approach that incorporates the complexity of the hydrological and ecological processes present. Accurate assessments of rangeland conditions will serve to inform further management actions and enable the evaluation of alternatives. In a review of current literature on rangeland hydrology and management, there is increasing emphasis on understanding the interactions between ecological and hydrological processes occurring on rangelands. Incorporation of these rangeland-specific ecohydrological processes into erosion models will provide a powerful decision making support tool. The following literature review will discuss recent advances in ecohydrology, provide a background of rangeland management and assessment practices, and demonstrate the necessity of incorporating rangeland-specific erosion models into future rangeland management decisions.

ECOHYDROLOGY

Rangeland degradation resulting in increased erosion is often preceded by changes in water distribution and vegetation patterns. The study of ecohydrology examines the interactions between the hydrological and ecological processes. Further integration of ecohydrological studies into rangeland management decision making tools will greatly benefit land managers' abilities to assess rangeland health and formulate management plans.

Ecohydrological studies have shown the water budget and vegetation dynamics are highly interconnected on rangelands (Ludwig et al. 2005; Urgeghe et al. 2010). Water is the limiting factor of vegetation growth in arid regions and the study of ecohydrology can provide insight to the distribution of water on rangelands (Rodriguez-Iturbe 2000; Ludwig et al. 2005). Conducting a rangeland assessment requires an understanding of the ecohydrological processes at work. Changes in vegetation can have a drastic effect on the storage and movement of water on the landscape. As land managers, it is necessary to understand the feedback cycles between water distribution and vegetation growth to create a comprehensive management plan.

Ecohydrological processes play an important role determining sediment yield in semi-arid environments. Degradation on rangelands is the result of changes in vegetation abundance and distribution, accompanied by the increase of runoff and erosion (Turnbull et al. 2008). Erosion results from a lack of adequate vegetation cover to retain water and soil on the hillside. Studies have demonstrated a strong link between the biomass on a hillslope and the amount of overland flow (Turnbull et al. 2008). Hillslope disturbance is evident in increased runoff and erosion rates. Severely degraded rangelands may display rills and gullies, leading to high erosion rates and often making restoration processes economically unfeasible (Turnbull et al. 2008).

The complexity of rangeland ground cover contributes to multiple eco-hydrological controls over runoff. Vegetation and ground cover can protect the surface from raindrop splash erosion and slow down overland flow, reducing the overall erosion. Vegetation patches act as sinks for capturing runoff, nutrients and sediment from inter-canopy bare patches (Ludwig et al., 2005; Urgeghe et al. 2010). Water and sediment are redistributed from bare to vegetated patches, concentrating resources and optimizing vegetation growth (Rodriguez-Iturbe 2000). Vegetation patches on rangelands also act as surface obstructions, slowing down and trapping runoff, sediments and nutrients that flow from in from the bare soil patches (Ludwig et al. 2005). The nutrients and water captured by vegetation lead to pulses of plant growth that increase or maintain existing patches.

Disrupting the spatial balance between vegetated and bare patches will lead to changes in the distribution of water and nutrients. Vegetation patches can increase infiltration rates and provide storage for runoff. Patches act as obstructions to runoff, slowing down the flow of water and reducing its erosive force. A decrease in vegetation patch size can reduce the ability to retain water, causing an increase of runoff and soil erosion. The lack of nutrients and water reaching the vegetated patches will cause a decrease in vegetation size, increasing the connectivity of bare soil patches and creating a feedback loop where runoff and erosion increase as vegetation patches continue to decrease in size (Urgeghe et al. 2010).

Limiting the connectivity of bare patches can improve rangeland condition by reducing a loss of water and nutrients due to runoff. Numerous studies support the concept that when a threshold level of bare soil is reached, the ecosystem becomes inefficient at trapping runoff (Urgeghe et al. 2010; Ludwig et al. 2005). When bare soil patches are isolated from each other, the per-unit area runoff on a hillslope scale decreases due to low connectivity. If vegetation cover is reduced sufficiently, connectivity between bare patches increases and erosion and runoff increase nonlinearly (Newman et al. 2006).

Preventing rangelands from progressing to this threshold point of bare cover is critical in rangeland management, as it is often difficult to reverse this process once connectivity of bare ground is established.

Once connectivity of bare ground is established, runoff increases nonlinearly with decreases in vegetation cover. Small decreases in cover can lead to large increases in runoff and erosion. Urgeghe et al. (2010) examined the effect of canopy cover on runoff at the hillslope scale. As canopy cover decreased, runoff increased in a non-linear manner. Runoff increased slightly as herbaceous cover was decreased from 35% to 19%, and then increased substantially as the cover was reduced to 9% and then 4% (Urgeghe et al. 2010). Using computer simulations, Urgeghe et al. (2010) demonstrated that flow into vegetated patches (run-on) was greatest when the amount of bare cover was classified as intermediate (26% bare cover and 19% vegetation). This study illustrated the trade-off between a source area for generating runoff and a sink area for capturing run-on. The difference between the total flow into and out of all herbaceous patches was not particularly sensitive to overall changes in vegetation cover. The greatest run-on occurred at an intermediate level of herbaceous cover (Urgeghe et al. 2010).

Slope is also a controlling factor in runoff, particularly on recently disturbed sites. A study by Al Hamdan et al. (2012) showed rock cover decreasing as slope increased where there was little vegetation. The negative correlation between rock cover and slope is only expected to hold until enough erosion exposes the underlying rocks. This study showed that the ability of flow discharge to predict erosion increases in the absences of roughness elements. The study also found that the correlation between slope and velocity becomes stronger as the presence of roughness elements decreases (Al-Hamdan et al. 2012).

Grazing affects ecohydrological processes occurring by reducing vegetation cover and compacting soil (Ludwig et al. 2005). Grazed hillslopes produced more sediment than ungrazed lands. Ludwig et al. (2005) found that annual sediment yields were three times as much on disturbed rangeland slopes as undisturbed rangeland slopes. Shallow, compacted soil causes water to flow in a wider path, as opposed to forming rills as the discharge increases (Al-Hamdan et al. 2012). A wider flow tends to encounter more obstacles along its path, increasing the hydraulic friction.

Intensive grazing removes large quantities of biomass, reducing the ability of vegetation to dissipate the energy of raindrops and leading to increased splash erosion and overland flow (Nearing et al. 2011). Grazing can significantly decrease the size and density of vegetation patches, reducing their abilities to trap sediment and runoff (Ludwig et al. 2005).

The literature demonstrated that cattle grazing can easily disrupt the ecohydrological processes, causing a shift in water distribution and vegetation cover. Managing grazing for the reduction of sediment yield will benefit vegetation communities by maintaining the ecohydrological processes present across the landscape. Rangeland management practices should strive to maintain the health and presence of vegetation patches and limit the connectivity of bare soil patches.

RANGELAND MANAGEMENT

Cattle grazing in the western U.S. began in the mid- 1800s and expanded dramatically over the course of the century, significantly altering western rangelands. The expansion of grazing was largely unchecked and there was little incentive to implement conservation measures. Grazing was especially concentrated along riparian areas, permanently degrading and changing the ecological structure of many rivers. Grazing significantly degraded western rangelands, making restoration to pre-1800s conditions impossible in many locations (Turnbull et al. 2008).

Management recommendations began in response to the unsustainable grazing practices of the 19^{th} and early 20^{th} century (Briske et al. 2011). Grazing systems have evolved out of a need to conserve and manage our natural resources. Current grazing practices aim to optimize the grazing capacity of a rangeland. Numerous studies have been performed to determine the optimum grazing rates (Briske et al. 2008). Early systems involved reducing stocking rates and imposing seasonal rest periods to allow plants to recover. Recent studies have shown that moderate, continuous grazing may be more beneficial to the biological diversity of a landscape than rotational grazing (Briske et al. 2011).

The detrimental effects of intensive cattle use have been well documented. For example, Loeser (2007) investigated the effects of two rangeland management alternatives on grassland plant communities located at an elevation of 2160 meters. The study compared a highly impacted site and a site where cattle had been removed. Within eight years, the high-impact grazing sites had changed plant composition to a much greater extent than cattle removal (Loeser 2007). High impact grazing also had the effect of decreasing diversity within the plant community. Sites where cattle had been removed showed little increase in native vegetation, demonstrating the difficulty of returning a rangeland to its previous condition without extensive intervention.

Forage quality is a key aspect within the design and implementation of grazing systems. It is influenced by the length and intensity of grazing, as well the rest periods between grazing. Continual, intensive grazing is detrimental to plant growth and survival due to the removal of leaf area necessary for photosynthesis processes (Briske et al. 2011). Rotating livestock has been a common management technique for the past 40-50 years. Rotational grazing systems (RGS) refer to concentrating cattle in relatively small areas at high intensities for a short period of time. In arid and semi-arid regions, the growing season is relatively short and there is little chance of regrowth after grazing. Fewer plants remain ungrazed with a RGS compared to continuous grazing; however, studies have found little difference in defoliation patterns between RGS and continuous grazing.

There is increasing evidence showing the effectiveness of moderate continuous grazing over rotational grazing (Briske et al. 2008; Holechek et al. 1998). Numerous studies have demonstrated that intensive, short duration grazing does not have any advantage over continuous grazing and does not measurably increase livestock production or plant diversity (Briske et al. 2008; Bailey and Brown 2011). Hart et al. (1988) conducted a study of a 6 year period comparing continuous grazing, deferred rotation and short duration grazing. Both heavy and moderate stocking rates were applied to each system.

There was no difference in the vegetation composition between the stocking rates, demonstrating that rotational grazing has no advantage over continuous grazing. A study on the Jornada Experimental Range in southern New Mexico showed black grama cover was highest when plants were conservatively grazed (Holechek et al. 1998).

Lighter grazing intensities are necessary for arid regions. Stocking rates should be determined to sustain the amount of vegetation needed. Light, continuous grazing allows cattle to select from a variety of plants rather than targeting the most palatable species. Studies have shown that rangeland productivity and vegetation diversity can be maintained through moderate, continuous grazing (Briske et al. 2008; Holechek et al. 1998; Loeser et al. 2007).

Livestock selectivity leads to uneven grazing patterns across landscapes. One of the primary problems with continuous grazing is the preference for certain areas, based on water, forage and cover. Fencing can control distribution of cattle. Rotating the cattle through water points and the placing salt licks away from water can also address issues of distribution, however it is generally agreed on that grazing capacity is reduced as distance from water increases and as slope increases (Holechek et al. 1998).

Riparian management often requires a different approach than upland areas because of the potential impacts along streams. Continuous grazing is most detrimental in riparian areas because animals will concentrate in these areas, as they provide cover, forage and water (Holechek et al. 1998). Riparian zones represent a small amount of the range area, but have a large concentration of resources and provide important ecosystem services.

Chronic, intensive grazing along waterways is likely to occur if animals remain in pastures with riparian zones (Bailey and Brown 2011). Riparian zones serve as natural filters; however, extensive grazing in this area can quickly reduce the effectiveness of the filter zone and allow sediments and pollutants to directly enter the river. Excluding cattle from the riparian area and creating a vegetation buffer zone can reduce the amount of sediment entering the stream.

Flennikan et al. (2001) examined the effects of cattle on a riparian zone. The study revealed that vegetation stem density was greatly reduced by cattle grazing and affected the flow characteristics through the riparian zone. Grazing reduced stem density, an important friction component that previously slowed overland flow. High intensity grazing resulted in a more uniform flow regime across the riparian zone. The micro-channels became less sinuous and carried a greater volume of water. Cattle grazing in the riparian zone affected the flow characteristics by decreasing the channel sinuosity and drainage density (Flennikan et al. 2001). Grazing in riparian zones reduces the vegetation buffering capacity. This study demonstrated the importance of stem density in the riparian zone. While the best method to rehabilitate riparian zones is a complete exclusion of cattle, this is often not feasible for ranchers. A management plan that ensures grazing of riparian zones does not occur during late summer can be more beneficial than rotational grazing systems (Bailey and Brown 2011). Rest-rotation appears to be one of the most practical means of restoring and maintaining riparian zones (Holechek et al. 1998).

In summary, light to moderate grazing has been demonstrated to have the most benefit on the health of vegetation communities. Riparian areas often need different management approaches than upland areas due to their sensitive nature and high concentration of resources. Maintaining healthy vegetation patches on hillslopes can prevent sediment from entering the riparian zone and causing sedimentation in the rivers. The integration of ecohydrological principles into rangeland management will serve to create more resilient ecosystems. The development and evaluation of rangeland management plans requires comprehensive rangeland assessment methods.

RANGELAND SPECIFIC EROSION MODELS

Recent approaches to rangeland assessments have taken a quantitative approach, using estimates of sediment yield to determine the vegetation conditions. Vegetation cover and spatial patterns can be used as indicators in rangeland health monitoring and assessments (Pyke et al. 2002; Urgeghe et al. 2010). Sediment yields are a quantitative measurement of rangeland health and vegetation cover. The development of erosion models specific to rangelands provides land managers with a quantitative method for evaluating rangelands. Few models, however, have been able to capture the complexity of rangeland vegetation and its variation across a landscape (Pierson et al. 2001). Compared with the development of agricultural erosion models, rangeland erosion models are relatively new and there has been a lack of soil loss data specific to rangelands to fully develop a rangeland-specific erosion model (Wei et al. 2009). Flow hydraulic processes on rangelands differ from that of croplands, creating the need for further rangeland-specific studies to thoroughly understand the biological and physical processes (Al-Hamdan et al. 2012; Wei et al. 2009).

Rangelands are inherently different from croplands, both in terms of hydrological and erosion processes, as well as management issues and practices (Nearing et al. 2011). Rainfall in arid and semi-arid regions tends to be highly variable, both spatially and temporally, leading to a much more complex distribution of vegetation cover on rangelands. Rangeland soils are generally less erodible than agricultural land because they have not been disturbed by tillage and have a higher rock cover. While rangelands may be less erodible, the topsoil layer is very thin, meaning that minimal erosion rates can significantly decrease the amount of available soil.

Soil erosion and conservation has been studied extensively in the context of agricultural lands and leading to the development of empirically based cropland-erosion models. Cropland erosion models use inter-rill erosion equations from relatively small plots that are not representative of the spatial heterogeneity present in rangelands (Wei et al. 2009). Rill erosion occurs as actively scouring channel and is the dominant erosive force on croplands. Extensive rill erosion can eventually lead to gully formation (Nearing et al. 2011). Although rills and gullies are often present on severely degraded rangelands, rangeland erosion usually occurs as thin sheet flow and splash erosion. Thin sheet flow occurs on inter-rill surfaces. Splash and sheet erosion is the removal of soil in thin layers and is caused by both raindrop splash and overland flow (Wei et al. 2009).

The Universal Soil Loss Equation (USLE) was one of the earliest empirically based models used to estimate erosion on rangelands (Spaeth et al. 2003). USLE was designed to predict soil loss due to rill and sheet erosion and provided decision makers with a long term average sediment yield based on soil, rainfall patterns and land cover. The Revised Soil Loss Equation (RULSE) included advancements in hydrology and erosion research and was designed to address steeper slopes (Spaeth et al. 2003). Due to the physical and biological differences between croplands and rangelands, RUSLE does not accurately predict erosion on rangelands. Spaeth et al. (2003) found that USLE overestimated erosion on rangeland plots, while RUSLE underestimated erosion. Many erosion models developed for croplands tend to over predict soil loss for small quantities and under predict soil loss for larger sediment yields. The precipitation patterns and hydraulic processes of rangelands are not accurately characterized within RUSLE because it does not allow for separation of factors that influence soil erosion, such as plant growth, infiltration, runoff, soil detachment and transport (Spaeth et al. 2003). Erosion on rangelands usually occurs as the result of a single rainstorm event (Nearing et al. 2005). An event based model is much more applicable to understanding the processes governing erosion on rangelands.

SPUR (Simulation of Production and Utilization of Rangelands) was one of the first erosion models developed specifically for rangelands by the USDA-ARS in 1987 (Wight and Skiles, 1987). It was a physically based model designed to simulate the ecosystem response to management actions. Modifications were made to the model over the following decade. SPUR operates on a daily time-step and was designed for small watersheds (Sasowksy and Gardner 1991). Sediment yield is estimated using USLE. Runoff was determined from the modified Soil Conservation Curve Number (CN). The shortcomings of SPUR included the inability to predict short term runoff. There was a weak link between vegetation and the hydrological processes within SPUR (Pierson et al. 2001). Because the hydrology component was set by a curve number, the hydrological processes are unresponsive to short term management or vegetation changes.

The Watershed Erosion Prediction Project (WEPP) was also developed in response to the need for a rangeland specific erosion model. WEPP is a process based model and was released in 1995. The advantages of WEPP include the capabilities to estimate spatial and temporal distributions of soil loss and to extrapolate to a wide range of conditions (Nearing et al. 2011). However, many of the model concepts and equations in WEPP were still developed based on cropland experiments, so it continues to have shortcomings when applied to rangelands.

Pierson et al. (2001) developed SPUR 2000 by incorporating the infiltration equations from WEPP into the existing SPUR model. SPUR 2000 was developed as an improved model for field-level rangeland hydrology assessments. SPUR 2000 was able to predict runoff more accurately than previous versions of SPUR, however the sediment yield predictions were not reliable. There was still a need for an erosion model that incorporated the influence of vegetation on infiltration and runoff and the differences between plant communities (Pierson et al. 2001).

The Rangeland Hydrology and Erosion Model (RHEM) is an event based runoff and water erosion model specifically designed to address erosion on western rangelands. It is a process based model currently being developed by the USDA Agricultural Research Service (USDA-ARS). The version used in this study had a build date of 10/26/2012. RHEM determines sediment load in runoff along a hillslope as the total net detachment and deposition from rainfall splash, overland sheet flow and concentrated flow (Nearing et al. 2011). The parameter estimation of RHEM relies on ecohydrological concepts established in Pierson et al. (2002), showing that hydrological and erosion processes are related to plant forms. The equations reflect hydrologic responses to differences in management, soil type and vegetation type (Nearing et al. 2011). Parameter equations for RHEM were determined from a wealth of data collected from rainfall simulator experiments across western rangelands. These studies contributed to an understanding of infiltration and runoff and provided data for developing parameterization equations in RHEM (Nearing et al. 2011).

Wei et al. (2009) used the results of these rainfall simulator experiments to develop a new splash erosion and thin sheet-flow transport equation specifically for RHEM. Inter-rill erosion is often modeled as a function of rainfall intensity (I) and runoff rate (q). The data revealed a relationship between rainfall intensity and runoff, a key difference in the parameterizations equations used in RHEM and equations used in previous erosion models (Wei et al. 2009). By utilizing splash and sheet flow erosion equations developed by Wei et al. (2009), RHEM is able to more accurately characterize the rate of splash and sheet erosion. Disturbances can reduce vegetation cover and cause the dominant erosion process to switch from inter-rill sheet flow erosion to rill erosion. To account for this, RHEM has the capacity to combine splash and sheet erosion with rill erosion based on the extent of disturbance (Nearing et al. 2011). RHEM is an important step in the modeling of ecohydrological processes on rangelands because of its ability to capture how interactions of plant species, disturbances and management practices influence erosion processes (Nearing et al 2011).

KINEROS was developed at the USDA-ARS as a model that routed runoff from hillslopes. It uses a set of planes and channels to route water across landscapes. It was originally developed as an event based model (Goodrich et al. 2012). KINEROS2 estimates runoff, erosion, sediment transport in overland flow. It has been successfully calibrated on experimental watersheds (Goodrich et al. 2012). For this study we used a version of KINEROS where RHEM is used to simulated runoff and erosion from a hillslope.

CONCLUSION

The recent advances in ecohydrology can provide insight to the interactions between ecological and hydrological processes occurring on rangelands. Integrating these processes in spatial models will serve to provide a framework capable of assessing rangeland condition and identifying areas of concern requiring management actions. Evaluating current rangeland conditions will help to implement management practices that will mitigate the effects of potential disturbances.

CHAPTER 3: METHODS

This chapter describes the methods used to evaluate current practices on the Kaler Ranch and details the development of the simulations applied within RHEM. This study developed a spatial modeling framework to quantify the benefits of removing cattle from the riparian zone and determine the threshold point of upland grazing that the riparian area could sustain.

SITE DESCRIPTION

The Kaler Ranch is located near Clifton, Arizona (Figure 1). Clifton receives an average of 13.36 inches of rain per year. Forty five percent of the rain falls during the monsoon season, between July and September, with a second rainy season in the winter months (http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/SEArizona/Climate/Morenci.htm, 4/26/2013). The ranch is 11,000 acres with elevations ranging from 3,000 feet to 7,000 feet. The field work was conducted in June, 2012, prior to the start of monsoons. Years 2011 and 2012 received precipitation values slightly below average, with 11.83 and 10.45 inches, respectively. At the time of this study, the ranch included a combination of privately owned land, state-leased land and BLM leased land. There had been grazing at the well located furthest south on the ranch from October of 2011 to April 2012.

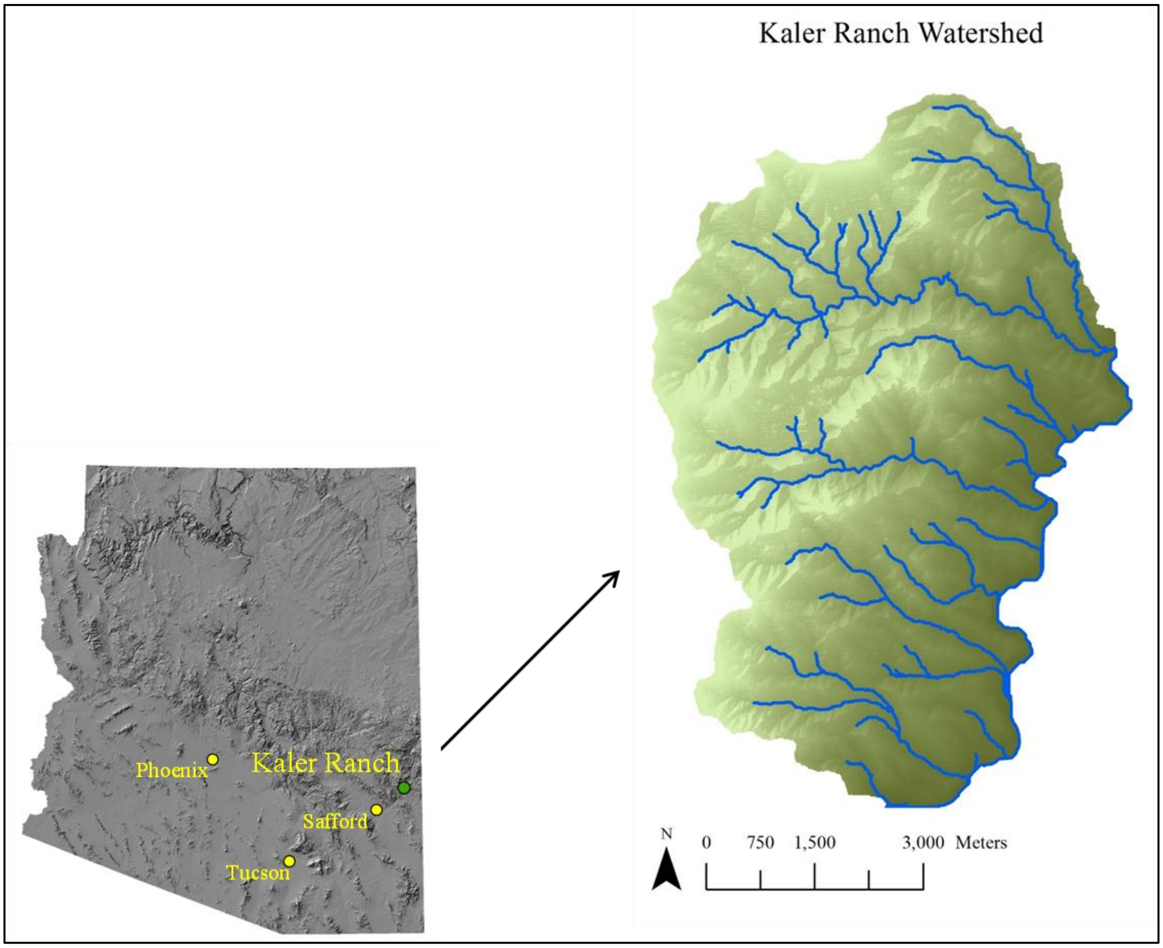

Figure 1. Study Site Location.

Kaler Ranch was purchased by Richard and Lois Kaler in 2001. When they purchased the ranch, it was in extreme disrepair. The riparian area had been heavily used by cattle and was in poor condition. Trash littered the property and there were unfinished culverts that emptied onto their property (Kaler, Pers. Comm. 2012). In 1972, the Phelps Dodge Mining Corporation and the State of Arizona began the construction of a road that was intended to replace a section of Highway 191. The project was abandoned due to the difficulty of the project and the costs involved, leaving partially completed culverts to empty into the riparian area on the Kaler Ranch (Gila Watershed Partnership, 2012). The large, unfinished culverts did not reach the river, and water diverted from the road ran directly onto the Kaler property. During a particularly large rainstorm after the purchase of the ranch, torrents of water flowed out of the culverts across the ranch's riparian area. The deluge of water carried topsoil and livestock waste from the surrounding area into the river. The runoff from the culverts also destabilized the river banks and caused extensive damage to the ranch. The runoff from the culverts exacerbated the water quality issues that existed in the San Francisco River.

The water quality and *E. coli* levels along the San Francisco River have been monitored extensively by the Gila Watershed Partnership (GWP). The San Francisco River was used as a water source for cattle, leading to the trampling of vegetation and the input of waste into the river. The San Francisco River is also a popular recreation area and there are visible impacts of recreational use along the river. Arizona Department of Environmental Quality (ADEQ) determined that there were elevated levels of *E. coli* in the river (http://gilawatershedpartnership.com, 5/2012).

The Kalers' sought assistance to address the environmental degradation caused by the unfinished culverts. They received grants from the ADEQ, GWP and the Arizona Watershed Protection Fund (AWPF) to address the presence of *E. coli* and reduce erosion caused by the culverts. The management practices implemented as a result of the grants included:

- Completion of the culverts.

- Replacing old fencing and adding additional fencing along the west side of the river.
- A vegetation buffer to increase the stability of the banks along the river.
- Installation of a bulwark to protect a section of the riverbank.
- Dust control to reduce sedimentation during construction.
- Road repair to fix damage from construction vehicles.
- Three wells have been installed from grants from the ADEQ, AWPF and the NRCS to remove cattle from the riparian area by providing an upland water source for the cattle.

Natural resource managers use ecological sites to classify rangelands and determine their condition. Ecological site descriptions enable land managers to identify transition zones present across a landscape and put management plans in place to move toward the preferred state. The Kaler Ranch lies in a transition zone between Land Resource Areas 38-1 and 41-3. Most of the land can be considered to be 38-1 with some of the south slopes being considered 41-3 (Pers. Comm. Carrillo, E., NRCS). LRA 38.AZ1 is the Mogollon Transition, with elevations ranging from 3000 to 4500 feet. Precipitation averages 12-16 inches per year (USDA-NRCS 2008). LRA41. AZ1 is the Mexican Oak-Pine and Oak Savannah. Elevations range from 4,500 to 10,700 feet with 16-30 inches of precipitation (USDA-NRCS 2008). The lower elevations of the ranch are loamy slopes (12-16) and volcanic hills (12-16). Further upland is granitic hills 12-16 complex and granitic hills 16-20 complex (USDA-NRCS, 2012).

APPLICATION OF AGWA

AGWA is a tool used to understand the effects of land use changes and evaluate management alternatives. It is operated with publicly available GIS data to evaluate watersheds on a spatial and temporal scale using reproducible methods. AGWA uses a GIS interface to support data organization, model parameterization, integration and visualization for its three available models: SWAT, KINEROS2 and RHEM (Goodrich et al. 2011). AGWA enables watershed delineation, discretization, model parameterization and results visualization.

KINEROS2 is a process based model that simulates the conversion of excess rainfall to overland flow (Miller et al. 2007). The model is most effective when applied to overland flow-dominated areas that are characteristic of semi-arid watersheds (Miller et al. 2007). KINEROS2 is applicable to smaller watersheds which are represented as overland flow planes and channels.

RHEM is a process based model that predicts hillslope-scale erosion and erosion rates under different land management and vegetation conditions. The parameterization equations were developed specifically from rangeland experimental data. RHEM models splash and sheet erosion as the dominant erosion process of concentrated flow erosion. The processes of infiltration, interception, retention, erosion, sediment detachment, transport and deposition are all explicitly treated in RHEM (Nearing et al. 2011). The model results include runoff, peak discharge, infiltration and sediment yield. AGWA imports and visually displays the results. This study used AGWA to integrate the required data layers and characterize the watershed for the application of RHEM.

Sediment yield and peak flow are the two metrics from the simulations used to evaluate and compare management scenarios. Sediment yield is an indicator of the quality and quantity of vegetation cover. As bare ground connectivity increases, erosion rates increase. Peak flow was reported at the selected outlet of the watershed containing the Kaler Ranch. Peak flow is a metric commonly used to describe flow regimes. The timing of peak flow indicates how quickly the overland flow reaches the outlet of the watershed. When the peak flow occurs sooner in the outflow hydrograph, it indicates that there is more runoff. This occurs in areas where there is less infiltration and more overland flow due to surface conditions. Areas with low infiltration often have higher peak flows that occur earlier. A hydrograph with more delayed, lower peak flows often indicates a healthier hydrological system because more rainfall infiltrates and runoff is slowed by vegetation, delaying the peak flow and often resulting in a lower peak discharge (Poff et al. 1997). The size and timing of the peak flow is an indicator of the energy available to transport sediment. Greater peak flows corresponds to a higher magnitude of sediment estimated at the outlet (Poff et al. 1997).

DATABASE CONSTRUCTION

The first step in characterizing the Kaler Ranch was the compilation of spatial data layers in ESRI ArcGIS 10. A common map projection is applied to all GIS layers.. The projection used was the Universal Transverse Mercator (UTM) Zone 12 North. The datum was North American Datum (NAD) 83. All additional layers created through the analysis maintained the same projection and datum.

The application of RHEM to the Kaler Ranch required the creation of a geo-spatial database. Data was gathered from online databases and field methods. RHEM requires input parameters that can be grouped into four categories: slope profile, soils, vegetation type and cover and climate. The vegetation cover was determined from the field data collected on the Kaler Ranch. The remaining inputs are available from online databases. The following layers were used for running AGWA-RHEM:

- Digital Elevation Model
- Land Cover and Soils
- Precipitation Frequency Data
- Vegetation cover values

DIGITAL ELEVATION MODEL

The topography of Kaler Ranch was determined from a 10 meter digital elevation model (DEM) downloaded from the USGS Seamless Viewer (http://nationalmap.gov/viewer.html). The USGS provides a database of bare earth DEM data from the National Elevation Dataset (NED). The DEM used for this project is 1/3 arc-second resolution (10 meters). The DEM was used for determining flow lengths, direction, and accumulation. A slope grid was created from the DEM where the slope between each cell was calculated.

SOILS AND LAND COVER

Spatially displayed soils data was obtained from the NRCS Soil Mart (http://soildatamart.nrcs.usda.gov/). The percent silt, sand and clay was calculated from the soils database. The North American Landscape Characterization Dataset (NALC) was used to parameterize the land cover. The clay, silt and sand percentages are calculated from the Soil Survey Geographic Database (SSURGO). Rock cover was determined from the field methods.

PRECIPITATION

The precipitation values were determined from the Precipitation Frequency Data Server developed by the NOAA Hydrometeorological Design Studies Center (http://dipper.nws.noaa.gov/hdsc/pfds/). This study uses the precipitation frequency data based on the frequency analysis of the partial duration series from the Clifton Station. The Clifton station was the station located closest to the Kaler Ranch. It is located at 3,000 feet in elevation and 6 miles downstream of the ranch area.

VEGETATION COVER

Vegetation cover data was collected on the Kaler Ranch to determine the current extent of cattle grazing and describe the baseline conditions. RHEM was designed to use vegetation cover data collected with the National Resources Inventory (NRI) methods (Weltz and Spaeth, 2012). The NRI is a standardized rangeland monitoring protocol developed by National Resources Conservation Service (NRCS), Agricultural Research

Service (ARS), Bureau of Land Management (BLM) and the U.S. Geological Survey to create a standardized monitoring and assessment method for rangeland health. The rangeland NRI follows a national, statistical-sampling strategy using GPS to locate and reference sampling sites.

Upland sample sites were distributed around three recently installed wells that now serve as water sources for cattle. When this data was collected, the cattle were not present on the ranch but had grazed the most southern well on the ranch October 2012 to April 2012 (Kaler, R. Pers comm. 2012). The other wells had minimal usage during this time.

Vegetation data was collected on the Kaler Ranch during June of 2012. There were a total of 31 upland locations and 12 riparian locations surveyed (Figure 2). The sampling protocol followed the National Resources Inventory (NRI) methods to determine plant canopy, litter, rock and plant basal cover. At each upland sample site, two perpendicular transects each 150 feet long were set up. They were oriented northeast-southwest and northwest-southeast using a compass. Point-intercept sampling was done every three feet along each transect. Ground and canopy cover were recorded at each point. The type of ground cover (plant basal, rock, litter) was recorded at each point. If there was more than one type of ground cover present, the top layer was recorded. Canopy was recorded as being present or absent. Photographs were taken looking south and north at each site.

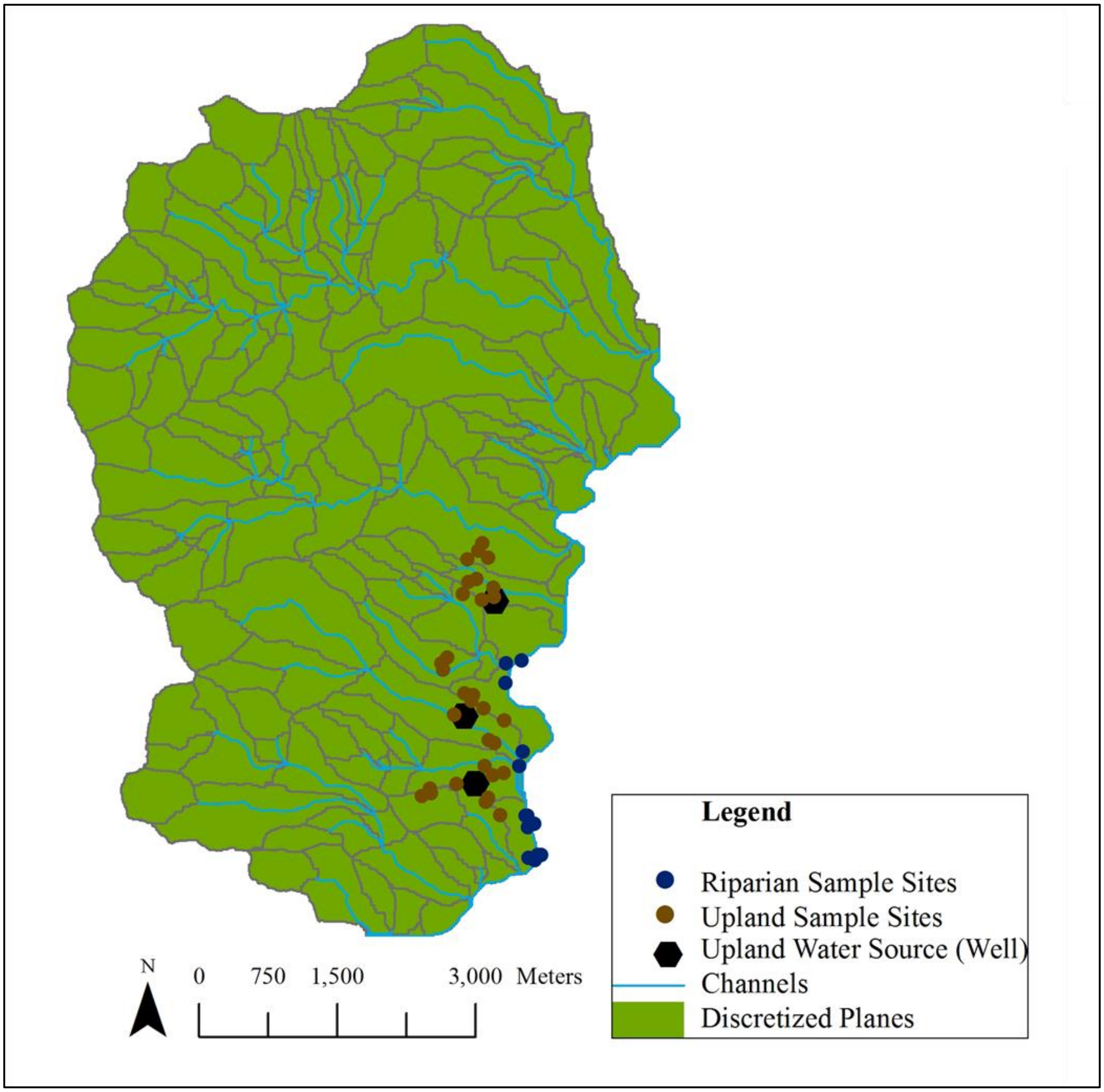

Figure 2. Vegetation sample site locations on the Kaler Ranch.

The sample locations are distributed around the three wells. The sample site locations were designed to be representative of the ranch with an emphasis on capturing the areas that received the greatest livestock use. The sites are concentrated around the water sources to provide a representation of the high use areas. Cattle use is highest on slopes less than 10% and within 1 mile of water sources (Holechek et al. 1998). Approximately half of the sample sites were located within a quarter-mile of the wells and the other half were located between a quarter to a half mile from the water source. Within the two distance classes, the sample sites were identified based on slope and accessibility. The slope groups used to classify the ranch are the following: 0-20%, 20-30%, 30-40%, 40-50% and greater than 50%. Very few samples were taken on the slopes over 50%, due to the distance from the roads and water sources. The actual sampling locations varied slightly from the original sites due to access and the need to accurately characterize the cattle usage occurring on the ranch.

The sample sites were determined using a stratified sampling method where sites were determined based on the following: distance from water source, slope of hillside and accessibility. While only 11% of the land area within the entire watershed falls between 0-20%, almost 20% of the land within 0.25 miles from a water source contains slopes between 0 to 20%. The sampling is concentrated within this location to characterize the areas used most frequently by cattle. Table 1 displays the distribution of sample sites.

Table 2. Allocation of vegetation and ground cover sampling site locations.

Percent Slope	Percentage of Entire Watershed Area	Percentage of Area within 0.25 miles of a water sources	Number of Sample Sites	Percent of Samples
0-20	11.2	20.7	8	26
20-30	14.2	23.4	8	26
30-40	16.7	22.2	7	22
40-50	13	15.4	8	26
50+	44.8	18.1	0	0

The locations of the wells were determined using Google Earth and the coordinates were imported to ArcMap. A buffer tool was applied to the wells at 0.25 miles and 0.5 miles. This allowed for the selection of sample locations based on distance and slope. Digital Orthophoto Quarter Quads (DOQQs) were imported into ArcMap and enabled the determination of sample site accessibility. The highest proportion of samples was collected in the 0-20% slope class with the goal of capturing the area most used by the cattle. Much of the ranch is extremely steep and rugged and it was not necessary to collect samples in remote areas not utilized by cattle. Some of the actual sample locations and slopes deviated slightly from the original site selection due to topography and an effort to accurately characterize the ranch.

The riparian sites were located primarily on the western side of the San Francisco River, as this was the side utilized by the cattle. The selection of the riparian sites was designed to characterize the stretch of the river located within the Kaler Ranch boundaries. The riparian sites were classified as "near" or "far" based on distance from the river. Near sites were located alongside the river at bankfull height. Bankfull height was located along the terrace between five and ten feet away from the water's edge at the time of sampling. Far sites were located within the floodplain at the transition area from riparian to upland. The far sites were characterized by larger trees and grasses. Near and far sites were paired together to characterize the riparian zone along the river. The riparian site sampling consisted of two parallel transects of 150 feet long spaced ten feet apart. The transects were located parallel to the river. Canopy and ground cover were recorded every three feet using the same methods applied to the upland sites.

FIELD DATA ANALYSIS

The vegetation cover values observed on the Kaler Ranch were analyzed in Excel using the Data Analysis Add-In. Statistical analyses were performed to determine if there are significant differences in vegetation cover values between the well sites. Statistical analyses were also applied to evaluate how cover values changed in relation to slope and distance from the water source. The riparian vegetation samples were analyzed independently of the upland samples.

A single-factor ANOVA test was run to determine if vegetation cover values varied significantly between the wells. A p-value of 0.05 was used as the level of significance.

An analysis of variance (ANOVA) was used to determine if there were any differences in average cover values between the well locations. The vegetation values were grouped by well location and an ANOVA was performed on each cover type to determine if the average canopy, basal, litter and rock cover varied based on well location.

A multiple regression was performed on cover type against slope and distance from water. There was a test for significance performed on the regression equations and the r-squared value was recorded. Linear regressions were performed to evaluate each variable independently. Where there was a significant regression, an equation was developed to illustrate the change in cover with distance or slope.

Statistical analyses were also performed on the riparian cover values. T-Tests were used to analyze differences in vegetation cover between near and far sites.

Once the statistical analyses were complete, the vegetation values could be interpolated onto the remainder of the watershed. A polygon shapefile was created in ArcGIS that contained an attribute table describing the variation of vegetation cover across the ranch, enabling the vegetation parameterization of the watershed.

APPLICATION OF AGWA AND RHEM

After the necessary data layers were imported into ArcGIS, AGWA was used to delineate the watershed of interest and parameterize vegetation and land cover values. The delineation function in AGWA identifies the boundaries of the watershed of interest. The DEM is first filled to remove low points and prevent unwanted water storage or water pooling. A flow direction grid (FDG) is created using an 8-direction pour point model to determine the direction of flow. The FDG is used to create a flow accumulation grid (FACG) by calculating the number of cells flowing into each individual cell in the model. This process creates the initial stream network. An outlet of the watershed is selected manually or within a given coordinate point to create a downstream boundary for the watershed. This process delineates the boundaries of the watershed.

Watersheds can be delineated as group or single watersheds. The group watershed allows the user to adjust the contributing source area individually for each watershed. When this method was selected during this study, however, it did not include the entire riparian area. To ensure the entire riparian zone was represented in the modeling process, it was necessary to use single-watershed delineation, where the delineation represented all land contributing to flow at the selected outlet. The watershed of interest in this study is a sub-watershed of the greater San Francisco River Basin. The DEM was clipped to the area of interest and an outlet was identified along the San Francisco River directly downstream of the Kaler Ranch. The watershed was delineated as a single watershed to include the entire riparian zone.

A stream grid and contributing planes are determined during the discretization process. A contributing source area (CSA) was set a flow length equal to 1000 meters, creating a new stream and contributing set of planes for each channel reach greater than 1000 meters. 1000 meters was chosen because allowed the watershed to be subdivided into a sufficient number of polygons that were able to reflect the changes in vegetation cover. RHEM uses a weighting scheme to parameterize each plane and using smaller planes allows for a greater variation in the vegetation values across the ranch (Figure 3).

During the discretization process, RHEM was selected as the model to be used, allowing AGWA to parameterize the watershed with the necessary data layers for running RHEM. The parameterization process intersects the discretized watershed with the soil, land cover and vegetation data described above (Figure 4). The parameters are added to the polygon and stream channel tables (Miller et al. 2007). This creates parameter input files that can be manually adjusted, if necessary. Soil characteristics in the channels are assumed to be sandy beds, giving channels a high hydraulic conductivity value and high transmission loss (Miller et al. 2007). Where perennial flow or groundwater contribution is present, the user can manually adjust the hydraulic conductivity values. Because the main reach of the San Francisco River is a perennial flow, the hydraulic conductivity values for the main reach were adjusted in the parameter files. The Ks values for the reach of the San Francisco River included in the delineated watershed were set equal to zero to represent the existence of a perennial stream.

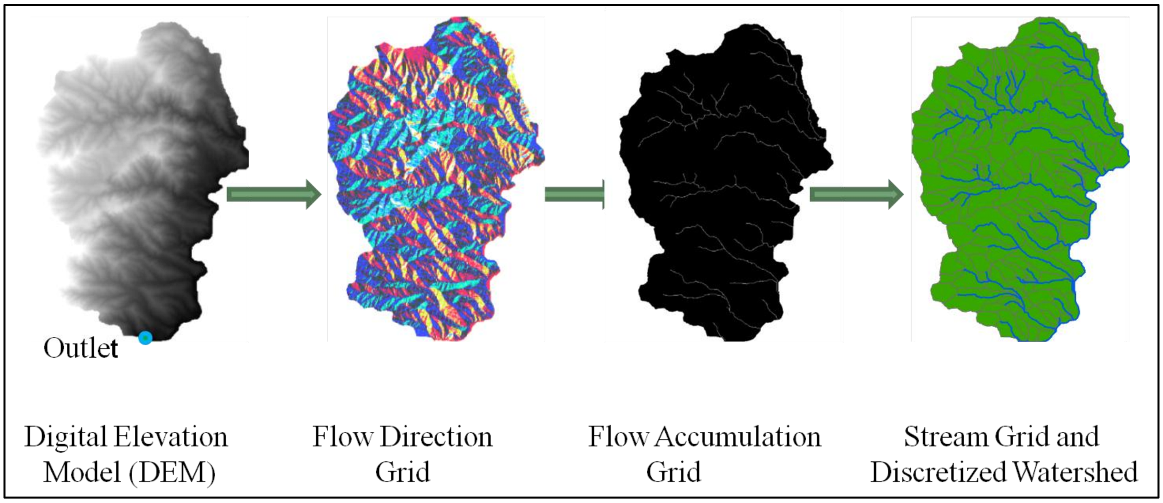

Figure 3. Kaler Ranch delineation and discretization into planes and channels.

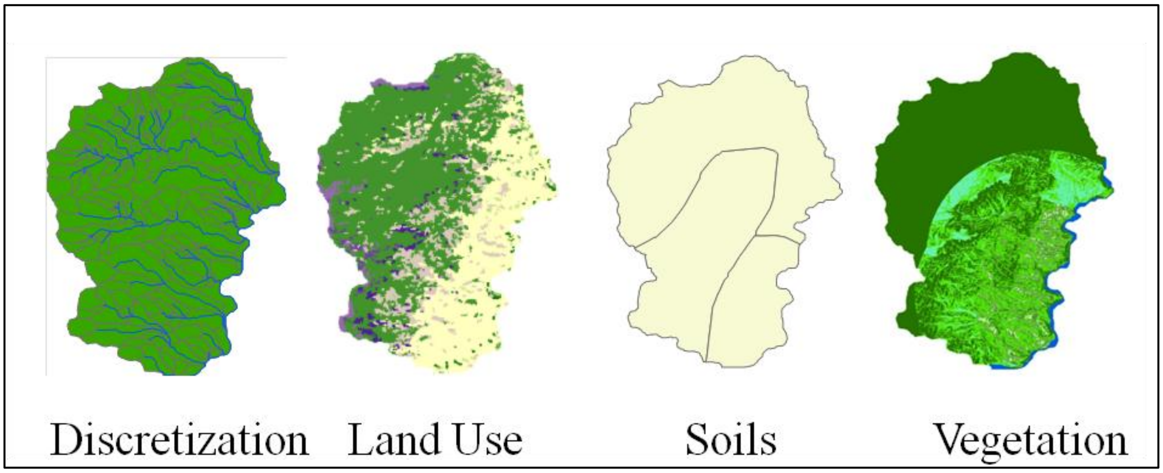

Figure 4. Kaler Ranch element parameterization.

Once all the layers are entered and the model is parameterized, the user can run simulations using varying precipitation data. Precipitation data was selected as a predefined design storm. This study used the precipitation frequency data for the Clifton Station. RHEM uses event based storm data and the user is able to specify the duration and intensity of the storm based on the previously downloaded precipitation frequency data. The outputs for RHEM include infiltration, runoff and sediment yield for the channels and planes.

Multiple simulations were run in RHEM to determine the effects of vegetation cover on runoff and sediment yield. Vegetation values were adjusted in the riparian and upland areas to reflect different management scenarios. A stream buffer zone was created on the San Francisco River using the DOQQs to delineate the riparian zone manually in ArcMap. Sections of the river had a wide riparian area, while the canyon walls narrowed the riparian area in other locations. Manually digitizing the riparian zone allowed for an accurate representation of the riparian habitat. The riparian zone was manually delineated using a combination of the DOQQs to visually see the location of riparian vegetation as well as the slope grid to include the flatter, low-lying areas. Riparian vegetation cover values were applied to this buffer zone. The buffer zone allowed for the simulation of different vegetation conditions in the upland and riparian areas. This enabled the analysis of an established riparian zone.

Multiple vegetation cover layers were created, each one representing a different management scenario. The simulations were all run using a one year, one hour return period rainfall event. A ten year and 25 year return period were applied to certain simulations to understand how the sediment yield changed with storm intensity and duration. The collection of these simulations represented a range of management scenarios. All runs used the New Mexico/ Eastern Arizona channel geometry and complex slopes unless otherwise specified. Channel geometry and slope are specified in the parameterization process.

BASELINE SIMULATIONS

The simulations used to describe the current conditions and determine the sensitivity of RHEM to different parameterizations are as follows:

CURRENT CONDITIONS

The original vegetation values were used to do an initial run simulating the current conditions on the ranch. After completing the statistical analyses, vegetation values were extrapolated to the remaining upland and riparian area. Upland vegetation cover was set as the field data averages, except in cases where it was determined that cover varied significantly with distance from water or slope. In this case, the regression equation was applied using the raster calculator, allowing vegetation cover to change as represented by the regression equation. However, the equation was limited to the upper and lower boundary of vegetation cover values observed. The average observed riparian values were applied to the riparian area.

UNIFORM SLOPES

One of the options within the RHEM parameterization is slope geometry. The ability of the user to choose between complex and uniform slopes is a new development within the AGWA toolkit. Uniform slopes are straight-line slopes that do not allow for sediment deposition. Complex slopes include concave, convex and s-shaped slopes. This allows RHEM to model sediment erosion and deposition along a slope, giving more accurate sediment yield results.

To determine the sensitivity of the model to uniform and complex slopes, a scenario was run using the uniform slope setting. The vegetation layer applied was the same as the baseline scenario, allowing for the comparison between complex and uniform slopes. The remaining simulations were completed with complex slopes.

DEFAULT CHANNEL GEOMETRIES

During the parameterization process, there is a hydraulic geometry option. This setting defines the channel geometry of the watershed. The default setting uses data from the Walnut Gulch Experimental Station in Southern Arizona. This simulation uses the default setting, combined with the baseline vegetation data. The goal of this simulation is to determine the sensitivity of the model to the different channel geometry settings. For remaining simulations in this study, the setting was on Eastern Arizona/New Mexico sites, as this was the closest to the study site.

SCENARIO SIMULATIONS

The rest of the scenarios applied in this study were designed to simulate poor, expected and good conditions in both the upland and riparian zone. These conditions were simulated through adjusting the vegetation values in accordance to the literature. Cattle usage of a grazing area varies with distance from water and slope (Holechek et al. 1998). Holechek et al (1998) give the following trends in cattle utilization based on distance from water and slope:

- 0-1.6km from water: No reduction in utilization.
- 1.6-3.2 km: 50% Reduction in utilization.
- Greater than 3.2 km: Ungrazed.
- 0-10% slopes: No reduction in utilization.
- 11-30% slopes: 30% Reduction in utilization.
- 30-60% slopes: 60 % Reduction in utilization.
- Exceeding 60%: Ungrazed.

Each scenario reflected a management alternative through adjusting the vegetation cover values based on Holechek’s observed utilization trends based on distance from water and slope. The regression analyses did not reveal a strong enough correlation or broad enough spread of cover values to provide the range of values needed to simulate the management scenarios. Instead, the observed vegetation values were ranked by ground cover, because the model is most sensitive to ground cover. Basal cover is often used as an indicator of vegetation condition because it does not vary seasonally. In this case, ground cover (sum of basal, rock and litter cover) values provided a greater range of conditions and better described the alternative management options. The upland and riparian samples were ranked separately and then were grouped by quartiles. The average canopy, basal, litter, rock and ground cover values were determined at each quartile. These values were then applied to the vegetation layer, based on Holechek's recommendations.

Where Holechek observed a reduction in utilization due to distance from water or increased slope, the vegetation cover values from higher quartiles were applied to reflect the effect a decreased number of cattle would have on the vegetation cover. Vegetation values were selected from the appropriate quartile to reflect the impacts of usage due to distance from water and slope. Less steep areas closer to water receive the highest usage, resulting in vegetation cover values from the lowest quartile, while areas further from water with steep slopes received vegetation cover values from the highest percentiles, illustrating the lack of grazing impact. Table 2 displays the vegetation percentiles assigned to each slope and distance class.

Table 2. Ground cover percentiles assigned based on slope and distance.

Distance (km)	0-10% Slopes	10-30% Slopes	30-60% Slopes	Greater than 60% Slopes
0 - 1.6	Lower 25%	Second 25%	3rd 25%	Upper 25%
1.6 - 3.2	Middle 50%	Middle 50%	3rd 25%	Upper 25%
> 3.2	Upper 25%	Upper 25%	Upper 25%	Upper 25%

At shallow slopes and close distance to water where Holechek predicts no reduction of grazing, the lowest 25 percentile of vegetation values is applied. Areas Holechek observed as ungrazed are assigned the highest 25 percentile of vegetation cover values. Where he predicts 30% and 60% reductions, the second and third quartiles are assigned, respectively. At mid-distance from water, the middle 50 percent of vegetation values are assigned. In locations where there are conflicting reductions (i.e. zero to 10 percent slopes located more than 3.2 km from water), the higher percentile of vegetation cover is assigned. All grazing in the riparian areas was considered to be intensive (and thus assigned the lowest vegetation cover percentile), due to the high concentration of cattle in a relatively small area. Anecdotal evidence revealed that when cattle were grazing in the riparian zone along the San Francisco River, the vegetation conditions were very poor (Mendolsohn, pers. Comm., 2012; Kaler, R. pers. Comm.., 2012).

The following section describes management scenarios evaluated in this study.

POOR RIPARIAN CONDITION

This simulation shows the effects of cattle grazing in the riparian zone, describing the ranch condition prior to moving cattle to upland region. The poor riparian condition is described by the lowest quartile of riparian vegetation cover values. The remaining area of the ranch is was assigned vegetation values according to the expected use based on distance from the river and steepness of slope listed in Table 2.

UPLAND GRAZING WITH A RIPARIAN ZONE

This scenario shows the effects of creating a riparian buffer zone by moving cattle from the riparian area to the upland. The vegetation values were distributed based on slope and distance from the well location as seen in Table 2. This simulation assigned vegetation values to the upland areas that would be expected based on Holechek's stocking rate conditions (1998). The riparian areas were assigned a "good" condition, represented by the upper 25% of observed riparian vegetation conditions.

OVERALL GOOD CONDITION

This scenario represents the condition of the ranch if there was very light to no grazing on the ranch. The riparian and upland areas were both assigned the upper 25 percentile of vegetation cover values.

INTENSIVE UPLAND GRAZING WITH A RIPARIAN BUFFER ZONE

Intensive upland grazing was represented by applying the lowest quartile of vegetation cover values to the upland area while maintaining a riparian buffer zone by applying the highest riparian values. This simulation was intended to demonstrate the effects of overgrazing uplands while still having a riparian buffer area in place.

UPLAND CHANNEL BUFFER ZONE

This scenario shows the effects of additional channel buffers around the major upland tributaries. The additional buffers were created ArcMap by applying the buffer tool and setting a buffer zone of 25 meters on either side of the major channels located closest to the wells. Twenty five meters was chosen as the buffer distance based on examining the DOQQs and the slope grid to determine the average width of the riparian zone. The area within the upland channel buffers was assigned the upper quartile of upland vegetation values, while the upper riparian values were applied to the San Francisco River riparian zone. The upland channels are ephemeral and display vegetation much more similar to the upland region than to the riparian area.

CHAPTER 4: RESULTS

The vegetation cover values collected on the Kaler Ranch provided the data necessary to use RHEM to simulate alternative management scenarios. This section will discuss the results of the field observations followed by the results of the simulations run in RHEM.

FIELD OBSERVATION RESULTS

The upland area was characterized by very rocky, rugged terrain. Vegetation was primarily shrubs, including prickly pear, ocotillo, and juniper bushes. The observed vegetation cover values for each sample site in the upland region are listed in Table Appendix A1. The riparian area was characterized by cottonwoods and mesquites. There were grasses along the river banks while places along the floodplain were rocky and sandy with little vegetation. The transition zone between the riparian and the upland area had many mesquite trees. The observed riparian cover values are listed in Appendix A2.

STATISTICAL ANALYSIS OF FIELD DATA: UPLAND OBSERVATIONS

The single factor ANOVA was run for each canopy, basal, litter and rock cover to determine if there was any variation between the three wells. The ANOVA returned a p-value of 0.76 for canopy cover indicating there was not a significant difference in canopy cover values among the three different well sites. An ANOVA was then performed on the basal, litter and rock values among the three wells, resulting in p-values of 0.95, 0.90, and 0.83, respectively. The ANOVA results demonstrated there was no significant difference in vegetation cover in the area around the three wells. The results are displayed in Tables

Appendix B1-4. Determining there was no significant difference in vegetation patterns between the wells allowed for the uniform application of cover values to each of the wells during the vegetation parameterization process in RHEM.

REGRESSION

Once it was determined vegetation cover did not vary between wells, the next step was to determine how ground cover varied with slope and distance from water. A multiple regression analysis was performed, where each cover type was regressed against slope and distance from the closest well.

Canopy cover did not have a significant correlation with slope and distance from water. The r-squared value of the multiple regression was 0.07, demonstrating a very low correlation. The p-value associated with distance from water was 0.28 and the slope p-value was 0.25. Assuming p-level of significant equal to 0.05, there was no significant correlation between canopy cover and distance from water or slope (Table Appendix B5).

A simple regression was performed where canopy cover was regressed against slope and distance from water. Canopy cover did not change as slope increased and decreased with distance from water. The p-value was 0.28 for the correlation with distance from water and 0.25 for slope. The r-squared, however, is very low for both regression equations and the statistical results do not indicate a significant change in vegetation across the landscape. The r-squared value for canopy cover regressed against distance from a water source was 0.02 and the r-squared value for percent canopy regressed against slope was 0.07.

The multiple regression for basal cover resulted in no significant correlation. The results are displayed in Appendix B6. The r-squared value of the multiple regression was 0.11, indicating a low correlation. The p-value associated with the distance from water variable was 0.69, and the p-value for the slope variable was 0.07. Both p-values were above 0.05, indicating there was not a significant relationship. In the simple regression equations, the percent basal cover did not change with slope or with distance from water. The individual r-squared values for the simple regressions are still very low, preventing any statement of correlation between basal cover and slope or distance from water. Based on the statistical results, basal cover does not vary significantly across the Kaler Ranch.

The multiple regression of litter cover against slope and distance to water resulted in an r-squared value of 0.15; a higher r-squared value than shown in either basal cover or canopy cover. While there was not a significant relation within the multiple regression (Table Appendix B7), a simple regression of litter cover plotted against the distance from water resulted in a significant relationship with a p-value of 0.04. There was not a significant relationship between litter cover and slope. Plotting litter cover against the distance from water resulted in an inverse relation where litter cover decreased as distance from water increased (Figure 5). The relationship resulted in a p-value of 0.041, which is below the set level of significance at 0.05. The resulting equation is the following:

$Y = -.03x + 53.48$, where x = distance from water in meters.

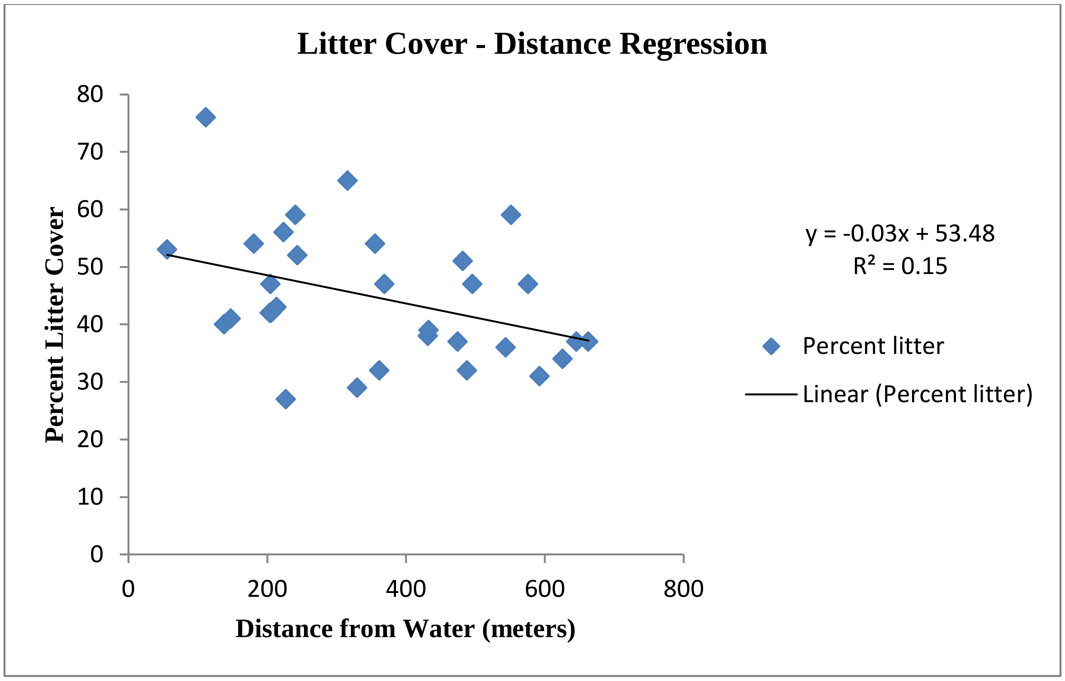

Figure 5. Regression line-fit plot of litter cover regressed against distance from water.

In a multiple regression analysis of rock, there was a significant correlation between rock cover and distance from water, indicated by a p-value of 0.03 (Table B8). There was not a significant relation to slope. Single regression analyses revealed there was a significant relationship with distance from water with a p-value = 0.02 and r-squared = 0.18 (Figure 6). The equation given by the regression equation is:

$Y = 0.03x + 28.80$ (where x= distance from water in meters)

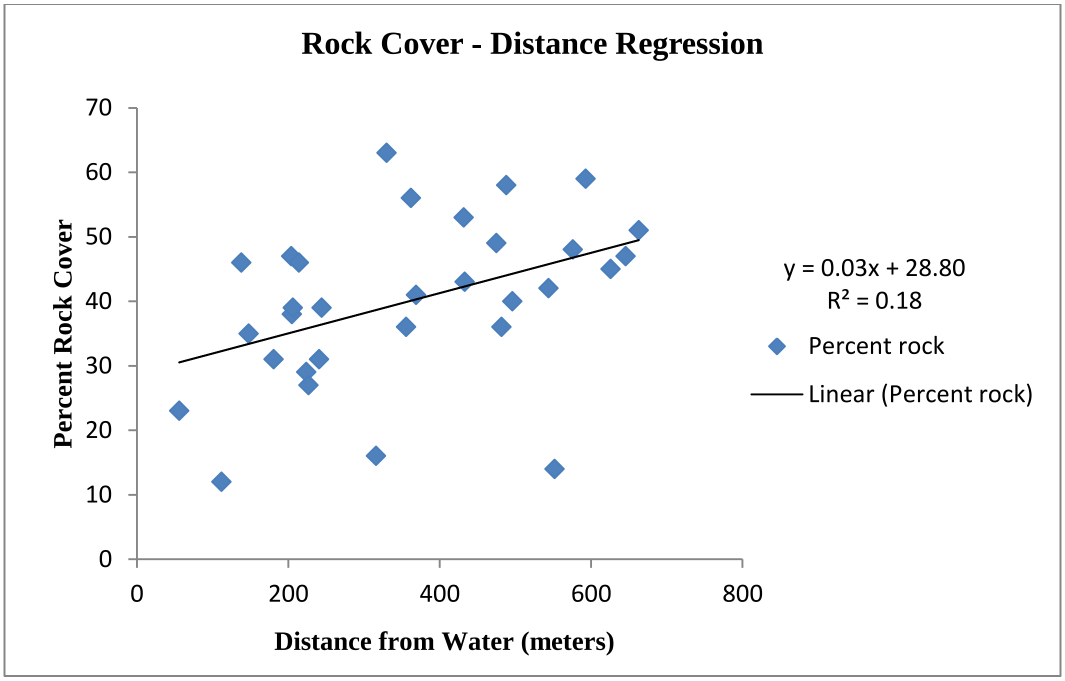

Figure 6. Regression line-fit plot of rock cover regressed against distance from water.

Rock cover is not expected to vary across a landscape due to grazing, however a lack of litter cover would cause an increase in the presence of rock cover recorded during the vegetation surveying. This is a result of the sampling methods used. The sampling methods for measuring ground cover required that only the first layer be recorded. If there was litter and rock present, only the top layer (usually litter) was recorded. In the absence of litter cover, the rock cover was recorded. Using these methods, rock cover appeared to increase in the absence of litter cover.

STATISTICAL ANALYSIS OF FIELD DATA: RIPARIAN OBSERVATIONS

A t-test was performed comparing the each cover type between the near and far sites. There was no significant difference between vegetation cover values near the river and those further upland. The t-test results are reported in Table Appendix B9. The slope ranged from 0-3% across the riparian zone, so it was unnecessary to perform a statistical analysis with regard to slope.

RHEM SIMULATIONS RESULTS

The statistical analyses of the vegetation cover data allowed for the assignment of vegetation values that would be representative of rangeland conditions. The results described above were used to parameterize the baseline condition simulation. The following results were all obtained by using a 1 year, 1 hour return period rainfall event when running RHEM.

BASELINE CONDITIONS

A baseline simulation was run using field data to show the current conditions. The statistical analysis allowed for the extrapolation of cover data onto the watershed area of interest to determine the baseline vegetation data. The average canopy and basal cover values were applied across the upland area, while litter and rock cover varied based on the regression equations discussed above. Because there was no significant variation in vegetation cover within the riparian zone, the riparian zone values were assigned the average cover values. The baseline condition resulted in a peak flow of 19.32 cubic meters/second, which occurred 136 minutes after the start of the storm. The sediment yield from the baseline run was 1.88 tonnes/hectare at the outlet downstream of the Kaler Ranch. The total sediment yield from the upland area was 6.45 tonnes/ha (Table 5).

The total upland sediment differed from the sediment yield at the river outlet due to the way the way RHEM models sediment transport. The upland sediment yield show the movement of sediment in the upland region, but some of this sediment is deposited into upland channels and does not reach the lower outlet, resulting in lower sediment yields at the outlet.

This study focuses on relative change because it provides way to compare management alternatives and quantify the benefits. An analysis of the percent change in sediment yield between the different simulations in displayed below in Table 6.

UNIFORM SLOPES

This study also evaluated the benefits of using a complex slope parameterization. The default setting within AGWA is to use a uniform slope, but RHEM enables the use of a complex slope. This simulation applied used a uniform slope geometry, while still using the baseline vegetation layer. The uniform slopes gave a peak outflow at 131 minutes, with a discharge of 23.57 cubic meters/second. The sediment yield was 3.80 tonnes/hectare at the outlet and 4.78 tonnes/hectare from the upland planes.

A comparison between applying uniform and complex slope geometry to the baseline simulation revealed the sensitivity of RHEM to slope geometry. There was a 102% increase in sediment yield from the complex geometry to the uniform geometry.

SCENARIO SIMULATIONS

The vegetation parameters were adjusted to portray alternative management plans. The upland and riparian vegetation values assigned to each scenario were determined from a cumulative distribution frequency (CDF) (Appendix Table C1 and C2). The average vegetation values for each percentile are displayed below in Table 3 and 4.

Table 3. Average upland vegetation values for each quartile based on ranks of ground cover.

	Percent Canopy	Percent basal	Percent litter	Percent rock	Ground Cover
0-25%	53	4	44	31	79
25-50%	46	2	41	45	89
25-75%	48	3	44	43	90
50-75%	50	4	46	41	91
75-100%	55	3	47	44	93

Table 4. Average riparian values for each percentile group based on ground cover.

	Canopy	Rock	Basal	Litter	Ground Cover
0-25%	47	5	2	54	61
25-75%	66	7	3	69	78
75-100	76	12	1	73	85

POOR RIPARIAN CONDITION

This scenario describes the condition of the ranch prior to the installation of the wells when cattle were grazing in the riparian zone. The riparian zone was assigned the lowest

25th percent of riparian cover values to represent the ongoing grazing (Appendix C). Using the vegetation layer that represented a poor riparian condition and a 1 year, 1 hour return period rainfall event, the poor riparian simulation resulted in a peak flow at 141 minutes after the start of the storm with a discharge of 15.2 cubic meters/second. The sediment yield for this event was 1.50 tonnes/hectare at the outlet. The sediment yield from the upland planes was 5.34 tonnes/hectare (Table 5).

The difference between the sediment yield from the planes and the sediment yield at the outlet is caused by a number of factors. The sediment yield given at the outlet is representative of how much sediment is transported from the uplands to the outlet selected along the San Francisco River. Much of the sediment that is transported across the planes into channels does not the reach the outlet within the simulation time. Sediment can be deposited in the upland channels, or within the main channel, never reaching the downstream outlet. This causes the sediment yield reported at the outlet to be lower than the value of sediment that is transported within the upland area.

UPLAND GRAZING WITH A RIPARIAN BUFFER ZONE

This simulation aimed to show the effects of creating a riparian buffer and moving cattle to the upland region. This scenario is what would be expected given the current management practices. The peak flow for this simulation occurred at 146 minutes after the start of the storm and had a maximum discharge rate of 12.83 cubic meters per second. The sediment yield was 1.40 kg/ha at the selected outlet and 4.99 tonnes/ha from the upland planes (Table 5). This scenario demonstrates that there is a 7% reduction in sediment yield at the outlet when the cattle are moved from the riparian zone to the upland region (Table 6 and Figures 7-9). There is a 5% reduction in sediment yield observed from the upland planes.

While the sediment yield between the riparian grazing scenario and the upland grazing scenario did not result in a large change, the peak flow was reduced by 18%, from 15.20 cubic meters/second to 12.83 cubic meters/second.

OVERALL GOOD CONDITION

This scenario represented good cover conditions throughout the entire ranch, demonstrating rangeland conditions in the absence of grazing. The results of this simulation give a sediment yield based on the highest observed cover values in both the upland and riparian areas. This simulation also gave the lowest peak flow, occurring the longest period of time after the start of the storm. The flow peaked at 149 minutes after the start of the storm with a discharge of 11.49 cubic meters/second. The sediment yield was 1.12 kg/ha at the outlet and 4.26 tonnes/ acre transported from the upland area (Table 5).

INTENSIVE UPLAND GRAZING

This simulation shows the impact of intensive grazing in the upland area with a riparian buffer. Intensive upland grazing resulted in the earliest peak flow at 121 minutes after the start of the storm. The peak discharge was 41.04 cubic meters/second.

The sediment yield at the outlet was 4.088 tonnes/hectare and 12.366 tonnes/hectare across the planes (Table 5). The sediment yield from the *Intensive Upland Grazing* was by far the highest of the simulations and exceeded the sediment yield of the *Poor Riparian* simulation by 173% (Figures 10 and 11).

UPLAND CHANNEL BUFFERS

This simulation showed the sediment yield if the riparian buffers were added to the major tributaries. The simulation resulted in a peak flow occurring at 146 minutes after the start of the storm with a discharge of 12.48 cubic meters/second. The sediment yield at the outlet was 1.32 tonnes/hectare and 4.78 tonnes/hectare across the planes (Table 5).

Table 5. Simulated estimates of sediment yield and peak flow results for the management scenarios run in RHEM.

Simulations	Sediment Yield at Outlet (Tonnes/ha)	Sediment Yield from Planes (Tonnes/ha)	Peak flow (cubic meter/second)
Baseline Condition	1.88	6.45	19.32
Uniform Slopes	3.80	13.43	23.57
Poor Riparian Condition	1.50	5.25	15.22
Upland Grazing with a Riparian Zone	1.40	4.98	12.84
Overall Good Condition	1.12	4.26	11.49
Intensive Upland Grazing	4.09	12.37	41.04
Upland Grazing with Channel Buffers	1.32	4.78	11.76

The hydrograph results show that as the cover conditions improved, the peak flow was reduced and delayed slightly (Figure 5). The timing of the peak flow varied about 10 minutes between the simulations. The storm across the watershed of interest has two peak flows, one occurring about an hour after the start of the rainfall, and another occurring about 130-140 minutes after the start of the rainfall. The two distinct peaks are due to the channel locations in the upland area. The first peak occurs when the runoff from the channels furthest downstream reach the outlet. The second peak is larger and occurs when the runoff from the channels further upstream reach the outlet. Because the channels upstream have a greater contributing area, the second peak is larger.

Table 6. Percent change in sediment yield and peak flow from the historic, poor riparian condition.

	Percent change in Sediment Yield from Poor Riparian Conditions	Percent Change in Peak Flow from Poor Riparian Conditions
Upland Grazing with a Riparian Zone	-7%	-16%
Overall Good Condition	-25%	-24%
Intensive Upland Grazing	+173%	+170%
Upland Grazing with Channel Buffers	-12%	-23%

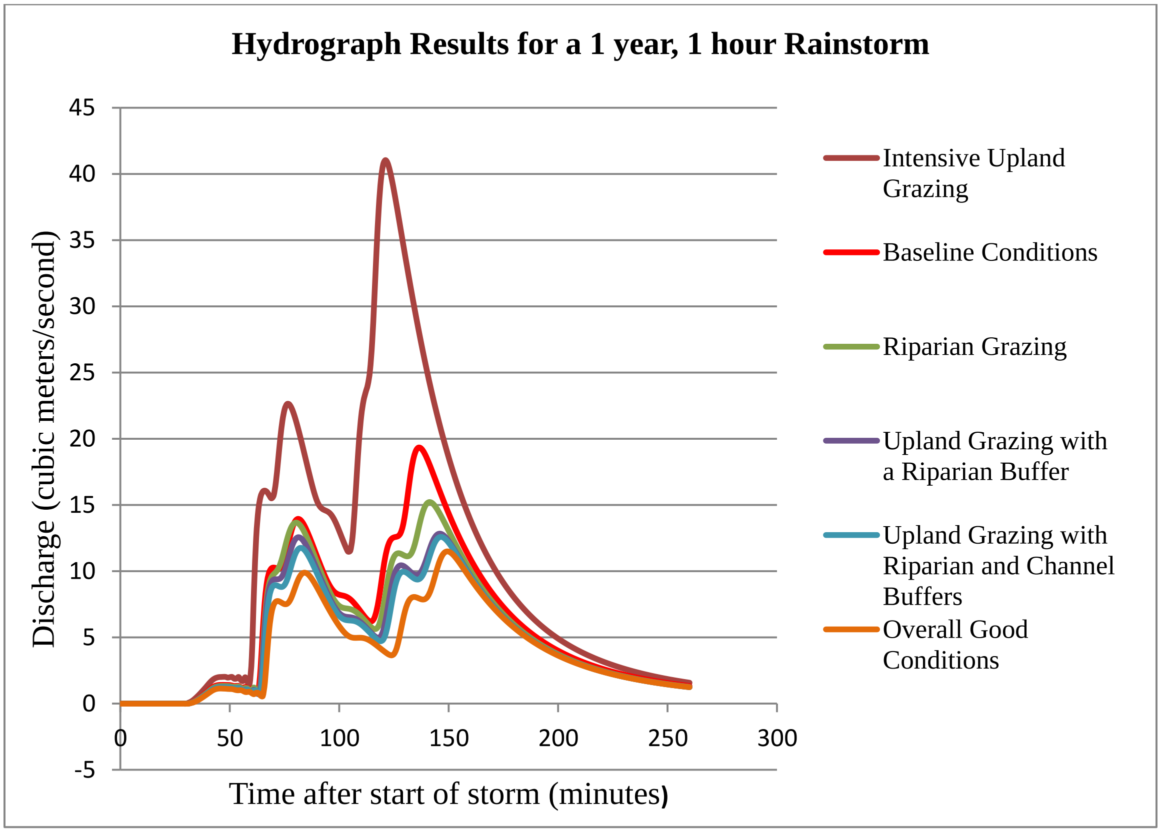

Figure 7. Runoff Hydrograph from each 1 year, 1 hour return period rainfall event simulation each management scenario.

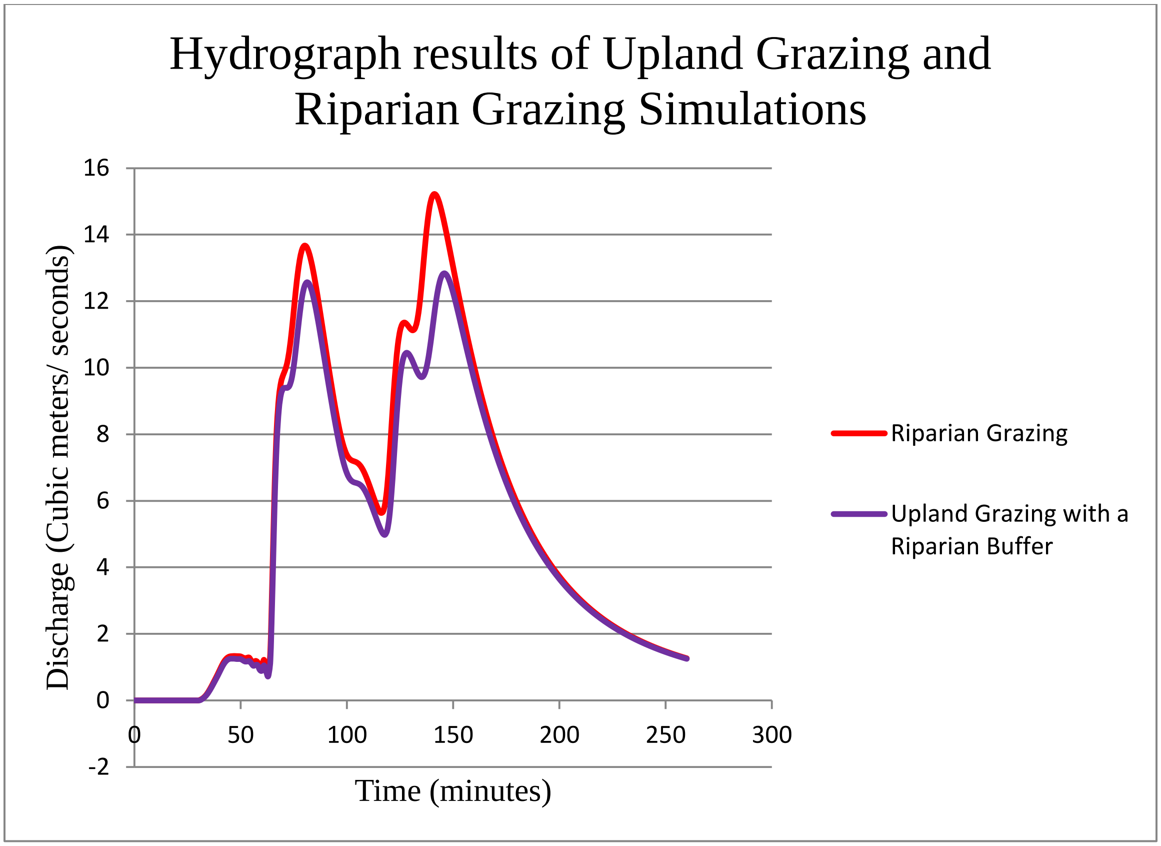

Figure 8**.** Hydrograph results from the upland grazing and riparian grazing simulations during a 1 year, 1 hour return period rainfall event.

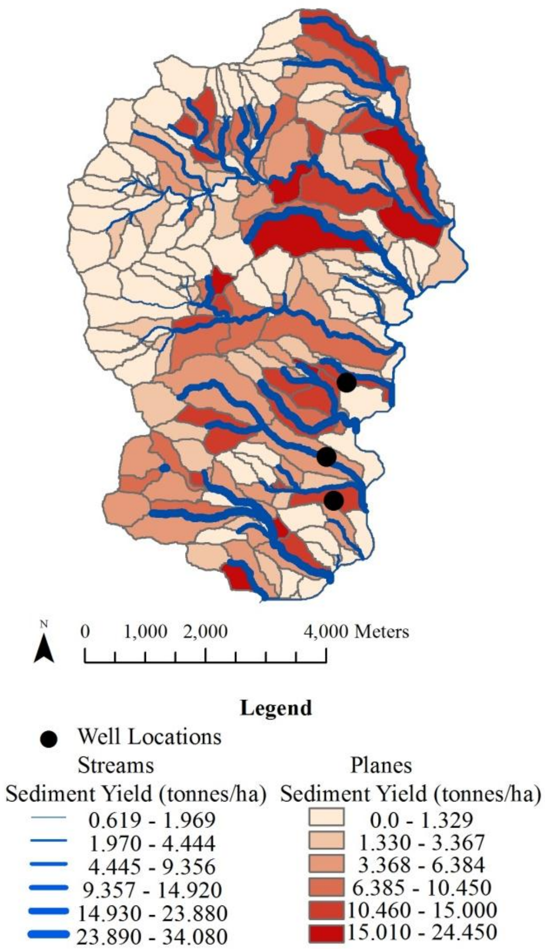

Figure 9. Sediment Yield from a 1 year, 1 hour Rainstorm: Poor Riparian Conditions

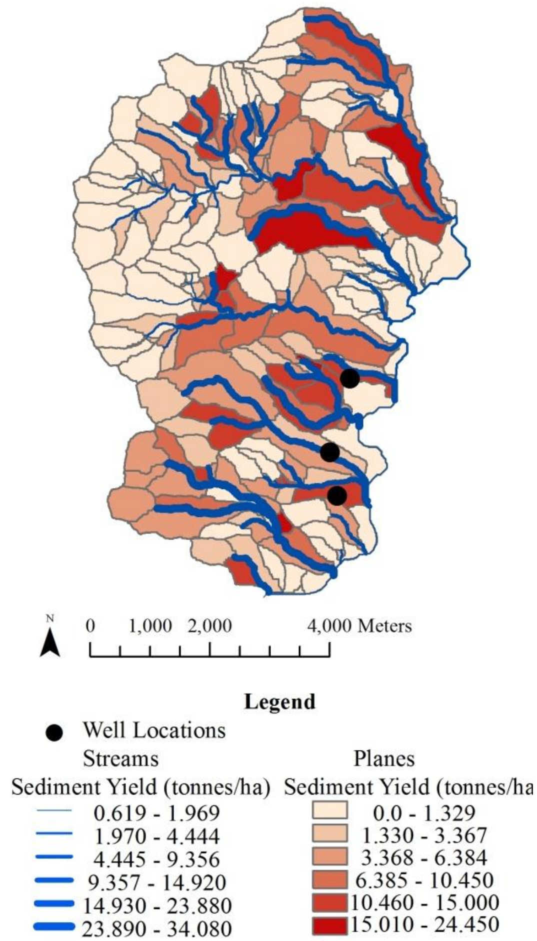

Figure 10. Sediment Yield from a 1 year, 1 hour Rainstorm: Upland Grazing Conditions

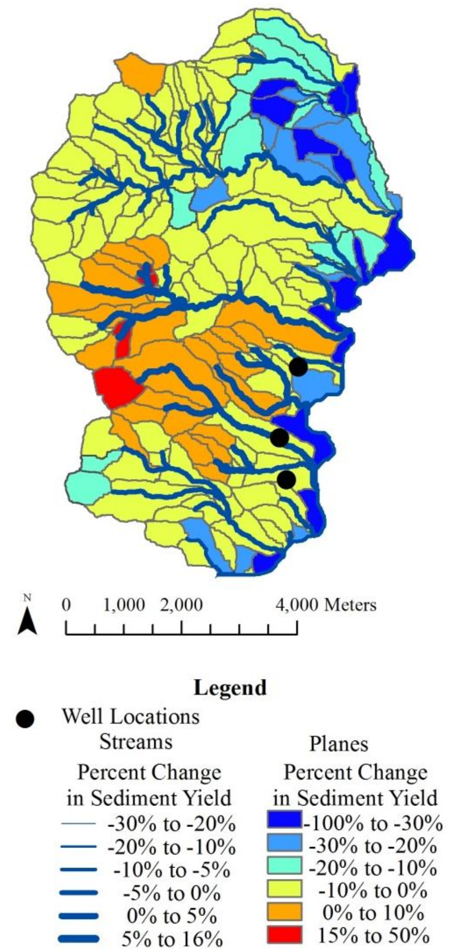

Figure 11. Percent Change from Poor Riparian Conditions to Upland Grazing Conditions with a Buffer Zone.

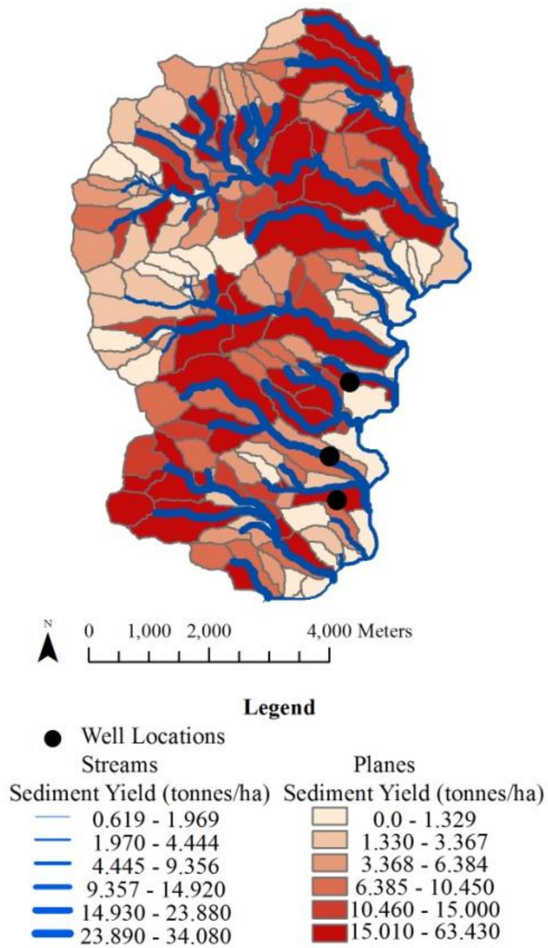

Figure 12. Sediment Yield from a 1 year, 1 hour Rainstorm: Intensive Upland Grazing Conditions

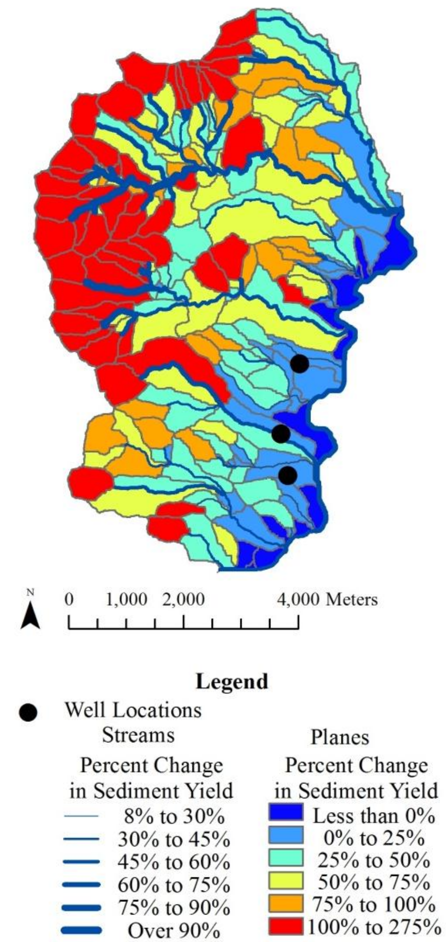

Figure 13. Percent Change from Poor Riparian Conditions to Intensive Upland Grazing

CHAPTER 5: DISCUSSION

This study estimated the possible effects of conservation practices recently implemented on the Kaler Ranch and provided a method for evaluating and assessing the impact of future changes in land management. The field methods used in this study allowed for the assignment of rangeland conditions based on the range of vegetation conditions observed.

Overall, the ranch was very rocky, ranging from 14% to 59% rock cover. The rock cover protected hillslope soils and prevented extensive erosion. There was little variation found in vegetation cover between samples sites, except for litter and rock cover varying with distance from the well. Areas of the ranch were extremely steep bedrock with no vegetation present. These areas would have an increased effect on runoff without contributing sediment. Because the areas of exposed bedrock made up such a small percentage of the watershed, these areas were overlooked during the specification of vegetation values based on slope and distance from water.

The significant relationship between distance and litter cover where litter decreased with distance from water was unexpected.

Within the different simulations, it was clear that slope geometry clearly affects the sediment yield during the application of RHEM. The uniform geometry is much faster and more time efficient to apply, however these results suggest that the time-efficient method of applying a uniform slope cannot make up for the accuracy of the complex geometry. Because the uniform slopes seemed to overestimate sediment yield, the remainder of the runs were parameterized with the complex slope geometry.

The *Baseline condition* gave a much higher sediment yield than any of the other simulations, except for the *Intensive Upland Grazing* simulation. The higher than expected sediment yield was partially due to the application of the average observed cover values to the entire watershed. Most of the sampling occurred on slopes less than 50% and within a mile of the water sources. While variation was observed in the rock and litter values with distance from water, the values applied were limited to the range of values observed and the remaining cover values were uniformly applied to the entire ranch. This simulation was based strictly on field data collected on represented the variation determined within the statistical analyses. This is likely an underestimate of the cover present on the higher elevation regions located further from the water sources. This scenario was not used in the comparison between the vegetation values. The vegetation in the scenarios representing the historic and future condition varied with distance and slope, so a much larger area in the watershed received high cover values.

The results from *Upland Grazing with a Riparian Zone* provide a more accurate description of the conditions to be expected in the future based on the current management actions on the ranch. This scenario uses vegetation values that vary with slope and distance representing cattle grazing in the upland area with a riparian buffer zone. The discrepancy in sediment yield between the baseline condition and the upland grazing simulation shows the effect the distribution of vegetation cover can have on a rangeland.

The historic condition of the Kaler Ranch was determined by simulating poor cover in the riparian cover. Based on anecdotal evidence, the area along the San Francisco River had been heavily grazed and degraded prior to the decision to the move the cattle to the upland area (Kaler, R. Pers. Comm., 2012). Comparing the sediment yield of *Upland Grazing* with the *Poor Riparian Zone* showed that moving cattle out of the riparian area into the uplands leads to a 7% decrease in sediment yield. This is not an especially significant amount, given the effort required to move the cattle. The percent change, however, does not encompass the greater effects removing cattle from the riparian zone has on waste reduction entering the river and the decrease of *E. coli* in the waterways. The percent change at the outlet also does not show the variation in the percent change in sediment yield occurring within the watershed.

The *Overall Good Condition* simulation gave the lowest sediment yield, a 25% decrease from the poor riparian simulation. While this scenario is unrealistic as a management plan because it assumes an absence of grazing, it also illustrates the best potential conditions across the ranch. The vegetation conditions were based on the upper quartile of observed values, and an absence of grazing may cause these values to increase further. The management plan that gave the closest values to *Overall Good Condition* was the implementation of channel buffers in the upland area. *Upland Grazing with Channel Buffers* resulted in a 12% reduction in sediment yield from *Riparian Grazing Condition*, however, this is still only a 5 % change from the *Upland Grazing with Good Riparian* conditions.

The *Intensive Upland Grazing* scenario was created to determine the limitation of a riparian buffer. This simulation resulted in the highest sediment yield out of all of the management scenarios, despite the presence of a riparian buffer zone. This simulation showed the limitation of a riparian buffer zone. While creating a riparian buffer and moving cattle to upland areas can be beneficial, this simulation demonstrates that the buffering capacity is exceeded very quickly as grazing intensity increases.

The *Intensive Upland Grazing* scenario also demonstrated the sensitivity of RHEM to vegetation changes in the upland areas. The relative change in sediment yield from the *Poor Riparian Conditions* to the *Intensive Upland Grazing* was 173%. This is much larger than any change than any other management actions.

Many erosion studies on rangelands report values in tons per acre per year, however, the majority of the sediment deposition and erosion occurs during a single event (Nearing et al. 2005). A study determined the sediment budget for the Walnut Gulch Experimental Watershed in southeastern Arizona using data collected over the course of 44 years (Nichols et al. 2013). Nichols et al. (2013) found that average sediment yield was 3.2 tonnes/hectare/year. In 17 out of the 44 years the sediment budget was measured, over half of the sediment yield resulted from a single storm. The sediment yield was measured at the outlet, disregarding the amount of sediment transported within the watershed but not reaching the outlet. Comparing that the results from Kaler Ranch of 1.3 tonnes/hectare during a 1 year, 1 hour return period rainfall event for the *Upland Grazing* *with A Riparian Zone* simulation, the results determined by RHEM seem reasonable and within a valid range.

A study by Nearing et al. (2005) evaluated the Lucky Hills watershed in Southern Arizona and provided the observed sediment yield for the watershed. Cattle grazing is the primary land use and the watershed has an average slope of 6%, much lower than the Kaler Ranch. Historical data indicated a 78 minute storm with a rainfall depth of 32.8 mm gave sediment yield of 3.075 tonnes per hectare. The rainstorm applied within RHEM was a less intense storm; it was an one hour duration with a depth of 17.78 mm, resulting in a sediment yield of 1.3 tonnes per hectare for the *Upland Grazing with a Riparian Zone simulation.* This is higher than sediment yield determined by RHEM on the Kaler Ranch because the rainstorm event used within RHEM had a lesser intensity 1 hour duration storm with a total rainfall of 17.78 mm

Nearing et al. (2005) also presented a second rainstorm of lesser intensity and longer duration. This storm was 133 minutes in duration with a rainfall depth of 18.8 mm. This storm gave a sediment yield of 0.721 tonnes/hectare, much less than the sediment yield determined in RHEM. Because the storm duration used in RHEM was shorter with a similar rainfall depth, it was expected to cause greater soil loss. The sediment yields from the Kaler Ranch simulations presented in this study fall in between the sediment yields observed on the Lucky Hills Watershed. Compared to the studies done by Nearing et al. (2005) and Nichols et al. (2013), the simulations run on the Kaler Ranch produced reasonable sediment yields given the storm event.

ASSUMPTIONS

There were assumptions made in this study during the applications of RHEM. The soils data was taken from the NRCS Soil Survey Geographic (SSURGO) database (http://soildatamart.nrcs.usda.gov/, 10/16/12). This soils layer gave only three groups across the entire ranch when there is likely more variation in the soil types. Soil type can influence the infiltration rate and vegetation. Another assumption made in the application of the model was the use of a design storm for the precipitation file. The precipitation data used in this study was applied uniformly across the watershed. This is an unrealistic representation of rainfall, given the elevation variation and the isolated nature of rainfall in semi-arid regions.

SUMMARY

The results show that vegetation changes in the riparian zone do not have a large effect on the overall sediment yield. The proportion of area represented by the riparian zone is minimal compared to the upland region so major changes in vegetation cover along the main channel do not cause large changes in the overall sediment yield. The weighting scheme currently used by RHEM to parameterize the upland planes is much more suited toward modeling changes in vegetation that occur in the upland region. While riparian areas contain a high concentration of resources, they make up a very small percentage of the overall watershed. The effects of changes in the riparian zone can be overshadowed in RHEM by the processes occurring in the greater watershed area.

While the relative change from a poor riparian zone to an upland grazing management plan only showed a 7% decrease in sediment yield, there are many more benefits that could not be quantified within RHEM. RHEM only models sediment transport over land; it does not model the effects of vegetation on bank stability or the reduction of *E. coli.*

This study demonstrated the applicability RHEM for assessing western rangelands and identified its limitations when applied to riparian areas. The following improvements were identified as ways RHEM may better assess rangeland riparian areas.

This study used a single watershed delineation within AGWA, which allowed for the inclusion of the entire riparian area. The drawback of this method was that the contributing flow length was defined as a single value for the entire watershed, rather than allowing the user to specify individual contributing flow lengths for the subwatersheds. A group watershed delineation allows the user to specify the contributing flow length individually for each sub-watershed, however, the delineation does not include the entire riparian areas. Planes that empty directly into the main channel are not included, because they do not contribute sediment or runoff to any tributary or sub-basin. This makes the group watershed delineation impractical for evaluating change along the riparian zone. An addition to RHEM allowing for the specification of individual flow lengths within a single watershed, or a method to include the entire riparian area in a group watershed delineation would enable the user to customize the model based on the area of interest.

While the single watershed delineation RHEM includes the entire riparian zone, it does not allow for the specification of a riparian area as a unique set of planes. The riparian area is included in larger sub-basins rather than a distinctive plane based on separate vegetation values. The only way to identify the riparian area is within the vegetation parameterization layer. The planes draining into the main channel are parameterized by the vegetation values using a weighted area. Because the riparian zone in this study is so narrow, vegetation values unique to the riparian zone are not well represented within the discretized planes.

CHAPTER 6: CONCLUSION

The results demonstrate a rangeland-specific erosion model for assessing rangeland health. This study provided an example of a cost-effective spatial modeling tool that can be used to evaluate rangeland management plans, enabling land managers to make recommendations based on quantitative data analysis. The development of an erosion model capable of predicting soil loss on rangelands enables natural resources managers to implement best management practices that encourage the sustainable use of rangelands.

This study estimated the effect of creating a riparian buffer along the San Francisco River on the Kaler Ranch, as well as estimating the limitations of this buffer zone. The results were comparable to observed sediment yields on the Walnut Gulch Experimental Watershed, however this study also revealed the limitations of RHEM, particularly with its applications to evaluating changes in riparian systems. RHEM is well suited for modeling overland flow and erosion on uplands, however it does not adequately represent the complex processes occurring along channel banks. RHEM does not model channel processes or bank stability. It also does not show the effects a riparian buffer has on *E. coli* levels in the river.

This study provides rangeland managers with a framework to apply RHEM in a manner that can be used to identify areas of concern and compare different management scenarios. The recent advances in our understanding of rangeland hydrology have enabled RHEM to incorporate rangeland-specific erosion processes to conduct large scale rangeland assessments.

While RHEM provides a framework for quantitatively assessing rangelands and determining potential management impacts, soil loss rate cannot convey all aspects of the ecological and hydrological processes occurring on a rangeland. Soil loss rate does not provide information on biodiversity or channel stability. Further research on the interactions between land use, vegetation change and runoff can be used to identify watersheds at risk and enable land managers to make management decisions to reduce future degradation (Miller et al. 2007). Further development of RHEM will enable it to more accurately represent riparian areas.

APPENDIX A

Table A1. Upland vegetation cover values.

Sample Site	Well ID	LAT	LON	Distance from Well (meters)	Percent Slope determined from DEM	Percent Canopy	Percent Basal	Percent Litter	Percent Rock	Percent Ground Cover
1	A	33.11802	109.2887	227	15.5	34	3	27	27	57
2	A	33.11845	109.2884	205	26.2	49	8	47	38	93
3	A	33.11987	109.2921	206	13.6	56	7	42	39	88
4	A	33.12062	109.2879	204	34.7	49	5	42	47	94
5	A	33.12085	109.2866	488	48.6	35	0	32	58	90
6	A	33.12152	109.2887	241	55.6	63	2	59	31	92
7	A	33.11677	109.2871	224	6.8	43	4	56	29	89
8	A	33.12372	109.2876	482	28	45	3	51	36	90
9	A	33.11945	109.2952	496	13.8	42	5	47	40	92
10	A	33.11895	109.295	330	44.4	45	1	29	63	93
11	A	33.11873	109.2961	593	39.7	43	0	31	59	90
12	A	33.12657	109.2922	112	22.9	84	3	76	12	91
13	B	33.12408	109.2883	214	34.5	50	3	43	46	92
14	B	33.12715	109.2888	432	4.3	38	0	38	53	91
15	B	33.12792	109.2902	138	22.2	33	2	40	46	88
16	B	33.12832	109.2897	244	41.1	71	4	52	39	95
17	B	33.12863	109.2909	369	50	64	2	47	41	90
18	B	33.12592	109.2864	433	6.8	47	1	39	43	83

19	B	33.131	109.2934	552	25.1	74	7	59	14	80
20	B	33.1316	109.2936	626	36.1	38	5	34	45	84
21	B	33.13218	109.2929	663	45.2	45	4	37	51	92
22	C	33.13802	109.2873	56	28	41	4	53	23	80
23	C	33.13885	109.2875	148	13.6	46	2	41	35	78
24	C	33.13775	109.2887	181	4.8	57	3	54	31	88
25	C	33.1383	109.291	362	56.1	52	0	32	56	88
26	C	33.13953	109.2902	356	40.9	59	2	54	36	92
27	C	33.13978	109.2893	316	34	77	3	65	16	84
28	C	33.14168	109.2904	544	25.1	65	6	36	42	84
29	C	33.1418	109.288	475	35	42	5	37	49	91
30	C	33.14252	109.2891	576	49.9	51	0	47	48	95
31	C	33.14325	109.2886	646	9.6	43	7	37	47	91

Table A2. Riparian vegetation cover values.

Sample Site	Proximity to River	Latitude	Longitude	Percent Canopy	Percent Basal	Percent Litter	Percent Rock	Percent Ground Cover
1	Near	33.1128	109.2828	77	0	82	2	84
2	Far	33.11282	109.2824	61	0	75	4	79
3	Near	33.1315	109.2861	73	2	57	18	77
4	Near	33.12288	109.2843	77	8	68	0	76
5	Far	33.12148	109.2847	69	2	60	14	76
6	Far	33.11583	109.2831	25	1	40	0	41
7	Near	33.11553	109.2839	48	4	62	1	67
8	Near	33.11663	109.2839	83	3	60	24	87
9	Far	33.16662	109.2841	63	1	76	1	78
10	Near	33.11228	109.2831	55	2	67	11	80
11	Far	33.11252	109.2838	72	0	83	4	87
12	Near	33.1296	109.2862	71	1	65	16	82

APPENDIX B. UPLAND STATISTICAL RESULTS

Table B1. Canopy Cover ANOVA Results

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	101.0111	2	50.50556	0.280198	0.757728	3.340386
Within Groups	5046.989	28	180.2496			

Table B2. Basal Cover ANOVA Results

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.529928	2	0.264964	0.047133	0.954036	3.340386
Within Groups	157.4056	28	5.621627			

Table B3. Litter Cover ANOVA Results

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	28.22455	2	14.11228	0.103309	0.90219	3.340386
Within Groups	3824.872	28	136.6026			

Table B4. Rock Cover ANOVA Results

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	64.98333	2	32.49167	0.186084	0.831222	3.340386
Within Groups	4889.017	28	174.6077			

Table B5. Canopy cover multiple regression results.

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	51.07	6.49	7.87	0.00	37.77	64.37	37.77	64.37
Distance from water	-0.02	0.01	-1.10	0.28	-0.04	0.01	-0.04	0.01
Percent Slope	0.18	0.16	1.18	0.25	-0.14	0.50	-0.14	0.50

Table B6. Basal cover multiple regression results.

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	4.41	1.11	3.97	0.00	2.13	6.68	2.13	6.68
Distance from water	0.00	0.00	0.40	0.69	0.00	0.01	0.00	0.01
% Slope from DEM	-0.05	0.03	-1.90	0.07	-0.11	0.00	-0.11	0.00

Table B7. Litter cover multiple regression results.

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	53.51	5.39	9.93	0.00	42.47	64.55	42.47	64.55
Distance from water	-0.02	0.01	-2.14	0.04	-0.05	0.00	-0.05	0.00
% Slope from DEM	0.00	0.13	-0.01	0.99	-0.27	0.26	-0.27	0.26

Table B8. Rock cover multiple regression results.

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	24.19	5.77	4.19	0.00	12.37	36.01	12.37	36.01
Distance from Water	0.03	0.01	2.26	0.03	0.00	0.05	0.00	0.05
% Slope from DEM	0.20	0.14	1.44	0.16	-0.08	0.48	-0.08	0.48

Table B9. T-test results from riparian vegetation cover values comparing the near and far locations.

	Canopy		Basal		Litter		Rock	
	Near	Far	Near	Far	Near	Far	Near	Far
Mean	53.667	69.143	0.667	2.857	58.500	65.857	14.500	10.286
Variance	400.667	163.476	0.667	6.810	649.100	65.810	612.700	90.238
P(T<=t) two-tail	0.119		0.075		0.482		0.684	

APPENDIX C. VEGETATION PARAMETERIZATION VALES

Table C1. Upland vegetation cover cumulative distribution frequency ranked by ground cover.

	Percent Canopy	Percent basal	Percent litter	Percent rock	Total Ground Cover	Rank	CDF
Poor Cover: Lower 25%	34	3	27	27	57	1	0.032258
	46	2	41	35	78	2	0.064516
	41	4	53	23	80	3	0.096774
	74	7	59	14	80	4	0.129032
	47	1	39	43	83	5	0.16129
	77	3	65	16	84	6	0.193548
	38	5	34	45	84	7	0.225806
	65	6	36	42	84	8	0.258065
25%- 50%: Second quartile	52	0	32	56	88	9	0.290323
	33	2	40	46	88	10	0.322581
	57	3	54	31	88	11	0.354839
	56	7	42	39	88	12	0.387097
	43	4	56	29	89	13	0.419355
	35	0	32	58	90	14	0.451613
	43	0	31	59	90	15	0.483871
50-75%: Third quartile	64	2	47	41	90	16	0.516129
	45	3	51	36	90	17	0.548387
	38	0	38	53	91	18	0.580645
	84	3	76	12	91	19	0.612903
	42	5	37	49	91	20	0.645161

	43	7	37	47	91	21	0.677419
	45	4	37	51	92	22	0.709677
	42	5	47	40	92	23	0.741935

	Percent Canopy	Percent basal	Percent litter	Percent rock	Total Ground Cover	Rank	CDF
Good Cover: Upper 25%	50	3	43	46	92	24	0.774194
	63	2	59	31	92	25	0.806452
	59	2	54	36	92	26	0.83871
	45	1	29	63	93	27	0.870968
	49	8	47	38	93	28	0.903226
	49	5	42	47	94	29	0.935484
	51	0	47	48	95	30	0.967742
	71	4	52	39	95	31	1

Table C2. Riparian vegetation cover cumulative distribution frequency ranked by ground cover.

	Canopy	Basal	Litter	Rock	Ground Cover	Rank	CDF
Poor Cover: Lower 25%	25	1	40	0	41	1	0.083333
	48	4	62	1	67	2	0.166667
	69	2	60	14	76	3	0.25
Average Cover: Middle 50%	77	8	68	0	76	4	0.333333
	73	2	57	18	77	5	0.416667
	63	1	76	1	78	6	0.5
	61	0	75	4	79	7	0.583333
	55	2	67	11	80	8	0.666667
Good Cover: Upper 25%	71	1	65	16	82	9	0.75
	77	0	82	2	84	10	0.833333
	72	0	83	4	87	11	0.916667
	83	3	60	24	87	12	1

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