AN ABSTRACT OF THE THESIS OF

Andrea S. Laliberte for the degree of Master of Science in Rangeland Resources
presented on April 17, 2000.
Title: The Use of Remote Sensing and Geographic Information Systems (GIS) in Assessing Changes in Stream Morphology and Vegetation.

Redacted for Privacy

Abstract approved: ______________________________
Douglas E. Johnson

Remote sensing and Geographic Information Systems (GIS) are well known tools for the study of time change analysis in natural systems. However, long-term studies of riparian systems using large-scale aerial photography are less common. The purpose of this project was to combine large scale aerial photography, GIS, Global Positioning Systems (GPS) and ground truthing for conducting a time change analysis study of an eastern Oregon riparian area over a 20 year time period.

The objectives were to assess changes in stream morphology and vegetation that occurred in grazed and exclosed areas from 1979 to 1998. In addition, the viability of using large-scale (1:4000) aerial photography combined with GIS/GPS and ground truthing in this study was evaluated.

GIS layers of vegetation and stream morphology parameters were developed from geocorrected images. Ground truthing included the collection of vegetation and stream channel measurements. In addition, older aerial photography and previously collected survey data were available for this study.

The area of land changing to water and vice versa was calculated over the 41 ha large study area. This area of change (3.65 ha) was slightly larger than the area of no change (3.2 ha). The length of the thalweg and streambank, sinuosity and stream area remained relatively the same. Most of the changes were associated with the islands. Their number decreased, but their area increased, suggesting an increase in stability. Stream width decreased in both grazed and exclosed sites.

Shrub and tree cover increased from 1979 to 1998 over the whole study area from 23% to 34%, and this increase was similar in grazed and exclosed sites. The variability of shrub/tree cover within and between the grazed and exclosed sites was high. Topography and stream dynamics appeared to control changes in stream morphology, including erosion, deposition and island formation. We could find no association between the observed changes and the grazing treatment.

The use of large-scale aerial photography, GIS and GPS proved to be a powerful tool for detecting change over time and it is expected that these techniques will become more common in rangeland analysis. It is anticipated that the methods used in this study can be applied to and will help in monitoring of other rangeland streams.

The Use of Remote Sensing and Geographic Information Systems (GIS) in Assessing Changes in Stream Morphology and Vegetation

by

Andrea S. Laliberte

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented April 17, 2000
Commencement June 2000

Master of Science thesis of Andrea S. Laliberte presented on April 17, 2000

APPROVED:

Redacted for Privacy

Major Professor, representing Rangeland Resources

Redacted for Privacy

Head of Department of Rangeland Resources

Redacted for Privacy

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Redacted for Privacy

Andrea S. Laliberte, Author

ACKNOWLEDGEMENTS

The completion of my thesis would not have been possible without the help of many people along the way. First and foremost, I want to thank my husband Marc for his undying love and support for me over the years. His encouragement and patience in putting up with my student life is greatly appreciated, and he was instrumental in getting me through the rough spots and to this point of my thesis completion.

I want to express my deepest gratitude to Dr. Douglas Johnson, my major professor, whose support and help went beyond his duties as an advisor. I greatly appreciate the freedom he gave me in shaping my project as I saw fit. At the same time, he gave me direction and encouragement when help was needed. His never-ending enthusiasm was inspirational for me.

I also want to thank the members of my committee for their guidance with my thesis. Dr. Tamzen Stringham was instrumental in getting me to pursue a Masters degree in the Range Department here at Oregon State University. Dr. Dave Thomas was extremely helpful with all questions regarding statistics. Dr. Steven Tesch served as the graduate council representative.

I want to acknowledge Dr. William Krueger for his support in my study, and to thank all the staff and faculty of the Department of Rangeland Resources for their support and advice.

Many thanks go to everyone who has helped me in the field. In addition to those mentioned above, Grant Casady, Dr. Douglas Green (Arizona State University), Cindy Meays, Jim and Mikah Wells spent many hours collecting data.

A very special thanks goes to the spatial analysis lab members: Norman Harris, who collected a lot of the early Catherine Creek data used in this study, Grant Casady, who spent many hours with a GPS unit on his back, and Mounir Louhaichi, who helped me solve many questions. The complex problems encountered with Remote Sensing, GIS and GPS often required a team approach, and everyone's expertise was greatly appreciated.

Finally, a thanks to all other graduate and undergraduate students who have helped me along the way and made this experience a positive one and a good time to remember.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

Chapter 3: Time Change Analysis of a Northeastern Oregon Riparian Ecosystem: Vegetation Changes at Catherine Creek from 1979 to 1998....................77

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF APPENDICES

The Use of Remote Sensing and Geographic Information Systems (GIS) in Assessing Changes in Stream Morphology and Vegetation

Chapter 1

Introduction and Literature Review

Background

The interaction between livestock grazing in riparian areas and possible impacts on vegetation, stream morphology and fish habitat is a topic often debated. In many cases, lack of long-term data makes it difficult or impossible to make a statement as to the amount of change that has occurred over time. Likewise, there is no reliable and cost-effective monitoring tool for measuring such long-term changes or for predicting future change from current knowledge and land use practices.

Remote sensing and Geographic Information Systems (GIS) have been used successfully to analyze vegetation, soils, landforms and other data. A ground coordinate system can be added by using the Global Positioning System (GPS). This technology can combine several layers of data and yield information about various parameters, and it is an excellent tool for time change analysis.

The selected study area at Catherine Creek in northeastern Oregon presents a unique opportunity for long-term study of a riparian ecosystem managed under the same grazing system for the past 20 years. In addition, the area has been studied extensively in the past, providing a large amount of accessible data. Lack of long-term data is usually one of the missing components for assessing natural variability in ecosystem studies (Rinne 1985). In order to make land management decisions, it is necessary to be aware of the variability to make reliable conclusions with regard to human, natural and managerial impacts.

Interaction between livestock grazing, riparian vegetation and stream morphology

Livestock are attracted to riparian areas for their lush, nutritious forage, shade and proximity to water. Considerable research has been done concerning the effects of livestock grazing on riparian vegetation, soil structure of the streambank and fisheries habitat (Meehan and Platts 1978; Kauffman and Krueger 1984; Dahlem 1979). In an eastern Oregon study, Roath and Krueger (1982) found that 81 % of total vegetation grazed by livestock came from a riparian zone accounting for only 1.9 % of total land area. In that study, steep topography and poor water distribution were responsible, but it demonstrates the attraction of riparian sites. Bohn and Buckhouse (1985) studied the relationship between different grazing systems and riparian soil responses and found that rest-rotation improved infiltration, while season long grazing reduced it. The authors also determined that increased soil moisture in the fall had a negative effect on infiltration rates. Similar results were reported by Marlow and Pogacnik (1985), who determined that the level of cattle use in riparian zones had little effect on streambank damage compared to the effect of soil moisture. With increasing soil moisture, streambank damage due to trampling increased respectively. The greatest amount of bank alteration occurred when soil moisture exceeded 10%.

Magilligan and McDowell (1997) studied four eastern Oregon streams for their responses to the removal of cattle grazing. In all four areas, cattle grazing had not occurred for at least 10 years. The authors found significant changes between grazed and ungrazed reaches, such as increased pool areas and channel narrowing in the exclosures. These changes were mostly attributed to increased vegetation and therefore increased channel roughness following removal of cattle grazing. However, the authors also determined that local effects, such as considerable flow reduction in the summer and particle size influenced the magnitude of channel adjustments.

Other authors reported no differences between exclosures and grazed sites or even differences in opposite direction. Medina and Martin (1988) observed channel width and depth increases in both exclosed and grazed areas in their study in southwestern New Mexico. The changes were attributed to a previous wildfire and hydrological processes of stream equilibrium. Kondolf (1993) measured cross-sections in exclosed and grazed areas in California and observed no significant differences between the two treatments. He concluded that this could possibly be attributed to a lag in adjustment of the stream channel after livestock had been excluded for 24 years from the site. Kondolf (1993) also pointed out that the management for the rest of the watershed had not changed and that the local influences might be smaller than those from the entire watershed. Bryant (1985) conducted an 8 year study of livestock grazing in a riparian ecosystem at Meadow Creek near La Grande in eastern Oregon. This site is only about 30 miles west of this project's study area. Bryant concluded that production of riparian vegetation was improved by using rest rotation and deferred rotation grazing systems without impacting the aquatic system in a negative manner. Forage utilization was limited to no more than

70%. The least amount of improvement occurred under season-long grazing, while a deferred rotation system resulted in the largest increase in grass production.

Previous surveys of the Catherine Creek study site (Kauffman 1982; Greene 1991; Korpela 1992; Greene and Kauffman 1995) have determined plant community types in detail, including the dominant species in each type. Kauffman (1982) studied the effects of livestock grazing on riparian areas at this site and produced a detailed map of 60 plant communities. In 1989, the study was continued focusing on the 8 most common communities. Those results showed that livestock grazing effects varied widely from one community to another, and the authors suggested that it would be unwise to make management decisions for a whole riparian area based on one community (Greene and Kauffman 1995).

These different responses to removal of cattle grazing demonstrate that it is difficult to make one sweeping statement about the effects of cattle grazing, or lack of it, on riparian areas or stream morphology. Many studies in the literature compare ungrazed sites with areas of season-long grazing. Those are the ones demonstrating the most differences between treatments. However, due to site specific circumstances, it is very important to assess the results of different levels of timing, intensity and frequency of grazing in order to compare one site to another. The grazing management should be tailored to the ecosystem, vegetation, and management objectives (Buckhouse and Elmore 1993). When examining the literature, one has to determine whether comparisons can be made between studies based on similarity of grazing regime, stream type, vegetation and topography.

Swanson and Myers (1994, p. 255) made a statement that sums up the interaction of vegetation and stream morphology with regard to management: "Ask how the vegetation will change the stream and how the stream will change the vegetation". This implies that one cannot just look at one parameter alone due to the strong interaction between the two. Vegetation is a large factor in stabilizing streambanks. Willows and other shrubs are usually found in coarser, gravelly soils, while grasses, sedges and rushes provide streambank stability in finer soils (Swanson and Myers 1994). Zimmerman et al. (1967) studied the influence of vegetation on channel width and found that both are closely related. A particular stream was consistently wider in forested than in meadow sites, a finding also reported by Clifton (1989). Zimmerman et al. (1967) determined that vegetation altered the roughness and shear strength of the streambanks and that herbaceous roots had a positive influence on the strength of the streambank. Beeson and Doyle (1995) found that unvegetated banks were five times as likely to undergo detectable erosion during flood events than vegetated banks. Major erosion occurred on unvegetated banks 30 times more often.

In a study of compressive strength of streambank soils, Kleinfelder et al. (1992) found that soil strength was greatest in sandy soils and that an increasing silt content decreased soil strength. Areas of greatest soil strength coincided with plant communities dominated by Nebraska sedge (*Carex nebrascensis* Dewey). This was confirmed by Swanson and Kamyab (1996) and Dunaway et al. (1994). In the latter study of particle erosion in different herbaceous communities and soil textures, it was determined that Nebraska sedge and Baltic rush (*Juncus balticus*) communities had the lowest erosion rates. They were followed by mixed sedges (*Carex* spp.), and mixed grass communities

(*Poa pratensis* and *Deschampsia caespitosa*). Another finding of interest in this study is that a percent increase in clay correlated with an increase in erosion. The authors attributed this to the decreased root density in clay, since clay inhibits root growth more than coarser soils. It was concluded that neither soil texture nor plant community alone could explain bank erosion, but that the interaction between the two parameters had to be taken into consideration.

In streams that have become degraded, the plant community may change. For example, an overgrazed stream may begin to widen, loss of vegetation will lead to increased erosion and more gravel deposition. This may result in the development of potential habitat for species that prefer gravelly soil, such as willows (Swanson and Myers 1994).

As can be seen, there is a close interaction between livestock grazing, vegetation, stream morphology and fish habitat. According to Platts (1983), a good trout stream has four major aspects: cover, bank stability, water temperature and fish production. Cover is not only important for fish habitat, but also for catchment and filtering of sediments and dissipation of stream energy. Bank stability is affected by bank vegetation since roots hold the banks in place. Trees and shrubs that fall into the stream dissipate stream energy, creating pools and keeping spawning gravels in place. Streamside vegetation also provides cover from predators, especially for young fish (Platts 1983). Pool quality with regard to depth and cover is indicative of good fish habitat. Myers and Swanson (1994) investigated grazing effects on pool forming features in central Nevada and found that after six years of rest, the stream channels narrowed, forming more undercuts. The authors suggested that management to improve pool formation would have a positive impact on fish habitat. Vegetation management can improve pool quality, however, the lag time between improvements in vegetation and those of stream morphology have to be considered (Kondolf 1993)

In streams bordered by trees, the input of large woody debris plays a considerable role in channel change. Large logs in the stream divert the flow of water and become sources of deposition and pools; bank erosion may be reduced or enhanced locally, and stream energy is dissipated (Keller and Swanson 1979). Similar findings were reported by Clifton (1989) in central Oregon in a study relating vegetation and land use to channel morphology over a 50 year period. The author determined that temporal variability was related to exclusion of grazing, while spatial variability (between different stream reaches) was due to the prevailing riparian vegetation, input of large organic debris and local physiography. Specifically, channel width, wetted perimeter and channel shape were mostly correlated with local vegetation variability (Clifton 1989).

A distinction has to be made between management impacts on stream morphology and 'natural' changes occurring over time. These natural changes can include warming or cooling trends that affect timing and intensity of spring runoff, and increased or decreased precipitation. A combination of management and climate change may also affect channel morphology. In addition, there is considerable variability in natural streamflow and its effect on ecosystems is often not known or ignored in terms of management (Poff et al. 1997). However, it appears that this natural variability may be crucial in sustaining aquatic and riparian ecosystems (Richter et al. 1996). This suggests that knowledge of the whole range of variability in streamflow may be as important as mean annual flow or peak flows alone.

It has been suggested that a threshold of stream power exists; when a stream floods, channel changes occur above that threshold of stream flow, but not below (Bull 1979). Nevertheless, both management and natural impacts are closely related, and a naturally unstable stream is more vulnerable to management stresses than a stable stream (Buckhouse and Elmore 1993). The Catherine Creek hydrograph displays high peaks each spring following rain on snow events and subsequent high flows. Impacts from these events have to be taken into account and separated from livestock grazing impacts.

Lateral migration is a normal process occurring in meandering streams over time, and the amount of lateral migration can be calculated, since it is a function of stream power, height of outer bank, and a resistance coefficient that depends on outer bank materials (Hickin and Nanson 1984). These authors determined that fine sand was least resistant to lateral erosion, while clays, larger gravel and cobbles were more resistant. This was attributed to the high cohesive strength of very fine as well as very coarse materials. Channel migration rates were largely controlled by bend curvature; the largest migration rates occurred when the ratio of bend radius to channel width was between 2 and 3.

Rosgen (1996) suggested that stream morphology changes due to disturbance might be predicted based on stream type. According to his classification, C type streams (such as Catherine Creek) are normally associated with lateral cutting and stream movement. Myers and Swanson (1992) also concluded that livestock bank damage and stream stability were related to streamtype. A C3 type stream fell into the category of 'more sensitive' to ungulate bank damage. However, when the same authors (Myers and Swanson 1996a) tested the possibility of predicting change due to disturbance based on stream type, they concluded that major stream changes occurred randomly, especially on B and C streams. The same authors determined in another study in Nevada that different stream types had different potential conditions and rates of recovery from degradation. This affected the effectiveness of management (Myers and Swanson 1996b).

If lateral movement is "natural" in a C stream, then it is to be expected that the banks on the outside of meanders are less stable, and that the stream may erode even well vegetated banks. This would agree with Zonge and Swanson (1996), who determined that vegetation had little effect on bank erosion, and that vegetated and bare banks retreated at similar rates in high water years.

The drawback of many studies regarding impacts of grazing on riparian areas is the fact that most of them are short-term studies. Changes in vegetation can be observed in a study of a few years (Kauffman 1982), however, it may be hard to predict if they are lasting changes. It is impossible to make general statements regarding riparian area response to livestock grazing, since each riparian area is unique (Greene and Kauffman 1995) and streams are naturally either stable or unstable (Buckhouse and Elmore 1993). Alterations in stream morphology may take longer than several years to manifest.

The role of GIS, GPS and remote sensing in time change analysis

Remote sensing describes the acquisition of information about an object or its measurements without coming into physical contact with it. Aerial photography, satellite imagery and video imagery are common remote sensing tools used in the natural resource field (Lillesand and Kiefer 1994). Geographic information systems allow for entry, manipulation and storage of either remotely sensed data or maps in a computer system within a spatial coordinate system. Layers may include spatial data, such as soil, vegetation and land cover maps. Within the GIS, the spatial information is tied to a database that can be queried and will yield output maps containing the requested information. Remote sensing coupled with the integration of multiple layers of spatial information helps to visualize land use and land cover change and becomes a powerful analysis tool for land management.

Cuplin (1985) listed a number of parameters indicating changes in a stream system that can be easily measured from color, or color-infrared aerial photography. They include vegetation ground cover, bare soil, stream width, channel and bank stability, and size of riparian area. With regard to observation of stream channel processes, the use of remote sensing, whether aerial photography or satellite imagery, is highly useful, since it allows for study of a larger portion of the landscape than could be examined with field studies alone. The upstream processes that generate downstream effects can also be often distinguished from photos. Coupled with detailed ground surveys, changes over time can be documented and analyzed with the GIS.

Over the last decade, much progress has been made in the fields of remote sensing, global positioning systems (GPS) and GIS (Anderson 1996). Satellite imagery and aerial photography have been used to detect the amount of weeds on rangeland (Anderson et al. 1993; Everitt and Deloach 1990), to assess shrub cover and phytomass (Strong et al. 1985), to monitor spatial change in seagrass habitat (Ferguson et al. 1993), and a combination of aerial video, GPS and GIS was used to map rangeland legumes (Everitt et al. 1993).

The use of GPS allows for the accurate positioning of a point on the earth's surface. It is based on the NAVSTAR system operated by the US Department of Defense (DoD), using 24 satellites orbiting the earth at an altitude of 20,200 km. The coordinates of a point on earth are calculated by measuring the distance from that point to a group of satellites. This is accomplished by establishing the travel time of radio signals from the satellites to the GPS receiver located at the point of interest. Since atomic clocks are used in the satellites, the measurements are highly accurate. Two different codes are generated; the precision or P-code is encrypted for military use, the coarse acquisition code (C/A-code) is not encrypted, but is less accurate. Differential correction is used to increase the accuracy of the data. Errors are removed by comparing the data collected with the receiver in the field with those received simultaneously at a base station with a known location (Trimble Navigation 1996).

A common use of GIS/GPS technology is the detection of vegetation change over time (Tueller 1996). Warren and Hutchinson (1984) studied the ratio of shrub to grass cover in New Mexico and concluded that satellite images were sufficiently detailed to determine this ratio and identify the direction of land cover change. Invasion of woody species into grasslands in New Mexico was examined by Yool et al. (1997), who used Landsat Multi Spectral Scanner (MSS) images for their change detection study. The authors combined remote sensing with GIS to map these changes at a regional scale and concluded that the chosen techniques measured and displayed landscape change successfully. Pilon et al. (1988) were able to separate natural changes from human-induced changes in their change detection study of northwestern Nigeria with Landsat MSS images. They cautioned, however, that the determination of natural changes was only possible due to the high annual variability in climatic influences in this environment, and that other environments might not be as suitable for separating natural change.

Several land management agencies such as the Forest Service and the Bureau of Land Management have developed their own guidelines for the use of remote sensing, GPS and GIS in natural resource management (Golden et al. 1996; Clemmer 1994; Grant 1988). However, even though this technology has been around for many years, it is still not a widely used tool in rangeland analysis and monitoring (Anderson 1996). As costs for this technology decrease and computer knowledge of land managers increases, these tools will become more widely used in the future.

Riparian areas are relatively easy to identify from aerial photography due to the lush, green vegetation. Aerial photography can be used to assess channel width and shape, sinuosity and valley width, however, most of this work has been done with high level aerial photos and satellite images, and over a larger area of the landscape than has been done for this study site (Ward 1988; Green et al. 1994). The advantage of low level aerial photography lies in its high resolution, which facilitates interpretation of parameters in the photos (Golden et al. 1996; Warner et al. 1996). Tueller (1996) defines large scale, near earth remote sensing as scales larger than 1:10,000, with an optimum scale around 1:1,000.

Usually, vegetation parameters of interest include vegetation cover, percent vegetated versus bare area, type of lifeform and phytomass. Although satellite images cover a larger area of the landscape, large scale aerial photography is capable of distinguishing features such as plant species, bare ground and soil erosion, which are important parameters for vegetation and grazing management. Baker et al. (1995) used aerial photography at two different scales (1:40000; 1:15000) to map a forest-tundra ecotone. Although their results were improved by better resolution compared to satellite images, they encountered problems with regard to spectral variation among photos, errors due to digitizing and lack of ground control points.

Time change analysis can be performed in a number of ways with a computerized digital image analysis program (Singh 1989). The simplest way is image subtraction, whereby one image is subtracted from another, and the resulting image demonstrates change occurring over time (Mather 1992). A second technique is image ratioing, correlating with vegetation properties. This involves mathematical calculations of different spectral bands and produces a vegetation index; one index used widely is the normalized difference vegetation index (NDVI) (Lillesand and Kiefer 1994). When the spectral reflectances change over time, this change can be detected, measured and displayed in an image.

Analysis of multitemporal images is often performed with principal components analysis (PCA) (Eastman and Fulk 1993). In this technique, the variance of a multivariate data set is partitioned. Each principal component represents a combination of spectral bands and can be calculated. A new band set of uncorrelated images is created, and they are ordered with regard to the variance explained in the original data. Therefore the correlation between the individual principal components can be analyzed (Mather 1992). Eastman and Fulk (1993) performed a time change analysis using satellite data from Africa. Their results showed that principal components analysis was very successful in isolating trends in long time series data. They discovered a multitude of change patterns in vegetation and precipitation and were even able to extract anomalies derived from the sensor system.

The time change analysis methods mentioned above have the drawback of having to correct the images for atmospheric and sensor differences between two dates. Another technique that can be used is the comparison of images after they have been classified separately. The values for percent cover for two dates can then be compared. Often, the interest lies in measuring not only the amount of change, but in acquiring specific numbers of vegetation cover for the years studied and comparing them. This also eliminates problems with accurate geo-registration of images from two different time periods or taken with sensors of differing quality (Singh 1994).

The choice of film used for aerial photos affects the result. Normal color film has a 3 three layer emulsion sensitive to blue, green and red wavelengths, which allows objects on the photo to be displayed in true to life colors. Color infrared film is sensitive to blue, green, red and infrared light, but the use of a filter omits the blue light (Knapp et al. 1990). The advantage of color film is that the human interpreter can relate real color to vegetation, topographic features, etc. Color infrared film, on the other hand, is capable of displaying phenological development of plants, leaf moisture content and health. This is possible, since the leaf pigments in vegetation absorb red light, while near infrared (NIR) light is reflected (Yool et al 1997). Knapp et al. (1990) examined vegetation change over 8 years with color and color infrared aerial photos, although they did not use digital image analysis techniques, but rather analyzed the images using a dot grid. Identification of specific cactus species was greatly enhanced by the color infrared photos, while it was nearly impossible on color photos.

Johnson et al. (1995) started using GIS and remote sensing to map and analyze the Catherine Creek area several years ago. The authors mapped ground truthed salmon redds and also observed stream changes that had occurred from 1979 to 1994. The current study was based on and expanded the earlier work done regarding time change analysis.

The aerial photos used in the current study showed that considerable changes in vegetation and stream morphology had occurred over the 20 year time period. The purpose was to measure this change using the same methods employed for time change analysis in satellite imagery and small-scale aerial photography. Since the large-scale aerial photos had very good resolution, it was hoped that this would yield detailed results.

Study objectives

The objectives of this project were:

- To assess changes in stream morphology and vegetation in space (between grazed and ungrazed areas) and time (1979 to 1998).
- To determine, if possible, to what extent these changes are associated with management, topography or other factors.
- To assess the viability of using large-scale (1:4000) aerial photography combined with GIS/GPS and ground truthing in time change analysis.

Major components of the study were: 1) collecting vegetation and stream morphology data at Catherine Creek. 2) developing GIS layers for vegetation and stream morphology parameters for different years in order to detect change over time.

3) evaluate the efficacy of remote sensing and GIS techniques in this particular study. The extensive body of knowledge available from previous ground surveys and aerial photography provided baseline data and helped to assess long-term changes.

The purpose of this study was to develop a viable method for monitoring stream morphology changes over time with a combination of ground truthing, low level aerial photography and GIS analysis. If successful, similar techniques can be tested at other rangeland streams. The information provided by this research is expected to assist land managers to predict and/or prevent adverse changes in streams and riparian areas.

Literature Cited

Anderson, G.L. 1996. The application of spatial technologies for rangeland research and management: state of the art. Geocarto 11(3):5-11.

Anderson, G.L., J.H. Everitt, A.J.Richardson and D.E. Escobar. 1993. Using satellite data to map false broomweed (*Ericameria austrotexana*) infestations on south Texas rangelands. Weed Tech. 7:865-871.

Baker, W.L., J.J. Honaker and P.J. Weisberg. 1995. Using aerial photography and GIS to map the forest tundra ecotone in Rocky Mountain National Park, Colorado for global change research. Photogramm. Eng. Rem. Sens. 61(3):313-320.

Beeson, C.E. and P.F. Doyle. 1995. Comparison of bank erosion at vegetated and non-vegetated channel bends. Wat. Res. Bull. 31(6):983-990.

Bohn, C.C. and J.C. Buckhouse. 1985. Some responses of riparian soils to grazing management in northeastern Oregon. J. Range Manage. 38(4):378-381.

Bryant, L.D. 1985. Livestock management in the riparian ecosystem. In: Riparian ecosystems and their management; reconciling conflicting uses. Proceedings of 1st North American Riparian Conference. April 16-18, 1985. Tucson, AZ. USDA Forest Service Gen. Tech. Rep. RM-120. Rocky Mt. Forest and Range Experiment Station. pp. 285-289.

Buckhouse, J.C. and W. Elmore. 1993. Grazing practice relationships:predicting riparian vegetation response from stream systems. In: T.E. Bedell (Ed.). Watershed management guide for the Interior Northwest. Oregon State University Publication EM 8436. Agricultural Communications, OSU, Corvallis, OR. pp. 47-52.

Bull, W.B. 1979. Threshold of critical power in streams. Geol. Soc. Amer. Bull. 90:453-464.

Clemmer, P. 1994. Riparian area management - the use of aerial photography to manage riparian - wetland areas. TR 1737-10. USDI, Bureau of Land Management-Service Center, Denver, CO. 54 pp.

Clifton, C. 1989. Effects of vegetation and landuse on channel morphology. In:Greswell, R.E., B.B. Barton and J.L. Kershner (ed.) Practical approaches to riparian resource management, an educational workshop. May 8-11, Billings, MT. US BLM: 121-129.

Cuplin, P. 1985. Riparian area inventory and monitoring using large scale color infrared photography. In: Riparian ecosystems and their management; reconciling conflicting uses. Proceedings of 1st North American Riparian Conference. April 16-18, 1985. Tucson, AZ. USDA Forest Service Gen. Tech. Rep. RM-120. Rocky Mt. Forest and Range Experiment Station. pp. 69-71.

Dahlem, E.A. 1979. The Mahagony watershed - with and without grazing. In: Proceedings: Forum on grazing and riparian/stream ecosystems. Trout Unlimited, Inc., Vienna, VA. pp. 31-34.

Dunaway, D., S. Swanson, J. Wendel, and W. Clary. 1994. The effect of herbaceous plant communities and soil textures on particle erosion of alluvial streambanks. Geomorphology 9:47-56.

Eastman, J.R. and M. Fulk. 1993. Long sequence time series evaluation using standardized principal components. Photogramm. Eng. Rem. Sens. 59(8):1307-1312.

Everitt, J.H. and C.J. Deloach. 1990. Remote sensing of Chinese tamarisk (*Tamarix chinensis*) and associated vegetation. Weed Sci. 38:273-278.

Everitt, J.H., D.E. Escobar, R. Villareal, M.A. Alaniz and M.R. Davis. 1993. Integration of airborne video, global positioning system and geographic information system technologies for detecting and mapping two woody legumes on rangelands. Weed Tech. 7:981-987.

Ferguson, R.L., L.L. Wood and D.B. Graham. 1993. Monitoring spatial change in seagrass habitat with aerial photography. Photogramm. Eng. Rem. Sens. 59(6):1033-1038.

Golden, M., J.Johnson, V. Landrum, J. Powell, V.Varner and T. Wirth. 1996. Guidelines for the use of digital imagery for vegetation mapping. EM-7140-25. USDA Forest Service. Engineering Staff. Washington, D.C. 125 pp.

Grant, G.E. 1988. The RAPID technique: A new method for evaluating downstream effects of forest proactices on stream channels. USDA-FS General Technical Report.PNW-GTR-220. USDA-FS, Pacific Northwest Research Station, Portland, OR.

Green, M.D. 1991. Soil conditions along a hydrologic gradient and successional dynamics in a grazed and ungrazed montane riparian ecosystems. PhD thesis. Oregon State University, Corvallis, OR. 236 pp.

Green, K., D. Kempka and L. Lackey. 1994. Using remote sensing to detect and monitor land-cover and land-use change. Photogramm. Eng. Rem. Sens. 60(3):331-337.

Green, M.D. and J.B. Kauffman. 1995. Succession and livestock grazing in a northeastern Oregon riparian ecosystem. J. Range Manage. 48:307-313.

Hickin, E.J. and G.C. Nanson. 1984. Lateral migration rates of river bends. J. Hydraul. Eng. 110(11):1557-1567.

Johnson, D.E, N.R. Harris, S. du Plessis and T.M. Tibbs. 1995. Mapping and analysis of Catherine Creek using remote sensing and geographic information systems (GIS). In: Eastern Oregon Agricultural Research Center Field Day Annual Report, Special Report 951, July 1995:10-26.

Kauffman, J.B. 1982. Synecological effects of cattle grazing riparian ecosystems. M.S. thesis. Oregon State University, Corvallis, OR.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications - a review. J. Range Manage. 37(4):430-348.

Keller, E.A. and F.J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4:361-380.

Kleinfelder, D., S. Swanson, G. Norris and Warren Clary. 1992. Unconfined compressive strength of some streambank soils with herbaceous roots. Soil Sci. Soc. Am. J. 56:1920-1925.

Knapp, P.A., Warren, P.L, and C.F. Hutchinson. 1990. The use of large-scale aerial photography to inventory and monitor arid rangeland vegetation. J. Environ. Manage. 31:29-38.

Kondolf, G.M. 1993. Lag in stream channel adjustment to livestock exclosure, White Mountains, California. Restor. Ecol. 1:226-230.

Korpela, E. 1992. Modeling riparian zone processes: biomass production and grazing. PhD thesis. Oregon State University, Corvallis, OR. 154 pp.

Lillesand, T.M. and R.W. Kiefer. 1994. Remote sensing and image interpretation. Third Edition. John Wiley and Sons, Inc. New York. 721 pp.

Magilligan, F.J. and P.F. McDowell. 1997. Stream channel adjustments following elimination of cattle grazing. J. Amer. Wat. Res. Assoc. 33(4):867-878.

Marlow, C.B. and T.M. Pogacnik. 1985. Time of grazing and cattle-induced damage to streambanks. In: Riparian ecosystems and their management; reconciling conflicting uses. First North American Riparian Conference, April 16-18, 1985, Tucson, AZ. USDA Forest Service, Gen. Tech. Rep. RM-120, pp. 279-284.

Mather, P.M. 1992. Remote sensing and the detection of change. ITE Symposium 27:60-68.

Medina, A.L. and S.C. Martin. 1988. Stream channel and vegetation changes in sections of McKnight Creek, New Mexico. Gr. Bas. Natur. 48(3):373-381.

Meehan, W.R. and W.S. Platts. 1978. Livestock grazing and the aquatic environment. J. Soil Wat. Cons. 33(6):274-278.

Myers, T.J. and S. Swanson. 1992. Variation of stream stability with stream type and livestock bank damage in northern Nevada. Wat. Res. Bull. 28(4):743-754.

Myers, T.J. and S. Swanson. 1994. Grazing effects on pool forming features in central Nevada. In: Effects of Human-Induced Changes on Hydrologic Systems. R.A. Marston and V.R. Hasfurther (Ed.). Proc. Annu. Sum. Symp. Amer. Wat. Res. Assoc., Jackson Hole, WY, pp. 235-244.

Myers, T.J. and S. Swanson. 1996a. Stream morphologic impact of and recovery from major flooding in north-central Nevada. Phys. Geogr. 17(5):431-445.

Myers, T.J. and S. Swanson. 1996b. Temporal and geomorphic variations of stream stability and morphology: Mahagony Creek, Nevada. Wat. Res. Bull. 32(2): 253-265.

Pilon, P.G., P.J. Howarth and R.A. Bullock. 1988. An enhanced classification approach to change detection in semi-arid environments. Photogramm. Eng. Rem. Sens. 34(12):1709-1716.

Platts, W.S. 1983. Those vital streambanks. Western Wildlands 3(9):7-10.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K. L Prestegaard, B.D. Richter, R.E. Sparks and J.C. Stromberg. 1997. The natural flow regime. BioScience 7(11):769-784.

Richter, B.D., J.V. Baumgartner, J. Powell and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conserv. Biol. 10(4):1163-1174.

Rinne, J.N. 1985. Livestock grazing effects on southwestern streams: a complex research problem. In: Riparian ecosystems and their management; reconciling conflicting uses. First North American Riparian Conference, April 16-18, 1985, Tucson, AZ. USDA Forest Service, Gen. Tech. Rep. RM-120, pp. 295-299.

Roath, L.R. and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range in the southern Blue Mountains of Oregon. J. Range Manage. 35(3):332-338.

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO. 8-43.

Singh, A. 1989. Digital change detection techniques using remotely-sensed data. Int. J. Rem. Sens. 10(6):989-1003.

Strong, L.L., R.W. Dana and L.H. Carpenter. 1985. Estimating phytomass of sagebrush habitat types from microdensitometer data. Photogramm. Eng. Rem. Sens. 51:467-474.

Swanson, S. and I. Kamyab. 1996. Simulated stream bank erosion of surface and subsurface samples from three meadow plant communities. In: Sixth Federal Interagency Sedimentation Conference, Las Vegas, Nevada. 1:100-107.

Swanson, S. and T. J. Myers. 1994. Streams, geomorphology, riparian vegetation, livestock, and feedback loops: thoughts for riparian grazing management by objectives. In: Effects of Human-Induced Changes on Hydrologic Systems. R.A. Marston and V.R. Hasfurther (Ed.). Proc. Annu. Symp. Amer. Wat. Res.Assoc., Jackson Hole, WY, pp. 255-264.

Trimble Navigation. 1996. Trimble Pathfinder Office^{TM}, Software Reference Guide. Trimble Navigation Ltd., Sunnyvale, CA.

Tueller, P.T. 1996. Near-earth monitoring of range condition and trend. Geocarto Int. 11(3):53-62.

Ward, J.F. 1988. A comparison of SPOT data with large format camera photography for riparian mapping on the Bighorn National Forest. In: Remote sensing for resource inventory, planning and monitoring: 2nd F.S. Remote Sensing Appl. Conf., Apr. 11-15, 1988. Am. Soc. Photogramm. Rem.Sens.Falls Church, VA. p. 48-64.

Warner, W.S., R.W. Graham and R.E. Read. 1996. Small Format Aerial Photography. American Society for Photogrammetry and Remote Sensing. Whittles Publishing, Scotland, UK. 348 pp.

Warren, P.L. and C.F. Hutchinson. 1984. Indicators of rangeland change and their potential for remote sensing. J. Arid Environ. 7:107-126.

Yool, S.R., M.J. Makaio and J.M. Watts. 1997. Techniques for computer-assisted mapping of rangeland change. J. Range Manage. 50(3):307-314.

Zimmerman, R.C., J.C. Goodlett, and G.H. Comer. 1967. The influence of vegetation on channel form of small streams. Int. Assoc. Sci. Hydrol. 75:255-275.

Zonge, L. and S. Swanson. 1996. Changes on streambanks in the Sierra Nevada mountains: perspectives from a dry and a wet year. Restor. Ecol. 4(2):192-199.

Chapter 2

Time Change Analysis of a Northeastern Oregon Riparian Ecosystem: Stream Morphology Changes in Catherine Creek from 1979 to 1998

Andrea S. Laliberte[1]

---

[1] Department of Rangeland Resources
Oregon State University
Corvallis, OR, 97333-2218, USA

Abstract

Remote sensing and Geographic Information System (GIS) techniques are common tools for time change analysis, however, in most cases satellite imagery or small-scale aerial photography is used. The increased resolution of large-scale aerial photos helps in identifying small features on the ground, and is highly useful in the assessment of riparian areas. The objectives of this study were to examine changes in stream morphology over 20 years, and to determine the feasibility of using large-scale aerial photography, GIS and Global Positioning Systems (GPS) techniques as a tool for assessing change over time. The 2.5 km long study area, consisting of the stream and riparian area was separated into exclosures and grazed areas in 1978. Aerial photos from 1979 and 1998 (scale of 1:4000) were geo-corrected with ground control points, and various stream features were digitized using a GIS. Stream length, stream width and areas of change were identified for both years. Although stream length remained the same, stream width decreased in both grazed and exclosed areas. The area of change (3.65 ha) was slightly larger than the area of no change (3.2 ha). Number of islands and island perimeter decreased, while the island area increased. Exclosures and grazed areas responded similarly, and it was concluded that the topography and stream dynamics had a greater impact than the grazing regime in this study. The use of large-scale aerial photography, GIS and GPS proved to be a powerful tool for detecting change and it is expected that these techniques will become more common in rangeland analysis in the future.

Introduction

Livestock grazing in riparian areas is a controversial topic. As in any rangeland situation, a complex interaction exists between grazing, vegetation, soils and climate. In a riparian area, additional parameters have to be considered, such as interactions of grazing with fish and fisheries habitat, aquatic insects and impacts on stream morphology. All of these parameters have been investigated in the past (Meehan and Platts 1978; Roath and Krueger 1982; Kauffman and Krueger 1984; Bohn and Buckhouse 1985; Bryant 1985; Marlow and Pogacnik 1985).

Bohn and Buckhouse (1985) studied the relationship between riparian soil responses and different grazing schemes and found that rest-rotation improved infiltration, while season long grazing reduced it. The authors also determined that increased soil moisture in the fall coupled with trampling had a negative effect on infiltration rates. Similar results were reported by Marlow and Pogacnik (1985), who determined that the level of cattle use in riparian zones had little effect on streambank damage compared to the effect of soil moisture. With increasing soil moisture, streambank damage due to trampling increased respectively. The greatest amount of bank alteration occurred when soil moisture exceeded 10%.

Magilligan and McDowell (1997) studied four eastern Oregon streams for their responses to the removal of cattle grazing. In all four areas, cattle grazing had not occurred for at least 10 years. The authors found significant changes between grazed and ungrazed reaches, such as increased pool areas and channel narrowing in the exclosures. These changes were mostly attributed to increased vegetation and therefore increased channel roughness following removal of cattle grazing. However, the authors also determined that local effects, such as considerable flow reduction in the summer and particle size influenced the magnitude of channel adjustments.

Other authors reported no differences between exclosures and grazed sites or even differences in opposite direction. Medina and Martin (1988) observed channel width and depth increases in both exclosed and grazed areas in their study in southwestern New Mexico. The changes were attributed to a previous wildfire and hydrological processes of stream equilibrium. Kondolf (1993) measured cross-sections in exclosed and grazed areas in California and observed no significant differences between the two treatments. He concluded that this could possible be attributed to a lag in adjustment of the stream channel after livestock had been excluded for 24 years from the site. Kondolf (1993) also pointed out that the management for the rest of the watershed had not changed and that the local influences might be smaller than those from the entire watershed.

Bryant (1985) conducted an 8 year study of livestock grazing in riparian ecosystems at Meadow Creek near La Grande in eastern Oregon. This site is only about 30 miles west of this project's study area. Bryant (1985) concluded in his study that production of riparian vegetation was improved without impacting the aquatic system in a negative manner. Forage utilization was limited to no more than 70%. The least amount of improvement occurred under season-long grazing, while a deferred rotation system resulted in the largest increase in grass production.

The differing results in the literature show that livestock grazing effects vary widely from one study to another. The same variability was found when examining results for different plant communities in the same riparian area (Green and Kauffman 1995). The authors suggested that it would be unwise to make management decisions for a whole riparian area based on one community. Buckhouse and Elmore (1993) suggested that the grazing management should be tailored to the ecosystem, vegetation, and management objectives.

Recent progress in the fields of remote sensing, global positioning systems (GPS) and geographic information systems (GIS) (Anderson 1996) has increased the use of this technology in rangeland studies. Aerial photography and satellite imagery have been used mainly for mapping vegetation and detecting vegetation changes over time. Examples include measuring rangeland weeds (Everitt and Deloach 1990), monitoring spatial change in seagrass habitat (Ferguson et al. 1993), mapping rangeland legumes (Everitt et al. 1993) and assessing shrub cover and phytomass (Strong et al. 1985).

However, there are fewer examples in the literature of the use of remote sensing/GIS in studying stream morphology change, especially over a long time period and using large-scale aerial photography. Miller et al. (1995) investigated changes in the landscape structure on the North Platte River. The authors examined aerial photos from 1937 and 1990, and found substantial landscape change, with a 75% decline in wetted area of the stream and a change from young, dense cottonwood stands to older, more open stands. In addition, the amount of landscape change decreased with increasing distance from the river.

Roth et al. (1996) used multiple spatial scales for the assessment of stream biotic integrity. At the local scale, vegetation was quantified on the ground, at the reach scale, aerial photos were used for measurements at 50 m intervals over a 1500 m stream distance, and GIS was used to quantify vegetation at the catchment scale.

Large-scale aerial photography can be defined as scales from 1:1000 up to 1:10000 (Tueller 1996), although larger scale images have been used successfully (Warren and Dunford 1986; Tueller et al. 1988). However, as mentioned above, most of the studies are concerned with vegetation mapping or change, not stream morphology. The advantage of low level aerial photography lies in its high resolution, which facilitates interpretation of parameters in the photos (Golden et al. 1996; Warner et al. 1996). This is the reason why large scale imagery is now increasingly being used in archeology and anthropology, since features and landscape patterns are recognized easier from the air than from the ground (Hinckley and Walker 1993). For that reason, large scale aerial photography is ideally suited for examining changes in stream morphology.

Johnson et al. (1995) started using GIS and remote sensing to map and analyze the Catherine Creek area several years ago. The authors measured some stream changes that had occurred from 1979 to 1994. The current study was based on and expanded the earlier work done regarding time change analysis.

The objectives of this study were:

- To assess changes in stream morphology in space (between grazed and ungrazed areas) and time (1979 to 1998).
- To determine, if possible, to what extent these changes are associated with management, topography or other factors.
- To assess the viability of using large-scale (1:4000) aerial photography combined with GIS/GPS and ground truthing in time change analysis.

Study Site

The study area is located in northeastern Oregon, about 15 km southeast of Union on the Hall Ranch, which is operated by the Eastern Oregon Agricultural Research Center (EOARC). Catherine Creek runs for a length of 2.5 km through the study area, which is 41 hectares in size. The elevation of the stream and meadows is approximately 990 m HAE (height above the ellipsoid). The height was computed using the National Geodetic Survey GEOID 96 model. Catherine Creek is a third order tributary to the Grande Ronde River. About 5 km (3 miles) downstream from the study area, the US Geological Service, Water Resources Division operates a stream gauging station (Number 13320000), which has provided relatively continuous flow records since 1911, however, the gauging station was discontinued in 1996. The average discharge from 1979 to 1995 was 3.3 m^3 / sec (Appendix 1); peak flows generally occur in April and May, associated with snow melt runoff, while low flow conditions last from August to early February (United States Geological Survey 1999). A typical hydrograph for Catherine Creek from 1979 is shown in Appendix 2.

Mean annual precipitation measured at the Eastern Oregon Agricultural Research Center was 35 cm (1912-1998 data) and 38 cm (1979-1998 data), while mean annual temperature was recorded at 8.7 degree Celsius (1979-1998 data) (Appendix 3 and 4).

Prior to 1978, this area was grazed under a season long grazing regime. In 1978, five exclosures were constructed in the study area; they straddle the stream and alternate with grazed areas, so that the linear run of the stream is divided into exclosed and grazed sites (Figure 2.1). Since 1977, the study area has been grazed for 3-4 weeks in the fall to a utilization level of 70 %, and a stubble height of 5 cm on Kentucky bluegrass.

Figure 2.1. Layout of the study area with 5 exclosures and outline of Catherine Creek in 1998

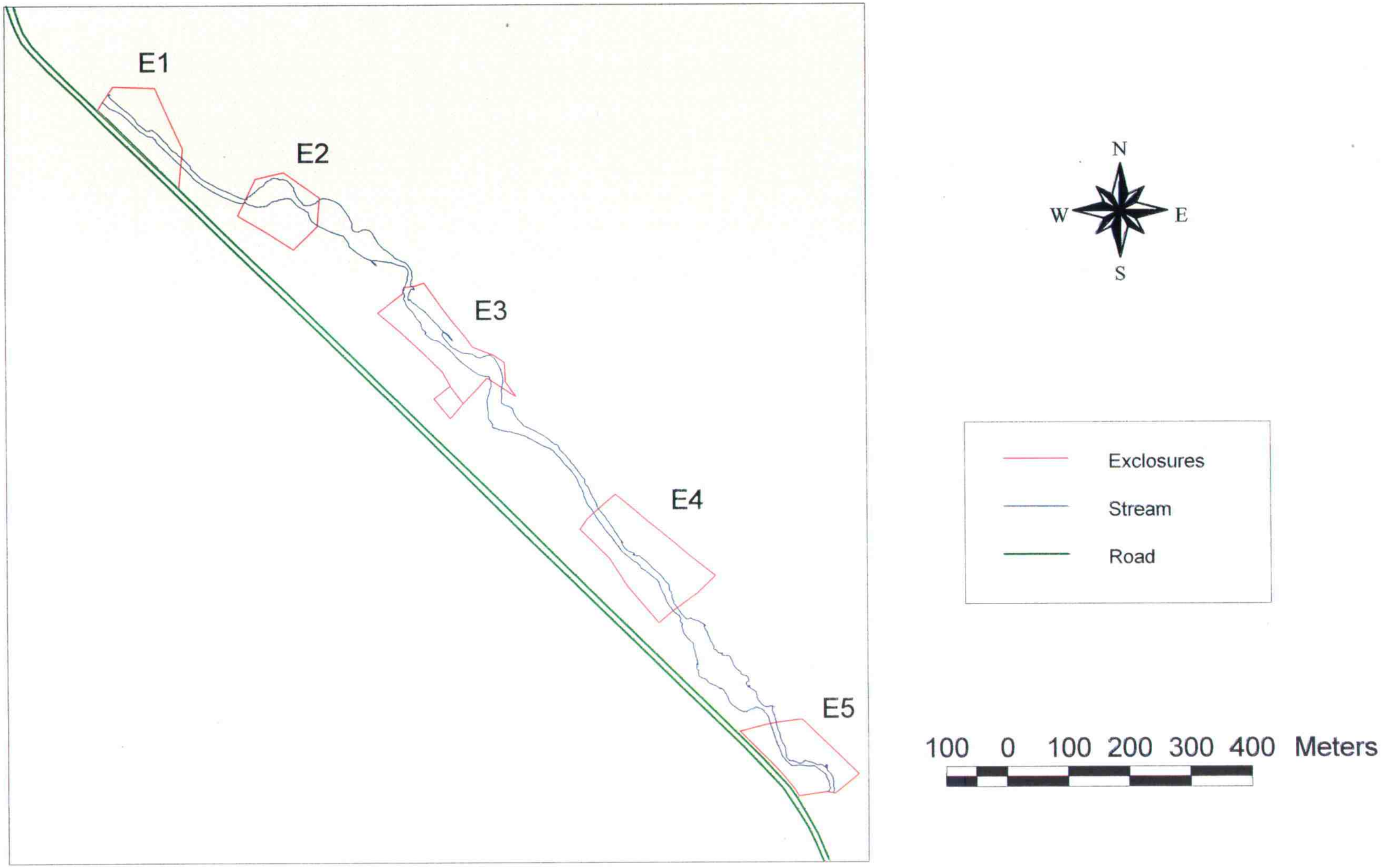


Table 2.1 shows the Animal Unit Months (AUM) for the Catherine Creek study site since 1977.

In 1958, and again in 1974/75, hawthorns were removed from the Hall Ranch at a distance of 50 m from the stream for pasture improvement. The shrub was piled and burned, and the pasture was not seeded afterwards. In the mid-70s, a large landslide occurred on the middle fork of Catherine Creek within the wilderness boundary. Sediment discharge occurred in the following years after every rainfall (M.Vavra, pers.comm.).

Table 2.1. Grazing period and AUMs (Animal Unit Months) for the Catherine Creek study area.

Year	Grazing Period	AUMs
1977	Aug 17 – Sept 2	72.4
1978	Aug 23 – Sept 13	63.8
1979	Aug 27 – Sept 17	56.8
1980	Aug 23 – Sept 16	90.0
1981	Aug 27 – Sept 16	59.3
1982	Aug 26 – Sept 15	40.7
1983	Aug 22 – Sept 11	57.7
1984	Aug 23 – Sept 13	63.8
1985	Aug 16 – Sept 4	66.5
1986	Aug 15 – Sept 3	67.9
1987	Aug 18 – Sept 14	60.5
1988	Aug 23 – Sept 20	43.5
1989	Aug 16 – Sept 28	46.6
1990	Aug 20 – Sept 10	16.8
1991	Aug 29 – Sept 11	53.5
1992	May 5 – June 1,	9.0
	Aug 6 – Aug 19	56.0
1993	Aug 23 – Sept 13	47.6
1994	Aug 17 – Sept 12	22.3
1995	Aug 22 – Sept 8	32.4
1996	Aug 13 – Sept 11	47.7
1997	Aug 12 – Sept 10	39.3
1998	Aug 17 – Sept 15	59.9

Methods and Materials

Aerial photography and ground targets

The aerial photography used in this study consisted of images of roughly two different scales. For the two main time periods of interest, 1979 and 1998, large-scale photography of 1:3100 and 1:4000 was used. While the study was in progress, older photography at a smaller scale (1:18,000) became available and was used as supplementary information. At that scale, one image covered the whole study area, and the resolution was lower compared to the large-scale images. Table 2.2 contains information for the images used for this study. Although aerial photos for several years between 1979 and 1998 were available and were used for reference, these photos were not scanned and analyzed due to time constraints.

Table 2.2. Date, scale, type and number of aerial photos taken of the Catherine Creek study area and used in the analysis.

	Large scale		Small scale			
	1979	1998	1937	1960	1969	1982
Date flown	June 28	Aug 3	Sept 10	Aug 6	Aug 3	June 16
Scale	1:3100	1:4000	1:21000	1:14300	1:19400	1:18300
Type	Color	Color/CIR	B/W	B/W	B/W	Color
# of photos	10	8	1	1	1	1

CIR: color infrared   B/W: black and white

The 1998 aerial photos were taken with a large format mapping camera with a focal length of 305.252 mm, using 24 cm film. The study area was photographed with both color and color infrared film. Photos were shot with 60 % overlap, with eight images covering the study area. The resulting scale was 1: 4000. The 1979 color aerial photos were taken with a Hasselblad camera fitted with a 80 mm lens using color negative film. No fiducial marks were present. Ten photos covered the study area, with an overlap of 10 %, and the scale was 1: 3100. The 1998 photos were of a higher resolution and better quality, with less distortion occurring near the photos' edges. All of the smaller scale images were taken with mapping cameras.

In 1998, one hundred and two targets were distributed in open areas all over the study site. These targets would become ground control points for geo-correction of the aerial photos. Targets used were one square foot paving stones, painted white, secured with metal rods and numbered consecutively from 1 to 102. Each target was geo-positioned using two Trimble® Pathfinder Pro XR® differential global positioning (DGPS) receivers with data loggers. One GPS unit was used as a base station, the other as a rover, and a phase processing mode was used with a residence time of 12 minutes. All points were differentially post-corrected by downloading the necessary data from the US Forest Service GPS page maintained on the Internet (USDA Forest Service GPS page 1999). The targets were positioned with an average Northing error of 7 cm, an Easting error of 14 cm, and an elevational error of 14 cm. Target positions were expressed in Universal Transverse Mercator (UTM) coordinates. The target positions were displayed as a map with the GPS software (Trimble Navigation 1996) and converted to a GIS vector file format as well as a spreadsheet containing UTM coordinates of target positions.

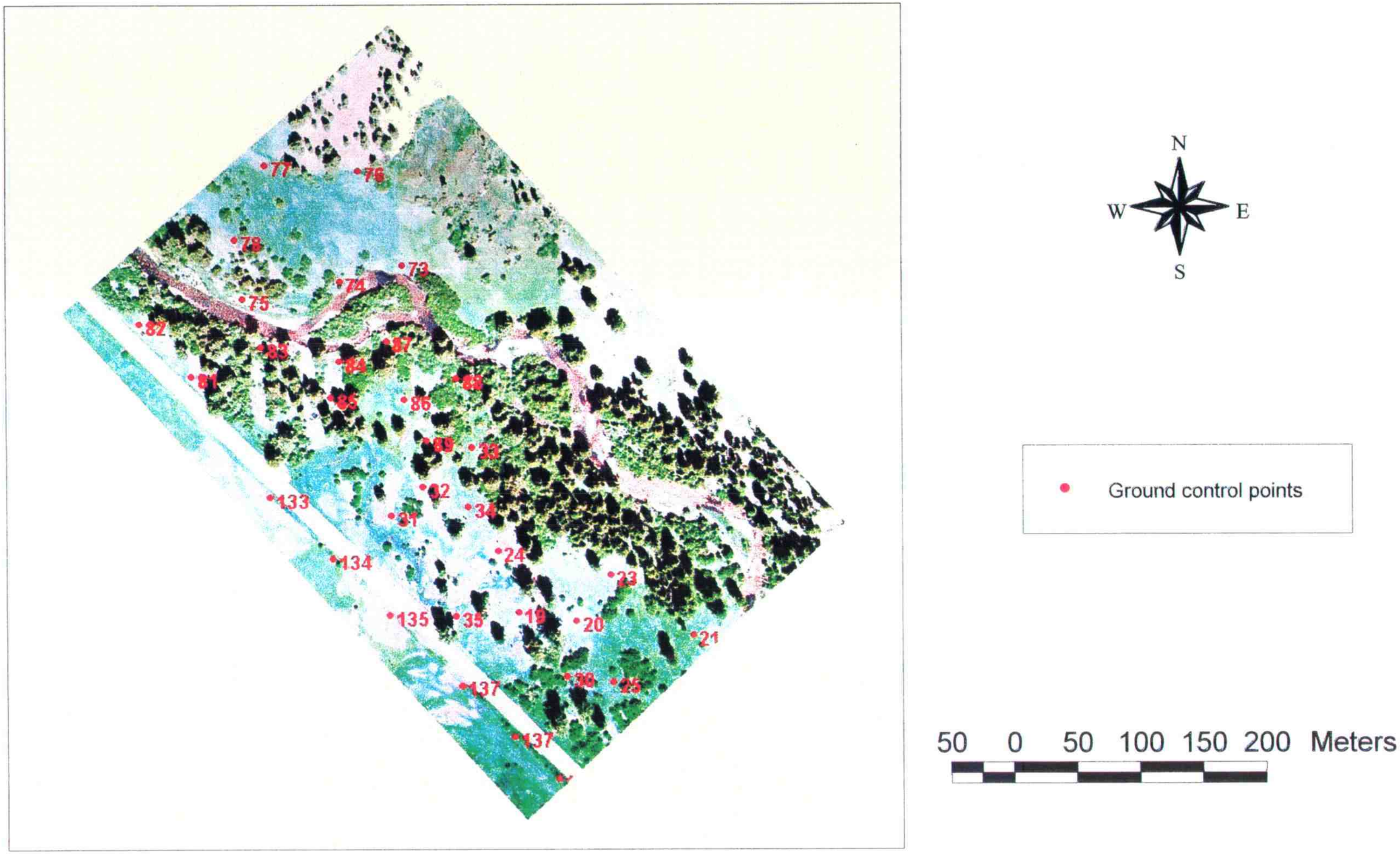
Image processing and geo-correction

The next step was geo-correction of the 1998 images, using the white targets that were easily identified on the photos. The 1998 images would then become the baseline for measurements and comparison of ground features with the 1979 images, and the smaller scale photography from all other years. Aerial photos were scanned with a Hewlett-Packard® ScanJet® 6100C flatbed scanner at a resolution of 600 dpi (dots per inch). Although this created large image files of 85 megabytes, a high resolution was necessary for determination of ground features. Color images were saved in a 24-bit Tagged Image File Format (TIFF) after scanning, and then imported into the digital image processing program.

The 1998 images were geo-corrected using the software program ERDAS Imagine® (ERDAS® Inc. 1997), using a second order polynomial geo-correction operation. Ground control points were located on the image on-screen and then assigned the correct UTM coordinates for each target. On average, 15 targets were visible per image and used for corrections. As a projection type the World Geodetic System (WGS) 84, with a UTM Zone 11 coordinate system was used. The Root Mean Square (RMS) error for this process was 1.56 (average for 8 images), with a pixel size of 10 cm, resulting in a ground accuracy of 16 cm. Figure 2.2 shows a corrected 1998 image with an overlay of the targets.

According to the 1947 Revision of the United States National Map Accuracy Standards, 90 % of tested points on maps with scales larger than 1:20,000 must have an error of less than 1/50 of an inch. This means that 90 % of accidental errors shall not be

Figure 2.2. Geocorrected aerial photograph with numbered ground control points



larger than 1.64 times the RMS (i.e., 1.64 standard deviations, assuming a normal distribution of errors; 1.64 is the z score probability of occurrence).

Following is a calculation for the allowable RMS for a map with a 1:4000 scale:

Allowable RMS = Acceptable error on the ground / 1.64

Acceptable error on the ground = Map error * scale conversion * units conversion
= 1/50 inch * 4000 * 0.0254 meters/inch
= 2.032 meters

Allowable RMS = Acceptable error on the ground / 1.64
= 2.032 meters / 1.64
= 1.24 meters

This means that the ground accuracy of 16 cm achieved in the geo-correction of the 1998 images was well below the US National Map Accuracy Standard.

Once all 1998 images had been rectified, the 1979 images were geo-corrected using the 1998 images as a baseline. Since both images were projected on-screen simultaneously, identifying the same points on two different images was simplified for the geo-correction process. Again, a second order polynomial geo-correction operation was used.

The image analysis program used offers several processes for geo-correction, one of them designed to remove distortion in aerial photography. It involves the use of a digital elevation model to correct for terrain distortion. For this operation it was necessary to scan the full aerial photo including the fiducial marks. The 1998 images had been geo-corrected previously by simple rubber sheeting after scanning them using a 8.5" X 11" flatbed scanner, which did not include the fiducial marks. In order to compare the differences for both types of correction processes, a 1998 image was scanned into a 12" X 17" flatbed scanner, including the fiducial marks, and was geo-corrected with the terrain distortion removal feature. When both images were compared after correction, the differences between UTM coordinates of the same points in both images were 0.303 m in the x direction, and 0.378 in the y direction. The image scanned with the larger scanner had considerably lower quality at the same resolution of 600 dpi. Therefore it was decided to use the previously scanned images and forego the terrain distortion removal correction. Higher resolution was considered to be more important for stream measurements than removal of terrain distortion, since the stream and adjacent vegetation was on relatively flat land, and had little topographic distortion.

Constraints in location of ground control points and error assessment

The geo-correction of the 1979 to the 1998 images was more complicated than the 1998 image correction due to the time difference involved, and the increased warping of the 1979 images, since they had not been taken with a mapping camera. Twenty identical points such as tree stumps, rocks and other landmarks were chosen on both images.

Five criteria had to be met for each of these ground control points: 1) points had remained unaltered for 20 years; 2) points had to be spread out over the 1979 image, to reduce the distortion in the rectification process; 3) points could not be located too close to the image's edge, since the 1979 photos were more distorted than the 1998 ones; 4) treetops were not a good choice, since there was too much parallax difference between the two years; 5) points should be located on flat ground, since terrain distortion would affect rectification.

Another problem was the fact that the stream was not centered in all of the 1979 images, while it was central to all 1998 images. The downstream portion of the study area consisted of more open grassland, while the upper area was more vegetated with shrubs and trees. The denser vegetation presented more problems, since it was difficult to identify certain shrubs or trees. In addition, the upper area had steeper topography, and the 1979 photos showed that the pilot had banked the plane to begin his flight, which resulted in considerable tilt in the first image.

It became obvious that the error in ground locations would be different in each image. The number of ground control points in each image was reduced from 20 to 16, after choosing the best points according the above criteria, while reducing the RMS error to below 1.05 pixels on average. Table 2.3 shows the RMS error for the 1998 images, and the RMS error for the 1979 images that were corrected to the 1998 images. Pixel size in the 1979 and 1998 images was 10 cm, translating to a ground accuracy of 15 cm for the 1998 images.

Due to the location of the stream away from the image center, the resulting distortion at the photo edge and lack of image overlap for the 1979 images, it was decided to perform error assessments in addition to the RMS error. After correction of the 1979 images, corresponding 1998 and 1979 images were put on-screen and geo-linked. In this state, a crosshair cursor applied to one image marks the same UTM coordinates in both images. For each corresponding image pair (1979/1998), eight points, visible on both images within 48 m of the stream edge were chosen. The points were chosen close to the stream, since this was the area of interest for measurements. If the image was warped at a distance away from the stream, this was of little concern for channel outlines.

Table 2.3. Root Mean Square (RMS) error after geo-correction of ten 1979 and eight 1998 aerial photos of Catherine Creek.

1979 image #[1]	RMS error	1998 image #[1]	RMS error
4	1.1115	10	1.4498
5	1.0367	9	1.4718
6	1.1487	8	1.3766
7	1.0718	7	1.8541
8	1.0903	6	1.8537
9	0.9902	5	1.4341
10	1.0546	4	1.4245
11	1.0999	3	1.6026
12	0.7953		
13	1.1101		
Average	1.0509	Average	1.5584

[1] 1979 and 1998 image numbers are the original aerial photo numbers and the order is reversed for that reason

UTM coordinates of the 1998 image were recorded first, then the same point was selected on the 1979 image, noting its coordinates. The differences in UTM coordinates in the x, y and z directions were calculated for the eight points. Table 2.4 shows these results, which indicate that the difference between the same location on the 1979 image and the 1998 image was on average 48 cm in the x and 47 cm in the y direction.

Digitizing of stream features

The outline of the stream was digitized on-screen from each aerial photo separately, using the software program ArcView (ESRI (Environmental Systems Research Institute) 1996). These vector files obtained from each photo were then appended into one vector file of the whole stream outline. Due to overlap at the photos' edges and the distortion

Table 2.4. Average differences (in m) of 8 UTM coordinates on 79 and 98 images in the x, y and z direction after geo-correction of images. Distance to stream center was measured from the 1998 photos.

Image Pair Numbers	Difference x	Difference y	Straight line Difference	Distance to stream center
	(m)			
79_4 – 98_10	0.4058	0.2714	0.5349	40.12
79_5 – 98_10	0.4130	0.2650	0.5527	31.38
79_6 – 98_9	0.7619	1.0696	1.4015	20.78
79_7 – 98_8	0.3978	0.4713	0.6765	32.21
79_8 – 98_7	0.3197	0.2564	0.4788	26.55
79_9 – 98_6	0.2528	0.3317	0.4543	23.63
79_10 – 98_5	0.2173	0.3333	0.4295	28.70
79_11 – 98_4	0.8812	0.4431	1.0097	41.95
79_12 – 98_4	0.3377	0.3758	0.5547	42.73
79_13 – 98_3	0.7906	0.8660	1.3071	48.25
Average	0.4778	0.4684	0.7400	32.63

in the lower quality 1979 photos, the vector lines from each image did not match up perfectly. The lines were joined in what was considered a best fit. As a control, it was decided to produce a mosaic of all 1979 images and overlay the finished stream outline to correct for any obvious errors.

A mosaic was created using a cut and feather option as opposed to a simple overlay. With an overlay, the stream and other features in the images did not line up properly, while the cut and feather option produced a best fit of both images. There were 14 joints in the mosaic, some of which did not fit well. For example, the stream bank would appear as a double line for a short distance in the overlap area. The complete digitized stream outline was overlaid on the mosaic images. In addition, the vector files for the stream outline of the separate images were also overlaid. It became visible whether the stream lines had been joined correctly or not. In some instances, the lines diverged considerably, and the finished stream outline was corrected to lie in between to minimize the error.

Due to the distortion in the original images, some error in the overlap areas was unavoidable and had to be accepted, since stream outlines from 2 years were to be compared later. The error in stream bank location occurring due to photo distortion in the image overlap area was calculated by measuring the length of the overlap and its coordinates. In addition, the maximum and average distances of the vector lines (digitized from each photo) to the final stream outline were measured and are shown in Table 2.5. The total length of overlap was 476.6 m, compared to a total stream length of 2318 m.

Table 2.5. Length of overlap in 1979 aerial photos, and errors after choosing the best fit line for the streambank. Maximum and average error indicate the distance from the lines digitized from each photo to the final complete stream vector line.

Overlapping images	Length of overlap	Maximum error of best fit line	Average error of best fit line
		(m)	
13 to 12	95.90	3.58	2.08
12 to 11	66.43	1.22	1.20
11 to 10	73.80	2.65	1.26
10 to 9	25.29	1.56	1.11
9 to 8	30.18	1.88	1.21
8 to 7	34.36	1.42	0.59
7 to 6	45.69	3.66	1.88
6 to 5	64.38	2.96	1.61
5 to 4	40.57	1.93	1.15
Total overlap	476.60	Average error	1.34

The 1979 image mosaic and stream outline then became the standard for comparison with the 1998 images. All islands, thalweg of stream, and woody debris larger than 20 cm in diameter were digitized on-screen from the 1979 image mosaic of the whole study area.

None of the problems with joining of stream outlines were encountered in the 1998 photos, which were of higher quality. Due to 60% overlap of these photos, only the middle of each photo was clipped and used for analysis, reducing edge distortion dramatically. A mosaic of all eight images was produced, and the vector files joined from separate images and overlaid on the mosaic fit well in all overlap areas. As was done for the 1979 images, vector files for the stream, islands, thalweg and woody debris were created for the 1998 images. In addition, outlines of all exclosures and perimeter fences were digitized from the 1998 photos. Summary statistics for the parameters of both years were then extracted from the ArcView database and used for comparison.

These statistics included:

- length of thalweg
- length of left and right streambank
- stream area
- wetted area of the stream, which equaled stream area minus island area
- number of islands
- island area (minimum, maximum and mean)
- island perimeter (minimum, maximum and mean)
- number of woody debris
- woody debris area (minimum, maximum and mean)
- woody debris perimeter (minimum, maximum and mean)

For the aerial photos from 1937, 1960, 1969 and 1982, that became available while the study was in progress, a similar procedure for geo-correction and digitizing was followed, with a few exceptions. Due to the smaller scale of these images, it was not possible to recognize enough of the same features on the photos for comparison with the 79 and 98 images. For that reason, additional GPS points were collected in the field to serve as ground control points for geo-correction. The smaller photo scale covered a larger land area and allowed us to use landmarks outside of the study area, such as corners of a barn and bridge, and corral posts. In addition, GPS locations of large cottonwood trees, snags and stumps visible in all photos were collected. In order to get a location for the middle of a tree, two GPS points at a distance of 10 m on either side of the tree were collected and later averaged. A total of 60 additional ground control points were collected in that manner. Table 2.6 shows the RMS error and pixel size of these images. The average values for the 1979 and 1998 images are included for comparison.

Due to the lower resolution, it was not possible to digitize the stream outline accurately in the black and white images (1937, 1960, 1969). Likewise, islands and woody debris were not defined clearly. The color image of 1982 was of better quality, however, it was decided to digitize only the thalweg for the 4 years available in small scale so that accuracy would not be compromised. The thalweg measurements were used to calculate sinuosity of the stream, which is the ratio of stream length to valley length.

Table 2.6. RMS error, pixel size and ground accuracy of aerial photography of Catherine Creek. Ground accuracy equals pixel size times RMS error.

	Small scale				Large scale	
	1937	1960	1969	1982	1979	1998
Scale	1:21000	1:14300	1:19400	1:18300	1:3100	1:4000
RMS error	0.7317	0.8613	0.8687	0.9183	1.0509	1.5584
Pixel size (m)	0.78	0.40	0.78	0.72	0.10	0.10
Ground accuracy (m)	0.57	0.34	0.68	0.66	0.11	0.16

Relationship between streamflow and stream width

Since the objective was to compare stream channel outlines and width for different years, the decision of where the channel was digitized became very important. Aerial photos had been acquired on different dates in different years, and the relationship between discharge and changing water level had to be accounted for. For that reason, wetted area of the stream was not used, since it would change the most as discharge changed. It was decided to attempt to digitize what was considered to be bankfull width. Bankfull is defined as the stage that "corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming of changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels" (Dunne and Leopold 1978). In streams that are not entrenched, bankfull refers to that location on the stream bank, which characterizes the change between a state where a stream flows within its channel, and the beginning of flooding stage (Rosgen 1996). Bankfull measurement would be the most reliable tool for comparing changes.

Measurement of bankfull was also conducted in the field on 5 cross-sections of the stream, so that an accurate bankfull width and stream type could be determined. In addition, a longitudinal profile of several sections of the study area was done to determine stream slope (Rosgen 1996).

Change analysis for stream and island areas

The objective was to determine the amount of change that had occurred in the stream channel and islands from 1979 to 1998. In GIS analysis, it is common to use a cross-classification method for the comparison of the same features in two different years (Eastman and McKendry 1991). A cross-classification shows all possible combinations of the categories on the two maps. The results from this process can be displayed in an image or in a cross-tabulation matrix.

Both of these display methods were used for the comparison of 1979 and 1998 stream channels and islands. Images showing areas of change and no change were created. The cross-tabulation matrix shows how many pixels or hectares in the image changed from stream to land, from land to stream, or remained the same.

Determination of stream width

In order to determine stream width for both years, the vector files of the left streambanks were converted to raster files, and then a distance module was run on the raster file. The result was an image with the left streambank at the center, surrounded by concentric ellipses representing increasing distance from the stream. For determination of stream width, the area of the islands had to be eliminated from the measurement. For that reason, two additional lines were digitized from the images, one line running down the middle of the stream around the left side of the islands, the other running down the stream middle and around the right side of the islands. As was done for the left streambank, distance modules were run on these two lines. Now three distance images were ready for further analysis: 1) left streambank, 2) middle left of islands, and 3) middle right of islands, each containing the distance from the line contained in the image. An image calculator was used next to combine these 3 images into one according to the following formula:

(distance image left bank)-(distance image middle left)+(distance image middle right).

This resulting image contained the distance from the left streambank excluding the areas of all islands. In order to obtain an image containing the width of the stream at every point on the line of the right streambank, the result from the above calculation was multiplied with a raster file of the right streambank. From this image, numeric values and a histogram of the stream width were extracted. This process was conducted for the whole stream, and separately for each exclosure and grazed area. Minimum, maximum, mean, and standard deviation of stream width values were obtained. The GIS program used for this procedure extracted 5070 measurements of stream width from a total stream bank length of 2375 meters (example for right streambank in 1998), corresponding to width measurements performed every 0.47 meters.

The histogram function has no choices available for measurement intervals, however, the class width is determined by the user. The class width affects the precision of the standard deviation, since it is calculated on the basis of class frequencies. Therefore, a narrower class width yields a more precise determination of the standard deviation. In order to determine an appropriate class width, several histograms of the stream width measurements were run, using class widths ranging from 0.1 to 4. The graphical display of the effect of class width on standard deviation shows the decrease of variability with decreasing class width (see Figure 2.3). A width of 0.5 was chosen, since the variability had leveled out between a class width of 1 and of 0.5. This yielded the 5070 measurements of stream width.

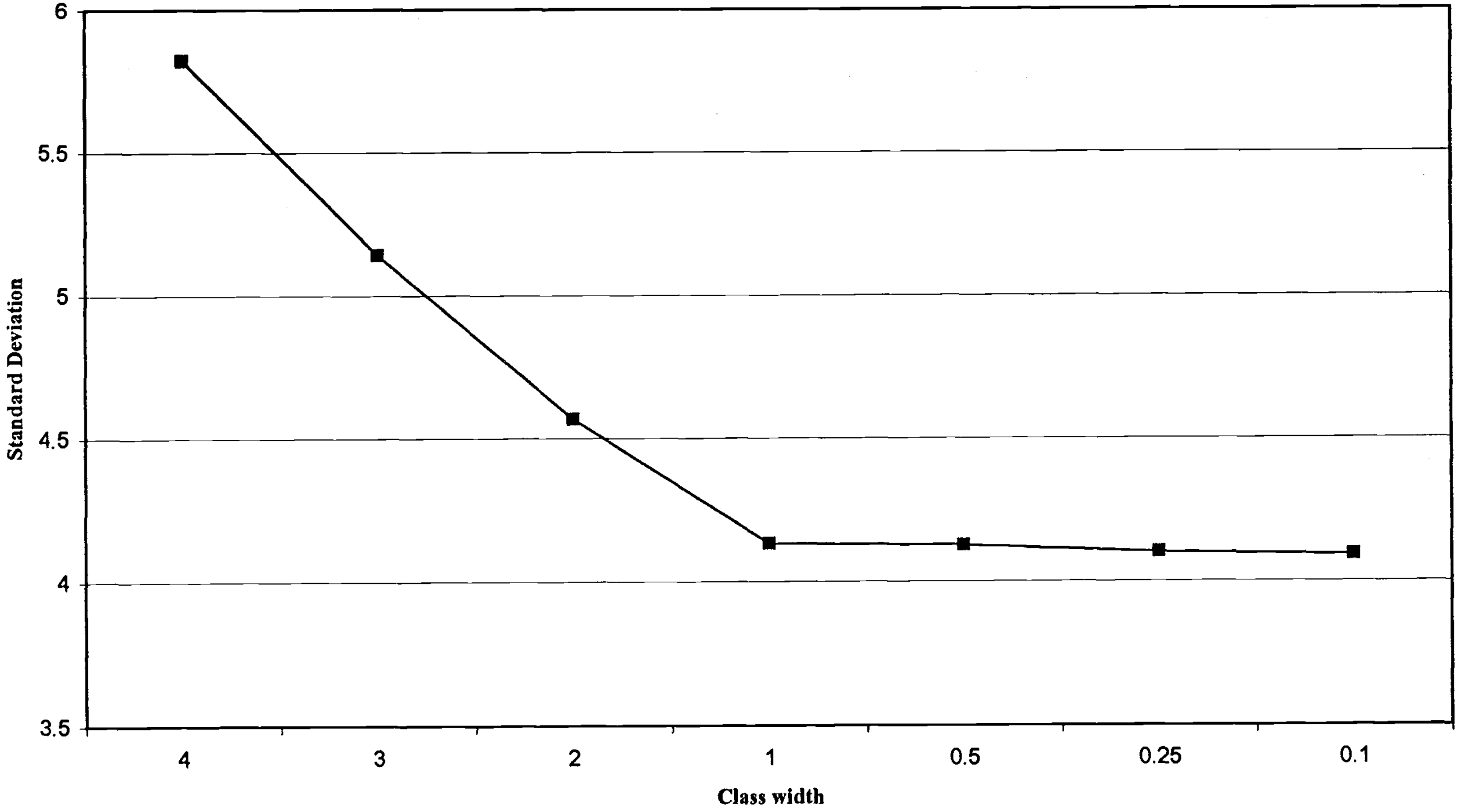
Supplementary information

A large amount of data was collected in previous surveys of the stream (Johnson et al. 1995) and was used in this study. In 1997, eighty-nine permanent transects were established at Catherine Creek for the purpose of measuring channel width, depth and bank locations (Appendix 5). The transects were spaced 24 m apart, with a random beginning in each exclosure or grazed area. The transect spacing represents between one and two average channel widths. Transects were marked with headstakes which were geo-positioned with a 12-channel, Trimble® Pathfinder Pro XL® differential global positioning (DGPS) receiver and data logger. Using a coarse acquisition code, the headstakes were positioned to an average accuracy of 1 meter (Appendix 6). Due to the dense streamside vegetation, the geo-positioning will make it easier to find the headstakes in the future.

Data analysis

The results obtained for stream width, length of bank and thalweg represent a measurement of the whole population. No sampling was involved, and therefore there was no need to apply statistics to these results. Instead, the results of these parameters in

Figure 2.3. Effect of class width in the histogram function of the GIS on precision of the standard deviation of the mean



exclosed and grazed areas were presented as such or as percent increase or decrease over 19 years.

Results and Discussion

Bankfull measurements

As a result of the field measurements, Catherine Creek was classified as a C3 type stream (Rosgen 1996). Measurements from 5 cross-sections are shown in Table 2.7.

Table 2.7. Morphological description of Catherine Creek from five cross-sectional measurements and values for a typical C type stream.

Headstake #	Bankfull Width	Entrenchment Ratio	Width/depth Ratio	Sinuosity	Slope
	(m)				(%)
34	12.10	5.2	18.56		
35	15.10	4.1	33.33		
49a[1]	11.60	1.0	17.55	1.17	1.3
49b[1]	8.50	2.8	17.35		
59	15.35	3.0	33.66		
90	15.20	4.6	28.60		
Typical C		>2.2	>12	>1.2	0.1-2.0

[1] cross-sections taken at a location where the channel flowed on either side of an island

All cross-sections except 49a indicated a C type stream. Cross-sections 49a and 49b were taken at a location where the stream flowed on either side of an island. For that reason, the entrenchment ratio of 49a is lower than for the other cross-sections, and at this point, one side of the channel (49a) was classified as an F type. Sinuosity was calculated from the aerial photography for the whole study area, while the slope was determined in the field by measuring a longitudinal profile over a distance of 637 meters.

The field measurements were taken in October during low flow. It became apparent that in some short sections of the stream, the channel was braided, with 3 to 4 different small channels. There was a large amount of mid-channel deposition of gravel and cobbles with the channels flowing at different elevations. This caused the water to flow perpendicular to the main channel in some places, moving from the higher to the lower elevation. Although no measurements were done in those areas, it is expected that these sections would have been classified as a D type channel, which indicates braiding.

Rosgen (1996) describes the progressive stages of a stream channel adjusting to changes in driving variables. These may include changes in sediment and flow regime, which in this case may be related to the large landslide that occurred in the watershed in the mid-70s. A C 4-type stream often progresses to a C 4 (bar 6), and then to a D 4 type. The difference between C 4 and C 3 is the channel material: cobbles for C 3, and gravel for C 4 type stream channels.

Field observations at the cross-sections 49, 35 and 34 (Table 2.7) and comparison with older aerial photos showed increased bar depositions and lowered sediment transport capability, resulting in larger islands and mid-channel bars in 1998 compared to 1979. It is possible that a progression from a C to a D type channel as described in Rosgen (1996) is occurring in this portion of the stream. This section is located below the straight stream section, and it is assumed that the increased sediment load resulting from the mid-70s landslide was at least partly responsible for this aggradation.

In the future, we plan to develop a detailed three-dimensional model of the stream channel, using a laser range finder and directional compass. These measurements will be repeated over the years to measure and possibly predict channel changes at a large scale.

Relationship between stream flow and stream width

Bankfull measurements conducted in the field showed that bankfull width had been underestimated somewhat from the aerial photos (Table 2.8). Due to time constraints, these field measurements were conducted after the GIS work had been completed, and no adjustments to the channel outline were done. Even in the field, it is not easy to determine bankfull, and it is common to underestimate bankfull width (Rosgen 1996).

Table 2.8. Comparison of bankfull measurements taken in the field and from aerial photos on the computer screen.

Headstake #	Bankfull width Field	Bankfull width On-screen
	(m)	(m)
34	12.10	11.60
35	15.10	12.50
49a	11.60	9.50
49b	8.50	7.50
59	15.35	13.00
90	15.20	13.50

Two different observers may come up with slightly different locations for bankfull. It is even more difficult to estimate this location from an aerial photo. However, bankfull is a consistent morphological index for comparing the stream in two different years, since it is the location of the flow with a recurrence interval of 1.5 years (Dunne and Leopold

1978). Ideally, the field measurements should have been done before digitizing the stream.

Changes in water level could potentially change the placement of the stream channel while digitizing it. In order to get an idea of how accurate the digitization was done (in other words, unaffected by fluctuations in stream flow), the relationship between discharge and stream surface area was determined. If the channel had been outlined too close to the wetted width, a change in discharge would have resulted in a large change in surface area. If, however, the channel was digitized close to bankfull, then a change in discharge should not have changed the surface area very much. Table 2.9 shows the relationship between discharge and surface area.

Table 2.9. Discharge, surface area and surface area/thalweg of Catherine Creek for 3 different dates of aerial photography.

Date	Discharge	Surface area	Surface area/thalweg
	(m³/sec)	(sqm)	(m)
June 28, 1979	5.66	50962.53	21.99
June 16, 1982	16.65	54383.88	23.51
August 3, 1998	1.27	49520.93	20.38

Since the stream gauging station was discontinued in 1996, the discharge for 1998 was estimated by averaging all stream flow values for August 3 from 1978 to 1996. The resulting value (1.27 m^3/sec) closely resembled discharge measurements for 14 days on either side of the date the aerial photo was taken in 1998.

1982 was a year of above average discharge for Catherine Creek (Appendix 1). While the average mean flow was 3.32 m^3/sec (1979-1995), the peak flow for that year was recorded at 18.29 m^3/sec (on May 25, 1982). This means that the aerial photo of

1982 was taken close to peak flow, which would give a reference point for bankfull width. The numbers in Table 2.9 show that a 3-fold increase in flow from 1979 to 1982 resulted in only a 6.7 % increase in surface area, while a 4.4 fold decrease in discharge from 1979 to 1998 resulted in a 2.8 % decrease in surface area. This small change in surface area caused by a rather large change in discharge means that the stream was able to absorb that increase by becoming deeper, and not much wider. Therefore, only a small portion of the width change observed was attributed to changes due to water level, and it appeared that the digitization of the stream channel was done as close to bankfull width as could be done from a photo. This means that any change in stream width occurring over the time period studied, would have to be attributed to actual change in the stream channel as opposed to changes in water level alone.

Change analysis for stream and island areas

The results of the change analysis for the stream and islands are shown in Table 2.10. This cross-tabulation matrix shows the areas of change and no change occurring from 1979 to 1998.

Table 2.10. Cross-tabulation matrix of land and stream areas (in ha) for 1979 and 1998 at Catherine Creek. Bold numbers along the diagonal represent areas of change, off-diagonal cells represent areas of no change.

		1979		
		Land	Stream	Total
1998	Land	37.82	**1.88**	39.70
	Stream	**1.74**	3.19	4.93
	Total	39.56	5.07	44.63

It can be seen that the 1979 stream area was 5.07 ha, compared to 4.93 ha in 1998, representing a 2.76 % decrease in stream area. Areas of change include 1.74 ha (1979 land to 1998 stream) and 1.88 ha (1979 stream to 1998 land), for a total of 3.62 ha of change. The area of 1979 stream that remained stream in 1998 is 3.19 ha (no change). This shows that the area of change is nearly the same as that of the area of no change. The size of the area of land in 1979 that remained land in 1998 (37.82 ha) is large, since the whole study area is included. Although this represents an area of no change, our interest lies in the change detection within the stream channel boundaries. The cross-tabulation image (Figure 2.4) shows areas of change colored blue (stream to land) and green (land to stream), while the stream channel area experiencing no change (stream to stream) is colored red. The processes of erosion and deposition can be seen clearly from this image; the stream erodes bank material in one area and deposits it downstream. The green area in the center of the study area shows how the outside of the stream meander is pushed outward, increasing the stream's sinuosity. In the lower right of the image in the upstream portion of the stream, large changes are visible. This is an area of the stream with several larger islands that have undergone changes, or where the stream channel changed from one side of an island to another.

Changes in the islands were also analyzed with cross-classification (Table 2.11). The interest was in determining how much of the island area of 1979 had remained the same within the stream channel, and how much had changed. Areas of change included areas of stream and land outside the stream channel moving to island and vice versa (islands moving to stream or land). Due to the nature of the cross-classification, areas being compared were island areas in 1979 and 1998, but the stream channel was not included.

Figure 2.4. Changes in the stream channel from 1979 to 1998

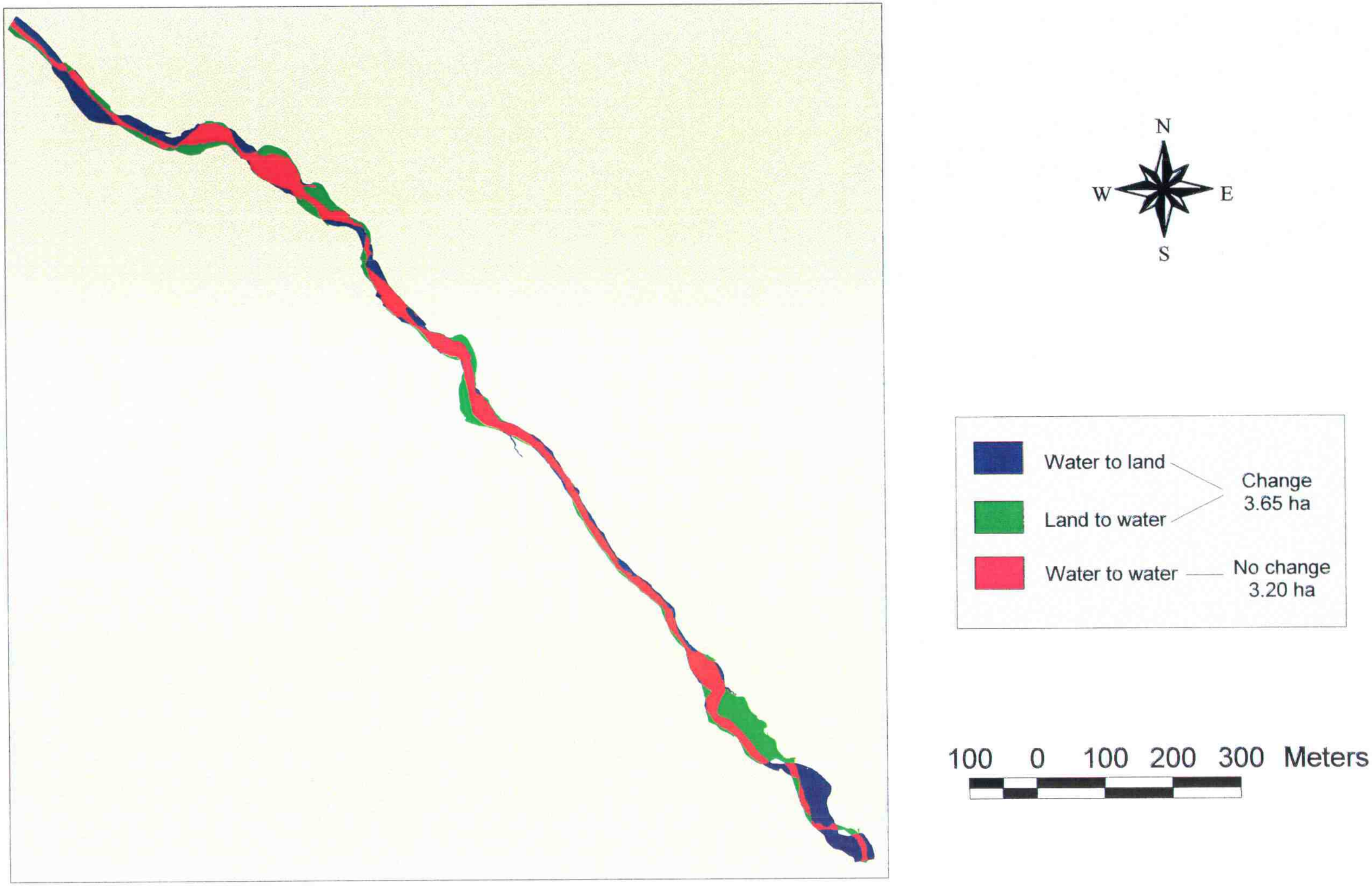


Table 2.11. Cross-tabulation matrix of island and 'not island' areas for 1979 and 1998 at Catherine Creek. The bold numbers represent areas of change, off-diagonal cells represent areas of no change. 'Not island' includes those areas that were not classified as island in either 1979 or 1998 and were left blank.

		1979		
		Not island	Island	Total
	Not island		**0.71**	
1998	Island	**1.55**	0.45	2.00
	Total		1.16	

For that reason, the area of 'not island' was left blank, since it consisted of the stream channel and the entire background of the image.

In this case, island area increased from 1.16 ha in 1979 to 2 ha in 1998, an increase of 72 %. The area of no change (0.45 ha) is very small compared to the areas of change (2.26 ha). The cross-tabulation image (Figure 2.5) shows areas of change in red and areas of no change in blue. It becomes obvious how much change occurred in island area. The nature of this change is further explained by the summary statistics derived from GIS layers and shown in Table 2.12.

While the total island area increased from 1979 to 1998 from 1.16 ha to 2 ha, the number of islands decreased from 50 to 23. Mean island perimeter increased from 62 m to 124 m, while minimum perimeter remained the same. Similar change was observed for mean island area, which increased dramatically (from 232 sqm to 868 sqm), while minimum island area remained relatively the same. These numbers indicate that although fewer islands occurred in 1998, they were much larger than they had been in 1979. This is obvious from studying the images, which also show more vegetation occurring on the islands. Observations of the images showed that what was a small island in 1979 had grown to a much larger, densely vegetated island in 1998.

Figure 2.5. Changes in the islands from 1979 to 1998

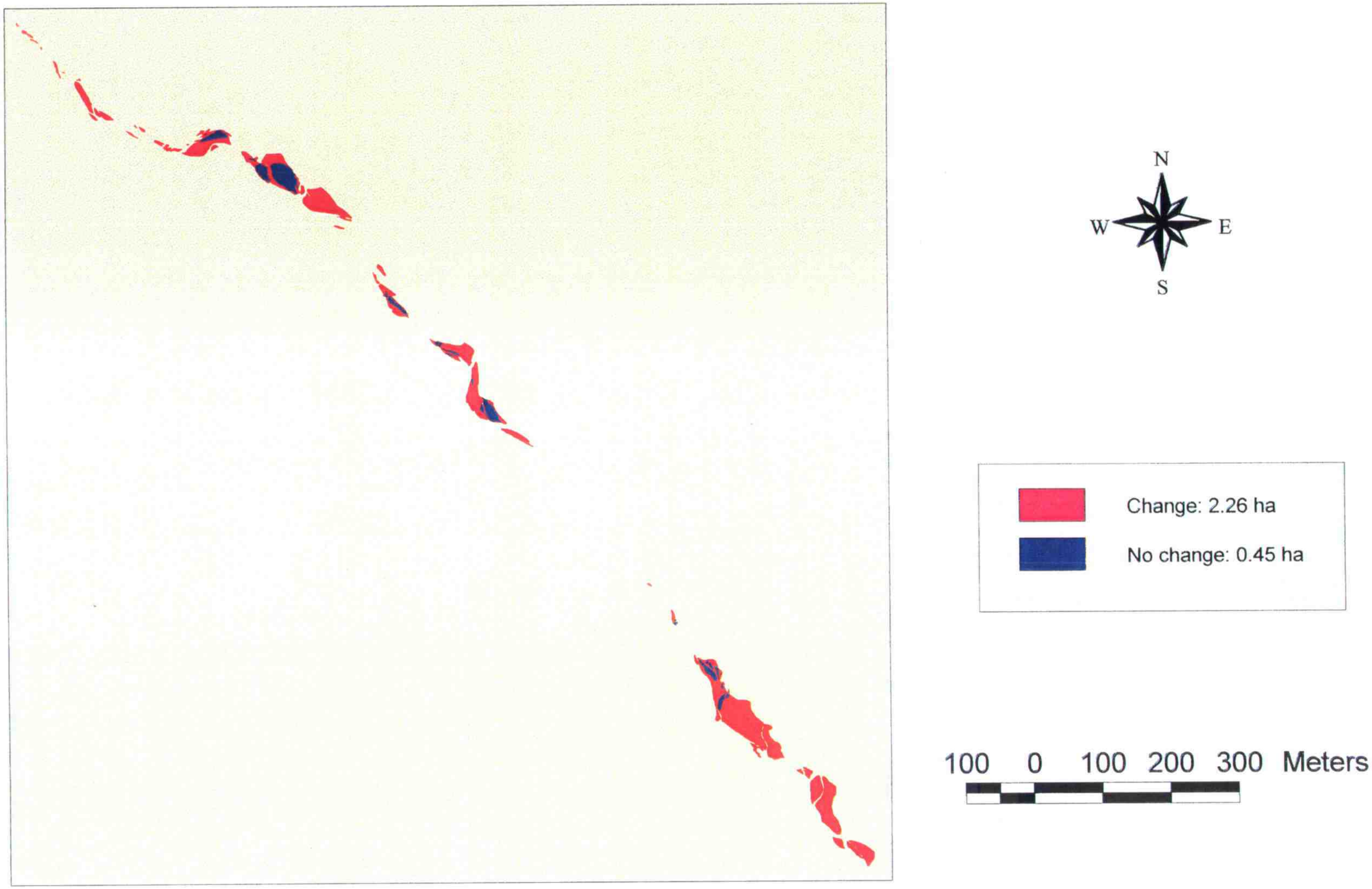


Table 2.12 Comparison of various measurements of Catherine Creek features from 1979 and 1998. Numbers were extracted from a GIS database.

Parameter	1979	1998	Change (%)
Length of left bank[1] (m)	2500.89	2544.64	1.75
Length of right bank (m)	2400.79	2374.96	-1.08
Stream perimeter (m)	4956.23	4948.18	-0.16
Stream area (sqm)	50962.53	49520.93	-2.83
Wetted area [2]	39352.97	29563.01	-24.88
Island area (sqm)	11609.56	19957.92	71.91
Mean	232.19	867.74	273.72
Max	2148.86	5962.06	177.45
Min	6.94	6.36	-8.36
Island perimeter (m)	3113.38	2853.87	-8.34
Mean	62.27	124.09	99.28
Max	250.52	470.06	87.63
Min	10.07	10.44	-2.43

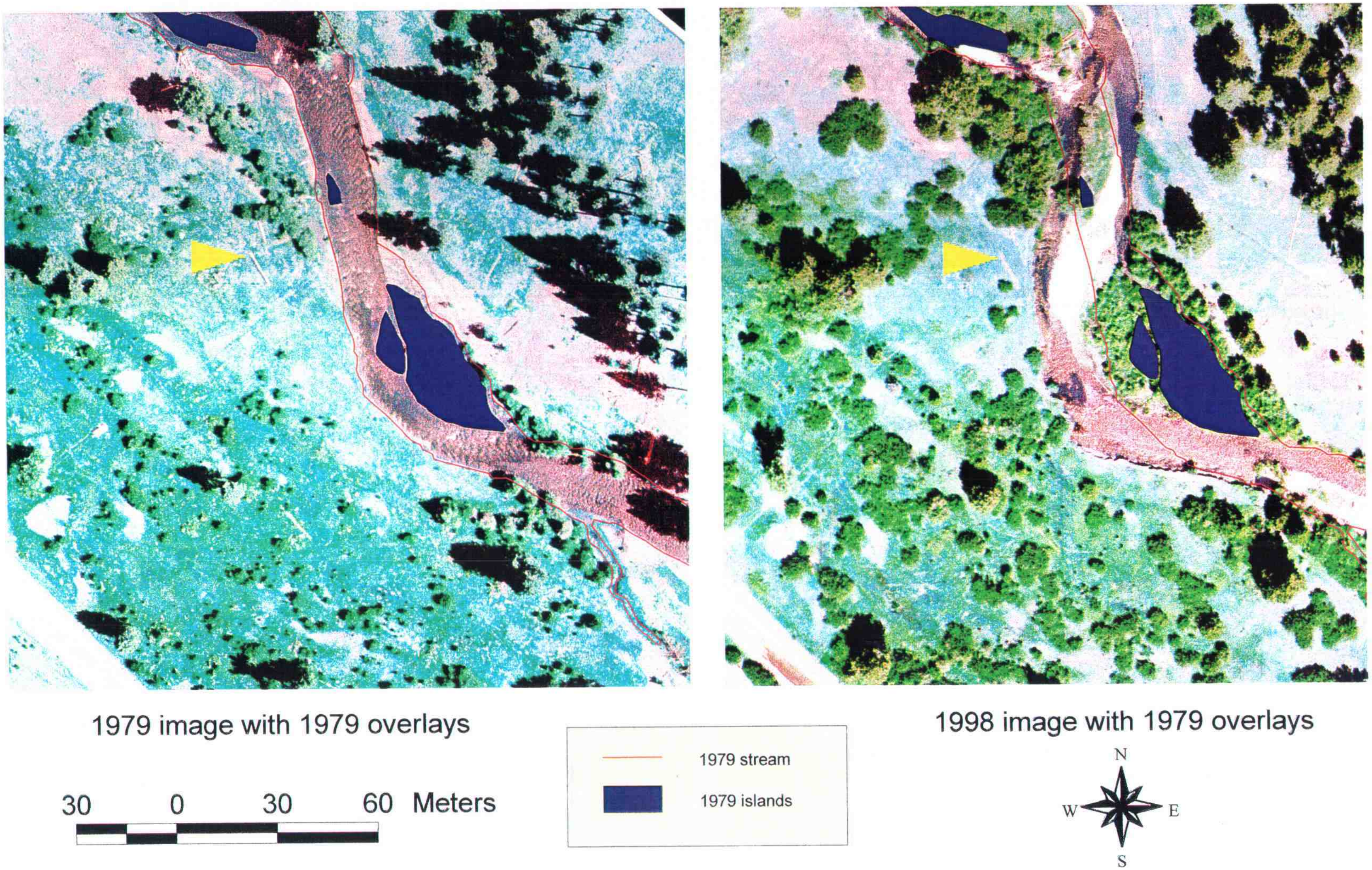
[1] Left bank looking upstream

[2] Wetted area = stream area minus island area

Figure 2.6 shows one such area. It appears that the small island began to capture sediments carried by the stream, and the island gradually grew in size by increasing this sediment capture, coupled with vegetation that was able to take hold on the island. Aerial photos from the years between 1979 and 1998 confirmed the gradual growth of this island.

Fewer, larger and more vegetated islands suggest an increase in stability occurring over the 19 years. The original increase in deposition may be related to the mid-70s landslide that resulted in large amounts of sediment being deposited over the years.

Figure 2.6. Stream morphology changes from 1979 to 1998. Arrows indicate the same log in both images



1979 image with 1979 overlays

1998 image with 1979 overlays

Other stream statistics

The length of right and left stream bank changed very little from 1979 to 1998, increasing 1.75 % from 2500 m to 2544 m for the left bank, and decreasing 1.08 % from 2400 m to 2375 m for the right bank (Table 2.12). Likewise, the stream perimeter remained almost the same (decrease of 0.16 %). The larger change in the wetted area (-24.88 %) can be explained by the changes observed in the islands. Although the stream area did not change much, the increase in island area within the channel reduced the size of the area actually covered by water.

In some areas, lateral movement of the channel was as much as 20 m, independent of island area change (Figure 2.6). In this particular location the stream eroded the outside of the meander, cutting into the bank, and depositing the material downstream. We observed deposition at downstream meanders and islands.

Another parameter of interest was length of thalweg and change in sinuosity, which is the ratio of stream length to valley length. Thalweg length was measured for both small and large-scale images; this allowed for a comparison of thalweg length and sinuosity over a period of 61 years. Figure 2.7 and Figure 2.8 show how these parameters changed over time.

The graph illustrates variability in thalweg length, with the highest value occurring in 1998; however, the increase from the lowest to highest value is relatively small: an increase of 6.3 % from 2287 m (1960) to 2430 m (1998). Likewise, an increase in sinuosity from 1.099 to 1.168 is not large. Rosgen (1996) uses sinuosity as one of his level II inventory criteria for determining stream type. Sinuosity carries the least weight of these criteria. However, a general guideline for high sinuosity in a C type stream is

Figure 2.7. Changes in the Catherine Creek thalweg from 1937 to 1998

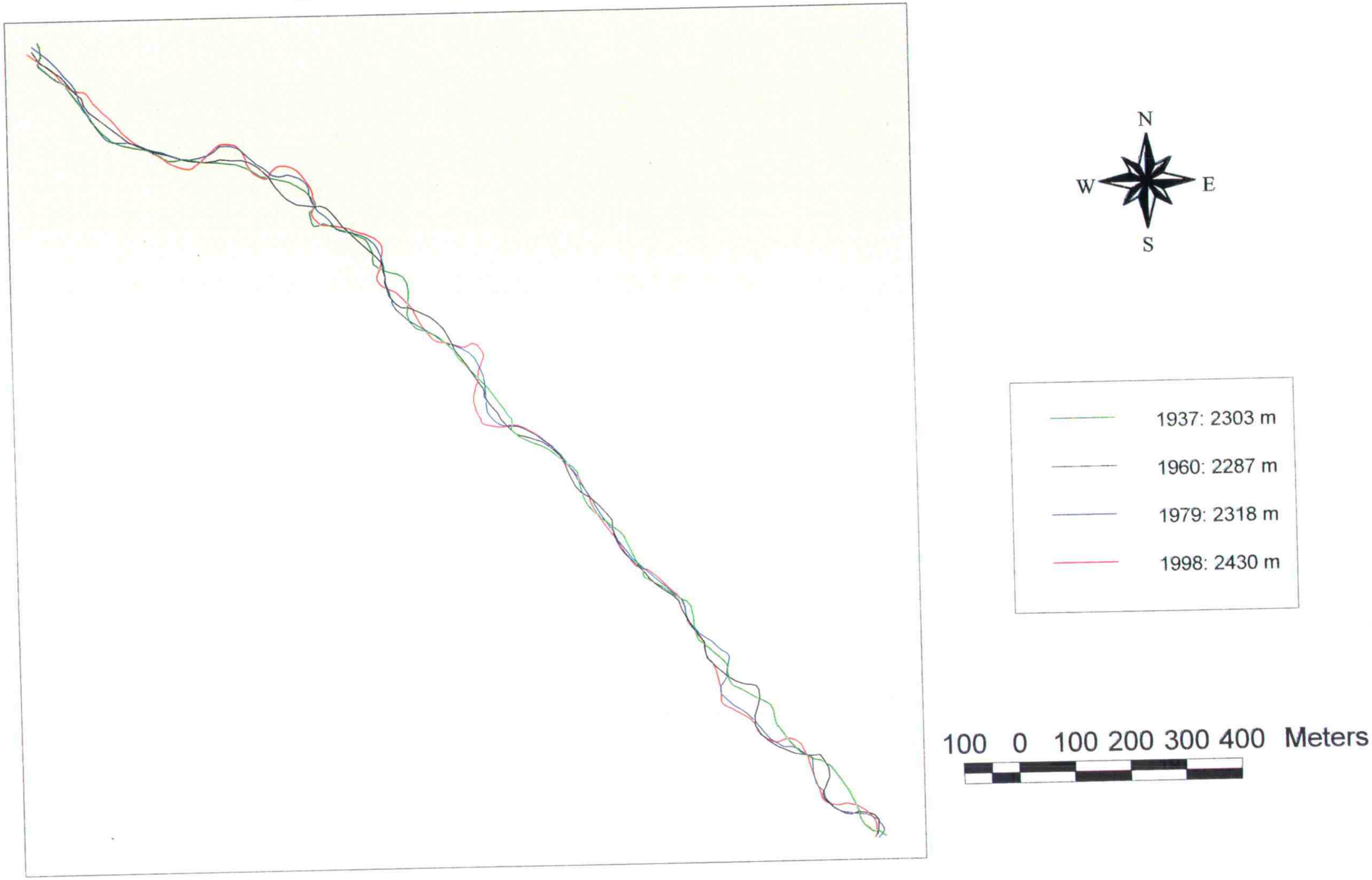
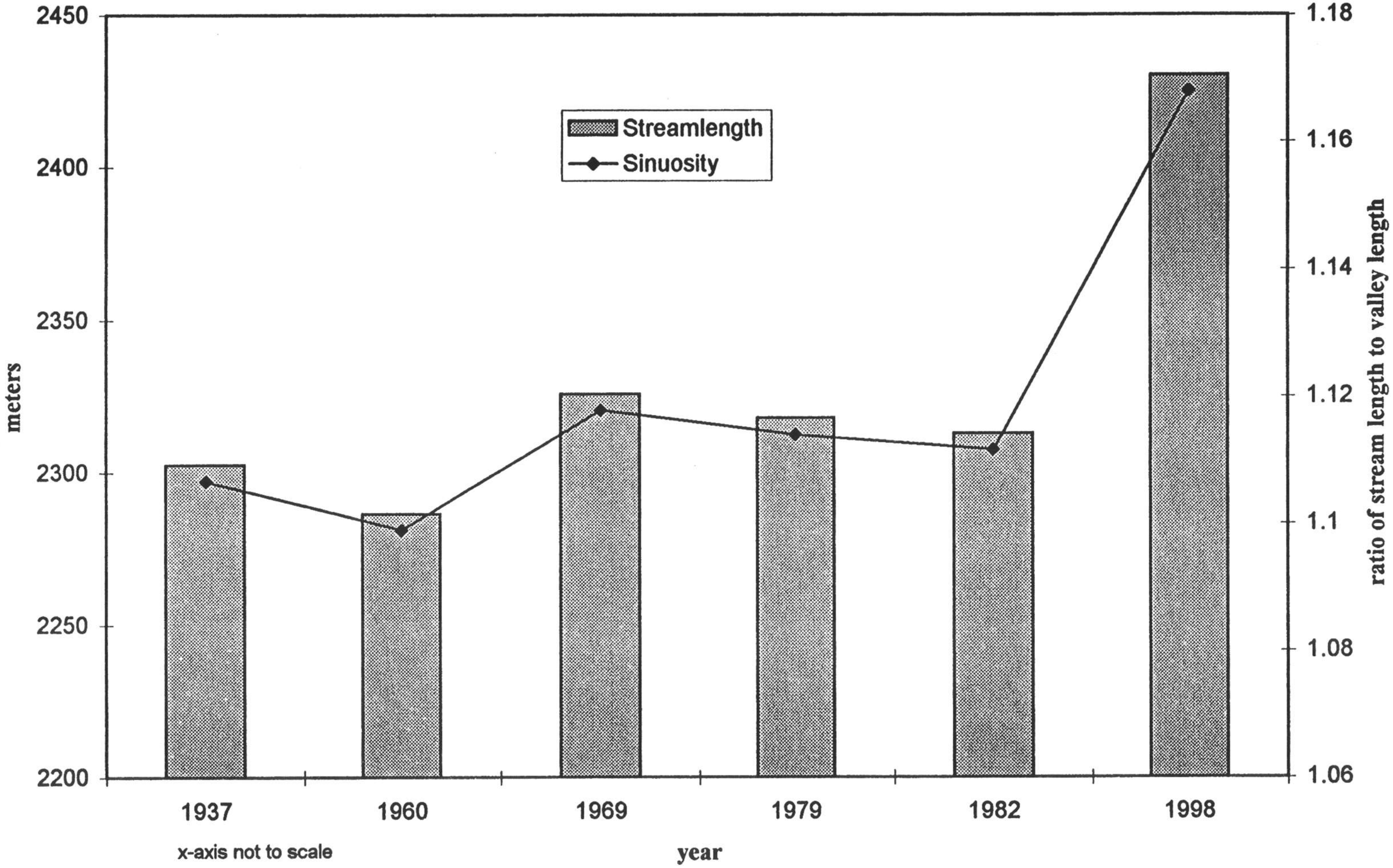


Figure 2.8. Changes in stream length and sinuosity of Catherine Creek over 61 years



>1.2, very high sinuosity in an E type stream is >1.5. In those calculations, sinuosity ratios can vary by +/- 0.2 units. Rosgen's (1996) work implies that the sinuosity change we observed is within normal range for C type streams.

The location of woody debris was digitized from the 1979 and 1998 images, but due to increased vegetation near the stream bank in the 1998 images, it was difficult to see the portion of the woody debris covered by bankside shrubs. It was concluded that although woody debris larger than 20 cm in diameter was clearly visible and could be digitized, the concealment by overhanging vegetation prevented an accurate measurement of its size. For that reason, woody debris size was not analyzed.

Determination of stream width

Stream width decreased in all exclosed and all grazed areas from 1979 to 1998 (Figure 2.9). Values for stream widths are displayed in Table 2.13. Mean stream width in exclosed sites decreased 36 % from 18.67 m to 11.85 m, compared to a 22 % width decrease in grazed areas from 16.62 m to 12.96 m.

This decrease in stream width has to be studied in conjunction with the change in island area. Since the stream width was calculated by excluding all islands, thereby measuring only wetted width, the decrease in stream width was related to the change in island area. In fact, when one looks at the overlay of island and stream outlines of both years, the large influence of the islands on stream width measurement becomes obvious.

However, it is not easy to discern a pattern at a larger scale, such as for grazed or

Figure 2.9. Mean stream width and standard deviation (in m) in exclosures and grazed areas in 1979 and 1998

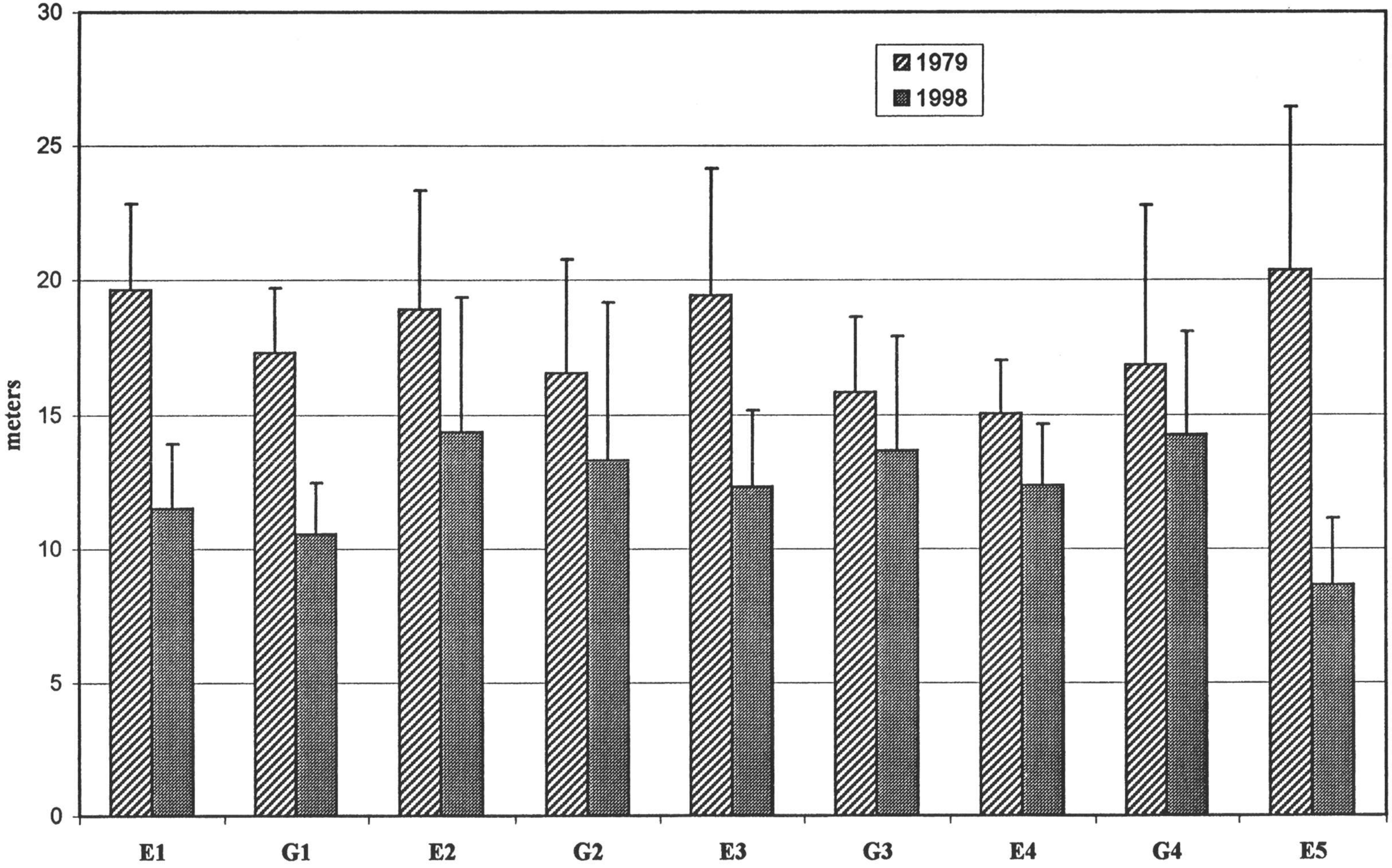


Table 2.13. Catherine Creek mean stream widths excluding islands for 1979 and 1998 in exclosures (E) and grazed areas (G). Stream width was measured every 0.5 m.

	1979	1998	Change
	(m)		(%)
E1	19.64	11.53	-41.29
E2	18.91	14.36	-24.06
E3	19.43	12.33	-36.54
E4	15.04	12.38	-17.69
E5	20.35	8.65	-57.49
G1	17.30	10.56	-38.96
G2	16.54	13.32	-19.47
G3	15.82	13.68	-13.35
G4	16.83	14.26	-15.27
Mean E	18.67	11.85	-36.54
Mean G	16.62	12.96	-22.06

exclosed sites. In one area (E3, Figure 2.10), a relatively large width decrease occurred concurrent with a large change in island area, while in E4 (Figure 2.11), a small change in width and a small change in island area occurred together.

On the other hand, the site of smallest change in stream width (G3) appears to have areas of little change, where the stream has remained straight, as well as areas of large increase in island area. G4 shows large changes in island area; however, these changes did not affect stream width to a high degree, since the channel split on either side of the island. In the area of largest stream width decrease (E5), there was also a large decrease in island area, causing the stream to become narrower. In E1, the stream tried to erode its banks near the road and was straightened by the Highway Department in 1990. This would account for the stream width decrease in that area.

These results show that over the whole length of the stream, one could observe an increase in island area and a narrowing of the channel, but locally (such as in E5), a

Figure 2.10. Changes in stream and islands in exclosure E3 and grazed area G3 from 1979 to 1998

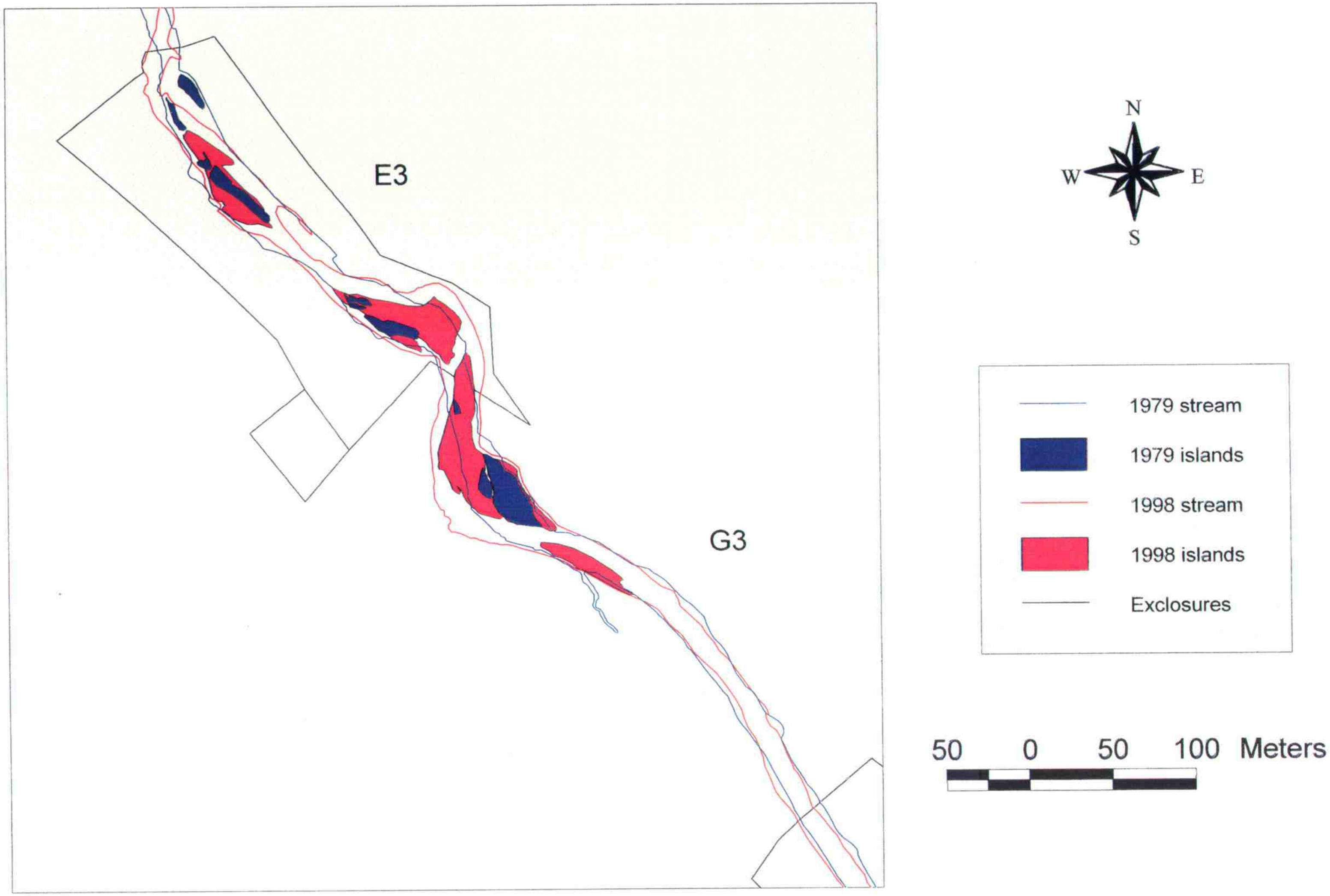
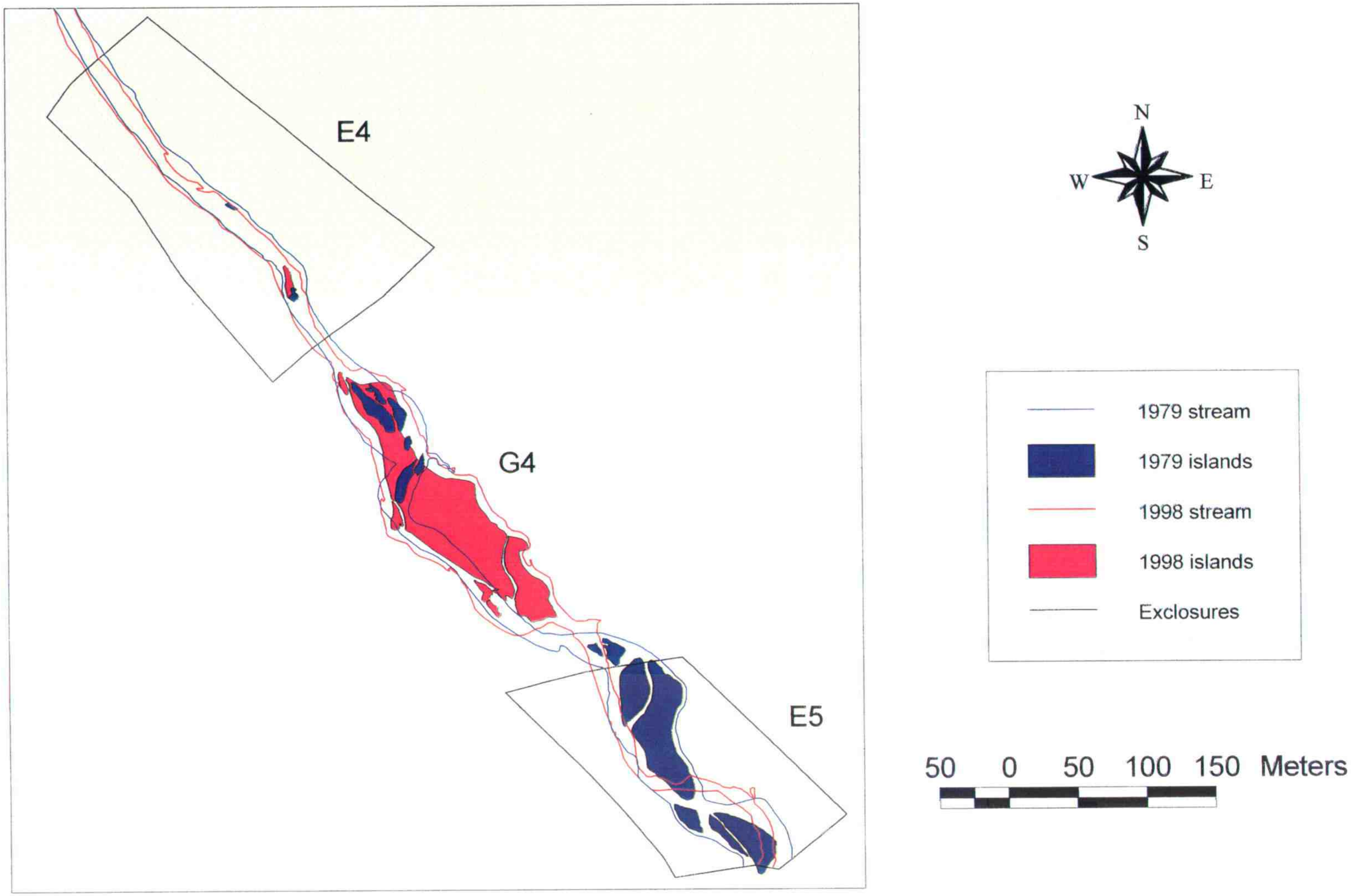


Figure 2.11. Changes in stream and islands in exclosures E4 and E5 and grazed area G4 from 1979 to 1998



decrease in island area was observed concurrently with narrowing of the channel in that section. This demonstrates the importance of scale when studying time change in a stream system. What occurs in one small area, may not reflect the response for 2.5 km of study area. The response of one exclosure did not reflect the response of all others. Since islands straddle fence lines in exclosed and grazed areas, the interaction of island change and stream width is difficult to interpret within these boundaries, and the assessment of the whole study area seems more appropriate for island change and its effect on stream width.

The stream width was highly affected by island morphology: if a stream section had a large island in the channel, with water flowing on either side, the stream width was narrower than it would have been without an island in that location. There was a large difference between a section of stream with one channel and another section where it flowed on either side of an island. Stream width as well as width to depth ratio are affected by these changes in stream morphology. When a stream becomes narrower, it also deepens. The narrowing of Catherine Creek, coupled with increased vegetation on islands and stream bank demonstrates a trend towards increased stability for this stream.

We did not find large differences between grazed and exclosed areas in our study. Medina and Martin (1988) found similar results and attributed similar channel width and depth changes in both treatment areas to other influences, such as wildfire and the particular hydrologic regime in their case.

At Catherine Creek, it appears that the topography, stream dynamics and the road have a larger impact on stream morphology than the grazing regime. The influence of local topography on channel morphology was also observed by Clifton (1989) in a central Oregon study relating vegetation and land use to channel morphology over a 50 year period. The author determined that temporal variability was related to exclusion of grazing, while spatial variability (between different stream reaches) was due to the prevailing riparian vegetation, input of large organic debris and local physiography. Specifically, channel width, wetted perimeter and channel shape were mostly correlated with local vegetation variability (Clifton 1989).

In streams bordered by trees, the input of large woody debris plays a considerable role in channel change. Large logs in the stream divert the flow of water and become sources of deposition and pools; bank erosion may be reduced or enhanced locally, and stream energy is dissipated (Keller and Swanson 1979). We observed similar channel changes in aerial photography from 1990, although those images had not been scanned and digitally analyzed at the same fine resolution of this study. A large Ponderosa pine tree fell in the stream in 1990, and in the photos of the following years, the diversion of water flow could be observed, leading to a knickpoint that moved downstream over the following years.

The impact of the road also has to be taken into consideration. In the 1937 aerial photo, the road is visible in the same location as it is today. Visits to the local museum in the town of Union confirmed that the hot springs upstream from the study area were a popular destination at the turn of the century. It is therefore assumed that the road has been in the same location for a long time. There is also evidence that the stream was moved to one side of the valley, possibly to accommodate the road. Old meanders visible on the aerial photography cross the road in several places. Large, old cottonwoods still remain near these meanders and are additional indicators of old stream channels. The remnants of these old channels were digitized from the images and overlaid on the map of the study area (Figure 2.12). Before Catherine creek enters exclosure E 5 at the southeast corner of the study area, the stream makes a sharp turn from flowing west to north-northwest, because it encounters the road. Rip-rap has been placed there by the highway department to reduce erosion. If the road were not present, the stream would continue on its westerly course, flowing in the old channel visible from the aerial photo.

For these reasons, it has to be assumed that the stream was moved over to accommodate the road and actions were taken over the years to reduce erosion at the point where road and stream met at a sharp angle. Further downstream, the road prevented the stream from flowing through its old channel, and the stream had to adjust to the lower sinuosity. This increased bank erosion, bar deposition and channel aggradation. The channel changes observed in portions of the stream may be the result of the stream's attempt at dealing with these changes.

Conclusions

Over the 19-year time period from 1979 to 1998, a variety of changes in stream morphology have taken place at the Catherine Creek study area. Some measured parameters changed to a large degree, others did not, and the observations can be categorized into those of small or large change. Parameters of small change included:

- The length of thalweg, and left and right streambank
- Sinuosity

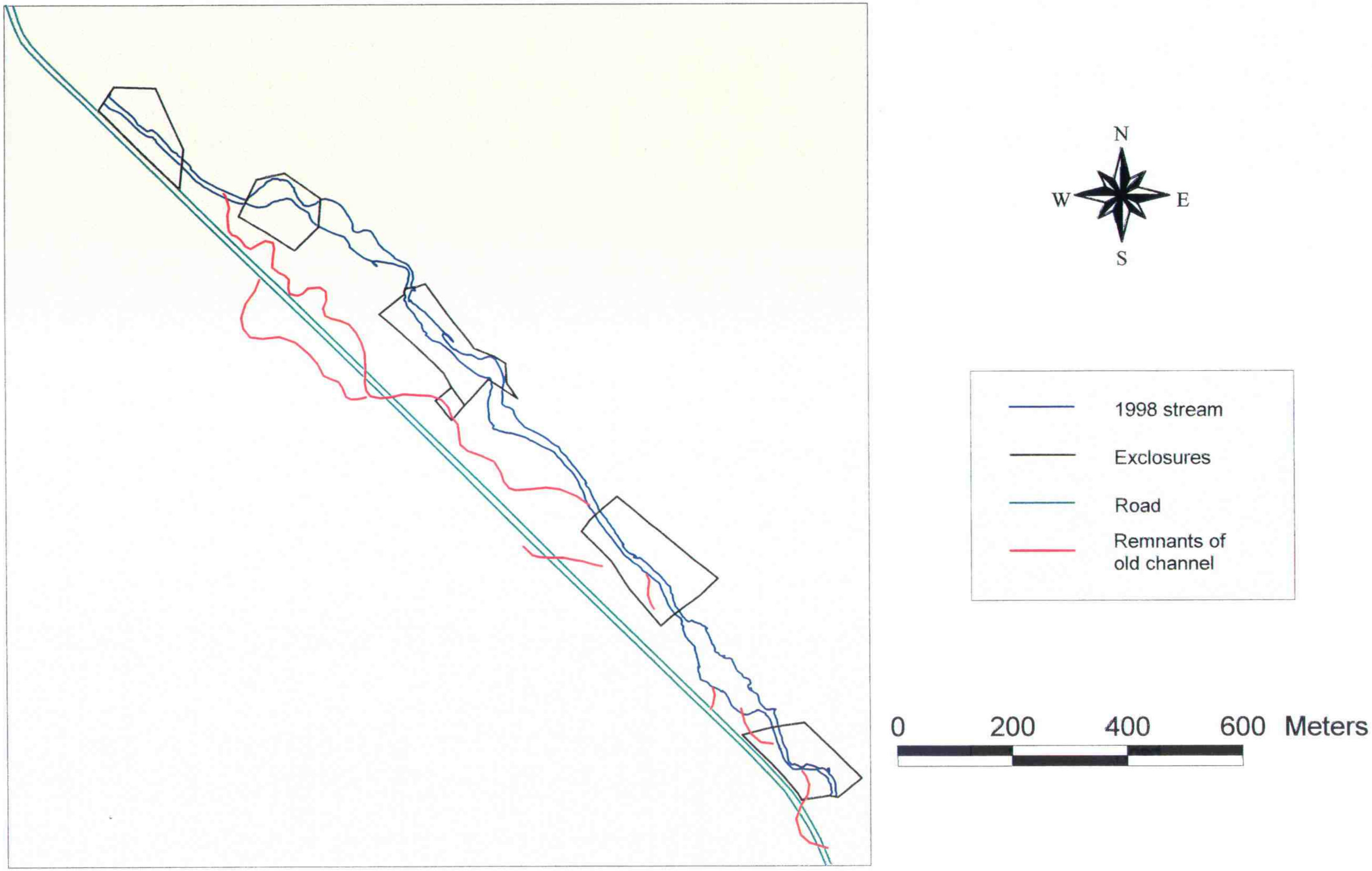


Figure 2.12. Study area in 1998 with overlay of old stream channel

- Stream perimeter
- Stream area (including islands)

Parameters of larger change were:

- Island area
- Island number
- Wetted area (excluding islands)
- Stream width

Although the stream area itself changed little, the results from the cross-classification showed that the area of change was almost equal to the area of no change, in terms of water changing to land, vice versa or remaining the same. It appears that at a small scale (i.e. the whole study area) the stream remains largely where it has been since 1979. On a larger scale however, localized changes become visible, for example, lateral movement of the stream bank or the increase in amplitude of some meanders, although this did not result in increased sinuosity. The topography of the area and the road prevent a large increase in sinuosity. Any large change observed seemed to be connected with the islands: their area increase or decrease affected the wetted area and therefore the stream width.

Several signs of increased stability have become apparent in this area over the time period studied. The decrease in island number and increase in island area coupled with increased vegetation on the islands demonstrates this trend. Narrowing of the stream is usually associated with greater stream depth and better fish habitat, although the lack of stream depth data for 1979 prevents us from making any detailed conclusions about changing stream depth.

Stream width decreased in grazed and exclosed area, but was smaller in grazed sites. However, the reason for width decrease was tied to the island changes, and it was observed that both an island area increase and decrease could result in a narrower stream.

The lack of distinct responses for grazed or exclosed areas suggests that the topography, stream dynamics (erosion, deposition and especially island formation) and the road have a larger impact on stream morphology than the grazing regime in this particular system.

Catherine Creek is confined by steep hills on one side and a road on the other. This is especially true in the upper 1/3 of the study area. In the lower portion (E1), the stream tried to erode its banks near the road and was straightened by the Highway Department. Rip-rap was added at the upper end near E 5. If allowed to run its course without the road, the stream would have had more meanders and increased sinuosity. Today, areas for sinuosity increase or change in meanders appear to be limited due to topography and the road.

The use of remote sensing, GIS/GPS and ground truthing provided a definite advantage over only ground data collection. Many of the statistics are quickly extracted from the GIS database for analysis. Other parameters would be difficult or nearly impossible to attain without these techniques. For example, a cross-classification is valuable in time change analysis, since it yields areas that have changed from land to water and vice versa. Without the GIS, it would have been time consuming to produce. The ability to overlay many features and measure distances on-screen is helpful in analyzing change. The visual aspect of GIS allows the user to perceive changes where they may not be obvious otherwise. Not many time change analysis studies have been done at such a large scale (1:4000), but this project demonstrates that it can be done successfully.

Literature Cited

Anderson, G.L. 1996. The application of spatial technologies for rangeland research and management: state of the art. Geocarto 11(3):5-11.

Bohn, C.C. and J.C. Buckhouse. 1985. Some responses of riparian soils to grazing management in northeastern Oregon. J. Range Manage. 38(4):378-381.

Bryant, L.D. 1985. Livestock management in the riparian ecosystem. In: Riparian ecosystems and their management; reconciling conflicting uses. Proceedings of 1st North American Riparian Conference. April 16-18, 1985. Tucson, AZ. USDA Forest Service Gen. Tech. Rep. RM-120. Rocky Mt. Forest and Range Experiment Station. pp. 285-289.

Buckhouse, J.C. and W. Elmore. 1993. Grazing practice relationships:predicting riparian vegetation response from stream systems. In: T.E. Bedell (Ed.). Watershed management guide for the Interior Northwest. Oregon State University Publication EM 8436. Agricultural Communications, OSU, Corvallis, OR. pp. 47-52.

Clifton, C. 1989. Effects of vegetation and landuse on channel morphology. In:Greswell, R.E., B.B. Barton and J.L. Kershner (ed.) Practical approaches to riparian resource management, an educational workshop. May 8-11, Billings, MT. US BLM: 121-129.

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Co., San Francisco, CA: 818 pp.

Eastman, J.R. and J.E. McKendry. 1991. Change and time series analysis. Explorations in Geographic Information Systems Technology, Vol. 1. United Nations Institute for Training and Research, Geneva, Switzerland. 78 pp.

ERDAS®, Inc. 1997. ERDAS® Field Guide™, Version 8.3.1, Atlanta, GA. 655 pp.

ESRI (Environmental Systems Research Institute). 1996. Getting to know ArcView. Environmental Systems Research Institute, Redlands, CA.

Everitt, J.H. and C.J. Deloach. 1990. Remote sensing of Chinese tamarisk (*Tamarix chinensis*) and associated vegetation. Weed Sci. 38:273-278.

Everitt, J.H., D.E. Escobar, R. Villareal, M.A. Alaniz and M.R. Davis. 1993. Integration of airborne video, global positioning system and geographic information system technologies for detecting and mapping two woody legumes on rangelands. Weed Tech. 7:981-987.

Ferguson, R.L., L.L. Wood and D.B. Graham. 1993. Monitoring spatial change in seagrass habitat with aerial photography. Photogramm. Eng. Rem. Sens. 59(6):1033-1038.

Golden, M., J.Johnson, V. Landrum, J. Powell, V.Varner and T. Wirth. 1996. Guidelines for the use of digital imagery for vegetation mapping. EM-7140-25. USDA Forest Service. Engineering Staff. Washington, D.C. 125 pp.

Green, M.D. and J.B. Kauffman. 1995. Succession and livestock grazing in a northeastern Oregon riparian ecosystem. J. Range Manage. 48:307-313.

Hinckley, T.K. and J.W. Walker. 1993. Obtaining and using low altitude large scale imagery. Photogramm. Eng. Rem. Sens. 59(3):310-318.

Johnson, D.E, N.R. Harris, S. du Plessis and T.M. Tibbs. 1995. Mapping and analysis of Catherine Creek using remote sensing and geographic information systems (GIS). In: Eastern Oregon Agricultural Research Center Field Day Annual Report, Special Report 951, July 1995:10-26.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications - a review. J. Range Manage. 37(4):430-348.

Keller, E.A. and F.J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4:361-380.

Kondolf, G.M. 1993. Lag in stream channel adjustment to livestock exclosure, White Mountains, California. Restor. Ecol. 1:226-230.

Magilligan, F.J. and P.F. McDowell. 1997. Stream channel adjustments following elimination of cattle grazing. J. Amer. Wat. Res. Assoc. 33(4):867-878.

Marlow, C.B. and T.M. Pogacnik. 1985. Time of grazing and cattle-induced damage to streambanks. In: Riparian ecosystems and their management; reconciling conflicting uses. First North American Riparian Conference, April 16-18, 1985, Tucson, AZ. USDA Forest Service, Gen. Tech. Rep. RM-120, pp. 279-284.

Medina, A.L. and S.C. Martin. 1988. Stream channel and vegetation changes in sections of McKnight Creek, New Mexico. Gr. Bas. Natur. 48(3):373-381.

Meehan, W.R. and W.S. Platts. 1978. Livestock grazing and the aquatic environment. J. Soil Wat. Cons. 33(6):274-278.

Miller, J.R., T.T. Schulz, N.T. Hobbs, K.R. Wilson, D.L. Schrupp and W.L. Baker. 1995. Changes in the landscape structure of a southeastern Wyoming zone following shifts in stream dynamics. Biol. Conserv. 72:371-379.

Roath, L.R. and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range in the southern Blue Mountains of Oregon. J. Range Manage. 35(3):332-338.

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO. 8-43.

Roth, N.E., J.D. Allan, and D.L. Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. Landscape Ecology 11(3):141-156.

Strong, L.L., R.W. Dana and L.H. Carpenter. 1985. Estimating phytomass of sagebrush habitat types from microdensitometer data. Photogramm. Eng. Rem. Sens. 51:467-474.

Trimble Navigation. 1996. Trimble Pathfinder Office^{TM}, Software Reference Guide. Trimble Navigation Ltd., Sunnyvale, CA.

Tueller, P.T. 1996. Near-earth monitoring of range condition and trend. Geocarto Int. 11(3):53-62.

Tueller, P.T., P.C. Lent, R.D. Stager, E. A. Jacobson and K.A. Platou. 1988. Rangeland vegetation changes measured from helicopter borne 35 mm aerial photography. Photogramm. Eng. Rem. Sens. 54(5):609-614.

United States Department of Agriculture Forest Service Global Positioning Systems page. 1999. Online. http://www.fs.fed.us/database/gps/ (Accessed Sept.12, 1999).

United States Geological Survey page. 1999. Online. National Water Information System(NWIS) data retrieval. Water resources data for Oregon. http: waterdata.usgs.gov nwis w O index.cgi statnum 13320000 (Accessed Mar.6, 1999).

Vavra, M. Superintendent, astern Oregon Agricultural esearch Center, Union, O . Personal communication, Aug.31, 1999.

Warner, W.S., R.W. Graham and R.E. Read. 1996. Small ormat Aerial Photography. American Society for Photogrammetry and emote Sensing. Whittles Publishing, Scotland, UK. 3 8 pp.

Warren, P. L. and C. Dunford. 1986. Sampling semiarid vegetation with large scale aerial photography. ITC ournal :273 279

Chapter 3

Time Change Analysis of a Northeastern Oregon Riparian Ecosystem: Vegetation Changes at Catherine Creek from 1979 to 1998

Andrea S. Laliberte[1]

---

[1] Department of Rangeland Resources
Oregon State University
Corvallis, OR, 97333-2218, USA

Abstract

Vegetation change over time is often analyzed with the help of remote sensing, Geographic Information Systems (GIS), Global Positioning Systems (GPS) and ground truthing. However, the use of large-scale aerial photography is less common. The objectives of this study were to examine changes in vegetation cover that had occurred in a riparian area over 20 years, and to determine the feasibility of using large scale aerial photography, GIS and GPS techniques as a tool for assessing change over time. The 2.5 km long study area, consisting of a stream and riparian area was separated into exclosures and grazed areas in 1978. Aerial photos from 1979 and 1998 (scale of 1:4000) were geo-corrected with ground control points, and various stream features were digitized using a GIS. Supervised classification of the images was used to classify ground cover into 5 classes: grass, shrub/tree, gravel, water and shadow. The shrub/tree cover increased over the whole study area from 23% to 34%. Increases were also seen in all exclosures and grazed areas except one exclosure where the cover remained the same. Large variability in shrub/tree cover was observed within as well as between exclosures and grazed areas. It was concluded that the grazing regime did not have a large influence on the shrub increases in this study. The use of large-scale aerial photography, GIS and GPS proved to be a powerful tool for detecting vegetation change and it is expected that these techniques will become more common in rangeland analysis in the future.

Introduction

A large component of range monitoring consists of measuring vegetation parameters, such as biomass, frequency and percent cover. These parameters often change over time, and may reflect climatic or managerial impacts. Considerable research has been done concerning the effects of livestock grazing on riparian vegetation (Meehan and Platts 1978; Roath and Krueger 1982; Kauffman and Krueger 1984; Bryant 1985). The animals are attracted to riparian areas for their lush, nutritious forage, shade and proximity to water. In one eastern Oregon study, it was determined that 81 % of total vegetation grazed by livestock came from a riparian zone accounting for only 1.9 % of total land area (Roath and Krueger 1982). All these studies depend on measuring vegetation parameters in one way or another.

Vegetation measurements can be time consuming, may be destructive if plots are clipped and are often based on visual estimates of percent cover (Daubenmire 1959; Pieper 1973). However, if remote sensing techniques such as color aerial photography are used, and the images are analyzed digitally, the result is not merely an estimate of cover but an actual measurement. In addition, an error assessment can be associated with that measurement (Rosenfield and Fitzpatrick-Lins 1986).

Over the last decade, much progress has been made in the fields of remote sensing, global positioning systems (GPS) and geographic information systems (GIS) (Anderson 1996). Satellite imagery and aerial photography have been used to detect the amount of weeds on rangeland (Anderson et al. 1993; Everitt and Deloach 1990), to assess shrub cover and phytomass (Strong et al. 1985), to monitor spatial change in seagrass habitat

(Ferguson et al. 1993), and a combination of aerial video, GPS and GIS was used to map rangeland legumes (Everitt et al. 1993).

Although these techniques are used in many studies, there are few research projects looking at long-term change in riparian areas and streams. Miller et al. (1995) examined changes in the landscape structure on the North Platte River. The authors examined aerial photos from 1937 and 1990, and found substantial landscape change. Young, dense cottonwood stands in 1937 had changed to older, more open stands in 1990. The amount of landscape change decreased with increasing distance from the river. Brown and Arbogast (1999) analyzed changes occurring over a 22-year period along the shores of Lake Michigan. They were able to define the movement of sand in coastal dunes and map changing patterns on the landscape. Simpson et al. (1994) examined landscape changes occurring over 48 years in Ohio.

Few studies involving remote sensing use large-scale aerial photography. Tueller (1996) defines large scale, near earth remote sensing as scales larger than 1:10000, with an optimum scale around 1:1000. The advantage of low level aerial photography lies in its high resolution, which facilitates interpretation of parameters in the photos (Golden et al. 1996; Warner et al. 1996). Tueller et al. (1988) used large scale (1:560 to 1:1650) aerial photography for assessment of rangeland vegetation and concluded that it was an effective method for detecting changes in shrubs and other ground cover. Warren and Dunford (1986) conducted a similar study. They compared ground measurements of vegetation with dot-grid and line intercept measures on photos and found good correlation between the two methods at scales ranging from 1:200 to 1:3000.

Increased resolution is of interest to everybody involved with remote sensing. In satellite imagery, the trend has gone to smaller scale imagery for larger areas due to better sensor capability. In aerial photography, large scale images are being used increasingly in various fields, including archeology, anthropology and a number of studies that require high resolution, including measuring methane production from landfills or assessing sprinkler irrigation trials (Hinckley and Walker 1993).

Each project requires a different approach for change detection. Some of the most commonly used are image subtraction, image ratioing, and principal components analysis (Singh 1989). However, these techniques require corrections for atmospheric and sensor differences between the two dates. For example, the choice of camera and focal length affects edge distortion and resolution in the images. Image quality and geocorrection accuracy greatly influence the results, especially in the case of image subtraction. If two images of the same area differ greatly in resolution, quality and ground accuracy, a simple image subtraction could potentially yield large areas of change (Lillesand and Kiefer 1994). Under these constraints, change detection may be achieved by other means. The vegetation can be classified separately for two dates, and the values for percent cover can then be compared. Often, the interest lies in measuring not only the amount of change, but in acquiring specific numbers of vegetation cover for the years studied and comparing them.

In digital image analysis, the process of categorizing all the pixels in an image into land cover classes is called image classification (Lillesand and Kiefer 1994). It is based on different spectral reflectance values of vegetation, water, soil, etc. between the bands present in the image. In a color image, these would consist of the red, green and blue bands. Two types of classification exist: unsupervised and supervised. In an unsupervised classification, the computer determines differences in reflectance values between the bands automatically by using cluster analysis. The classification is based on the number of user-determined classes. The more classes are chosen, the more differentiated the output becomes. With fewer classes, pixels from different land cover classes may be lumped together. In a supervised classification, training sites are established. These are areas of known land cover outlined on the image. The computer then places each pixel into the class it most closely resembles based on the training sites (Lillesand and Kiefer 1994).

In both types of classification, an accuracy assessment of the data has to be performed. A comparison of the classified data with the actual ground cover determined from ground truthing is commonly summarized in an error matrix. The Kappa Index of Agreement (KIA), a correlation coefficient ranging from 0 to 1, is another indicator of classification accuracy (Rosenfield and Fitzpatrick-Lins 1986).

The photos showed an increase in shrub and tree cover, and the purpose of this study was to measure this increase using the same methods employed for mapping vegetation and assessing changes in satellite imagery and small-scale aerial photography. Since the large-scale aerial photos had very good resolution, it was hoped that this would yield detailed results.

The objectives of this study were:

- To assess changes in vegetation in space (between grazed and ungrazed areas) and time (1979 to 1998).

- To assess the viability of using large-scale (1:4000) aerial photography combined with GIS/GPS and ground truthing in time change analysis.

Study Site

The study area is located in northeastern Oregon, about 15 km southeast of Union on the Hall Ranch, which is operated by the Eastern Oregon Agricultural Research Center (EOARC). Catherine Creek runs for a length of 2.5 km through the study area, which is 41 hectares in size. The elevation of the stream and meadows is approximately 990 m HAE (height above the ellipsoid). The height was computed using the National Geodetic Survey GEOID 96 model. Catherine Creek is a third order tributary to the Grande Ronde River. About 5 km (3 miles) downstream from the study area, the US Geological Service, Water Resources Division operates a stream gauging station (Number 13320000), which has provided relatively continuous flow records since 1911, however, the gauging station was discontinued in 1996. The average discharge from 1979 to 1995 was 3.3 m^3 / sec (Appendix 1); peak flows generally occur in April and May, associated with snow melt runoff, while low flow conditions last from August to early February (United States Geological Survey 1999). A typical hydrograph for Catherine Creek from 1979 is shown in Appendix 2.

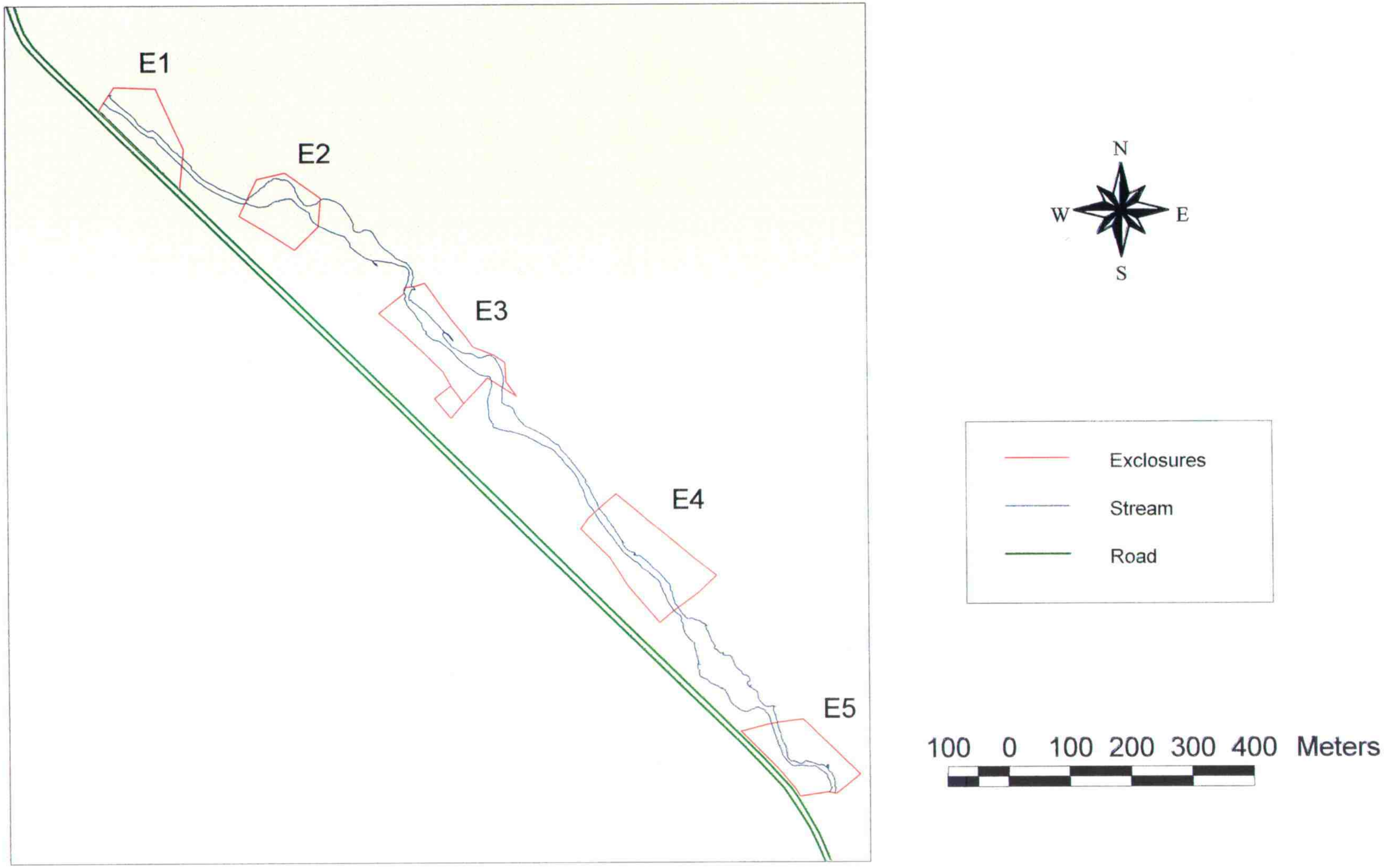
Mean annual precipitation measured at the Eastern Oregon Agricultural Research Center was 35 cm (1912-1998 data) and 38 cm (1979-1998 data), while mean annual temperature was recorded at 8.7 degree Celsius (1979-1998 data) (Appendix 3 and 4).

Prior to 1978, this area was grazed under a season long grazing regime. In 1978, five exclosures were constructed in the study area; they straddle the stream and alternate with grazed areas, so that the linear run of the stream is divided equally into exclosed and grazed sites (Figure 3.1). Since 1977, the study area has been grazed for 3-4 weeks in the fall to a utilization level of 70 %, and a stubble height of 5 cm on Kentucky bluegrass. Table 3.1 shows the Animal Unit Months (AUM) for the Catherine Creek study site since 1977.

Table 3.1. Grazing period and AUMs (Animal Unit Months) for the Catherine Creek study area.

Year	Grazing Period	AUMs
1977	Aug 17 – Sept 2	72.4
1978	Aug 23 – Sept 13	63.8
1979	Aug 27 – Sept 17	56.8
1980	Aug 23 – Sept 16	90.0
1981	Aug 27 – Sept 16	59.3
1982	Aug 26 – Sept 15	40.7
1983	Aug 22 – Sept 11	57.7
1984	Aug 23 – Sept 13	63.8
1985	Aug 16 – Sept 4	66.5
1986	Aug 15 – Sept 3	67.9
1987	Aug 18 – Sept 14	60.5
1988	Aug 23 – Sept 20	43.5
1989	Aug 16 – Sept 28	46.6
1990	Aug 20 – Sept 10	16.8
1991	Aug 29 – Sept 11	53.5
1992	May 5 – June 1 and	9.0
	Aug 6 – Aug 19	56.0
1993	Aug 23 – Sept 13	47.6
1994	Aug 17 – Sept 12	22.3
1995	Aug 22 – Sept 8	32.4
1996	Aug 13 – Sept 11	47.7
1997	Aug 12 – Sept 10	39.3
1998	Aug 17 – Sept 15	59.9

Figure 3.1. Layout of the study area with 5 exclosures and outline of Catherine Creek in 1998



In 1958, and again in 1974/75, hawthorns were removed from the Hall Ranch at a distance of 50 m from the stream for pasture improvement. The shrub was piled and burned, and the pasture was not seeded afterwards. In the mid-70s, a large landslide occurred on the middle fork of Catherine Creek within the wilderness boundary. Sediment discharge occurred in the following years after every rainfall (M.Vavra, pers.comm.).

Methods and Materials

Aerial photography and ground targets

The aerial photography used in this study consisted of images of roughly two different scales. For the two main time periods of interest, 1979 and 1998, large-scale photography of 1:3100 and 1:4000 was used. While the study was in progress, older photography at a smaller scale (1:18,000) became available and was used as supplementary information. At that scale, only one image covered the whole study area, and the resolution was lower compared to the large-scale images. Table 3.2 contains information for the images used for this study.

Table 3.2. Date, scale, type and number of aerial photos taken of the Catherine Creek study area.

	Large scale		Small scale			
	1979	1998	1937	1960	1969	1982
Date flown	June 28	Aug 3	Sept 10	Aug 6	Aug 3	June 16
Scale	1:3100	1:4000	1:21000	1:14300	1:19400	1:18300
Type	Color	Color/CIR	B/W	B/W	B/W	Color
# of photos	10	8	1	1	1	1

CIR: color infrared   B/W: black and white

The 1998 aerial photos were taken with a large-format mapping camera with a focal length of 305.252 mm, using 24 cm film. The study area was photographed with both color and color infrared film. Photos were shot with 60 % overlap, with eight images covering the study area. The resulting scale was 1: 4000. The 1979 color aerial photos were taken with a Hasselblad camera fitted with a 80 mm lens using color negative film. No fiducial marks were present. Ten photos covered the study area, with an overlap of 10 %, and the scale was 1: 3100. The 1998 photos were of a higher resolution and better quality, with less distortion occurring near the photos' edges. All of the smaller scale images were taken with mapping cameras.

In 1998, one hundred and two targets were distributed in open areas all over the study site. These targets would become ground control points for geo-correction of the aerial photos. Targets used were one square foot paving stones, painted white, secured with metal rods and numbered consecutively from 1 to 102. Each target was geo-positioned using two Trimble® Pathfinder Pro XL® differential global positioning (DGPS) receivers with data loggers. One GPS unit was used as a base station, the other as a rover, and a phase processing mode was used with a residence time of 12 minutes. All points were differentially post-corrected by downloading the necessary data from the US Forest Service GPS page maintained on the Internet (USDA Forest Service GPS page 1999). The targets were positioned with an average Northing error of 7 cm, an Easting error of 14 cm, and an elevational error of 14 cm. Target positions were expressed in Universal Transverse Mercator (UTM) coordinates. The target positions were displayed as a map with GPS software (Trimble Navigation 1996) and converted to a GIS vector file format as well as a spreadsheet containing UTM coordinates of target positions.

Image processing and geo-correction

In general, vegetation classification is performed on un-rectified images, since some information may get lost due to the correction process. In this case, however, the images were rectified, because the exclosed and grazed areas had to be clipped from the images for comparison. For that reason, the vector files containing the exclosures had to be overlayed on the 1979 and 1998 images, and geo-correction is a necessary first step for overlaying GIS files. Since the ground features would have been too difficult to identify on the classified images, it would not have been possible to perform rectification after the classification process.

The 1998 images were corrected first, using the white targets that were easily identified on the photos. The 1998 images would then become the baseline for measurements and comparison of ground features with the 1979 images, and the smaller scale photography from all other years. Aerial photos were scanned with a Hewlett-Packard® ScanJet® 6100C flatbed scanner at a resolution of 600 dpi (dots per inch). Although this created large image files of 85 megabytes, a high resolution was necessary for determination of ground features. Color images were saved in a 24-bit Tagged Image File Format (TIFF) after scanning, and then imported into the digital image processing program.

The 1998 images were geo-corrected using the software program ERDAS Imagine® (ERDAS® Inc. 1997), using a second order polynomial geo-correction operation. Ground control points were located on the image on-screen and then assigned the correct UTM coordinates for each target. On average, 15 targets were visible per image and used for corrections. As a projection type the World Geodetic System (WGS) 84, with a UTM Zone 11 coordinate system was used. The Root Mean Square (RMS) error for this process was 1.56 (average for 8 images), with a pixel size of 10 cm, resulting in a ground accuracy of 16 cm.

According to the 1947 Revision of the United States National Map Accuracy Standards, 90 % of tested points on maps with scales larger than 1:20,000 must have an error of less than 1/50 of an inch. This means that 90 % of accidental errors shall not be larger than 1.64 times the RMS (i.e., 1.64 standard deviations, assuming a normal distribution of errors; 1.64 is the z score probability of occurrence).

Following is a calculation for the allowable RMS for a map with a 1:4000 scale.

Allowable RMS = Acceptable error on the ground / 1.64

Acceptable error on the ground = Map error * scale conversion * units conversion
= 1/50 inch * 4000 * 0.0254 meters/inch
= 2.032 meters

Allowable RMS = Acceptable error on the ground / 1.64
= 2.032 meters / 1.64
= 1.24 meters

This means that the ground accuracy of 16 cm achieved in the geo-correction of the 1998 images was well below the US National Map Accuracy Standard.

Once all 1998 images had been rectified, the 1979 images were geo-corrected using the 1998 images as a baseline. Since both images were projected on-screen simultaneously, identifying the same points on two different images was simplified for the geo-correction process. Again, a second order polynomial geo-correction operation was used.

The image analysis program used offers several processes for geo-correction, one of them designed to remove distortion in aerial photography. It involves the use of a digital elevation model to correct for terrain distortion. For this operation it was necessary to scan the full aerial photo including the fiducial marks. The 1998 images had been geo-corrected previously by simple rubber sheeting after scanning them using an 8.5" X 11" flatbed scanner, which did not include the fiducial marks. In order to compare the differences for both types of correction processes, a 1998 image was scanned into a 12" X 17" flatbed scanner, including the fiducial marks, and was geo-corrected with the terrain distortion removal feature. When both images were compared after correction, the differences between UTM coordinates of the same points in both images were 0.303 m in the x direction, and 0.378 in the y direction. The image scanned with the larger scanner had considerably lower quality at the same resolution of 600 dpi. Therefore it was decided to use the previously scanned images and forego the terrain distortion removal correction. Higher resolution was considered to be more important for measurements than removal of terrain distortion, since the stream and adjacent vegetation was on relatively flat land, and had little topographic distortion.

Constraints in location of ground control points and error assessment

The geo-correction of the 1979 to the 1998 images was more complicated than the 1998 image correction due to the time difference involved, and the increased warping of the 1979 images, since they had not been taken with a mapping camera. Twenty identical points such as tree stumps, rocks and other landmarks were chosen on both images.

Five criteria had to be met for each of these ground control points: 1) points had remained unaltered for 20 years; 2) points had to be spread out over the 1979 image, to reduce the distortion in the rectification process; 3) points could not be located too close to the image's edge, since the 1979 photos were more distorted than the 1998 ones; 4) treetops were not a good choice, since there was too much parallax difference between the two years; 5) points should be located on flat ground, since terrain distortion would affect rectification. Another problem was the fact that the stream was not centered in all of the 1979 images, while it was central to all 1998 images. The downstream portion of the study area consisted of more open grassland, while the upper area was more vegetated with shrubs and trees. The denser vegetation presented more problems, since it was difficult to identify certain shrubs or trees. In addition, the upper area had steeper topography, and the 1979 photos showed that the pilot had banked the plane to begin his flight, which resulted in considerable tilt in the first image.

It became obvious that the error in ground locations would be different in each image. The number of ground control points in each image was reduced from 20 to 16, after choosing the best points according the above criteria, while reducing the RMS error to below 1.05 pixels on average. Table 3.3 shows the RMS error for the 1998 images, and the RMS error for the 1979 images that were corrected to the 1998 images. Pixel size in the 1979 and 1998 images was 10 cm, translating to a ground accuracy of 16 cm for the 1998 images.

Table 3.3. Root Mean Square (RMS) error after geo-correction of ten 1979 and eight 1998 aerial photos of Catherine Creek.

1979 image #	RMS error	1998 image #	RMS error
4	1.1115	10	1.4498
5	1.0367	9	1.4718
6	1.1487	8	1.3766
7	1.0718	7	1.8541
8	1.0903	6	1.8537
9	0.9902	5	1.4341
10	1.0546	4	1.4245
11	1.0999	3	1.6026
12	0.7953		
13	1.1101		
Average	1.0509	Average	1.5584

Digitizing of stream features

The outline of the stream was digitized on-screen from each aerial photo separately, using the software program ArcView (ESRI (Environmental Systems Research Institute) 1996). These vector files obtained from each photo were then appended into one vector file of the whole stream outline. Due to overlap at the photos' edges and the distortion in the lower quality 1979 photos, the vector lines from each image did not match up perfectly. The lines were joined in what was considered a best fit. As a control, it was decided to produce a mosaic of all 1979 images and overlay the finished stream outline to correct for any obvious errors.

A mosaic was created using a cut and feather option as opposed to a simple overlay. With an overlay, the stream and other features in the images did not line up properly, while the cut and feather option produced a best fit of both images. There were 14 joints in the mosaic, some of which did not fit well. For example, the stream bank would appear as a double line for a short distance in the overlap area. The complete digitized stream outline was overlaid on the mosaic images. In addition, the vector files for the stream outline of the separate images were also overlaid. It became visible whether the stream lines had been joined correctly or not. In some instances, the lines diverged considerably, and the finished stream outline was corrected to lie in between to minimize the error.

Due to the distortion in the original images, some error in the overlap areas was unavoidable and had to be accepted. The error in stream bank location occurring due to photo distortion in the image overlap area was calculated by measuring the length of the overlap and its coordinates. In addition, the maximum and average distances of the vector lines (digitized from each photo) to the final stream outline were measured and are shown in Table 3.4. The total length of overlap was 476.6 m, compared to a total stream length of 2318 m.

Table 3.4. Length of overlap in 1979 aerial photos, and errors after choosing the best fit line for the streambank. Maximum and average error indicate the distance from lines digitized from each photo to the final complete stream vector line.

Overlapping images	Length of overlap	Maximum error of best fit line	Average error of best fit line
		(m)	
13 to 12	95.90	3.58	2.08
12 to 11	66.43	1.22	1.20
11 to 10	73.80	2.65	1.26
10 to 9	25.29	1.56	1.11
9 to 8	30.18	1.88	1.21
8 to 7	34.36	1.42	0.59
7 to 6	45.69	3.66	1.88
6 to 5	64.38	2.96	1.61
5 to 4	40.57	1.93	1.15
Total overlap	476.60	Average error	1.34

The 1979 image mosaic and stream outline then became the standard for comparison with the 1998 images. None of the problems with joining of stream outlines were encountered in the 1998 photos, which were of higher quality. Due to 60% overlap of these photos, only the middle of each photo was clipped and used for analysis, reducing edge distortion dramatically. A mosaic of all eight images was produced, and the vector files joined from separate images and overlaid on the mosaic fit well in all overlap areas. As was done for the 1979 images, vector files for the stream and islands were created for the 1998 images. In addition, outlines of all exclosures and perimeter fences were digitized from the 1998 photos.

For the aerial photos from 1937, 1960, 1969 and 1982, that became available while the study was in progress, a similar procedure for geo-correction and digitizing was followed, with a few exceptions. Due to the smaller scale of these images, it was not possible to recognize enough of the same features on the photos for comparison with the 79 and 98 images. For that reason, additional GPS points were collected in the field to serve as ground control points for geo-correction. The smaller photo scale covered a larger land area and allowed us to use landmarks outside of the study area, such as corners of a barn and bridge, and corral posts. In addition, GPS locations of large cottonwood trees, snags and stumps visible in all photos were collected. In order to get a location for the middle of a tree, two GPS points at a distance of 10 m on either side of the tree were collected and later averaged. A total of 60 additional ground control points were collected in that manner. Table 3.5 shows the RMS error and pixel size of these images. The average values for the 1979 and 1998 images are included for comparison.

Table 3.5. RMS error, pixel size and ground accuracy of aerial photography from Catherine Creek. Ground accuracy equals pixel size times RMS error.

	Small scale				Large scale	
	1937	1960	1969	1982	1979	1998
Scale	1:21000	1:14300	1:19400	1:18300	1:3100	1:4000
RMS error	0.7317	0.8613	0.8687	0.9183	1.0509	1.5584
Pixel size (m)	0.78	0.40	0.78	0.72	0.10	0.10
Ground accuracy (m)	0.57	0.34	0.68	0.66	0.11	0.16

Ground truthing of vegetation

In order to identify vegetation classes from the aerial photography, and to assess the accuracy of a computerized classification process, ground truth data are necessary. During the summer of 1998, areas of shrub, tree, grass and gravel cover were outlined on copies of aerial photos of the study area. Due to the large scale of the photos, the cover classes were also relatively easy to identify from the photos alone. In addition, several different shrub and tree species were outlined on the photos for an attempt at pulling out these species with a computer classification later. The species included willow, alder, hawthorne, cottonwood and several conifer species.

A detailed vegetation map describing 60 plant communities at Catherine Creek was developed by Kauffman (1982), and plant frequency data were collected in 1979 and 1980. Green (1991) used this plant community map to collect frequency data in 1987 and 1989 in the eight most widely occurring communities of the study area. The eight most common plant communities defined by Green (1991) in the study area are:

- Moist meadow: *Poa pratensis* - *Phleum pratense* – *Carex* spp. – mixed dicot
- Dry meadow: *Poa pratensis* – mixed dicot
- Cheatgrass: *Bromus tectorum*

- Ponderosa Pine/Kentucky bluegrass: *Pinus ponderosa / Poa pratensis*
- Black cottonwood: *Populus trichocarpa* – mixed conifer
- Thinleaf alder/Kentucky bluegrass: *Alnus incana / Poa pratensis*
- Black hawthorn/Kentucky bluegrass: *Crataegus douglasii / Poa pratensis*
- Gravel bars: *Salix* spp. – mixed dicot

In July of 1999, the frequency data were collected again, however, this time the start and end of each transect were recorded with a GPS unit. This will make it easier to locate the transects in the future, and to determine changes in the plant communities. Species frequency data were collected using a 25 x 25 cm quadrat, reading thirty plots along a thirty meter long transect. Of the original 60 transects, 55 were measured in these 8 communities; the lower number was due to the fact that some communities were too dense to sample or could not be found, since the stream had moved laterally. For this study, the 1999 frequency data were not compared with the other years, since this was not the objective of this study. Instead, the data only represent baseline information as to the frequency of the species present in those communities.

Vegetation classification over whole area

The main purpose of the vegetation classification from the aerial photos was to measure the shrub and tree increase visible in the photos over the 19-year period from 1979 to 1998, in which no shrub removal had occurred. Land cover classes were also determined for the 4 small-scale images. By overlaying the vector file of the 5 exclosures in the study area, nine areas of interest (AOI) were windowed out from the existing images for both years. These AOIs consisted of 5 exclosures and 4 grazed areas. For the small-scale images from 1937, 1960, 1969 and 1982, the whole study area was assessed for land cover classes, since the division into exclosures and grazed areas had only occurred in 1978, after the exclosures were built.

Both an unsupervised and a supervised classification were done initially on the images. It became obvious that an unsupervised classification did not differentiate the vegetation well enough. For that reason, a supervised classification of the images was done using the ERDAS Imagine® (ERDAS® Inc. 1997) software. The seed growing properties module was used, choosing 50,000 pixels as the constraint area over a spectral euclidian distance of around 20-30 DN (digital number). In this module one pixel is selected, for example in a grassy area. The computer then either accepts or rejects the adjacent pixels within the spectral distance from the mean of the seed pixel and outlines the selected area. If it is acceptable, the result is added to a signature file under the class name 'grass'. The procedure is repeated for each desired class, and a signature file containing all classes is produced. The computer uses this file to run a supervised classification; all pixels are classified according to the spectral reflectance information contained in the signature file.

Five different classes were chosen: water, gravel, grass, shadow, and shrub/tree. The 1979 images did not have as good a color contrast as did the 1998 images. Often, it was necessary to choose several different spectral reflectance values within some of the classes, for example, 2 classes for water and 3 classes for shrubs were chosen to cover all of the water or shrub areas in the image. Some of the final signature files contained as many as 20 different classes, however, three separate classes for shrubs did not necessarily represent different species, but rather different values of 'green' . These 3 classes were not merged for the classification, since that would have led to confusion with other classes in the signature file itself, but the resulting area values were later added together to get results for the 5 original cover classes. Since the 1998 images had better resolution, it was possible to obtain additional classes, such as dry grass and wet meadows. However, the 1979 images did not have the same quality, therefore all grass classes were grouped into one for comparison purposes.

After the supervised classification, the image was filtered four times using a mean low pass filter with a 7 x 7 kernel. Filtering reduces the amount of single pixels of one class present within another class and has the result of 'smoothing' out the image. Filtering has to be done with care, so that no information is lost. After each filtering, the image was checked to make sure that no single shrubs were lost in this process. The area of each class in hectares was then obtained from the filtered images and used to calculate percent of each class covered in exclosures and grazed areas for both years.

An accuracy assessment of the classification process included an error matrix, calculation of errors of omission and comission, and a Kappa Index of Agreement (KIA). The latter is a correlation coefficient ranging from 0 to 1. Zero indicates no correlation, while 1 indicates perfect correlation (Rosenfield and Fitzpatrick-Lins 1986).

Vegetation classification near the streambank

One objective in this study was to determine the amount of shrub, grass or gravel cover present near the stream bank in 1979 and 1998. In essence, this was a line transect running parallel to the stream near the bank. An attempt to use the vector line of the streambank for extraction of the vegetation information proved to be difficult, since there was some confusion between the boundary of water and gravel. During the classification process, some of the pixels belonging to gravel were assigned to water and vice versa. By using the streambank vector file, too large of an area would have been assigned to the water class. For that reason, another line 2 meters away from but parallel to the stream bank, was digitized from the images. It was concluded that a distance of 2 m away from the stream was still sufficient to represent the vegetation close to the stream, but far enough away to prevent confusion with the water class.

A multiplication of the image containing this line with the previously classified image yielded a new image containing the information as to what classes were covered by the line. Since this was a raster file, the line was exactly one pixel wide and as long as each exclosure or grazed area. The area of each class covered by this line was extracted from this image and used to calculate percent cover of each class for the line transect in exclosures and grazed areas.

Data analysis

The results obtained for percent cover for all land cover classes represent a measurement of the whole population. No sampling was involved, and therefore there was no need to apply statistics to these results. Instead, the results of percent cover of the class in exclosed and grazed areas were presented as such or as a percent increase or decrease from 1979 to 1998.

Results and Discussion

Frequency

The data from the frequency plots were summarized in three different formats. The species and their corresponding frequency are listed in Appendix 7. In order to locate the frequency plots again in the future, a table with the community number and its location is shown in Appendix 8. The coordinates from the GPS survey show the start and end of each transect line. In some areas, the 30 m line fell outside of the community; in those cases, two transect lines of 15 m each were surveyed. In addition, the coordinates of all these points were imported into the GIS, and a point file was constructed. The labelled points were then overlayed on a geocorrected aerial photo (Appendix 9). In the future, the start and end of each transect line can be located with either a GPS unit or visually from these maps. This ensures that future vegetation surveys will be conducted in exactly the same location as the past.

Species determination

It was not possible to pull out different shrub and tree species from the photos in a reliable manner. One of the problems was the fact that many of the species grew together in clumps and could not be separated, neither with the naked eye, nor the computer. This was especially true for willow, cottonwood, alder and hawthorn thickets. However, even large single cottonwoods were not pulled out well by the classification. One explanation for this is the large scale and high resolution of the images. If a classification is done on a smaller scale image, such as a 1:20000, the resolution will usually be lower. Assuming a pixel size of 1 meter, a cottonwood tree with a diameter of 8 meters would take up an area of 50 m^2. At a 1 meter pixel size, 50 pixels would represent this tree. In the high resolution, large-scale images used in this study, however, the pixel size was 10 cm. The same cottonwood tree was made up of 5000 pixels. This means that there were pixels with many different reflectance values represented in one tree, and it became more difficult to single out the tree from a spectral reflectance perspective. Many of the pixels were also present in conifers or shrubs and were confused. This was the main reason why several different spectral reflectance classes had to be used within the main 5 classes (shrub, water, etc.). Although it was easy to pull out all the shrubs in this manner by using and then combining different classes, the computerized identification of single species was not possible, since they were not unique enough from a spectral perspective.

High resolution was a distinct advantage for differentiating spectrally different classes from each other, such as gravel from grass, or water from gravel, but the resolution also resulted in many different values of green. These were really close to each other in spectral reflectance, and were repeated in shrubs, cottonwood, and even in some grasses. However, by choosing several classes for shrub or water and later combining their area, this problem was solved.

Accuracy assessment of classified images

After the supervised classification was completed, an accuracy assessment was performed on one half of the classified images, with the aid of an error matrix. One such error matrix is shown in Table 3.6.

Table 3.6. Error matrix for an image of Catherine Creek from classifying randomly sampled points.

		Reference						Total	Total
Class	Cover class	1	2	3	4	5	6	Classified	Reference
1	Dry grass	25	1			3	1	30	33
2	Shrub/tree	1	27				2	30	30
3	Shadow			30				30	30
4	Water		1		28	1		30	28
5	Gravel	7	1			21	1	30	25
6	Green grass						30	30	34
	Total	33	30	30	28	25	34	180	180

Class	Users Accuracy	Producers Accuracy	Kappa Index of Agreement
1	25/30 = 83.33%	25/33 = 75.75%	0.7959
2	27/30 = 90.00%	27/30 = 90.00%	0.8800
3	30/30 = 100.00%	30/30 = 100.00%	1.0000
4	28/30 = 93.33%	28/28 = 100.00%	0.9211
5	21/30 = 70.00%	21/25 = 84.00%	0.6516
6	30/30 = 100.00%	30/34 = 88.24%	1.0000
Total	89.44%	89.67	0.8748

The number of rows and columns (1-6) equals the number of land cover classes whose classification accuracy is being assessed. Reference 1-6 represents known cover types while Classes 1-6 are the points actually classified. In this case, 180 random points were dropped onto the classified image by the computer. Each point was then visually checked as to its classification accuracy. Points along the diagonal, from upper left to lower right were classified accurately. All other cells are either errors of commission (for example 1 shrub/tree, 1 green grass and 3 gravel points were included in the dry grass category), or errors of ommission (8 points=7+1 were ommitted from the dry grass category). The user's accuracy is a measure of commission error, while the producer's accuracy measures ommision error, which basically indicates how well points of a cover type are classified. The overall accuracy is calculated by adding all correctly classified points and dividing them by the total number of reference points (161/180 = 89.44%) (Lillesand and Kiefer 1994).

The Kappa index of agreement (KIA), which is a correlation coefficient is automatically calculated in such accuracy assessments; the Kappa index of 0.8748 means that this classification is 87% better than one resulting from chance alone. The KIA was developed by Cohen (1960). It is a desirable means of accuracy assessment, since it takes into account all cells of the error matrix, not just the diagonals. It is a measure of the agreement (diagonals) minus the chance agreement (product of row and column marginals) (Rosenfield and Fitzpatrick-Lins 1986; Fung and LeDrew 1987). The error matrix shows that shadow, water, green grass and shrub all had a Kappa index greater than 0.88, with shadow and green grass at 1. The least reliable classified class was gravel. This is understandable, since some of the gravel intergrades with grass. The overall accuracy achieved with this classification is relatively high and demonstrates that land cover classes can be assessed well at the chosen scale with this method.

Supervised classification

The percent area covered by each class is illustrated in Figure 3.2. It can be seen that most of the study area was covered in grass, followed by shrubs, both in 1979 and 1998. However, a large shrub increase and a decrease in grasses also became visible over time. This shrub increase was observed over the whole study site, as well as in each exclosure and grazed area, with the exception of E5 (Figure 3.3 and Figure 3.4). The smaller shrub increase in the upper part of the stream in G4, or the slight shrub decrease in E5 is

Figure 3.2. Percent cover of 5 vegetation classes at the Catherine Creek study site

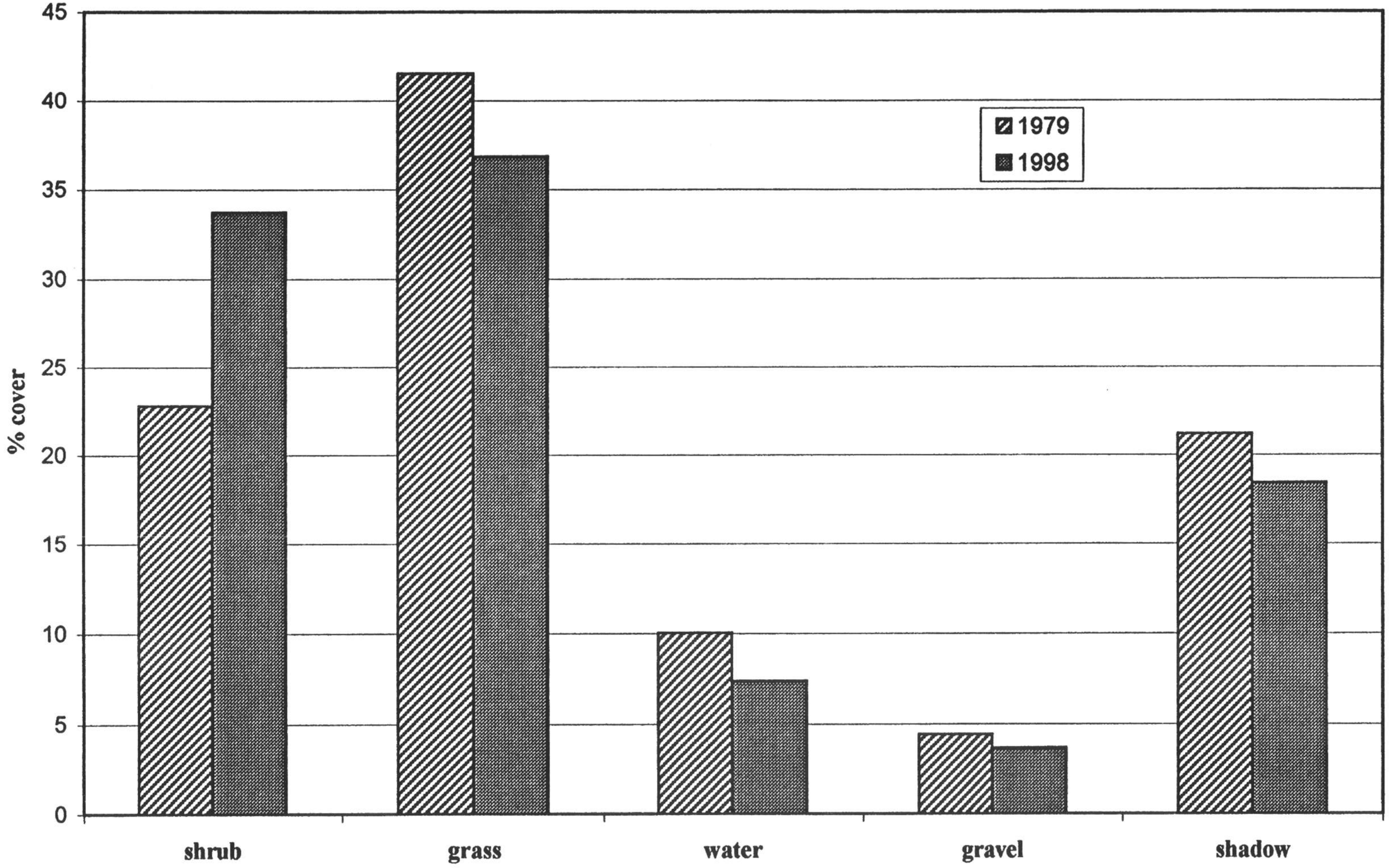


Figure 3.3. Shrub/tree cover in exclosures and grazed areas at Catherine Creek

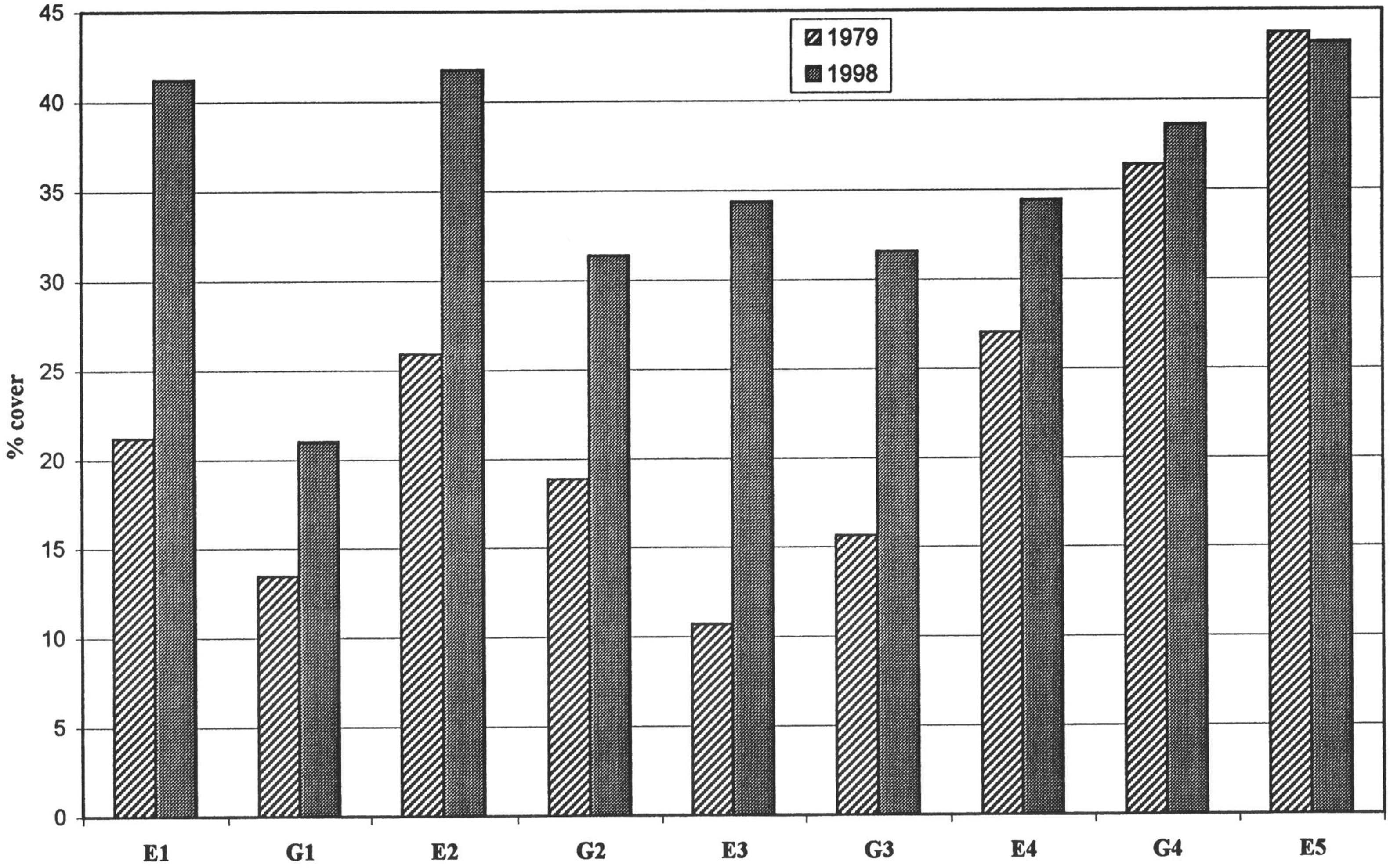
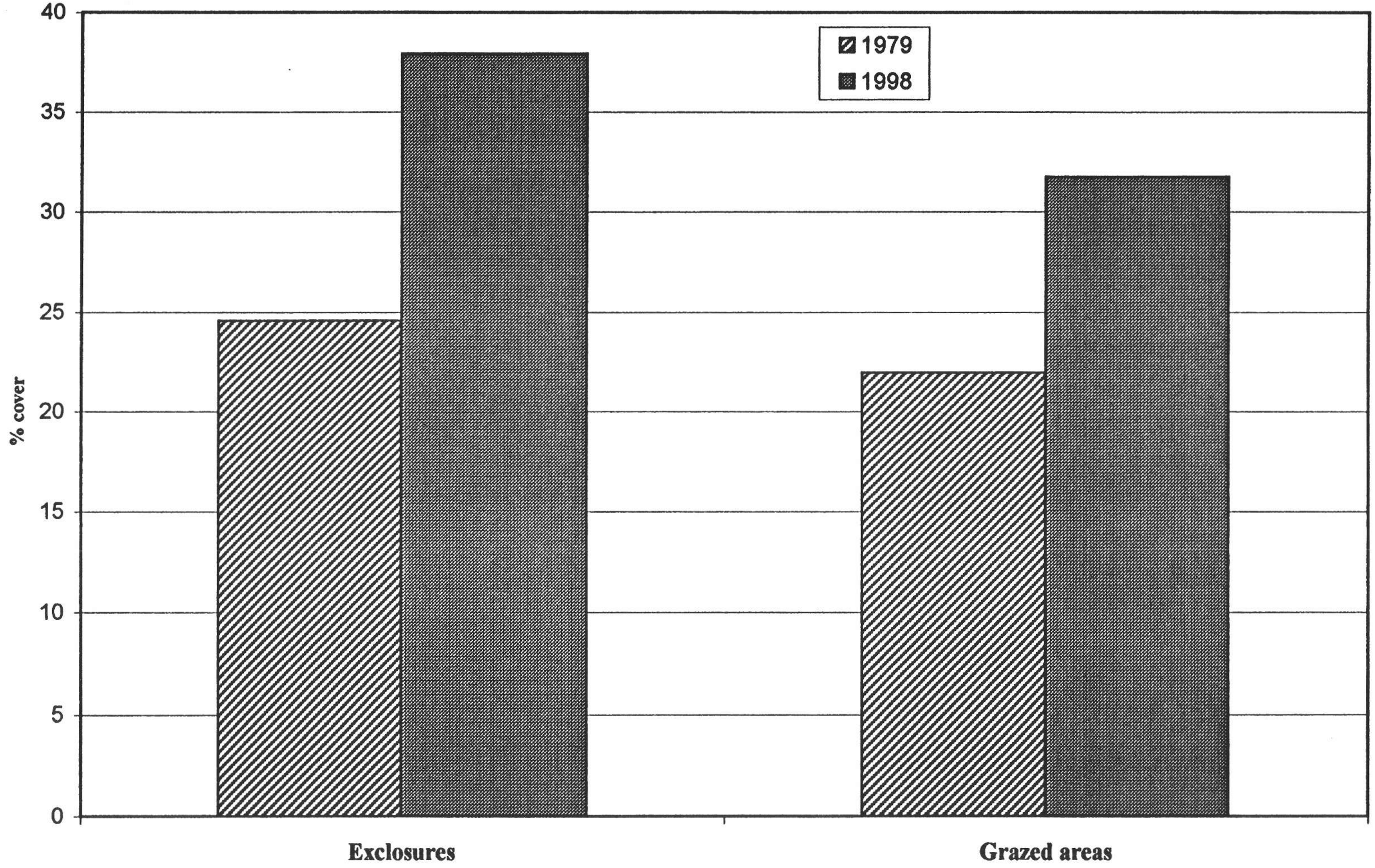


Figure 3.4. Percent shrub cover in all exclosures and grazed areas in 1979 and 1998



explained by the fact that this area had more shrub and tree cover to begin with. This tree cover consisted of Ponderosa Pine, Douglas-fir and some Grand fir. Since there was less grass area, less changed to shrub. There was a high variability in percent shrub cover within exclosures and grazed areas, as well as between them (Figure 3.4), which had to be taken into consideration for interpretation. Table 3.7 shows the results for percent cover in 1979 and 1998.

These numbers show several trends: shrub increased overall, while grass cover decreased. In most areas, gravel cover did not change much. Shadow areas were not classifiable, since they obscured underlying vegetation. In areas of high shrub and tree cover, the shadow would cover more of it, while in meadows, the shadow would overlie grassy areas. In most sites, with the exception of E4, shadow area was comparable between 1979 and 1998, making it easier to compare change over time.

The area classified by the computer as water decreased between 1979 and 1998. This discrepancy was not seen in the surface area of the stream, which only decreased by 2.8%. We concluded that the decrease in the water class was due to increase in shrub and tree cover near and over the streambank. This made the visible water surface smaller. This also implies that in an unsupervised classification, the stream surface area would be underestimated. The same holds true for stream width. As Kondolf (1993) also observed, streamside vegetation can make a stream channel appear narrower due to dense, overhanging vegetation. Since exclosed areas usually have more dense streambank vegetation, this may lead to the conclusion of narrower stream width. Channel measurements are necessary to verify this.

Table 3.7. Percent cover for 5 cover classes in exclosures (E) and grazed areas (G) at Catherine Creek. Results are from supervised classification of aerial photos of 1979 and 1998.

	E1		E2		E3		E4		E5	
	1979	1998	1979	1998	1979	1998	1979	1998	1979	1998
Shrub	21.20	41.21	25.91	41.74	10.69	34.39	27.05	34.43	43.69	43.21
Grass	32.58	32.29	35.82	28.19	45.14	35.84	20.43	34.29	16.64	21.03
Water	25.01	12.13	17.50	11.23	18.65	12.85	9.51	8.82	10.87	7.97
Gravel	14.53	3.29	7.25	2.31	9.57	5.07	0.98	2.05	2.75	7.00
Shadow	6.68	11.08	13.53	16.53	15.95	11.85	42.03	20.42	26.04	20.79

	G1		G2		G3		G4	
	1979	1998	1979	1998	1979	1998	1979	1998
Shrub	13.47	21.02	18.85	31.38	15.63	31.56	36.39	38.60
Grass	64.36	58.42	51.81	44.98	58.78	43.84	19.87	17.57
Water	6.96	4.24	7.77	5.31	7.66	6.83	7.35	6.45
Gravel	2.61	1.57	3.95	2.03	3.35	2.65	3.97	7.31
Shadow	12.60	14.76	17.61	16.30	14.58	15.12	32.42	30.06

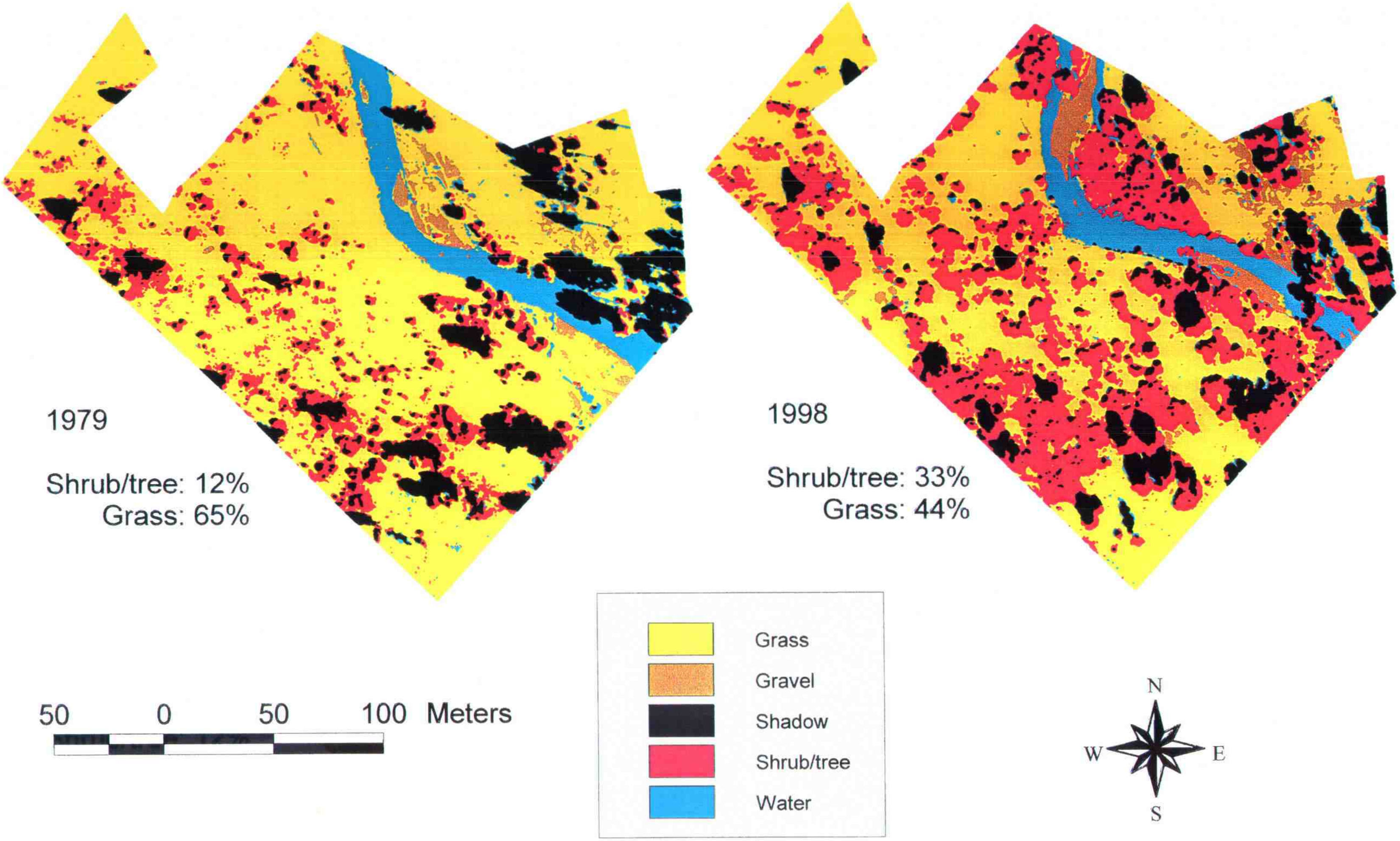
	E		G		Total area	
	1979	1998	1979	1998	1979	1998
Shrub	24.60	37.94	21.94	31.75	22.79	33.70
Grass	30.02	31.40	46.95	39.33	41.54	36.83
Water	15.44	10.57	7.49	5.90	10.03	7.38
Gravel	6.30	3.80	3.57	3.57	4.44	3.65
Shadow	23.65	16.28	20.06	19.45	21.20	18.45

When the images were classified, great care was taken to classify shrubs and trees accurately, since this was the main objective. Although there was some confusion between yellow grasses and gravel, and gravel and water, we made sure that the boundaries of shrubs were outlined accurately. Therefore the numbers for shrub increase are considered to be the most reliable of all classes. Figure 3.5 shows a comparison of two classified images from 1979 and 1998. It is a typical example of what was observed over the whole study site: an obvious shrub increase at the expense of the grass cover.

Over the whole study area, the shrub cover increased from 23 % to 34 %, representing a 48 % increase. In grazed areas alone, shrubs increased by 45 % (from 22 % to 32%), while the increase was 54 % in exclosures (from 25 % to 38 %). This similar response in grazed and exclosed sites suggests that the grazing regime in this pasture seems to be appropriate for this particular area, and that the cattle did not have a detrimental effect on total shrub cover over the 19-year period.

Livestock may have a negative effect on the shrub component of a pasture, usually due to decreasing palatability and availability of herbaceous vegetation (Roath and Krueger 1982). This means that a sufficient herbaceous layer maintained by proper grazing intensity, frequency and duration for the area should ensure that shrubs are not overutilized. Clary et al. (1996) compared stem density and diameter of willows and cottonwood under light spring, moderate fall, heavy season-long and no grazing. The authors found no differences in stem density and parameter between the treatments when all shrub species were considered together, although density differences were apparent for single species. Since all shrub and tree species were considered together in our study, single species responses may have occurred, but could not be measured. Only the overall

Figure 3.5. Supervised classification of two color aerial photos from 1979 and 1998



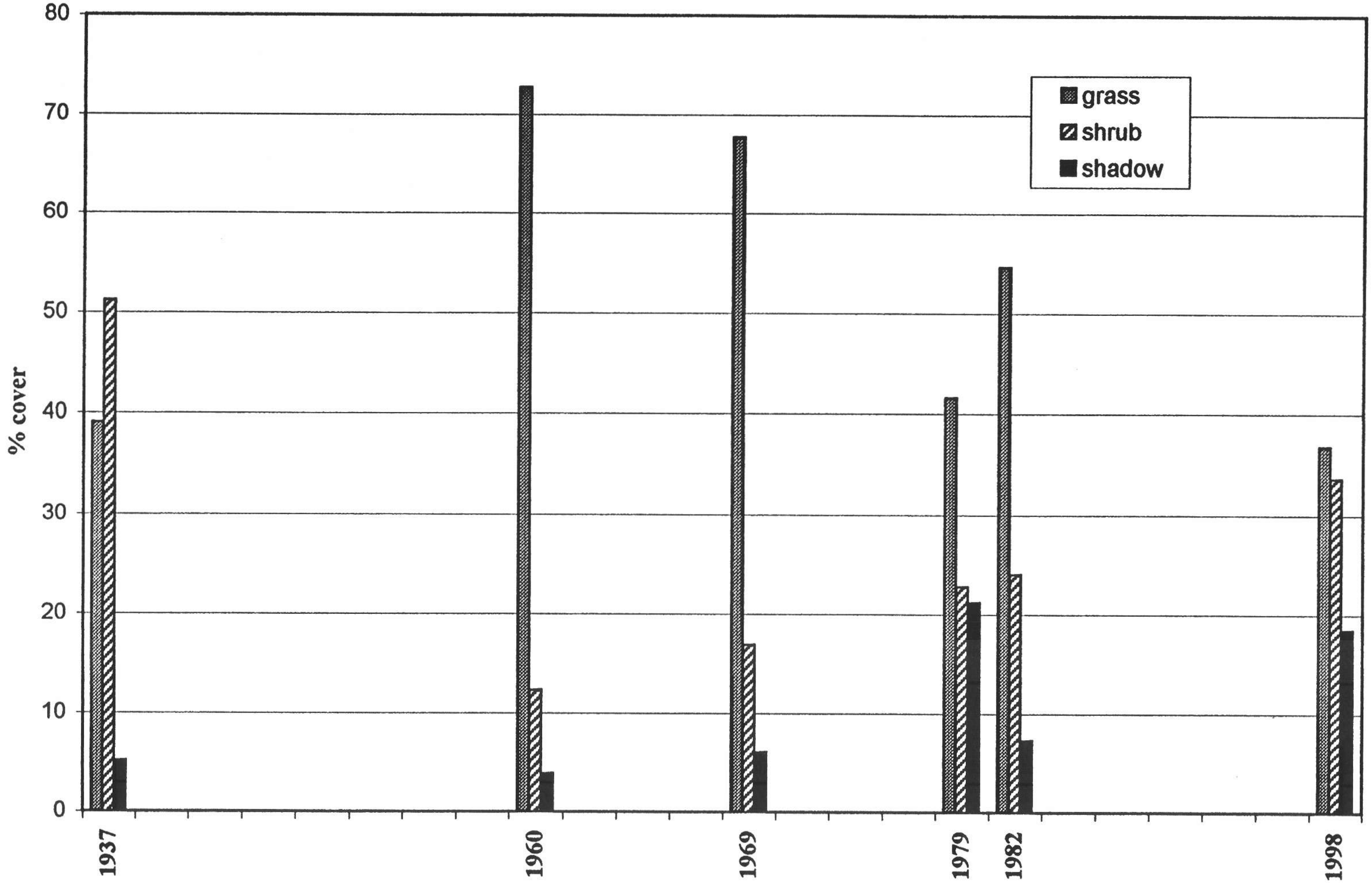
shrub and tree cover was analyzed in our case. Although single species could not be separated digitally, it was visible from the aerial photos that hawthorn was the shrub species that had expanded the most. Since it had reduced the extent of the grass area over time, the hawthorn was removed in 1958 and 1974/75 to improve cattle grazing.

In a vegetation study conducted at this site, Kauffman et al. (1983), found that shrub utilization was generally light, except on very palatable shrubs. Hawthorn was most palatable to cattle when it was less than 1 m in height. Once it exceeded 2 m, it was rarely browsed. This would explain the size increase of the hawthorne thickets observed on the aerial photos.

The small-scale images from 1937, 1960, 1969 and 1982 were also analyzed with a supervised classification (Figure 3.6). The classes for gravel and water are not shown, since they had comparable values for those years and were of less interest for the analysis. One of the problems was the shadow; there was more shadow in the large-scale images of 1979 (21%) and 1998 (18%), compared to the small-scale images. Their shadow cover ranged from 4-7%. This made it more difficult to compare the cover values of small and large-scale images at the same time.

During the times when shrubs were not removed, it can be seen that from 1960 to 1969, shrub cover increased from 12% to 17%, and from 1979 to 1998 shrub cover changed from 23% to 34%. In the small-scale images, the study area was not divided into exclosures and grazed areas, since they were only installed in 1978; therefore the whole study area was measured.

Figure 3.6. Percent cover of grass, shrub/tree and shadow over the whole study area for 6 different years



Classification of line transect

The same trend of shrub increase observed in the classification of the whole image was also seen in the classification of the line transect running 2 m from the streambank, but to a lesser degree. Shrub cover was already relatively high near the streambank in 1979 at 42%, and increased to 49% in 1998 in the exclosures. Similar numbers were observed for the grazed areas, where the shrub cover increased from 33% in 1979 to 38% in 1998. However, while the shrub cover increased over the whole study area, and in all exclosures and grazed areas combined (Figure 3.7), this was not the case for all E and G locations (Figure 3.8). Shrub increases as well as shrub cover decreases were observed in exclosures as well as grazed areas.

After comparison of the 1979 and 1998 images, the reason for these changes became obvious. The majority of increase or decrease in shrub cover was relatively small. This was true for E1, E4, G1, G2, and G4. In the other locations, larger shrub increases (E3, G3) as well as decreases (E5) were observed. The images show that in E5, an island existed in the channel in 1979. In 1998, the stream had abandoned one of the channels, resulting in the line transect running over gravel in 1998, while it was located under shrub cover in 1979. Similar observations were made for the other locations that showed a shrub increase that was much larger than that observed for the whole area. In another location (G3), the line transect was located over gravel in 1979; in 1998, shrub had encroached this area to a large extent.

These observations show again the impact of scale on the interpretation of the shrub cover numbers. On a larger scale, such as in one exclosure or grazed area, a variety of factors come into play. In areas where the stream channel changed to a large degree, the

Figure 3.7. Percent shrub cover in exclosures and grazed areas
over a line transect located 2 m from the streambank

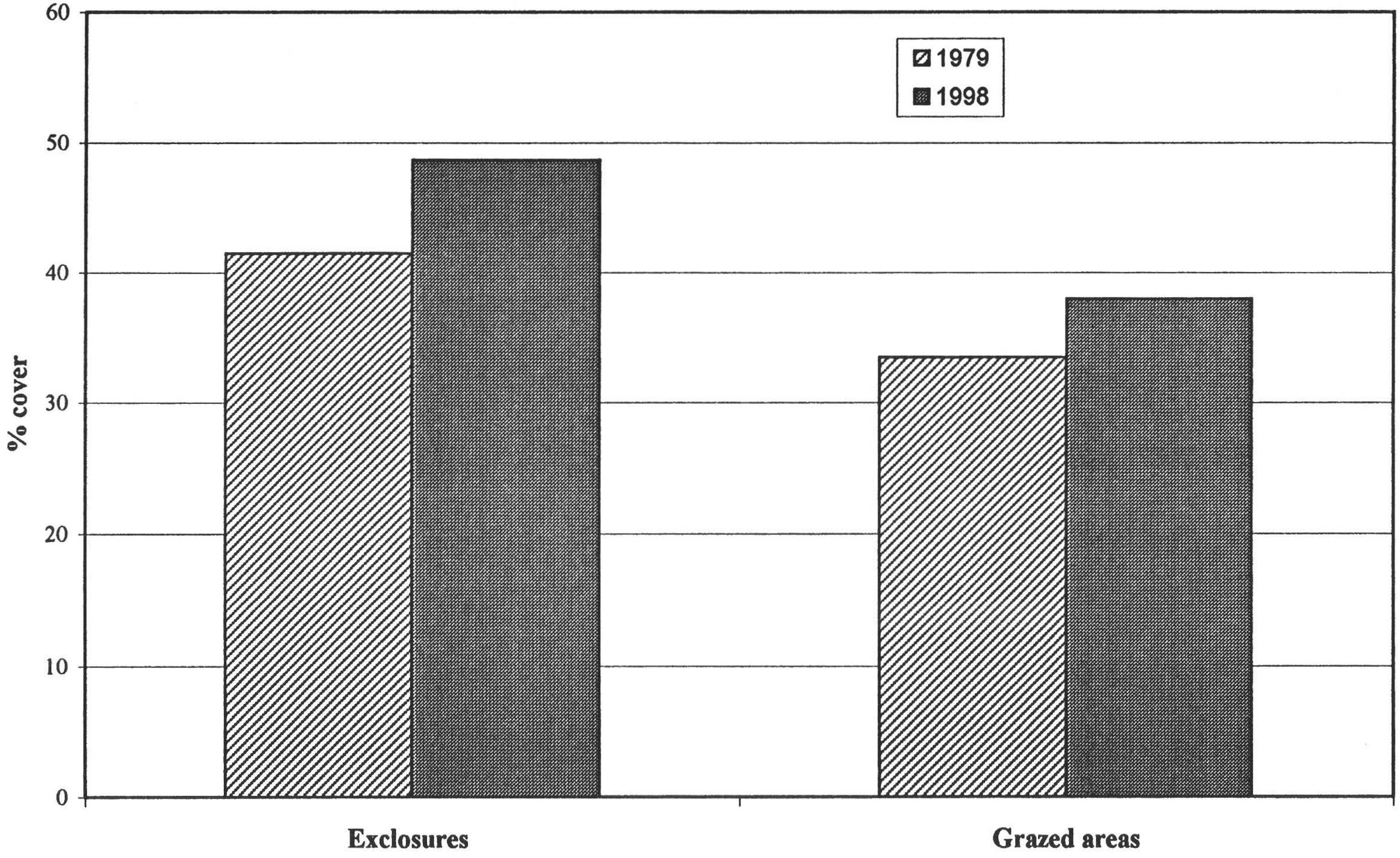
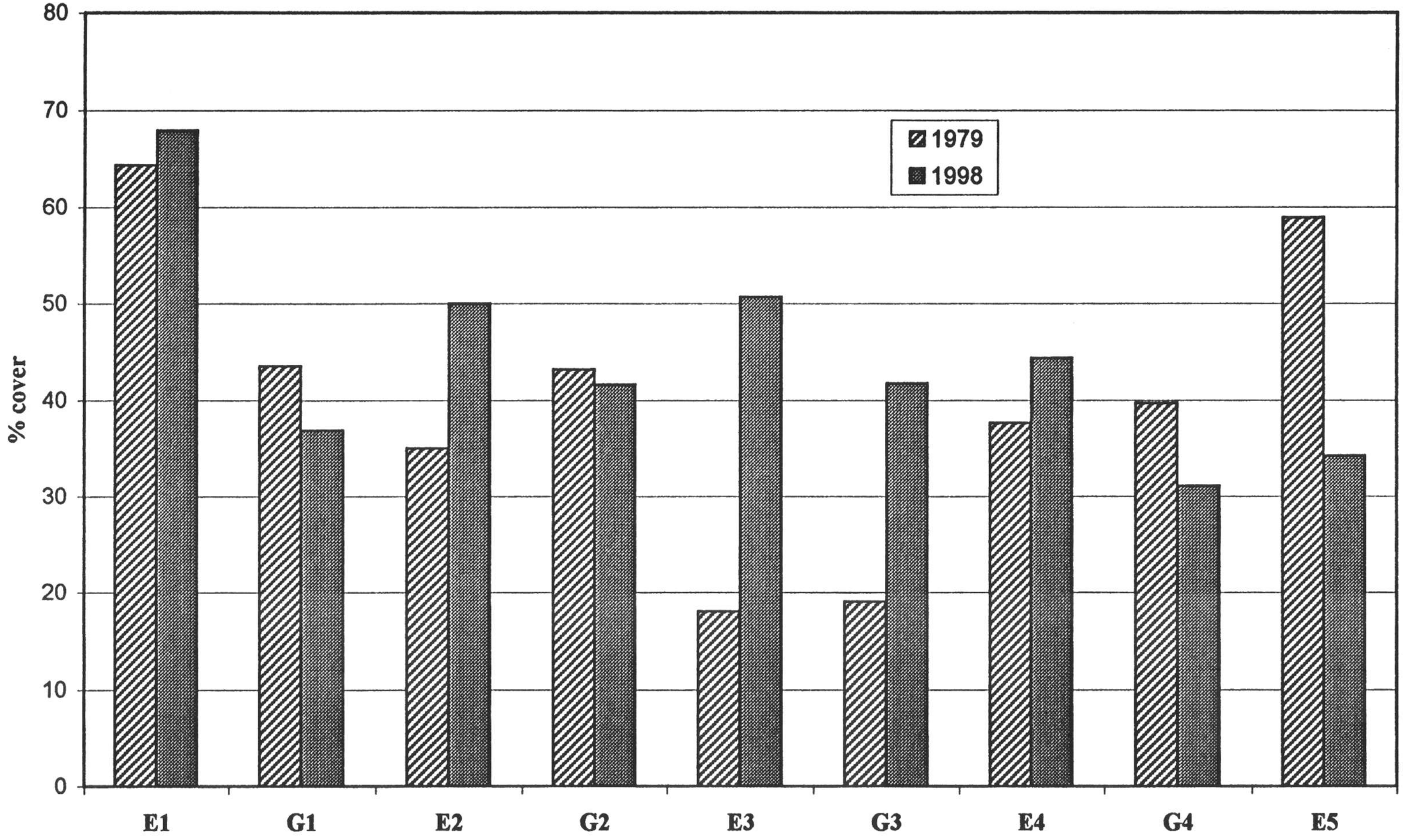


Figure 3.8. Percent shrub cover in exclosures (E) and grazed areas (G) over a line transect located 2 m from the streambank



location of the line transect changed with it. This means that the comparisons between 1979 and 1998 shrub cover did not necessarily come from the exact same location of the line transect. In some areas, the distance between the line transects of 1979 and 1998 was as much as 35 m, while in others, the transects overlapped closely, reflecting the changes in the stream channel. For that reason, the changes in shrub cover observed in the line transects have to be interpreted while keeping the changes in the stream channel in mind.

Use of digital elevation models

GIS is an excellent tool for spatial analysis of changing landscapes. It offers not only a two-dimensional, but also a three-dimensional view of the landscape. This is useful for visualization purposes and offers another insight into the nature of change. An oblique view of a portion of the study area is shown in Figure 3.9. These images were created by overlaying a geo-corrected aerial photo over a digital elevation model (DEM) of the same area. The software program allows the user to choose any elevation above ground level, viewing angle, direction and image resolution. The image can be rotated, and a simulated fly-through is also possible. All this allows for a view of the area from different perspectives.

The shrub cover increase and changing stream channel are clearly visible on these images. Although no measurements would be done from these images, they offer a good impression of the magnitude of change. One of the limitations encountered was the fact that the DEM available for this area had a pixel size of 30 m. Since the change in

Figure 3.9. Oblique view of the same area at Catherine Creek in 1979 and 1998

1979

1998

Images were created by overlaying each aerial photo over a digital elevation model and displaying them using identical elevation, azimuth, pitch and field of view.

elevation is much less over the area visible in the image, it appears quite 'flat'. However, the human eye substitutes the missing elevation information from the aerial photo, for example, we can see the difference between a steep and shallow streambank. A detailed DEM of the area would be more desirable for the creation of this perspective view, and will be constructed for the study area in the near future.

Conclusions

The shrub/tree cover increased over the whole study area from 23% to 34%, and the shrub increase was very similar for grazed and exclosed sites. Since this area has been managed under the same grazing regime for the last 20 years, the results suggests that the livestock did not have a detrimental effect on the shrub/tree component. However, one has to keep in mind that species could not be separated in the classification, and it may be possible that palatable species such as cottonwood or willows may be impacted by cattle. Additional ground truth data would be necessary to verify this.

Shrub/tree cover was higher near the streambank than in the whole study area for both years, and it also increased from 1979 to 1998, but to a lesser degree. A large variability of shrub cover was observed within the exclosures and grazed areas, as well as between them. This was true for both the line transect measurements, as well as those of the entire areas (E and G). This was attributed to the changing topography and vegetation cover as the stream flows through the study area; the upstream area is covered by larger trees, while the lower area is more open, with more grass cover. This has to be taken into account when comparing vegetation responses over time. Since the sites are not entirely homogeneous, the changes that are observed have to be interpreted by studying initial conditions in the images.

Although an unsupervised classification was not sufficient to differentiate the 5 desired classes of grass, shrub/tree, shadow, water and gravel, the supervised classification process worked well on these large-scale images. In order to capture all the reflectance values within the classes, several spectral reflectance values had to be collected for each class. However, the software made this process relatively simple, and the increased accuracy made it a worthwhile effort.

The use of remote sensing, GIS and GPS provided a large advantage in this study, since it allowed for data collection difficult to obtain on the ground. We were able to classify land cover classes, extract percent cover values for both years, compare the numbers and assess the shrub increase. If these data were collected on the ground, they would have represented a sample, while we were able to measure the whole population with these techniques. In essence, more data can be collected and analyzed in less time. The large scale of the photography was an additional asset, since it gave better resolution.

It can be concluded that large-scale aerial photography combined with GIS/GPS and ground truthing is a viable technique for assessing vegetation changes over time in a rangeland ecosystem.

Literature Cited

Anderson, G.L. 1996. The application of spatial technologies for rangeland research and management: state of the art. Geocarto 11(3):5-11.

Anderson, G.L., J.H. Everitt, A.J.Richardson and D.E. Escobar. 1993. Using satellite data to map false broomweed (*Ericameria austrotexana*) infestations on south Texas rangelands. Weed Tech. 7:865-871.

Brown, D.G. and A.F. Arbogast. 1999. Digital photogrammetric change analysis as applied to active coastal dunes in Michigan. Photogramm. Eng. Rem. Sens. 65(4):467-474.

Bryant, L.D. 1985. Livestock management in the riparian ecosystem. In: Riparian ecosystems and their management; reconciling conflicting uses. Proceedings of 1st North American Riparian Conference. April 16-18, 1985. Tucson, AZ. USDA Forest Service Gen. Tech. Rep. RM-120. Rocky Mt. Forest and Range Experiment Station. pp. 285-289.

Clary, W.P., N.L. Shaw, J.G. Dudley, V.A. Saab, J.W. Kinney and L.C. Smithman. 1996. Response of a depleted sagebrush steppe riparian system to grazing control and woody plantings. USDA Forest Service INT-RP-492, Intermountain Research Station, Ogden, UT.

Cohen, J. 1960. A coefficient of agreement for nominal scales. Educ. Psychol. Measure. 20(1):37-46.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

ERDAS®, Inc. 1997. ERDAS® Field Guide™, Version 8.3.1, Atlanta, GA. 655 pp.

ESRI (Environmental Systems Research Institute). 1996. Getting to know ArcView. Environmental Systems Research Institute, Redlands, CA.

Everitt, J.H. and C.J. Deloach. 1990. Remote sensing of Chinese tamarisk (*Tamarix chinensis*) and associated vegetation. Weed Sci. 38:273-278.

Everitt, J.H., D.E. Escobar, R. Villareal, M.A. Alaniz and M.R. Davis. 1993. Integration of airborne video, global positioning system and geographic information system technologies for detecting and mapping two woody legumes on rangelands. Weed Tech. 7:981-987.

Ferguson, R.L., L.L. Wood and D.B. Graham. 1993. Monitoring spatial change in seagrass habitat with aerial photography. Photogramm. Eng. Rem. Sens. 59(6):1033-1038.

Fung, T. and E. LeDrew. 1987. Application of Principal Components Analysis to change detection. Photogramm. Eng. Rem. Sens. 53(12):1649-1658.

Golden, M., J. Johnson, V. Landrum, J. Powell, V. Varner and T. Wirth. 1996. Guidelines for the use of digital imagery for vegetation mapping. EM-7140-25. USDA Forest Service. Engineering Staff. Washington, D.C. 125 pp.

Green, M.D. 1991. Soil conditions along a hydrologic gradient and successional dynamics in a grazed and ungrazed montane riparian ecosystems. PhD thesis. Oregon State University, Corvallis, OR. 236 pp.

Hinckley, T.K. and J.W. Walker. 1993. Obtaining and using low altitude large scale imagery. Photogramm. Eng. Rem. Sens. 59(3):310-318.

Kauffman, J.B. 1982. Synecological effects of cattle grazing riparian ecosystems. M.S. thesis. Oregon State University, Corvallis, OR.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications - a review. J. Range Manage. 37(4):430-348.

Kauffman, J.B., W.C. Krueger and M. Vavra. 1983. Effects of late season cattle grazing on riparian plant communities. J. Range Manage. 36(6):685-691.

Kondolf, G.M. 1993. Lag in stream channel adjustment to livestock exclosure, White Mountains, California. Restor. Ecol. 1:226-230.

Lillesand, T.M. and R.W. Kiefer. 1994. Remote sensing and image interpretation. Third Edition. John Wiley and Sons, Inc. New York. 721 pp.

Meehan, W.R. and W.S. Platts. 1978. Livestock grazing and the aquatic environment. J. Soil Wat. Cons. 33(6):274-278.

Miller, J.R., T.T. Schulz, N.T. Hobbs, K.R. Wilson, D.L. Schrupp and W.L. Baker. 1995. Changes in the landscape structure of a southeastern Wyoming zone following shifts in stream dynamics. Biol. Conserv. 72:371-379.

Pieper, R.D. 1973. Measurement techniques for herbaceous and shrubby vegetation. Department of Animal and Range Sciences, New Mexico State University, Las Cruces, N.M., 149 pp.

Roath, L.R. and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range in the southern Blue Mountains of Oregon. J. Range Manage. 35(3):332-338.

Rosenfield, G.H. and Fitzpatrick-Lins, K. 1986. A coefficient of agreement as a measure of thematic classification accuracy. Photogramm. Eng. Rem. Sens. 52(2):223-227.

Simpson, J.W., R.E.J. Boerner, M. N. DeMers, L.A. Berns, F.J. Artigas, and A. Silva. 1994. Forty-eight years of landscape change on two contiguous Ohio landscapes. Landsc. Ecol. 9(4):261-270.

Singh, A. 1989. Digital change detection techniques using remotely-sensed data. Int. J. Rem. Sens. 10(6):989-1003.

Strong, L.L., R.W. Dana and L.H. Carpenter. 1985. Estimating phytomass of sagebrush habitat types from microdensitometer data. Photogramm. Eng. Rem. Sens. 51:467-474.

Trimble Navigation. 1996. Trimble Pathfinder Office™, Software Reference Guide. Trimble Navigation Ltd., Sunnyvale, CA.

Tueller, P.T. 1996. Near-earth monitoring of range condition and trend. Geocarto Int. 11(3):53-62.

Tueller, P.T., P.C. Lent, R.D. Stager, E. A. Jacobson and K.A. Platou. 1988. Rangeland vegetation changes measured from helicopter borne 35 mm aerial photography. Photogramm. Eng. Rem. Sens. 54(5):609-614.

United States Department of Agriculture Forest Service Global Positioning Systems page. 1999. Online. http://www.fs.fed.us/database/gps/ (Accessed Sept.12, 1999).

United States Geological Survey page. 1999. Online. National Water Information System(NWIS) data retrieval. Water resources data for Oregon. http://waterdata.usgs.gov/nwis-w/OR/index.cgi?statnum=13320000 (Accessed Mar.6, 1999).

Vavra, M. Superintendent, Eastern Oregon Agricultural Research Center, Union, OR. Personal communication, Aug.31, 1999.

Warner, W.S., R.W. Graham and R.E. Read. 1996. Small Format Aerial Photography. American Society for Photogrammetry and Remote Sensing. Whittles Publishing, Scotland, UK. 348 pp.

Warren, P. L. and C. Dunford. 1986. Sampling semiarid vegetation with large-scale aerial photography. ITC Journal 4:273-279

Chapter 4

Summary

Remote sensing, GIS and GPS have been used extensively in time change analysis (Tueller 1996; Warner and Hutchinson 1984; Yool et al. 1997). Most studies, however, have used either satellite imagery (Pilon et al. 1988) or small scale aerial photography (Baker et al. 1995) and concentrated on vegetation change. Long-term studies of stream morphology change are less common (Miller et al. 1995), as is the use of large scale aerial photography (1:4000) in time change analysis. The purpose of this project was to combine large scale aerial photography, GPS, GIS and ground truthing for conducting a time change analysis study of an eastern Oregon riparian area over a 20 year time period. We anticipate that the methods used in this study can be applied to and will help in monitoring of other rangeland streams.

The objectives of this study were:

- To assess changes in stream morphology and vegetation in space (between grazed and ungrazed areas) and time (1979 to 1998).
- To determine, if possible, to what extent these changes are associated with management, topography or other factors.
- To assess the viability of using large-scale (1:4000) aerial photography combined with GIS/GPS and ground truthing in time change analysis.

Geo-corrected aerial photography from 1979 and 1998 was used for development of GIS layers of vegetation and stream morphology parameters. Smaller scale images from

1937, 1960, 1969 and 1982 were used to gain information for an earlier time period, although they were black and white photography. In addition, vegetation and stream channel measurements were collected on the ground. Extensive data was available from previous ground surveys, and aerial photography from years others than those analyzed digitally provided baseline data and helped to assess long-term changes.

Some areas of the stream underwent large changes, others did not. While the length of the thalweg and streambank, sinuosity and stream area remained relatively the same, the number of islands, island area, and stream width changed to a larger degree. Most of the changes were associated with the islands. Their number decreased, but their area increased, suggesting an increase in stability. Scale played a large role. At a small scale, (i.e. the whole study area), the stream remained largely where it had been. However, at a larger scale, lateral movement of the stream bank became obvious. In one area, the stream had moved 50 m laterally from 1937 to 1998.

Shrubs and trees increased over the whole study area from 23% to 34%, and this increase was similar in grazed and exclosed sites. The variability of shrub/tree cover within and between the grazed and exclosed sites was high. This reflects the changing topography and vegetation of the study area; more trees were present in the upstream section than further downstream.

In this study area, it is the topography and stream dynamics that control changes in stream morphology, including erosion, deposition and island formation. We could find no association between the observed changes and the grazing treatment.

The use of remote sensing, GIS and GPS techniques was extremely valuable for this study. The large scale and high resolution of the images allowed us to rectify them with a low RMS error, since our ground control points were easily visible. As a result, the digitization and measurements were highly accurate. Additional error assessment of the lower quality 1979 images yielded a measurable error term. The GIS software allowed for data collection that would have been difficult or impossible to obtain on the ground. A large spatial database can be accumulated in short time, and the advantage is that each point has a coordinate associated with it. Therefore, one can return in the future and measure the same area for change detection. Information such as length of stream bank or stream area was quickly extracted from the GIS database. Other operations (cross-classification, determination of stream width) are either built-in modules or are easily adapted to ones' needs. The ability to overlay different years of the stream's outline or islands on an image and to measure distances on-screen was an excellent tool for measuring change.

In addition, the visualization component of the GIS is most valuable in demonstrating the results. Geocorrected aerial photos are overlaid on digital elevation models, and the result can be manipulated, i.e. one can change field of view, viewing angle and elevation by moving the mouse over the image. The software program also allows the user to fly through the scenery. When the same area in two different years is 'flown' simultaneously, one can easily see the changes that occurred in the stream and vegetation.

Although GIS and remote sensing have been used extensively for time change analysis, very little of this work has been done at this large scale (1:4000). This study shows that it can be done successfully. More detailed digital elevation models (DEM) of the stream would have been useful for understanding the movement of gravel and cobbles in the stream channel, and for predicting changes in the channel. The DEM that was used for overlaying the aerial photo had a resolution of 30 m, and was therefore much coarser than the resolution of the photo. Acquisition of detailed DEMs is desirable if time change analysis is performed with large-scale aerial photography.

In this case, we worked with photos taken in 1979, but at that time, they were not taken with the intent to be analyzed by a computer. If this study was to be repeated at a different site, all images should be taken with a large format mapping camera to reduce distortion and improve accuracy of measurements. Ground control points are also a necessity, as it proved to be difficult to recognize the same features in 1979 and 1998. It is also important to take field measurements such as stream cross-sections, bankfull width and depth measurements to determine change. It is advisable to take the field measurements before digitizing the stream, since bankfull width can be somewhat difficult to measure, even on the ground, and it is typically underestimated.

The combination of remotely sensed and field data, coupled with GPS and GIS technology is considered to be an excellent tool for time change analysis in rangelands using large-scale images. Due to the ever improving technology in computer software and hardware in this field, future research will utilize these tools to a greater degree and yield more detailed results. The information provided by this research is expected to assist land managers to predict and/or prevent adverse changes in streams and riparian areas.

Literature Cited

Baker, W.L., J.J. Honaker and P.J. Weisberg. 1995. Using aerial photography and GIS to map the forest tundra ecotone in Rocky Mountain National Park, Colorado for global change research. Photogramm. Eng. Rem. Sens. 61(3):313-320.

Miller, J.R., T.T. Schulz, N.T. Hobbs, K.R. Wilson, D.L. Schrupp and W.L. Baker. 1995. Changes in the landscape structure of a southeastern Wyoming zone following shifts in stream dynamics. Biol. Conserv. 72:371-379.

Pilon, P.G., P.J. Howarth and R.A. Bullock. 1988. An enhanced classification approach to change detection in semi-arid environments. Photogramm. Eng. Rem. Sens. 34(12):1709-1716.

Tueller, P.T. 1996. Near-earth monitoring of range condition and trend. Geocarto Int. 11(3):53-62.

Warren, P.L. and C.F. Hutchinson. 1984. Indicators of rangeland change and their potential for remote sensing. J. Arid Environ. 7:107-126.

Yool, S.R., M.J. Makaio and J.M. Watts. 1997. Techniques for computer-assisted mapping of rangeland change. J. Range Manage. 50(3):307-314.

Bibliography

Anderson, G.L. 1996. The application of spatial technologies for rangeland research and management: state of the art. Geocarto 11(3):5-11.

Anderson, G.L., J.H. Everitt, A.J.Richardson and D.E. Escobar. 1993. Using satellite data to map false broomweed (*Ericameria austrotexana*) infestations on south Texas rangelands. Weed Tech. 7:865-871.

Baker, W.L., J.J. Honaker and P.J. Weisberg. 1995. Using aerial photography and GIS to map the forest tundra ecotone in Rocky Mountain National Park, Colorado for global change research. Photogramm. Eng. Rem. Sens. 61(3):313-320.

Beeson, C.E. and P.F. Doyle. 1995. Comparison of bank erosion at vegetated and non-vegetated channel bends. Wat. Res. Bull. 31(6):983-990.

Bohn, C.C. and J.C. Buckhouse. 1985. Some responses of riparian soils to grazing management in northeastern Oregon. J. Range Manage. 38(4):378-381.

Brown, D.G. and A.F. Arbogast. 1999. Digital photogrammetric change analysis as applied to active coastal dunes in Michigan. Photogramm. Eng. Rem. Sens. 65(4):467-474.

Bryant, L.D. 1985. Livestock management in the riparian ecosystem. In: Riparian ecosystems and their management; reconciling conflicting uses. Proceedings of 1st North American Riparian Conference. April 16-18, 1985. Tucson, AZ. USDA Forest Service Gen. Tech. Rep. RM-120. Rocky Mt. Forest and Range Experiment Station. pp. 285-289.

Buckhouse, J.C. and W. Elmore. 1993. Grazing practice relationships:predicting riparian vegetation response from stream systems. In: T.E. Bedell (Ed.). Watershed management guide for the Interior Northwest. Oregon State University Publication EM 8436. Agricultural Communications, OSU, Corvallis, OR. pp. 47-52.

Bull, W.B. 1979. Threshold of critical power in streams. Geol. Soc. Amer. Bull. 90:453-464.

Clary, W.P., N.L. Shaw, J.G. Dudley, V.A. Saab, J.W. Kinney and L.C. Smithman. 1996. Response of a depleted sagebrush steppe riparian system to grazing control and woody plantings. USDA Forest Service INT-RP-492, Intermountain Research Station, Ogden, UT.

Clemmer, P. 1994. Riparian area management - the use of aerial photography to manage riparian - wetland areas. TR 1737-10. USDI, Bureau of Land Management-Service Center, Denver, CO. 54 pp.

Clifton, C. 1989. Effects of vegetation and landuse on channel morphology. In:Greswell, R.E., B.B. Barton and J.L. Kershner (ed.) Practical approaches to riparian resource management, an educational workshop. May 8-11, Billings, MT. US BLM: 121-129.

Cohen, J. 1960. A coefficient of agreement for nominal scales. Educ. Psychol. Measure. 20(1):37-46.

Cuplin, P. 1985. Riparian area inventory and monitoring using large scale color infrared photography. In: Riparian ecosystems and their management; reconciling conflicting uses. Proceedings of 1st North American Riparian Conference. April 16-18, 1985. Tucson, AZ. USDA Forest Service Gen. Tech. Rep. RM-120. Rocky Mt. Forest and Range Experiment Station. pp. 69-71.

Dahlem, E.A. 1979. The Mahagony watershed - with and without grazing. In: Proceedings: Forum on grazing and riparian/stream ecosystems. Trout Unlimited, Inc., Vienna, VA. pp. 31-34.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

Dunaway, D., S. Swanson, J. Wendel, and W. Clary. 1994. The effect of herbaceous plant communities and soil textures on particle erosion of alluvial streambanks. Geomorphology 9:47-56.

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Co., San Francisco, CA: 818 pp.

Eastman, J.R. and M. Fulk. 1993. Long sequence time series evaluation using standardized principal components. Photogramm. Eng. Rem. Sens. 59(8):1307-1312.

Eastman, J.R. and J.E. McKendry. 1991. Change and time series analysis. Explorations in Geographic Information Systems Technology, Vol. 1. United Nations Institute for Training and Research, Geneva, Switzerland. 78 pp.

ERDAS®, Inc. 1997. ERDAS® Field Guide™, Version 8.3.1, Atlanta, GA. 655 pp.

ESRI (Environmental Systems Research Institute). 1996. Getting to know ArcView. Environmental Systems Research Institute, Redlands, CA.

Everitt, J.H. and C.J. Deloach. 1990. Remote sensing of Chinese tamarisk (*Tamarix chinensis*) and associated vegetation. Weed Sci. 38:273-278.

Everitt, J.H., D.E. Escobar, R. Villareal, M.A. Alaniz and M.R. Davis. 1993. Integration of airborne video, global positioning system and geographic information system technologies for detecting and mapping two woody legumes on rangelands. Weed Tech. 7:981-987.

Ferguson, R.L., L.L. Wood and D.B. Graham. 1993. Monitoring spatial change in seagrass habitat with aerial photography. Photogramm. Eng. Rem. Sens. 59(6):1033-1038.

Fung, T. and E. LeDrew. 1987. Application of Principal Components Analysis to change detection. Photogramm. Eng. Rem. Sens. 53(12):1649-1658.

Golden, M., J.Johnson, V. Landrum, J. Powell, V.Varner and T. Wirth. 1996. Guidelines for the use of digital imagery for vegetation mapping. EM-7140-25. USDA Forest Service. Engineering Staff. Washington, D.C. 125 pp.

Grant, G.E. 1988. The RAPID technique: A new method for evaluating downstream effects of forest proactices on stream channels. USDA-FS General Technical Report. PNW-GTR-220. USDA-FS, Pacific Northwest Research Station, Portland, OR.

Green, M.D. 1991. Soil conditions along a hydrologic gradient and successional dynamics in a grazed and ungrazed montane riparian ecosystems. PhD thesis. Oregon State University, Corvallis, OR. 236 pp.

Green, M.D. and J.B. Kauffman. 1995. Succession and livestock grazing in a northeastern Oregon riparian ecosystem. J. Range Manage. 48:307-313.

Green, K., D. Kempka and L. Lackey. 1994. Using remote sensing to detect and monitor land-cover and land-use change. Photogramm. Eng. Rem. Sens. 60(3):331- 337.

Johnson, D.E, N.R. Harris, S. du Plessis and T.M. Tibbs. 1995. Mapping and analysis of Catherine Creek using remote sensing and geographic information systems (GIS). In: Eastern Oregon Agricultural Research Center Field Day Annual Report, Special Report 951, July 1995:10-26.

Hickin, E.J. and G.C. Nanson. 1984. Lateral migration rates of river bends. J. Hydraul. Eng. 110(11):1557-1567.

Hinckley, T.K. and J.W. Walker. 1993. Obtaining and using low altitude large scale imagery. Photogramm. Eng. Rem. Sens. 59(3):310-318.

Kauffman, J.B. 1982. Synecological effects of cattle grazing riparian ecosystems. M.S. thesis. Oregon State University, Corvallis, OR.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications - a review. J. Range Manage. 37(4):430-348.

Kauffman, J.B., W.C. Krueger and M. Vavra. 1983. Effects of late season cattle grazing on riparian plant communities. J. Range Manage. 36(6):685-691.

Keller, E.A. and F.J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4:361-380.

Kleinfelder, D., S. Swanson, G. Norris and Warren Clary. 1992. Unconfined compressive strength of some streambank soils with herbaceous roots. Soil Sci. Soc. Am. J. 56:1920-1925.

Knapp, P.A., Warren, P.L, and C.F. Hutchinson. 1990. The use of large-scale aerial photography to inventory and monitor arid rangeland vegetation. J. Environ. Manage. 31:29-38.

Kondolf, G.M. 1993. Lag in stream channel adjustment to livestock exclosure, White Mountains, California. Restor. Ecol. 1:226-230.

Korpela, E. 1992. Modeling riparian zone processes: biomass production and grazing. PhD thesis. Oregon State University, Corvallis, OR. 154 pp.

Lillesand, T.M. and R.W. Kiefer. 1994. Remote sensing and image interpretation. Third Edition. John Wiley and Sons, Inc. New York. 721 pp.

Magilligan, F.J. and P.F. McDowell. 1997. Stream channel adjustments following elimination of cattle grazing. J. Amer. Wat. Res. Assoc. 33(4):867-878.

Marlow, C.B. and T.M. Pogacnik. 1985. Time of grazing and cattle-induced damage to streambanks. In: Riparian ecosystems and their management; reconciling conflicting uses. First North American Riparian Conference, April 16-18, 1985, Tucson, AZ. USDA Forest Service, Gen. Tech. Rep. RM-120, pp. 279-284.

Mather, P.M. 1992. Remote sensing and the detection of change. ITE Symposium 27:60-68.

Medina, A.L. and S.C. Martin. 1988. Stream channel and vegetation changes in sections of McKnight Creek, New Mexico. Gr. Bas. Natur. 48(3):373-381.

Meehan, W.R. and W.S. Platts. 1978. Livestock grazing and the aquatic environment. J. Soil Wat. Cons. 33(6):274-278.

Miller, J.R., T.T. Schulz, N.T. Hobbs, K.R. Wilson, D.L. Schrupp and W.L. Baker. 1995. Changes in the landscape structure of a southeastern Wyoming zone following shifts in stream dynamics. Biol. Conserv. 72:371-379.

Myers, T.J. and S. Swanson. 1992. Variation of stream stability with stream type and livestock bank damage in northern Nevada. Wat. Res. Bull. 28(4):743-754.

Myers, T.J. and S. Swanson. 1994. Grazing effects on pool forming features in central Nevada. In: Effects of Human-Induced Changes on Hydrologic Systems. R.A. Marston and V.R. Hasfurther (Ed.). Proc. Annu. Sum. Symp. Amer. Wat. Res. Assoc., Jackson Hole, WY, pp. 235-244.

Myers, T.J. and S. Swanson. 1996a. Stream morphologic impact of and recovery from major flooding in north-central Nevada. Phys. Geogr. 17(5):431-445.

Myers, T.J. and S. Swanson. 1996b. Temporal and geomorphic variations of stream stability and morphology: Mahagony Creek, Nevada. Wat. Res. Bull. 32(2): 253-265.

Pieper, R.D. 1973. Measurement techniques for herbaceous and shrubby vegetation. Department of Animal and Range Sciences, New Mexico State University, Las Cruces, N.M., 149 pp.

Pilon, P.G., P.J. Howarth and R.A. Bullock. 1988. An enhanced classification approach to change detection in semi-arid environments. Photogramm. Eng. Rem. Sens. 34(12):1709-1716.

Platts, W.S. 1983. Those vital streambanks. Western Wildlands 3(9):7-10.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K. L Prestegaard, B.D. Richter, R.E. Sparks and J.C. Stromberg. 1997. The natural flow regime. BioScience 7(11):769-784.

Richter, B.D., J.V. Baumgartner, J. Powell and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conserv. Biol. 10(4):1163-1174.

Rinne, J.N. 1985. Livestock grazing effects on southwestern streams: a complex research problem. In: Riparian ecosystems and their management; reconciling conflicting uses. First North American Riparian Conference, April 16-18, 1985, Tucson, AZ. USDA Forest Service, Gen. Tech. Rep. RM-120, pp. 295-299.

Roath, L.R. and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range in the southern Blue Mountains of Oregon. J. Range Manage. 35(3):332-338.

Rosenfield, G.H. and Fitzpatrick-Lins, K. 1986. A coefficient of agreement as a measure of thematic classification accuracy. Photogramm. Eng. Rem. Sens. 52(2):223-227.

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO. 8-43.

Roath, L.R. and W.C. Krueger. 1982. Cattle grazing influence on a mountain riparian zone. J. Range Manage. 35(1):100-103.

Roth, N.E., J.D. Allan, and D.L. Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. Landscape Ecology 11(3):141-156.

Simpson, J.W., R.E.J. Boerner, M. N. DeMers, L.A. Berns, F.J. Artigas, and A. Silva. 1994. Forty-eight years of landscape change on two contiguous Ohio landscapes. Landsc. Ecol. 9(4):261-270.

Singh, A. 1989. Digital change detection techniques using remotely-sensed data. Int. J. Rem. Sens. 10(6):989-1003.

Strong, L.L., R.W. Dana and L.H. Carpenter. 1985. Estimating phytomass of sagebrush habitat types from microdensitometer data. Photogramm. Eng. Rem. Sens. 51:467-474.

Swanson, S. and I. Kamyab. 1996. Simulated stream bank erosion of surface and subsurface samples from three meadow plant communities. In: Sixth Federal Interagency Sedimentation Conference, Las Vegas, Nevada. 1:100-107.

Swanson, S. and T. J. Myers. 1994. Streams, geomorphology, riparian vegetation, livestock, and feedback loops: thoughts for riparian grazing management by objectives. In: Effects of Human-Induced Changes on Hydrologic Systems. R.A. Marston and V.R. Hasfurther (Ed.). Proc. Annu. Sum. Symp. Amer. Wat. Res. Assoc., Jackson Hole, WY, pp. 255-264.

Trimble Navigation. 1996. Trimble Pathfinder Office^{TM}, Software Reference Guide. Trimble Navigation Ltd., Sunnyvale, CA.

Tueller, P.T. 1996. Near-earth monitoring of range condition and trend. Geocarto Int. 11(3):53-62.

Tueller, P.T., P.C. Lent, R.D. Stager, E. A. Jacobson and K.A. Platou. 1988. Rangeland vegetation changes measured from helicopter borne 35 mm aerial photography. Photogramm. Eng. Rem. Sens. 54(5):609-614.

United States Department of Agriculture Forest Service Global Positioning Systems page. 1999. Online. http://www.fs.fed.us/database/gps/ (Accessed Sept.12, 1999).

United States Geological Survey page. 1999. Online. National Water Information System (NWIS) data retrieval. Water resources data for Oregon. http://waterdata.usgs.gov/nwis-w/OR/index.cgi?statnum=13320000 (Accessed Mar.6, 1999).

Vavra, M. Superintendent, Eastern Oregon Agricultural Research Center, Union, OR. Personal communication, Aug.31, 1999.

Ward, J.F. 1988. A comparison of SPOT data with large format camera photography for riparian mapping on the Bighorn National Forest. In: Remote sensing for resource inventory, planning and monitoring: the second Forest Service Remote Sensing Applications Conference, Apr. 11-15, 1988. Am. Soc. Photogramm. Rem. Sens. Falls Church, VA. p. 48-64.

Warner, W.S., R.W. Graham and R.E. Read. 1996. Small Format Aerial Photography. American Society for Photogrammetry and Remote Sensing. Whittles Publishing, Scotland, UK. 348 pp.

Warren, P. L. and C. Dunford. 1986. Sampling semiarid vegetation with large-scale aerial photography. ITC Journal 4:273-279.

Warren, P.L. and C.F. Hutchinson. 1984. Indicators of rangeland change and their potential for remote sensing. J. Arid Environ. 7:107-126.

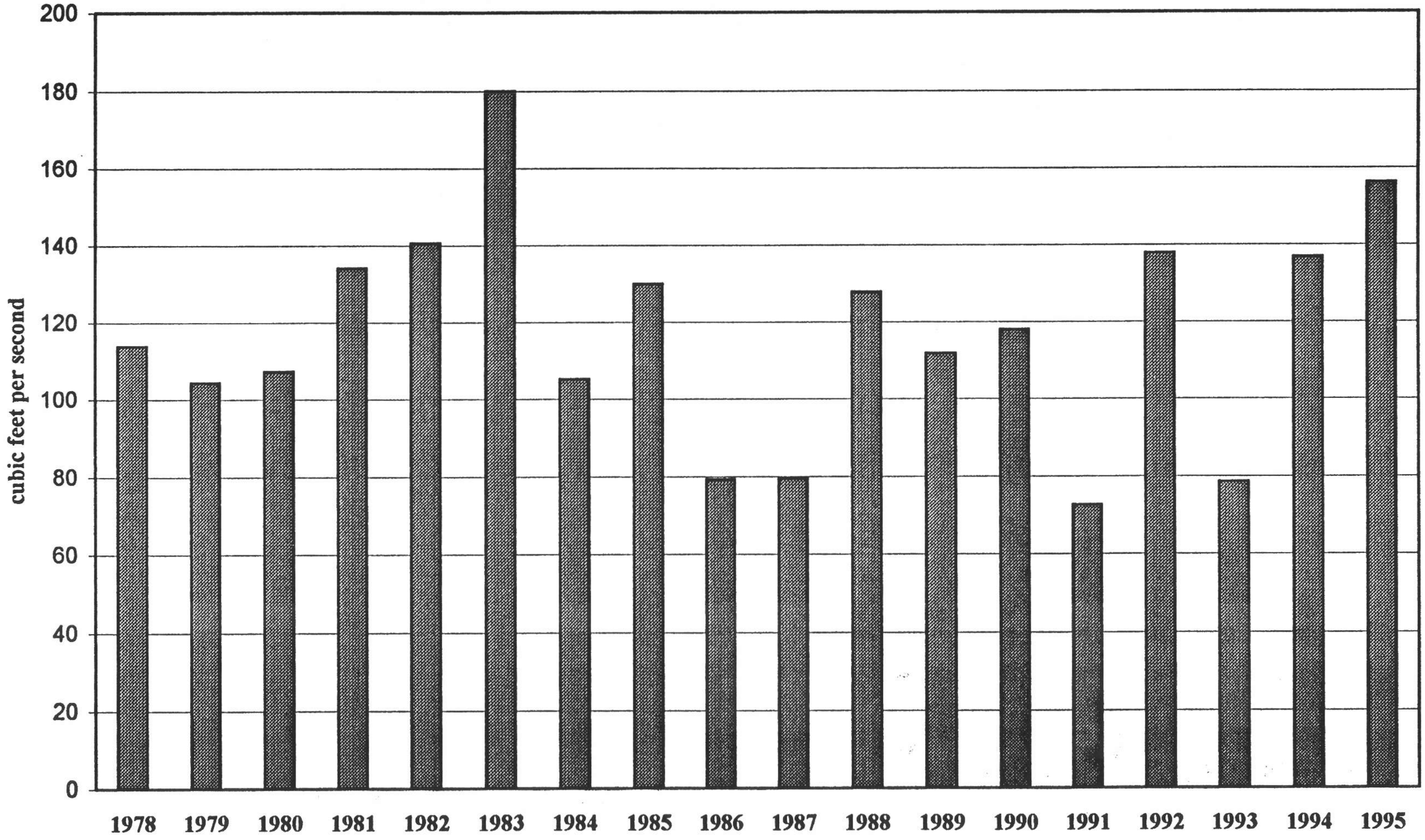
Yool, S.R., M.J. Makaio and J.M. Watts. 1997. Techniques for computer-assisted mapping of rangeland change. J. Range Manage. 50(3):307-314.

Zimmerman, R.C., J.C. Goodlett, and G.H. Comer. 1967. The influence of vegetation on channel form of small streams. Int. Assoc. Sci. Hydrol. 75:255-275.

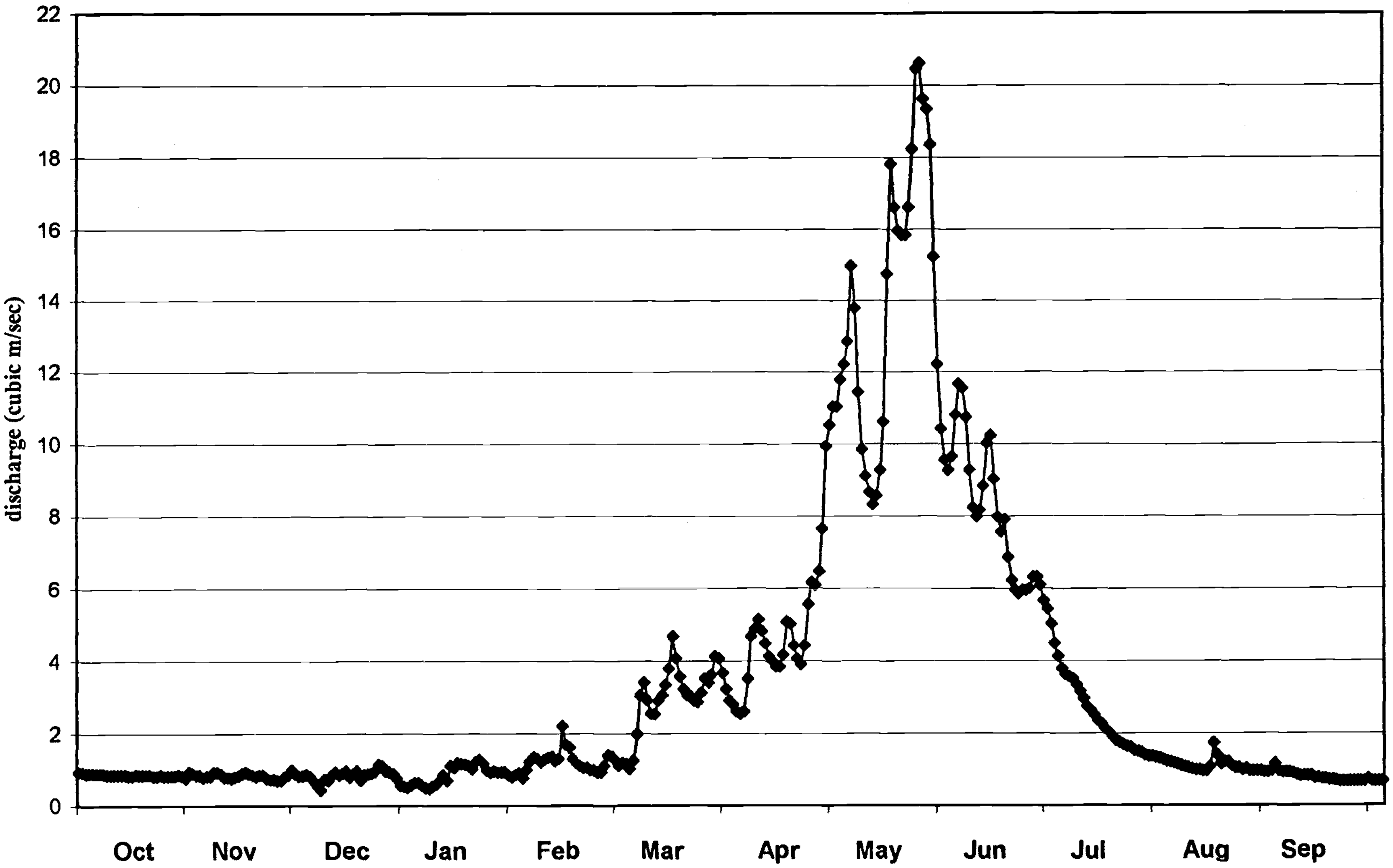
Zonge, L. and S. Swanson. 1996. Changes on streambanks in the Sierra Nevada mountains: perspectives from a dry and a wet year. Restor. Ecol. 4(2):192- 199.

Appendices

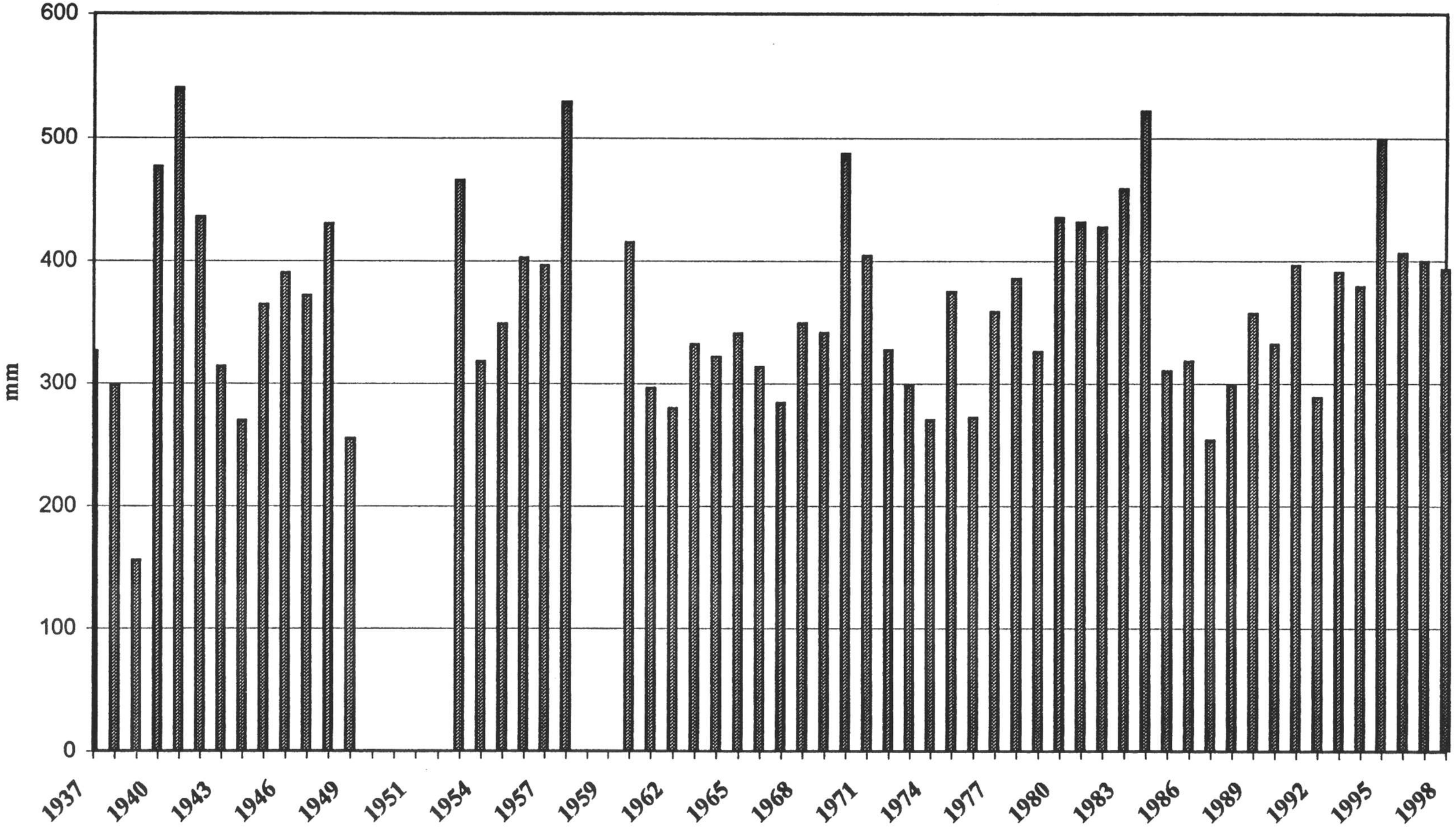
Appendix 1. Mean annual streamflow at Catherine Creek from 1978 to 1995



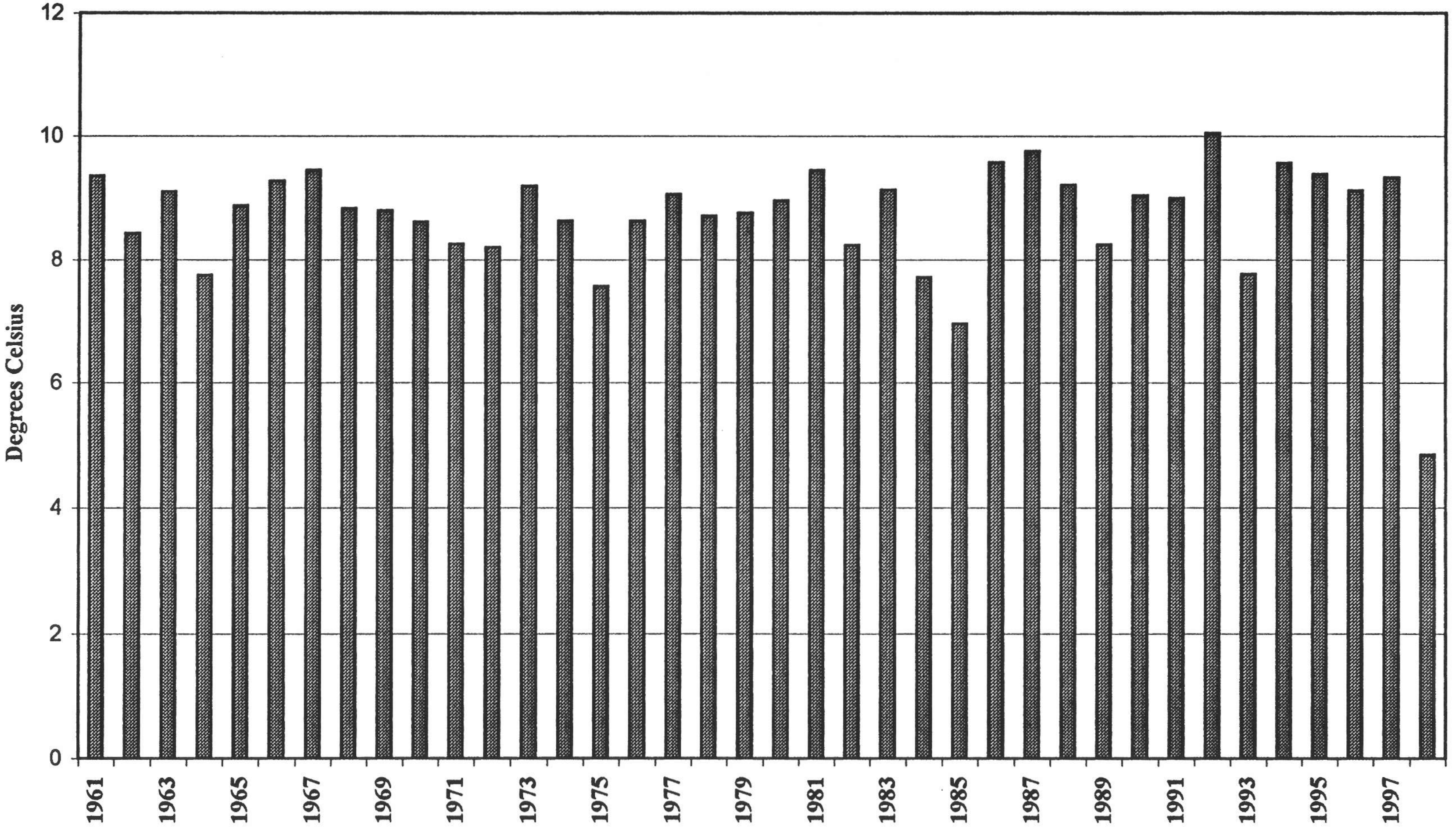
Appendix 2. Catherine Creek hydrograph for the water year Oct. 1978 to Sept. 1979
(Station #1332000)



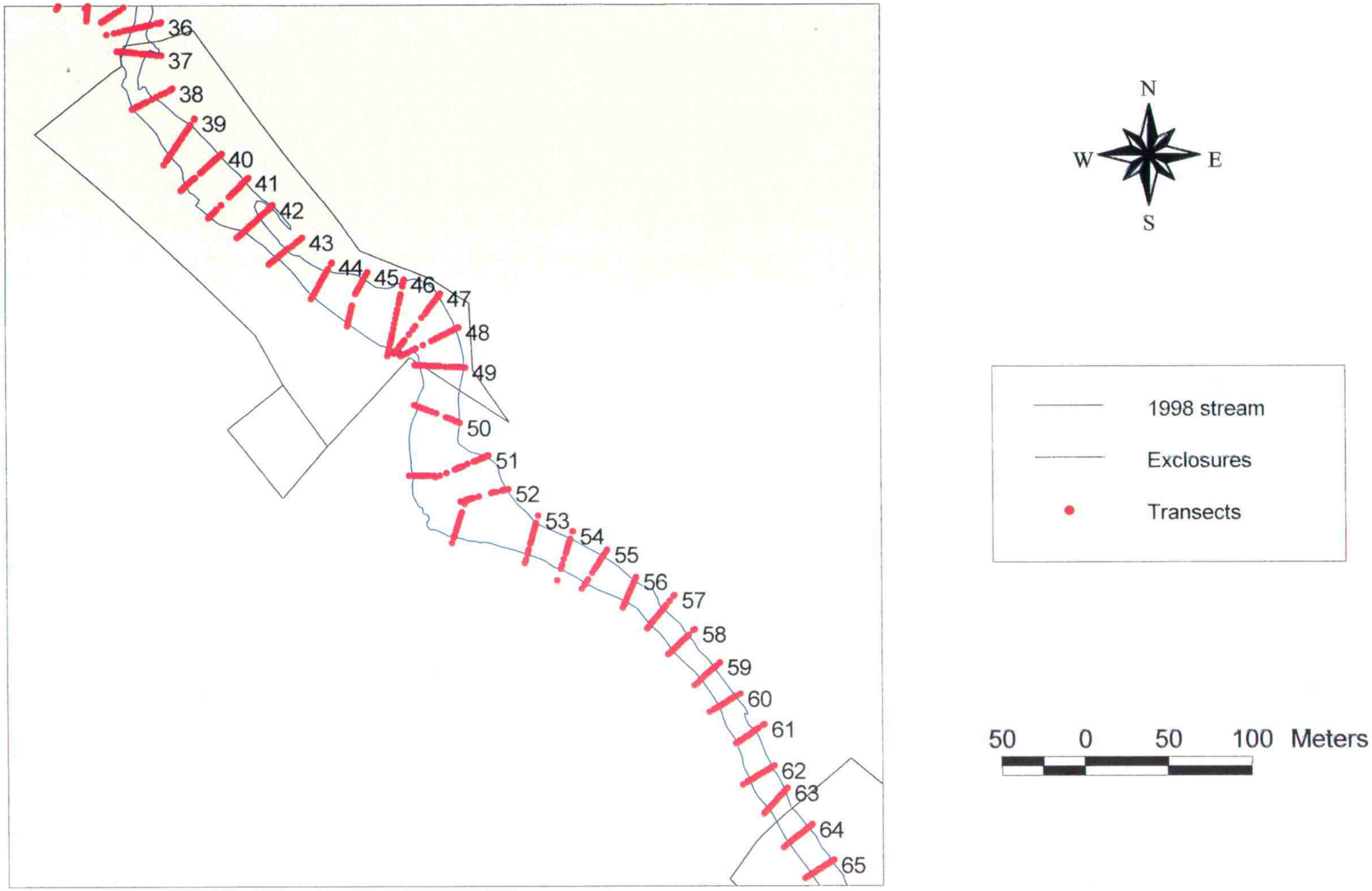
Appendix 3. Mean annual precipitation (Jan.1 - Dec.31) recorded at the Union Agricultural Experiment Station



Appendix 4. Mean annual temperature (Jan.1 - Dec.31) recorded at the Union Agricultural Experiment Station



Appendix 5. Portion of the Catherine Creek study area with numbered permanent transects. Geopositioned headstakes are located on either end of transect.



Appendix 6. Location of right, middle and left headstakes at the Hall Ranch

Coordinate System WGS 84 UTM 11 N (m)

Description	Northing	Easting	Elevation
1L	4998457.225	443511.688	989
1R	4998430.558	443491.675	988
2L	4998448.622	443534.475	991
2R	4998419.188	443511.033	988
3L	4998434.633	443551.949	989
3R	4998410.800	443525.129	985
4L	4998418.130	443568.991	987
4R	4998395.506	443542.739	988
5L	4998396.785	443575.134	989
5R	4998380.138	443558.376	987
6L	4998380.492	443590.729	988
6R	4998361.346	443583.582	987
7L	4998365.470	443610.204	990
7R	4998350.788	443593.799	986
8L	4998348.198	443625.966	988
8R	4998336.949	443612.011	988
9L	4998332.077	443642.796	989
9R	4998318.672	443628.913	988
10L	4998313.568	443658.775	989
10R	4998301.198	443647.499	988
11L	4998301.802	443677.793	992
11R	4998285.001	443664.641	989
12L	4998279.336	443689.467	989
12R	4998270.642	443681.921	988
13L	4998267.649	443710.542	989
13R	4998249.190	443701.171	992
14L	4998258.510	443732.722	989
14R	4998242.111	443724.868	989
15L	4998250.223	443754.486	990
15R	4998232.188	443746.913	991
16L	4998247.357	443778.048	991
16R	4998224.065	443769.928	993
17L	4998250.825	443802.658	991
17R	4998218.952	443815.081	991
18L	4998267.193	443819.555	991
18ML	4998250.227	443830.876	1010
18R	4998230.271	443846.573	991
19L	4998280.079	443838.206	992
19MR	4998249.995	443852.269	1008

L: Left
R: Right
M: Middle

E2S3:
G4S1: Potential salmon spawning transects

Appendix 6. continued

Description	Northing	Easting	Elevation
19R	4998228.542	443855.033	990
20L	4998277.502	443862.604	991
20ML	4998263.950	443862.042	
20MR	4998248.875	443861.417	
20R	4998234.375	443860.815	994
21L	4998262.746	443881.692	992
21R	4998234.925	443865.366	993
22L	4998241.177	443887.920	992
22R	4998228.853	443876.734	993
23L	4998226.853	443907.114	992
23R	4998213.681	443900.326	991
24L	4998230.110	443927.472	993
24ML	4998216.622	443938.058	1006
24MR	4998184.277	443934.925	1017
24R	4998181.032	443922.608	994
25L	4998232.494	443950.769	997
25ML	4998213.589	443950.33	1014
25MR	4998176.277	443947.275	1012
25R	4998168.432	443943.152	996
26L	4998230.622	443973.774	991
26ML	4998211.459	443963.949	1009
26MR	4998170.47	443943.938	1025
26R	4998163.647	443945.909	994
27L	4998209.466	443988.265	997
27ML	4998200.123	443974.646	1016
27MR	4998175.795	443957.94	1008
27R	4998165.099	443952.148	999
28L	4998186.684	443999.575	995
28R	4998156.640	443962.579	995
29L	4998170.466	444012.618	1001
29M	4998166.312	444002.792	
29R	4998155.524	443977.277	996
30L	4998164.954	444037.421	996
30ML	4998158.298	444030.732	1013
30MR	4998139.866	444018.803	1010
30R	4998123.686	444009.660	994
31L	4998145.668	444051.971	1001
31R	4998105.927	444036.325	996
32L	4998130.725	444069.815	995
32MR	4998114.843	444067.947	1015

Appendix 6. continued

Description	Northing	Easting	Elevation
32R	4998088.350	444048.892	995
33L	4998116.210	444089.645	994
33ML	4998098.395	444081.164	995
33MR	4998075.726	444070.162	993
33R	4998071.420	444067.625	995
34L	4998104.286	444106.527	995
34ML	4998092.254	444101.903	995
34MR	4998073.935	444086.317	995
34R	4998064.541	444085.425	996
35L	4998085.208	444127.979	991
35ML	4998079.123	444108.389	996
35R	4998062.893	444094.112	997
36L	4998062.875	444130.333	997
36M	4998065.969	444110.454	995
36R	4998055.885	444099.420	1001
37L	4998042.806	444130.438	997
37R	4998045.522	444105.305	995
38L	4998022.759	444137.041	996
38R	4998010.534	444112.660	997
39L	4998004.936	444150.315	997
39R	4997977.760	444132.152	996
40L	4997983.642	444166.327	1002
40R	4997963.868	444144.346	997
41L	4997969.114	444182.024	999
41R	4997945.422	444158.625	998
42L	4997952.474	444196.517	999
42R	4997933.946	444176.352	999
43L	4997932.860	444214.208	999
43R	4997919.290	444196.943	1001
44L	4997918.144	444231.945	998
44R	4997896.643	444219.957	999
45L	4997912.212	444253.260	1000
45ML	4997899.933	444246.491	1012
45MR	4997892.119	444243.996	1019
45R	4997877.792	444240.703	1001
46L	4997907.616	444275.146	1000
46R	4997864.776	444265.852	1004
47L	4997898.828	444296.833	1001
47R	4997864.674	444270.525	1003
48L	4997878.642	444308.053	1001
48R	4997863.086	444276.293	1001

Appendix 6. continued

Description	Northing	Easting	Elevation
49L	4997854.613	444311.861	1002
49R	4997856.094	444281.205	1003
50L	4997821.101	444308.437	1000
50R	4997831.922	444281.321	1002
51L	4997801.532	444325.534	1000
51ML	4997791.614	444308.165	1001
51MR	4997789.469	444296.068	1000
51R	4997789.425	444277.509	1001
52L	4997781.605	444337.329	1003
52ML	4997774.090	444329.894	1003
52MR	4997774.791	444311.723	1000
52R	4997750.117	444303.625	1002
53L	4997765.661	444355.144	1003
53R	4997737.384	444347.311	998
54L	4997756.090	444375.886	1003
54R	4997725.772	444366.187	1005
55L	4997745.148	444396.493	1003
55R	4997720.796	444380.742	1003
56L	4997728.588	444413.754	1007
56R	4997710.187	444405.860	1002
57L	4997717.488	444436.656	1002
57R	4997697.960	444420.530	1002
58L	4997697.224	444448.844	1003
58R	4997681.500	444432.503	1003
59L	4997676.980	444463.852	1005
59R	4997663.363	444448.802	1004
60L	4997658.237	444476.158	1005
60R	4997647.171	444457.883	1004
61L	4997639.571	444490.534	1005
61R	4997626.787	444471.730	1003
62L	4997614.467	444496.433	1007
62R	4997604.103	444478.911	1005
63L	4997601.025	444504.134	1005
63R	4997584.791	444489.364	1006
64L	4997578.932	444518.899	1004
64R	4997565.006	444501.524	1006
65L	4997557.633	444532.029	1005
65R	4997547.671	444516.620	1006
66L	4997538.465	444545.441	1005
66R	4997527.920	444531.149	1006
67L	4997520.092	444560.233	1007

Appendix 6. continued

Description	Northing	Easting	Elevation
67R	4997509.000	444546.640	1007
68L	4997505.486	444577.421	1007
68R	4997489.380	444564.189	1007
69L	4997489.556	444595.481	1008
69R	4997473.952	444582.425	1007
70L	4997475.235	444612.726	1008
70R	4997460.781	444598.187	1007
71L	4997454.707	444629.874	1013
71R	4997444.398	444618.386	1007
72L	4997439.766	444646.372	1011
72R	4997439.629	444630.437	1008
73L	4997420.957	444658.130	1008
73R	4997416.842	444634.754	1008
74L	4997398.754	444665.767	1009
74R	4997388.885	444647.348	1010
75L	4997382.636	444675.239	1009
75R	4997368.938	444659.450	1009
76L	4997376.631	444677.088	1008
76R	4997366.861	444665.374	1010
77L	4997362.63	444704.977	1012
77M	4997343.843	444688.493	
77R	4997334.137	444679.976	1008
78L	4997350.158	444726.8	1010
78R	4997327.493	444682.231	1010
79L	4997330.126	444739.559	1010
79R	4997310.519	444696.417	1009
80L	4997306.341	444744.657	1011
80R	4997278.690	444701.928	1011
81L	4997290.795	444762.314	1010
81ML	4997280.298	444746.417	
81MR	4997259.413	444730.582	1026
81R	4997255.174	444708.368	1010
82L	4997289.261	444787.212	1011
82ML	4997271.736	444766.506	
82MR	4997248.205	444738.703	
82R	4997235.672	444723.895	1011
83L	4997266.108	444792.81	1011
83ML	4997256.058	444777.837	1023
83MR	4997239.022	444763.888	
83R	4997220.500	444744.111	1012
84L	4997247.761	444806.392	1012

Appendix 6. continued

Description	Northing	Easting	Elevation
84ML	4997242.42	444800.332	
84MR	4997230.429	444786.727	
84R	4997208.834	444762.223	1012
85L	4997244.114	444831.235	1016
85R	4997199.843	444767.546	1012
86L	4997224.435	444836.424	1014
86R	4997178.903	444785.790	1012
87L	4997200.849	444832.746	1014
87M	4997181.642	444829.339	
87R	4997152.436	444824.159	1012
88L	4997180.644	444859.506	1015
88R	4997161.020	444842.906	1014
89L	4997162.241	444872.386	1014
89R	4997150.776	444853.984	1013
90L	4997143.197	444877.321	1015
90R	4997138.379	444863.917	1015
91L	4997120.305	444882.497	1014
91R	4997118.241	444866.506	1011
92L	4997098.182	444890.608	1016
92R	4997090.697	444878.334	1015
93L	4997078.778	444903.239	1013
93R	4997069.773	444888.826	1015
94L	4997063.127	444919.924	1015
94R	4997047.542	444915.160	1016
95L	4997061.821	444943.756	1015
95R	4997032.746	444937.570	1016
96L	4997063.324	444968.598	1013
96R	4997020.811	444948.448	1015
97L	4997047.167	444982.890	1015
97R	4997020.048	444957.014	1017
98L	4997024.574	444992.370	1016
98R	4997018.688	444958.792	1017
E2S3	4998223.116	443910.013	992
E3S1	4997465.407	444619.843	1012
E4S1	4997455.540	444609.209	1007
E5S2	4997111.841	444885.780	1012
E5S2	4997107.209	444870.653	1013
G3S2	4997713.872	444398.219	1012
G3S2	4997736.628	444402.886	1004
G4S3	4997162.295	444827.847	1011
G4S1	4997290.525	444755.351	1012

Appendix 7.

Average percent frequency of plant species in 8 different plant communities along the Catherine Creek study area

Appendix 7.1. Average percent frequency of plant species in dry meadow, moist meadow and hawthorn communities at the Catherine Creek study site E=Exclosure, G=Grazed area

	Dry meadow		Moist meadow		Hawthorn	
	E	G	E	G	E	G
Grasses						
Agropyron inerme	-	14.7	-	-	-	-
Agropyron repens	1.7	7.3	-	2.7	2.0	8.9
Agrostis sp.	1.7	10.0	-	5.3	12.7	-
Arrhenatherum elatus	-	-	-	-	0.7	1.1
Bromus inermis	0.8	-	-	-	-	-
Bromus marginatus	24.2	20.0	1.7	6.0	6.0	1.1
Bromus mollis	-	13.3	-	-	10.0	6.7
Bromus tectorum	17.5	4.0	-	-	0.7	4.4
Dactylis glomerata	-	-	-	-	-	-
Deschampsia caespitosa	-	-	-	5.3	-	-
Elymus glaucus	-	2.7	-	-	8.0	5.6
Festuca elatior	-	13.3	-	-	-	-
Glyceria elata	-	-	-	-	-	-
Glyceria grandis	-	-	-	-	-	-
Holcus lanatus	-	-	-	-	-	-
Melica bulbosa	-	2.0	-	-	-	6.7
Phleum pratense	-	32.0	2.5	62.7	10.0	4.4
Poa compressa	-	1.3	-	-	-	-
Poa pratensis	99.2	93.3	81.7	82.0	96.7	86.7
Poa sandbergii	-	-	-	-	-	-
Stipa columbiana	-	-	-	-	-	-
Sedges and Rushes						
Carex hoodii	4.2	8.7	26.7	14.7	4.7	12.2
Carex nebraskensis	-	-	9.2	10.7	-	-
Carex rostrata	-	-	26.7	14.7	0.7	-
Carex sp.	-	-	13.3	17.3	2.0	1.1
Juncus balticus	-	12.0	35.8	34.7	-	-
Juncus sp.	-	-	-	-	-	-
Luzula campestris	-	-	0.8	-	-	-
Scirpus microcarpus	-	-	-	4.0	-	-

Appendix 7.1. Continued

	Dry meadow		Moist meadow		Hawthorn	
	E	G	E	G	E	G
Forbs						
Achillea millefolium	32.5	21.3	25.8	36.7	31.3	15.6
Agoseris glauca	-	3.3	3.3	-	0.7	1.1
Aster foliaceus	-	12.0	35.0	24.7	38.0	4.4
Aster sp.	15.8	-	13.3	7.3	-	-
Anaphalis margaritacea	-	4.0	-	-	-	-
Angelica	-	-	-	-	-	-
Aquilegia formosa	-	-	-	-	11.3	-
Castilleja cusickii	2.5	-	-	-	-	-
Cerastium viscosum	0.8	-	0.8	2.0	4.0	5.6
Cirsium arvense	-	10.7	-	-	-	-
Cirsium canescens	-	-	6.7	-	0.7	-
Cirsium vulgare	-	-	-	-	0.7	-
Descuriana pinnata	-	-	-	-	-	-
Draba verna	2.5	-	-	-	-	-
Epilobium paniculatum	-	-	-	-	-	-
Equisetum arvense	-	3.3	4.2	5.3	4.0	3.3
Eriogonum heracloides	-	-	0.8	0.7	1.3	-
Erodium circutarium	3.3	2.0	-	-	-	-
Fragaria virginiana	-	15.3	15.0	33.3	31.3	13.3
Galium asperrimum	-	-	0.8	2.7	-	-
Galium boreale	-	0.7	1.7	0.7	4.7	17.8
Geum macrophyllum	0.8	5.3	6.7	7.3	3.3	5.6
Heracleum lanatum	-	-	-	0.7	-	-
Holosteum umbellatum	-	-	-	-	0.7	-
Iris missouriensis	-	-	-	1.3	-	-
Lactuca serriola	-	-	-	-	-	-
Lathyrus polyphyllus	-	-	-	-	-	-
Lepidium perfoliatum	-	1.3	-	-	-	-
Lepidium virginicum	-	-	-	-	-	-
Lupinus leucophyllus	3.3	7.3	-	-	-	-
Mimulus guttatus	-	-	-	-	-	-
Montia perfoliata	-	-	-	-	0.7	4.4
Osmorhiza chilensis	-	-	-	-	-	13.3
Penstemon rydbergii	-	0.7	5.8	1.3	-	-
Polemonium occidentale	-	-	0.8	4.0	-	-
Polygonum douglasii	0.8	-	-	-	1.3	-
Potentilla gracilis	-	9.3	27.5	35.3	2.0	-

Appendix 7.1. Continued

	Dry meadow		Moist meadow		Hawthorn	
	E	G	E	G	E	G
Prunella vulgaris	-	0.7	-	-	-	1.1
Pteridium aquilinum	-	-	-	-	-	-
Ranunculus acris	-	18.7	1.7	5.3	11.3	17.8
Rorippa nasturtium	-	-	-	0.7	-	-
Rumex acetosella	0.8	4.0	0.8	4.0	-	-
Senecio serra	9.2	21.3	15.0	18.7	34.7	33.3
Silene douglasii	-	-	-	-	-	-
Silene oregana	-	2.0	-	-	-	-
Smilacina stellata	6.7	-	-	-	0.7	3.3
Stellaria longifolia	29.2	-	8.3	5.3	9.3	7.8
Stellaria nitins	1.7	-	-	-	3.3	-
Taraxacum officinale	-	7.3	5.8	8.7	5.3	24.4
Tragopogon dubius	5.8	8.7	1.7	8.0	6.0	3.3
Trifolium pratense	2.5	8.0	-	6.7	11.3	-
Trifolium repens	0.8	5.3	-	0.7	-	3.3
Urtica dioica	-	-	-	-	-	1.1
Veratrum californicum	-	-	7.5	16.7	-	-
Verbascum thapsus	0.8	-	-	-	-	-
Veronica americana	-	-	-	0.7	2.7	-
Veronica arvensis	10.0	2.0	-	-	-	-
Vicia americana	41.7	10.0	13.3	27.3	-	-
Viola adunca	7.5	4.0	4.2	3.3	1.3	7.8
Unknown	3.3	0.7	-	-	-	2.2
Shrubs and Trees						
Alnus incana	-	-	-	-	-	1.1
Amelanchier alnifolia	-	-	-	-	-	1.1
Crataegus douglasii	0.8	-	0.8	0.7	12.0	3.3
Pinus ponderosa	0.8	-	-	-	-	1.1
Populus trichocarpa	-	-	-	-	-	-
Ribes cereum	-	-	-	-	-	-
Rosa woodsii	0.8	-	5.0	0.7	0.7	-
Rubus idaeus	-	-	-	-	-	-
Salix exigua	-	-	-	-	-	-
Salix lutea	-	-	-	-	-	-
Salix sp.	-	-	-	-	-	-
Symphoricarpus albus	17.5	13.3	1.7	8.0	12.0	15.6

Appendix 7.2.Average percent frequency of plant species in alder, Ponderosa pine and gravel bar communities at the Catherine Creek study site E=Exclosure, G=Grazed area

	Alder		Ponderosa Pine		Gravel bar	
	E	G	E	G	E	G
Grasses						
Agropyron inerme	-	-	-	-	-	-
Agropyron repens	1.1	3.3	1.7	1.1	6.7	0.8
Agrostis sp.	7.8	8.9	1.7	-	22.2	40.0
Arrhenatherum elatus	-	-	-	-	-	-
Bromus inermis	-	-	-	-	-	-
Bromus marginatus	-	-	-	4.4	-	-
Bromus mollis	-	-	11.7	5.6	-	8.3
Bromus tectorum	-	-	11.7	2.2	-	-
Dactylis glomerata	-	-	-	-	-	0.8
Deschampsia caespitosa	-	-	-	-	-	-
Elymus glaucus	38.9	40.0	6.7	10.0	25.6	4.2
Festuca elatior	-	-	-	1.1	-	5.8
Glyceria elata	1.1	-	-	-	-	-
Glyceria grandis	7.8	-	-	-	-	-
Holcus lanatus	-	-	-	-	-	17.5
Melica bulbosa	-	-	-	10.0	-	4.2
Phleum pratense	-	11.1	-	5.6	1.1	75.0
Poa compressa	1.1	5.6	-	1.1	-	4.2
Poa pratensis	57.8	51.1	66.7	75.6	30.0	62.5
Poa sandbergii	-	-	-	-	-	-
Stipa columbiana	-	-	1.7	-	-	-
Sedges and Rushes						
Carex hoodii	4.4	4.4	-	3.3	-	3.3
Carex nebraskensis	-	-	-	-	-	-
Carex rostrata	6.7	7.8	-	-	-	1.7
Carex sp.	12.2	12.2	-	3.3	8.9	14.2
Juncus balticus	-	-	-	1.1	-	10.0
Juncus sp.	-	-	-	-	-	2.5
Luzula campestris	1.1	-	-	-	-	3.3
Scirpus microcarpus	1.1	-	-	-	-	3.3

Appendix 7.2. Continued

	Alder		Ponderosa Pine		Gravel bar	
	E	G	E	G	E	G
Forbs						
Achillea millefolium	-	1.1	13.3	18.9	2.2	13.3
Agoseris glauca	-	-	-	-	-	-
Aster foliaceus	1.1	7.8	-	6.7	23.3	20.8
Aster sp.	2.2	-	11.7	7.8	7.8	-
Anaphalis margaritacea	-	-	-	-	-	-
Angelica	-	1.1	-	-	-	-
Aquilegia formosa	6.7	1.1	-	16.7	-	-
Castilleja cusickii	-	-	-	-	-	-
Cerastium viscosum	-	1.1	-	5.6	3.3	3.3
Cirsium arvense	-	-	-	-	1.1	-
Cirsium canescens	-	-	-	-	-	-
Cirsium vulgare	-	-	-	-	-	-
Descuriana pinnata	-	-	-	-	-	-
Draba verna	-	-	-	-	-	-
Epilobium paniculatum	-	-	-	-	-	-
Equisetum arvense	1.1	3.3	-	8.9	1.1	23.3
Eriogonum heracloides	-	-	-	-	-	-
Erodium circutarium	-	-	-	-	-	-
Fragaria virginiana	-	3.3	-	-	3.3	18.3
Galium asperrimum	-	-	-	-	-	-
Galium boreale	5.6	12.2	-	28.9	-	-
Geum macrophyllum	11.1	12.2	-	1.1	-	4.2
Heracleum lanatum	13.3	8.9	-	-	-	-
Holosteum umbellatum	-	-	-	-	-	-
Iris missouriensis	-	-	-	-	-	-
Lactuca serriola	-	-	-	-	-	-
Lathyrus polyphyllus	-	-	-	3.3	-	-
Lepidium perfoliatum	-	-	-	-	-	-
Lepidium virginicum	-	-	-	-	-	-
Lupinus leucophyllus	-	-	-	3.3	-	-
Mimulus guttatus	1.1	-	-	-	-	-
Montia perfoliata	2.2	10.0	-	22.2	-	-
Osmorhiza chilensis	1.1	6.7	-	8.9	-	-
Penstemon rydbergii	-	-	-	-	7.8	2.5
Polemonium occidentale	-	-	-	-	-	-
Polygonum douglasii	-	-	-	-	-	-
Potentilla gracilis	-	-	-	-	-	-

Appendix 7.2. Continued

	Alder		Ponderosa Pine		Gravel bar	
	E	G	E	G	E	G
Prunella vulgaris	-	1.1	-	-	6.7	9.2
Pteridium aquilinum	-	1.1	-	-	-	-
Ranunculus acris	6.7	42.2	-	12.2	4.4	30.8
Rorippa nasturtium	-	7.8	-	-	-	-
Rumex acetosella	-	-	-	-	1.1	5.8
Senecio serra	24.4	6.7	-	5.6	7.8	1.7
Silene douglasii	1.1	-	-	-	-	-
Silene oregana	-	-	-	-	-	-
Smilacina stellata	11.1	8.9	10.0	7.8	-	-
Stellaria longifolia	-	10.0	18.3	-	1.1	-
Stellaria nitins	-	-	1.7	-	1.1	-
Taraxacum officinale	1.1	7.8	1.7	12.2	3.3	24.2
Tragopogon dubius	-	-	-	2.2	1.1	5.0
Trifolium pratense	-	-	3.3	6.7	-	5.0
Trifolium repens	-	-	-	1.1	13.3	38.3
Urtica dioica	1.1	-	-	-	-	-
Veratrum californicum	-	-	-	-	-	-
Verbascum thapsus	-	-	1.7	-	1.1	-
Veronica americana	-	-	-	-	-	-
Veronica arvensis	-	-	-	-	-	-
Vicia americana	-	-	-	15.6	-	0.8
Viola adunca	4.4	3.3	-	8.9	-	-
Unknown	28.9	16.7	-	-	-	-
Shrubs and Trees						
Alnus incana	10.0	-	-	-	2.2	2.5
Amelanchier alnifolia	-	-	-	-	-	-
Crataegus douglasii	1.1	2.2	3.3	3.3	-	0.8
Pinus ponderosa	-	-	-	-	-	0.8
Populus trichocarpa	-	-	-	-	25.6	-
Ribes cereum	3.3	-	-	-	-	-
Rosa woodsii	3.3	-	5.0	1.1	2.2	-
Rubus idaeus	1.1	-	-	-	-	-
Salix exigua	-	-	-	-	10.0	0.8
Salix lutea	-	-	-	-	5.6	1.7
Salix sp.	1.1	-	-	-	-	0.8
Symphoricarpus albus	30.0	3.3	25.0	18.9	-	-

Appendix 7.3. Average percent frequency of plant species in cottonwood and cheatgrass communities at the Catherine Creek study site
E=Exclosure, G=Grazed area

	Cottonwood		Cheatgrass	
	E	G	E	G
Grasses				
Agropyron inerme	-	-	-	-
Agropyron repens	-	2.2	6.7	-
Agrostis sp.	-	2.2	-	-
Arrhenatherum elatus	-	-	-	-
Bromus inermis	-	-	-	-
Bromus marginatus	-	5.6	-	-
Bromus mollis	-	6.7	11.1	18.9
Bromus tectorum	-	6.7	76.7	91.1
Dactylis glomerata	-	1.1	-	-
Deschampsia caespitosa	-	-	-	-
Elymus glaucus	11.1	10.0	-	-
Festuca elatior	-	5.6	-	-
Glyceria elata	-	1.1	-	-
Glyceria grandis	-	-	-	-
Holcus lanatus	-	-	-	-
Melica bulbosa	-	-	-	-
Phleum pratense	-	11.1	-	-
Poa compressa	-	10.0	-	-
Poa pratensis	48.9	75.6	-	30.0
Poa sandbergii	-	-	32.2	23.3
Stipa columbiana	-	-	-	2.2
Sedges and Rushes				
Carex hoodii	-	7.8	-	-
Carex nebraskensis	-	-	-	-
Carex rostrata	-	-	-	-
Carex sp.	4.4	3.3	-	-
Juncus balticus	-	5.6	-	-
Juncus sp.	-	-	-	-
Luzula campestris	-	-	-	-
Scirpus microcarpus	-	4.4	-	-

Appendix 7.3. Continued

	Cottonwood		Cheatgrass	
	E	G	E	G
Forbs				
Achillea millefolium	10.0	7.8	-	2.2
Agoseris glauca	-	-	-	-
Aster foliaceus	10.0	4.4	-	-
Aster sp.	-	-	-	-
Anaphalis margaritacea	-	-	-	-
Angelica	-	-	-	-
Aquilegia formosa	-	-	-	-
Castilleja cusickii	-	-	-	-
Cerastium viscosum	-	-	-	-
Cirsium arvense	3.3	-	-	-
Cirsium canescens	-	-	-	-
Cirsium vulgare	-	-	-	-
Descuriana pinnata	-	-	2.2	-
Draba verna	-	-	-	-
Epilobium paniculatum	-	3.3	-	-
Equisetum arvense	-	-	-	-
Eriogonum heracloides	-	-	4.4	-
Erodium circutarium	-	-	-	2.2
Fragaria virginiana	-	3.3	1.1	3.3
Galium asperrimum	-	-	-	-
Galium boreale	1.1	1.1	-	-
Geum macrophyllum	-	2.2	-	-
Heracleum lanatum	2.2	-	-	-
Holosteum umbellatum	-	-	-	-
Iris missouriensis	-	-	-	-
Lactuca serriola	-	-	1.1	-
Lathyrus polyphyllus	-	-	-	-
Lepidium perfoliatum	-	-	11.1	15.6
Lepidium virginicum	-	-	-	12.2
Lupinus leucophyllus	-	-	-	-
Mimulus guttatus	-	-	-	-
Montia perfoliata	-	-	-	-
Osmorhiza chilensis	-	-	-	-
Penstemon rydbergii	-	-	-	-
Polemonium occidentale	-	-	-	-
Polygonum douglasii	-	-	6.7	5.6
Potentilla gracilis	-	-	-	-

Appendix 7.3. Continued

	Cottonwood		Cheatgrass	
	E	G	E	G
Prunella vulgaris	-	-	-	-
Pteridium aquilinum	-	-	-	-
Ranunculus acris	2.2	10.0	23.3	18.9
Rorippa nasturtium	-	-	-	-
Rumex acetosella	-	-	-	-
Senecio serra	6.7	2.2	-	-
Silene douglasii	-	-	-	-
Silene oregana	-	-	-	-
Smilacina stellata	42.2	14.4	-	-
Stellaria longifolia	1.1	-	-	-
Stellaria nitins	-	-	16.7	18.9
Taraxacum officinale	-	5.6	-	-
Tragopogon dubius	-	3.3	8.9	-
Trifolium pratense	-	1.1	-	-
Trifolium repens	-	-	-	-
Urtica dioica	-	-	-	-
Veratrum californicum	-	-	-	-
Verbascum thapsus	-	-	-	1.1
Veronica americana	-	-	-	-
Veronica arvensis	-	-	14.4	31.1
Vicia americana	13.3	6.7	-	-
Viola adunca	-	-	-	-
Unknown	-	-	-	-
Shrubs and Trees				
Alnus incana	1.1	1.1	-	-
Amelanchier alnifolia	2.2	-	-	-
Crataegus douglasii	1.1	2.2	-	-
Pinus ponderosa	2.2	-	-	-
Populus trichocarpa	-	1.1	-	-
Ribes cereum	-	-	-	-
Rosa woodsii	7.8	3.3	1.1	-
Rubus idaeus	-	-	-	-
Salix exigua	-	-	-	-
Salix lutea	-	-	-	-
Salix sp.	-	-	-	-
Symphoricarpus albus	34.4	21.1	2.2	1.1

Appendix 8. Location of frequency transects at the Hall Ranch
Coordinate System WGS 84 UTM 11 N (m)

Community #	Location	Easting	Northing	Elevation
1	start	444229.002	4997803.359	1001.049
1	end	444259.085	4997799.842	1001.113
3	start	444276.854	4997791.948	1002.587
3	end	444270.463	4997821.258	1002.446
17	start	444362.261	4997712.969	1002.098
17	end line 1	444368.816	4997697.263	1002.676
17	start line 2	444363.85	4997711.53	1002.352
17	end line 2	444351.041	4997704.247	1002.777
22	start line 1	444371.552	4997680.393	1004.014
22	end line 1	444371.884	4997664.496	1002.678
22	start line 2	444376.225	4997680.329	1004.853
22	end line 2	444376.266	4997662.637	1003.762
23	start	444424.016	4997689.642	1004.006
23	end	444400.573	4997708.315	1002.469
25	start line 1	444409.017	4997671.515	1004.212
25	end line 1	444402.972	4997656.392	1003.833
25	start line 2	444407.279	4997672.812	1001.902
25	end line 2	444399.505	4997660.026	1002.760
30	start	444382.403	4997631.049	1003.471
30	end	444353.009	4997624.817	1004.096
34	start	444444.171	4997587.345	1006.062
34	end	444412.785	4997589.528	1005.458
35	start at 5 m	444480.014	4997601.786	1005.731
35	end	444462.401	4997619.304	1003.839
36	start line 1	444486.906	4997567.252	1005.490
36	end line 1	444506.284	4997560.045	1006.361
36	start line 2	444487.634	4997568.626	1006.128
36	end line 2	444497.319	4997565.114	1006.832
40	start	444517.359	4997544.199	1006.051
40	end	444505.7	4997516.165	1008.315
44	start	444535.759	4997510.434	1006.905
44	end 25m	444530.728	4997486.593	1006.830
51	start	444573.938	4997468.541	1007.303
51	end	444579.568	4997437.725	1009.055
52	start	444590.565	4997460.447	1006.485
52	end	444592.336	4997432.463	1008.603
57	start	444616.54	4997418.501	1009.741
57	end line2	444603.201	4997428.506	1010.446
67	start	444622.389	4997379.317	1008.694
67	end	444638.943	4997361.662	1009.628
76	start line 1	444653.943	4997292.795	1009.007
76	end line 1	444643.632	4997280.357	1016.567
79	start line 1	444693.295	4997298.102	1016.327
79	end line 1	444699.577	4997283.898	1013.907

Appendix 8. continued

Community #	Location	Easting	Northing	Elevation
79	start line 2	444689.678	4997298.953	1012.171
79	end line 2	444692.892	4997283.763	1012.585
83	at 20m	444681.137	4997248.492	1012.254
83	at 15m line 1	444676.721	4997253.784	1010.987
83	at 10 m	444676.356	4997255.424	1015.076
83	start line 2	444676.554	4997261.574	1017.237
83	end line 2	444678.739	4997254.511	1014.613
85	start	444715.329	4997229.676	1012.381
85	end	444725.818	4997220.175	1011.990
99	start line 1	444739.855	4997202.744	1013.313
99	end line 1	444746.653	4997187.985	1012.806
99	start line 2	444739.169	4997201.198	1012.414
99	end line 2	444745.525	4997188.253	1011.760
104out	start	444851.393	4997140.079	1012.595
104out	end	444822.536	4997149.487	1013.999
104in	start line 1	444853.204	4997138.152	1014.531
104in	end line 1	444861.338	4997127.329	1016.448
104in	start line 2	444845.964	4997137.621	1013.101
104in	end line 2	444856.564	4997121.354	1017.515
118	start	444937.404	4997022.872	1017.003
118	end	444916.046	4997042.323	1014.376
122dense	start line 1	444960.412	4997034.037	1015.677
122dense	end line 1	444976.738	4997024.879	1015.225
122dense	start line 2	444962.125	4997034.559	1015.164
122dense	end line 2	444972.124	4997030.137	1013.723
122sparse	start line 1	444962.911	4997038.839	1015.972
122sparse	end line 1	444962.723	4997039.075	1015.885
127in	start	444201.083	4997878.141	999.384
127in	end	444230.587	4997872.075	1000.438
127out	start	444191.998	4997855.684	999.925
127out	end	444165.242	4997841.195	998.931
133	start	444147.716	4997920.84	998.555
133	end	444170.297	4997901.331	997.519
134	start	444146.587	4997933.255	997.238
134	end 22m	444164.12	4997918.349	998.804
134	line 2 start	444146.583	4997936.615	997.366
134	line 2 end	444155.082	4997936.133	997.384
142in	start	444067.202	4998003.879	997.550
142in	end	444083.493	4997989.357	997.258
142in	line 2 start	444060.917	4997999.323	997.759
142in	line 2 end	444066.44	4997992.673	999.098
142out	start	444065.337	4998006.657	996.961
142out	end	444038.486	4998017.986	993.949
139	start	444141.766	4997964.798	997.059
139	end	444129.2	4997976.778	995.621
139	start line 2	444130.435	4997978.914	997.267

Appendix 8. continued

Community #	Location	Easting	Northing	Elevation
139	end line 2	444140.515	4997969.95	994.623
140	start line 1	444115.453	4997977.363	995.214
140	end line 1	444106.674	4997954.138	996.215
140	end line 2	444111.253	4997956.214	1000.006
144	start	444095.775	4998018.146	996.874
144	end	444113.048	4997993.454	997.477
147	start	444040.257	4998067.606	996.972
147	end	444014.445	4998080.631	999.067
148	start	444107.974	4998065.766	996.046
148	end	444091.699	4998091.745	995.065
150	start	444046.159	4998081.77	993.614
150	end	444023.68	4998104.511	996.060
154	start	443957.442	4998053.321	993.995
154	end	443937.485	4998075.401	996.495
156A	start line 1	443910.514	4998133.653	992.621
156A	end 19m line 1	443915.459	4998152.351	993.903
156A	line 2 start	443913.812	4998134.254	993.838
156A	line 2 end	443916.896	4998145.808	992.404
156	start at 5m	443965.435	4998129.758	994.524
156	end	443955.897	4998145.354	991.614
165	start	443859.514	4998167.649	991.703
165	end	443849.147	4998196.359	992.990
170	start	443838.132	4998227.373	991.724
170	end	443823.201	4998217.246	992.476
173	start	443855.3	4998207.686	995.334
173	end at 17m	443873.351	4998208.183	991.846
175	start	443789.121	4998197.676	992.932
175	end	443818.232	4998189.155	991.970
184	start	443715.165	4998241.912	990.885
184	end	443684.546	4998244.422	989.405
186	start	443708.018	4998246.18	991.822
186	end	443728.63	4998239.297	990.692
194	start	443637.625	4998282.565	989.421
194	end	443612.604	4998300.785	988.802
201	start line 1	443485.165	4998424.272	988.331
201	end line 1	443502.164	4998417.656	987.470
201	start line 2	443486.733	4998430.391	986.423
201	end line 2	443500.72	4998421.876	988.267
206in	start	443575.975	4998414.66	986.170
206in	end	443598.248	4998435.236	985.890
206out	start	443617.819	4998422.272	987.175
206out	end	443645.477	4998410.703	987.655
227	start	443789.006	4998244.891	990.387
227	end	443759.28	4998247.614	989.733
230out	start line 1	443839.855	4998291.292	990.773
230out	end line 1	443848.243	4998320.077	990.387

Appendix 8. continued

Community #	Location	Easting	Northing	Elevation
230in	start line 2	443870.172	4998276.537	991.265
230in	line 2	443870.613	4998277.802	991.822
230in	end line 2	443855.866	4998280.969	992.154

Appendix 9. Location of frequency transects overlayed on aerial photo