The use of multispectral digital imagery to map hydrogeomorphic stream units in Soda Butte and Cache Creeks, Montana and Wyoming
by Andrea Wright

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
Multispectral digital imagery acquired from Soda Butte and Cache Creeks, (Montana and Wyoming) was used in conjunction with field data to classify and map hydrogeomorphic stream units on four stream reaches. Field measurements included water depths, pebble counts, and ground mapping of the hydrogeomorphic units: eddy drop zones, glides, low gradient riffles, high gradient riffles, lateral scour pools, attached bars, detached bars, and large woody debris based on the classification of such units developed by Ladd et ah, 1998. Unsupervised and supervised classification of the imagery was used to develop both a maximum joint probability classification and an alternative joint probability classification of the stream reaches. Classification schemes were developed on the two reaches mapped on Soda Butte Creek and were tested on all other stream reaches in the study after the field maps had been rectified to the imagery. Maximum likelihood classification allowed only one of the image classes to represent each hydrogeomorphic unit on the field map and resulted in relatively low overall accuracies for identification of these units (i.e. 10% to 50%). The ‘other likelihood’ classification allowed all image classes with a likelihood of occurrence greater than random to represent each hydrogeomorphic unit on the field map (i.e. two or three image classes were assigned to represent each hydrogeomorphic unit) resulting in higher overall accuracies (i.e. 28% to 80%) for identification of these units on the field map. Accurate classification of hydrogeomorphic units was hampered in part by poor rectification of imagery with the field maps due to a lack of ground control points. In general, hydrogeomorphic units largest in area were most likely to be accurately classified while hydrogeomorphic units that were small in area or spatially linear were least likely to be accurately classified. The results of this study demonstrated that multispectral digital imagery has the potential to be a useful tool for mapping hydrogeomorphic stream units at small scales. In order for the imagery to be used as an effective tool, however, careful measures - such as accurate documentation of ground control points, must be taken to ensure accurate rectification of the imagery with field maps.

THE USE OF MULTISPECTRAL DIGITAL IMAGERY TO MAP HYDROGEOMORPHIC STREAM UNITS IN SODA BUTTE AND CACHE CREEKS, MONTANA AND WYOMING

by

Andrea Wright

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY-BOZEMAN
Bozeman, Montana
April 1998

APPROVAL

of a thesis submitted by

Andrea Wright

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies

W. Andrew Marcus (Graduate Committee, Chair) — W. Andrew Marcus (Signature) — April 17, 1998 (Date)

Approved for the Department of Earth Sciences

W. Andrew Marcus (Department Head) — W. Andrew Marcus (Signature) — April 17, 1998 (Date)

Approved for the College of Graduate Studies

Joseph Fedock (Interim Graduate Dean) — Joseph J. Fedock (Signature) — 4/21/98 (Date)

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University-Bozeman, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature Andrea Wright

Date 4/17/98

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Multispectral digital imagery acquired from Soda Butte and Cache Creeks, (Montana and Wyoming) was used in conjunction with field data to classify and map hydrogeomorphic stream units on four stream reaches. Field measurements included water depths, pebble counts, and ground mapping of the hydrogeomorphic units: eddy drop zones, glides, low gradient riffles, high gradient riffles, lateral scour pools, attached bars, detached bars, and large woody debris based on the classification of such units developed by Ladd et al., 1998. Unsupervised and supervised classification of the imagery was used to develop both a maximum joint probability classification and an alternative joint probability classification of the stream reaches. Classification schemes were developed on the two reaches mapped on Soda Butte Creek and were tested on all other stream reaches in the study after the field maps had been rectified to the imagery. Maximum likelihood classification allowed only one of the image classes to represent each hydrogeomorphic unit on the field map and resulted in relatively low overall accuracies for identification of these units (i.e. 10% to 50%). The 'other likelihood' classification allowed all image classes with a likelihood of occurrence greater than random to represent each hydrogeomorphic unit on the field map (i.e. two or three image classes were assigned to represent each hydrogeomorphic unit) resulting in higher overall accuracies (i.e. 28% to 80%) for identification of these units on the field map. Accurate classification of hydrogeomorphic units was hampered in part by poor rectification of imagery with the field maps due to a lack of ground control points. In general, hydrogeomorphic units largest in area were most likely to be accurately classified while hydrogeomorphic units that were small in area or spatially linear were least likely to be accurately classified. The results of this study demonstrated that multispectral digital imagery has the potential to be a useful tool for mapping hydrogeomorphic stream units at small scales. In order for the imagery to be used as an *effective* tool, however, careful measures - such as accurate documentation of ground control points, must be taken to ensure accurate rectification of the imagery with field maps.

CHAPTER 1

INTRODUCTION AND PREVIOUS WORK

INTRODUCTION

Reach scale maps of stream channel characteristics are critical for monitoring and understanding changes in channel morphology and documenting riparian and channel habitats for wildlife managers. Data on channel and floodplain characteristics and change have traditionally been collected by research scientists in the field. Historically, most field studies of channel morphology have been based on field surveys at representative, defined river reaches. The drawback to these surveys is that they are local in extent, time consuming, and therefore seldom carried out for more than several years. Aerial photographs have also been used to document channel characteristics since the 1940's and multispectral digital imagery has been used in more recent years. The use of remote sensing has increased because so many of the world's rivers lie in geographically remote areas making field study difficult. Remotely sensed digital imagery also often allows spatial and temporal observation and monitoring of fluvial systems at scales of interest, and provides a data base that is more easily used with computers for quantitative analysis.

The goal of this study is to use digital imagery collected from an airplane and GIS to classify and map hydrogeomorphic stream units in two alpine streams in and adjacent to Yellowstone National Park. This study will evaluate if variations in spectral reflectances can be used to map channel morphology using a hydrogeomorphic classification system developed by Bisson et al. (1982) and Church and Jones (1982) and modified by Ladd (1995). The distribution of heavy metals following mining were shown to be correlated with these hydrogeomorphic units in Soda Butte Creek, (Ladd, 1995; Marcus et al., 1995a, 1996; Ladd et al., 1998). This study was developed to determine if digital imagery can be used to quickly and effectively map these hydrogeomorphic units on the ground. The objectives of the study are: (1) to field map morphologically distinct stream reaches in the study area, (2) to develop a classification scheme based on the remotely sensed spectral data, and (3) to test the classification algorithms on other mapped stream reaches to determine overall accuracy for use as a mapping tool of this hydrogeomorphic classification scheme.

PREVIOUS WORK

Remotely sensed images, in the form of aerial photography have been used to successfully document changes in fluvial regions since the 1940's (Reeves, 1975). Most studies using aerial photos have focused on documenting changes in the planform of rivers (Lewin and Weir, 1977; Furguson and Werritty, 1983; Ruth, 1988; Schumann, 1989) and variations in water depth (Milton et al., 1995). Studies using aerial photography suffer, however, from the limited extent of coverage of the photos and the frequency with which these photographs are taken.

Satellite imagery has enabled researchers to measure fluvial changes over a larger area of study and on a more frequent basis than air photos (Lyzenga,1980; Ramasamy et al., 1981; Salo and Kalliola, 1986; Jacobberger, 1988; Stumph, 1992; Blasco and Bellan, 1992; Reddy 1993; Mertes et al., 1993). While satellite imagery is useful for measuring and studying small scale fluvial features on large rivers, small scale features that exist at the reach scale on low order streams are better studied with higher resolution, multi-spectral scanner systems attached to airplanes. Gilvear and Watson (1995) used Daedalus Airborne Thematic Mapper data to map floodplains and depth to the water table on streams in Scotland. Daedalus Airborne Thematic Mapper was also used in a similar study (Gilvear and Winterbottom, 1992) to map physical features of a stream reach on the River Tay in Scotland following floods. Hooper (1992) measured spectral response curves from surfaces such as soil, water, and bars in the fluvial environment with this type of multi-spectral imagery.

Two studies that used remotely sensed data to quantify and map morphological channel features are Hardy et al. (1994) and Gilvear et al. (1995). Hardy et al. (1994) classified relative water depths of mesoscale hydraulic features; 'turbulent', 'shoal', 'pool', 'eddy', and 'run', on the Green River, Utah through the use of multi-spectral video imagery. Three band multi-spectral videography in the green (550nm), red (650nm) and near-infrared (850nm) portion of the electromagnetic spectrum was used with spatial resolutions on the order of 0.25 to 3.0 meters. This study found that both unsupervised and supervised classification results showed close agreement between the ground based mapping of these features, although the delineation of water depth was impaired when turbulence occurred at the surface.

A study in the Circle Mining District of Alaska by Gilvear et al. (1995) used enhanced scanned panchromatic aerial photographs of Faith Creek to provide a quantitative estimate of stream features (runs, glides, and exposed gravel bars) and water depths before and after mining operations on the creek. These photographs varied in scale and the average width of pixels ranged from 13.5m to 17.3m. A logarithmic transformation of the digital number (DN) values was applied to the contrast enhanced aerial photos in an effort to simulate the exponential decline of light levels reaching the substrate with depth. These image processed DN values were compared with known water depths for the stream reach. The highest DN values corresponded with the deep water areas and the lowest DN values corresponded to the shallowest areas of the channel. The results of dividing aerial photographs of the channel from different dates into fifteen water depth categories from the DN values showed that prior to mining in the area, all water depth classes were well represented with many pool-riffle sequences and channel bars. During mining, however, their study found that there was a noticeable absence of deep water areas. These deep water areas increased during the time period following the cessation of mining, although shallow areas still dominated five years later.

Remote sensing has far reaching applications. Remotely sensed data has been successfully used in studies that document channel change, measure vegetation in riparian zones, determine amounts of suspended sediment in ocean environments, map streams, rivers, lakes, and coastlines, model bed planform in rivers, and reconstruct historical river migrations. For the purpose of this study, remotely sensed imagery is supplemented with field data to create a mapping system for hydraulic-based geomorphologic stream units. Previous studies have successfully used remote sensing to map stream channel morphology, however none to date have attempted to use digital imagery to develop classification methods for mapping the hydrogeomorphic stream units identified in this study. If successful, digital aerial mapping may reduce field costs and help with sampling plans for projects which require knowledge of hydrogeomorphic units (such as metals sampling).

CHAPTER 2

STUDY AREA AND METHODS

STUDY AREA

The two cobble and gravel bed alpine streams selected for this study were Soda Butte Creek and Cache Creek. Four stream reaches were mapped in each stream (a total of eight stream reaches) as part of other ongoing studies. Only two stream reaches of approximately 250 meters in length were selected from each stream (a total of four stream reaches) to be used in this study. The creeks drain adjacent watersheds of similar topography and area (approximately 250 km^2) and flow into the Lamar River inside Yellowstone National Park, Wyoming (Fig. 1).

Both Soda Butte and Cache Creek drain watersheds composed primarily of Eocene volcanic and volcaniclastic rocks (Elliot, 1979). Soda Butte Creek also contains Paleozoic carbonate, shale, and sandstone sediments at its headwaters. Sediments within the stream channels in both watersheds are dominated by cobble and gravel sized particles with occasional pockets of clay and silt.

Soda Butte Creek ranges from an elevation of 3,060m at its headwaters to 2,525m at its confluence with the Lamar River (Table 1). Reach 1, the upper of the two stream reaches in Soda Butte Creek is in a third order braided channel with many small

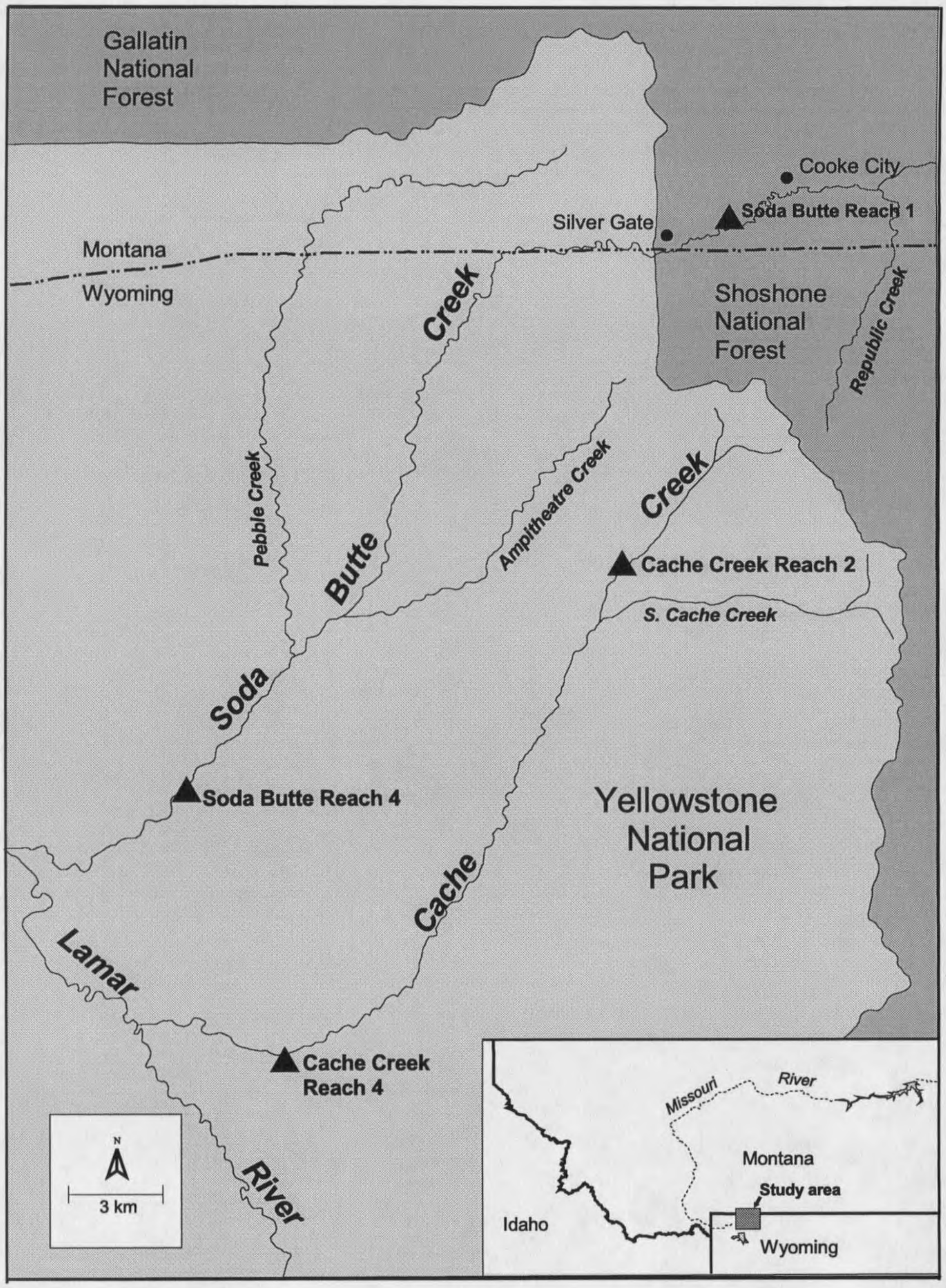

Figure 1 - Study area map of Soda Butte and Cache Creeks

hydrogeomorphologic features (Table 1). Reach 4 is farther downstream and is in a fourth order channel with much larger braided channels and a broad floodplain (Table 1). Soda Butte Creek was largely unaffected by the 1988 Yellowstone fires.

Stream elevations in Cache Creek range from 2,980m at its headwaters to 2,590m at its confluence with the Lamar River (Table 1). Reach 2, the upstream reach, is in a third order channel with relatively small hydrogeomorphic units (Table 1). The downstream reach (Reach 4) is located in a wide fourth order channel and is braided with a broad floodplain (Table 1). The Cache Creek drainage was severely burned by the 1988 Yellowstone fires while the Soda Butte Creek drainage was largely unaffected. These fires have resulted in extensive large woody debris in and along Cache Creek relative to the mapped Soda Butte Creek reaches.

Table 1 - Description of Soda Butte Creek and Cache Creek stream reaches.

Reach #	Length (m)	Maximum Bankfull Width (m)	Average Elevation (m)
Soda Butte 1	252	47	2,900
Soda Butte 4	250	180	2,559
Cache Creek 2	470	43	2,610
Cache Creek 4	280	16	1,925

Vegetation on Soda Butte and Cache Creeks varies with stream reach. Reach 1 in Soda Butte and reach 2 in Cache Creek have vegetation that consists mainly of lodgepole pine and spruce-fir forest. Cache Creek reach 4 and Soda Butte reach 4 are bordered by willow, grasses, forbes, and sedges with occasional lodgepole and cottonwood trees.

METHODS

Field Mapping and Data Collection

Seven types of hydrogeomorphic units were identified and mapped in each of the four study reaches using two systems of classification first proposed by Bisson et. al. (1982) and Church and Jones (1982) and modified by Ladd (1995) for Soda Butte Creek. The modified Bisson et al. classification system was selected because the system was developed for low order forested alpine streams and because it is often used by the U.S. Forest Service and the U.S. Fish and Wildlife Service for stream habitat classification. The Church and Jones system provides a simple classification for emergent bars. The combined classification system used in this study is also being used as part of other ongoing studies in Cache Creek and Soda Butte Creek (Ladd, 1995; Marcus et al., 1996; Ladd et al., 1998). Each of the four study reaches contain seven in-stream hydrogeomorphic units. Attached bars and detached bars were identified following Church and Jones (1982). Glides, lateral scour pools, low gradient riffles, high gradient riffles, and eddy drop zones were identified following Bisson et al. (1982).

Reaches were mapped using 100 m tapes and a Brunton Compass. A 100 m baseline was run along the reach and it's azimuth was determined using a Brunton Compass. Distances to key features were measured along perpendicular transects from the baseline. Global Position Systems (GPS) were used on two different occasions to obtain real world coordinates for the baselines, but in both cases the data was unusable because of failures at local base stations.

Field mapping of the four stream reaches occurred in the summer months of July and August 1995 after the majority of spring runoff had occurred and the streams were at low flow. This was done to help ensure that no major channel change occurred before the digital data collection commenced in early September 1995.

The hydrogeomorphic units mapped in the four stream reaches varied in size and frequency but were easy to identify visually based on geographic distribution within the stream channel and water surface characteristics (Ladd et al.,1998). Glides have a smooth glassy water surface. They exhibit low turbulence and have a relatively consistent and shallow water depth throughout the unit. Lateral scour pools are identified by both bank and channel bed scour as a result of high velocity flow being diverted along a channel bank. Lateral scour pools often contain the deepest water in the stream and only span a portion of the channel width. Low gradient riffles are identified by having a turbulent flow and generally have the largest surface area of the units in the streams. Low gradient riffles typically span the entire channel width and may be continuous for tens of meters. They appear to have a choppy surface and typically have a bed gradient less than 1%.

High gradient riffles are identified by having turbulent flow and breaking “white” water. Water depth is typically shallow and bed gradients range between 1% and 4%. These units usually contain the largest sized sediments of all the morphological units and are typically dominated by cobbles and gravel. High gradient riffles can be found spanning the entire channel or as isolated units spanning only a portion of the channel.

Eddy drop zones, also called backwater pools, form when an obstruction such as large woody debris or a bank outcrop diverts flow. These units are identified by a slow eddy current and smooth water surface. Eddy drop zones typically contain the finest sediments of the hydrogeomorphic units.

Attached bars are identified as areas of deposition above water which are connected to the bank on at least one side of the unit. This type of bar typically lacks vegetation and has relatively large sediment size on its surface. Attached bars in the study area tend to be sparsely vegetated, if at all. Detached bars are islands within a stream channel and are areas of deposition. Large detached bars identified in this study were often vegetated with willow and grassses.

Two Wolman pebble counts for two hundred pebbles total (Wolman, 1954) were made for the hydrogeomorphic units in each stream reach on Soda Butte Creek to determine the range of sediment size within each unit. Lateral scour pools were not sampled because depth prohibited collection. Sediment size sampling was done in order to better understand the relationship between morphology and spectral reflectance. One person was responsible for all pebble count measurements to maintain consistency and avoid user bias (Marcus et al., 1995b).

Multispectral digital data from the streams was needed to analyze fine detail on the ground. One meter pixel resolution digital imagery was available locally and was chosen to explore whether standard four band multispectral digital imagery could be used to identify field mapped hydrogeomorphic units. This is important because no existing studies have used this approach. Positive Systems of Kalispell, Montana collected the multispectral data (Table 2) using the raster based digital imaging system ADAR 500 with approximately one meter pixel scale resolution. The time of day of each flight was chosen to minimize shadows from riparian and surrounding vegetation. Flights took place on the 14th of September, 1995 between 11:30am and 1:30pm, when weather had been dry for several days and the water in the streams was clear and sediment free.

Table 2 - Description of spectral bands and band widths used

Band	Bandwidth (nm)	Predominant Color
1	400-480	Blue
2	460-570	Green
3	610-690	Red
4	780-1000	Near Infrared

Image and Data Processing

In order to classify hydrogeomorphic units using multispectral imagery, it was necessary to overlay and register the imagery onto the field maps. To accomplish this, the four field maps of the Soda Butte Creek and Cache Creek stream reaches were digitized as polygons into ARC/INFO (Figs. 2 and 3). Water depths, sediment size, and vegetation attributes were then assigned to each individual hydrogeomorphic unit from data collected in the field. The digitized field maps were converted into raster maps in the ARC/INFO module GRID, with a 1m cell size. The multispectral images were georectified to the raster field maps of each corresponding reach using ERDAS Imagine, so the two data sets could be overlaid. Lack of precision in the ground truth maps, due in part to failure of GPS control, created significant problems with georectification. These