Final Report

Mapping annual surface area changes since 1984 of lakes and reservoirs in Wyoming that are not gauged using multi-temporal Landsat data

(Mar 2103 – Feb 2015)

Focus Category: *Water Quantity (WQN), Models (MOD), Education (EDU)*
Keywords: *Lake surface area, Reservoirs, remote sensing*

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SUMMARY

Data about water stored in lakes and reservoirs are essential for their prudent management. However if these water bodies are not gauged, information about the amount of water entering and leaving the reservoir is unknown. Without this information it is difficult for planners and policy makers to devise appropriate management plans. This research project tested the utility of Landsat data (collected and distributed at no-cost by US Geological Survey) to map surface area changes of seven Wyoming lakes and reservoirs that are not gauged. First, challenges associated with identifying various types of water bodies (clear, shallow and turbid) in Landsat images were tested. Mapping medium-large size water bodies (Bull Lake and Keyhole) off of Landsat images was relatively easier in comparison to small water bodies that were shallow or contained turbid water. Second, analyst bias and its influence on surface area estimation was more pronounced on small and turbid water bodies. However differences between analysts were relatively smaller for larger water bodies. Obtaining cloud-free images for some reservoirs was challenging which resulted in data-gaps in the time series. Findings from this research lead us to conclude that a) it is possible to map different types of water bodies using Landsat data, and b) analysts had to be trained with several sample images before they could gain the confidence to map water bodies. Methods developed through this proposal can be used in conjunction with the newly launched Landsat 8 data for mapping future surface area changes in Wyoming water bodies.

Another highlight of this project was the nine undergraduate students who were trained in remotely sensed image processing and information extraction techniques. Three student interns presented their research in the Geospatial Conference of the West held in Laramie (September 2013) and another student intern presented his work in the Wyoming Undergraduate Research Day held in Laramie (April 2014).

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1. INTRODUCTION

Mapping water surface area or shorelines of large water bodies with Landsat and similar moderate resolution satellite data is not new (Elmore and Guinn 2010). Spectral properties of water are distinct from most other land cover features (bare ground, forest, built surface etc) which makes the task of distinguishing them in remotely sensed images relatively easy (Campbell 2006).

Remotely sensed data collected by Landsat Thematic Mapper satellite since 1984 comprise a long time series of earth observation data (http://landsat.usgs.gov) that can be used for monitoring changes in earth's natural resources. Studies have shown that spatial and spectral resolutions of Landsat data can be used for mapping water bodies because of the spectral reflectance properties of water. Chen and Rau (1998) mapped shoreline changes in tidal areas using a series of Landsat images, and Ouma and Tateishi (2006) mapped changes in shorelines of the five East African Rift Valley lakes with Landsat images. However presence of suspended solids (turbid waters) or floating vegetation (algae for example) alters water's spectral reflectance thus posing some difficulties while processing the images (Jensen 2000).

Given the dynamic nature of water bodies (intra- and inter-annual changes) and also the fact the techniques developed at one location might not work elsewhere, it is imperative that the utility of Landsat data have to be tested at different areas of interest. This will enable us to identify problems that are unique to each location. Gray and Sivanpillai (2010) tested the utility of multi-temporal (1985-2009) Landsat data for mapping surface area changes in Ocean Lake, Wyoming. They reported that shallow portions along the western and southeastern portions of this lake posed some challenges to accurately delineate the shoreline. However when the water level was higher (i.e., more area) it was not a problem to delineate the shoreline.

Next step is to geographically extend the study conducted by Gray and Sivanpillai (2010) to include more reservoirs and lakes especially those that have complex shorelines, turbid waters, or presence of vegetation. The overall goal of the research project funded by the University of Wyoming Water Research Program was to estimate changes in surface area values of some reservoirs in Wyoming, especially those that are not gauged.

2. OBJECTIVES

a. Assess the suitability of Landsat images for mapping water bodies in Wyoming. Given the differences in shape and related characteristics of these lakes and reservoirs, it is not possible to use the same classification technique for all of them (objective #2 in the proposal).
b. Map surface area changes of the lakes and reservoirs that are not gauged for recording the amount of inflow and outflow. Some of these water bodies had records in the past but do not have gauges now, while for some either inflow or outflow but not both are measured (objective #1 in the proposal).

c. Water bodies to be mapped in this proposal will include Bull, Fontenelle, Glendo, Keyhole, Lower Sunshine, Park, Viva Naughton, Wheatland Reservoir #2, and Woodruff Narrows (objective #3 in the proposal).

3. METHODOLOGY

We downloaded 104 cloud-free Landsat images from the USGS data archives (GloVis http://glovis.usgs.gov and EarthExplorer http://earthexplorer.usgs.gov). Acquisition dates of these images spanned from 1984 through 2011. Individual spectral bands (3 visible and 3 infrared) were stacked and pixel digital numbers (DNs) were converted to the Top of the Atmosphere reflectance values using the methodology described by Chander et al. (2009).

At the end of the above step, we found that there were not sufficient cloud-free images for some reservoirs identified in section 2.c. Therefore we replaced these reservoirs with others identified from the managers and stakeholders during the Wyoming Water Association Meeting (October 2012, Lander, WY). Updated list of reservoirs (**objective c**) analyzed in this study: Cameahwait, Ray Lake, Washakie, Viva Naughton, Pilot Buette, Bull Lake and Keyhole reservoirs.

From each Landsat image subsets corresponding to the spatial extent of each reservoir were extracted and stored as a separate file (Figure 3.1). This process minimizes the chances for potential spectral overlap between water stored in the reservoirs and outside.

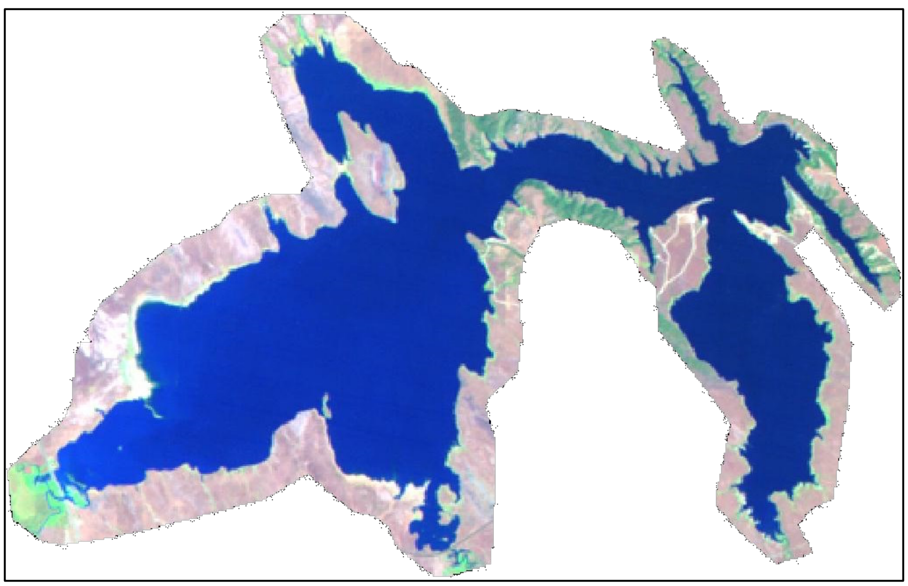

Figure 3.1. *Landsat 5 Thematic Mapper image clipped (or subset) to the spatial extent of Keyhole Reservoir. Clear and deep water appears in darker shades of blue, while shallow water appears in lighter shades of blue. Vegetation appears in green color.*

3.A. LANDSAT SUITABILITY STUDIES (PILOT PROJECTS)

As part of the first objective (**objective a**), Landsat data for the following reservoirs were used for pilot studies: Bull Lake, Cameahwait, Keyhole, Sand Mesa #1 and Sixty Seven.

Funding for this project was finalized only in June 2013. Hence resources from **WyomingView** (another USGS funded project through AmericaView) were used to recruit undergraduate interns to work on pilot projects. WyomingView student interns and the reservoir they selected for the pilot study are listed in table 1.

Table 1: Reservoirs mapped by the undergraduate student interns funded through the WyomingView internship program in spring 2013 semester

#	Student name & major	Reservoir	# of Landsat images
1	**Kate Richardson**, BS Rangeland Ecology and Watershed Management	Bull Lake	10
2	**Cody Booth**, BS Rangeland Ecology and Watershed Management	Cameahwait & Sand Mesa #1	5 & 5
3	**Bailey Terry**, BS Rangeland Ecology and Watershed Management	Key Hole	8
4	**Christopher Steinhoff**, BS Rangeland Ecology and Watershed Management	Sixty Seven	18

Water bodies included in these images represented a range of conditions: clear, turbid, and shallow. Few images had water bodies with floating vegetation. WyomingView interns classified each Landsat images in order to assess their suitability for mapping water bodies and documented the potential and limitations.

3.B. QUANTIFYING ANALYST BIAS

Analyst bias is part of any remotely sensed image analysis and can introduce errors in the estimated values of the surface area. To quantify the analyst bias, same sets of images were assigned to at least 3 analysts. Each analyst independently classified the images and mapped the surface area of the reservoir. File names of the images were scrambled and identities of analysts were kept confidential.

To quantify analyst bias, digitally classified Landsat data corresponding to 7 reservoirs (Table 2) were assigned to undergraduate interns and volunteers in fall 2013. Their task was to assign the clusters in the images to water or non-water thematic class. We provided classified Landsat images to each analyst instead of raw bands, in order to eliminate potential errors associated with classification procedures.

We also tested whether analyst's experience in image processing would result in differences in area estimates. So we requested 3 analysts with 1 year (undergraduate student), 10 years (volunteer) and 22 years (volunteer) of image processing experience to classify the same set of images.

Table 2: Reservoirs mapped by the undergraduate student interns funded through Water Research Program grant and volunteers.

<table>
<tr><th>#</th><th>Student name & major</th><th>Reservoir name</th><th># of Landsat images</th></tr>
<tr><td>1a</td><td>Shane Black, BS Rangeland Ecology and Watershed Management</td><td rowspan="3">Anchor, Cameahwaitl, & Washakie
(shallow reservoirs)</td><td rowspan="3">6 images each</td></tr>
<tr><td>1b</td><td>Julia Vold, BS Agricultural Business*</td></tr>
<tr><td>1c</td><td>Zac Tuthill, BS Rangeland Ecology and Watershed Management</td></tr>
<tr><td>2a</td><td>James Scharffarzick, BS Rangeland Ecology and Watershed Management</td><td rowspan="3">Gillette, La Prele, and Grey Rock
(water with floating vegetation)</td><td rowspan="3">5 images each</td></tr>
<tr><td>2b</td><td>Thoa Pham, BS Agroecology*</td></tr>
<tr><td>2c</td><td>Mary Harris, Undeclared major</td></tr>
<tr><td>3a</td><td>Bailey Terry, BS Rangeland Ecology and Watershed Management</td><td rowspan="3">Keyhole Reservoir</td><td rowspan="3">6 images each</td></tr>
<tr><td>3b</td><td>Mike Pritchard, Undeclared Masters' student *</td></tr>
<tr><td>3c</td><td>Ken Driese, Research Scientist, UW Botany*</td></tr>
</table>

*volunteers

3.C. ESTIMATING SURFACE AREA CHANGES

Using the insights gained from steps 3.a and 3.b we classified Landsat 5 images acquired from 1986 through 2011 and extracted the surface areas of the reservoirs listed in objective 2.c. We used unsupervised classification techniques to extract the water surface areas from each image. We generated between 50 and 75 clusters during the classification which provided the flexibility to control the number of clusters that were assigned to water class. We did not try to distinguish different types of water bodies such as: clear, turbid or shallow.

4. PRINCIPAL FINDINGS

We accomplished all three objectives of this project. However we had to select a different reservoirs than the ones proposed because of the non-availability of cloud-free images. Findings from each objective are listed below.

4.A. LANDSAT SUITABILITY STUDIES (PILOT PROJECTS)

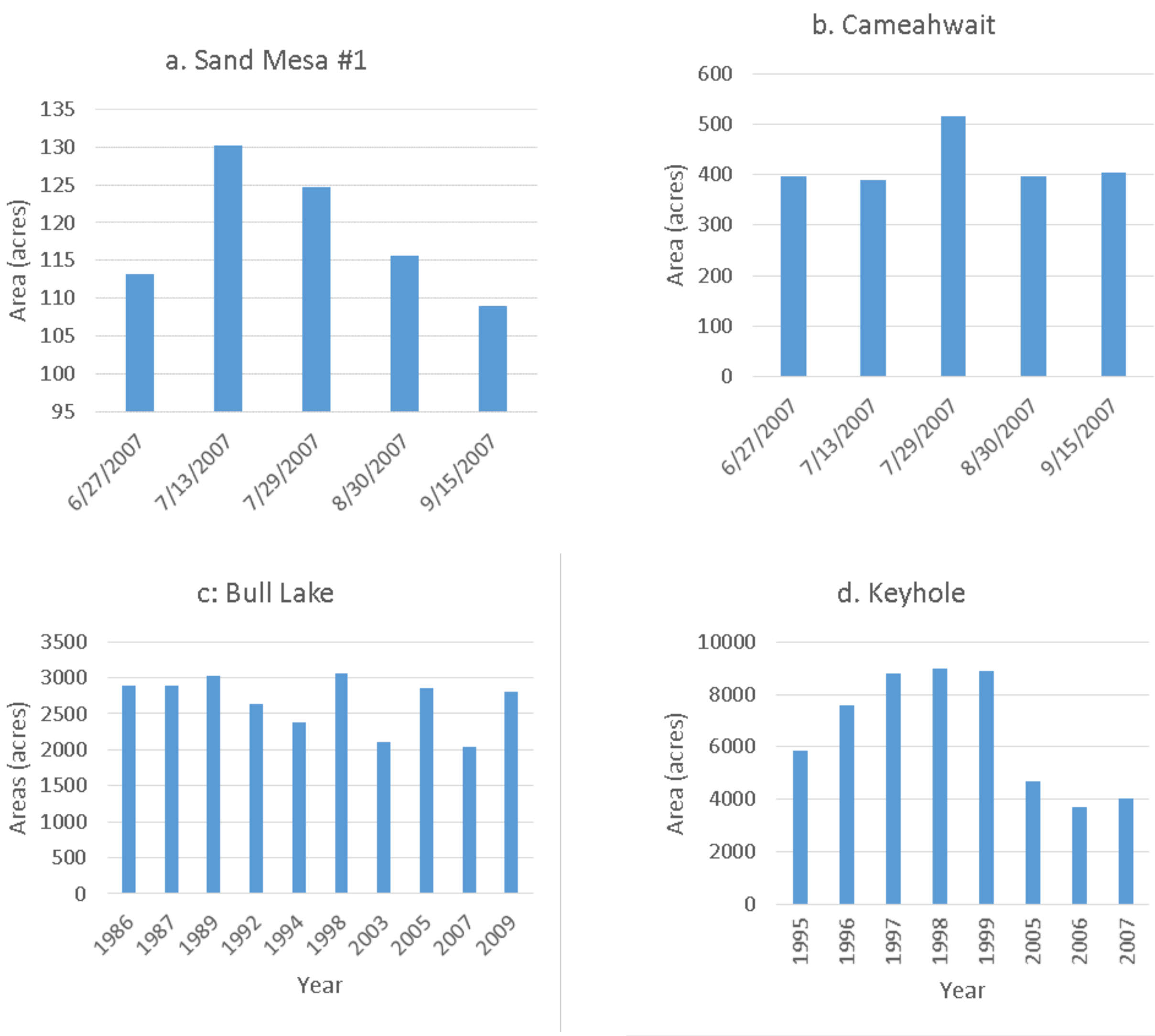

Figure 4.1: *WyomingView interns were able to successfully map the reservoirs off of the Landsat images. However consistently distinguishing shorelines both within and between the images posed challenges.*

Mapping large water bodies (Bull Lake and Keyhole) from Landsat images posed little to no problems (Figure 4.1). Spectral reflectance values of water bodies were distinctly different from surrounding features. Analysts were able to easily assign the clusters in the classified images to with relatively high degree of confidence. Delineating the shoreline posed some challenges to the analysts. However as they processed more images they become more confident with delineating the shorelines.

Mapping smaller water bodies that were shallow (Cameahwait) or contained turbid water (Sand Mesa #1 and Sixty Seven) was relatively more challenging to the analysts (Figure 4.1). As witnessed in the case of large reservoirs, as analysts processed more images they become more confident in delineating water bodies from Landsat images.

Results from these pilot studies lead us to conclude that a) we can map different types of water bodies using Landsat data, and b) analysts (students) had to be trained with several images before they could gain the confidence to map water bodies.

4.B. QUANTIFYING ANALYST BIAS

Classifying small lakes and reservoirs that were either shallow (Anchor Res.) or contained vegetation along the shoreline (Gillette Lake) from Landsat images posed major challenges. There were major differences in surface area estimates for these reservoirs which lead us to conclude that estimates derived for these and similar small lakes might not be consistent and also less accurate (Figure 4.2).

However as the surface area of the water bodies increased, differences in area estimates started to decrease. Analysts were also more confident in their results, which lead us to conclude that the effect of analyst bias will be minimum for medium to large size water bodies. Therefore estimates derived from different analysts will not vastly vary for such water bodies (Figure 4.2).

Shallow Reservoirs **Reservoirs with vegetation along the edges**

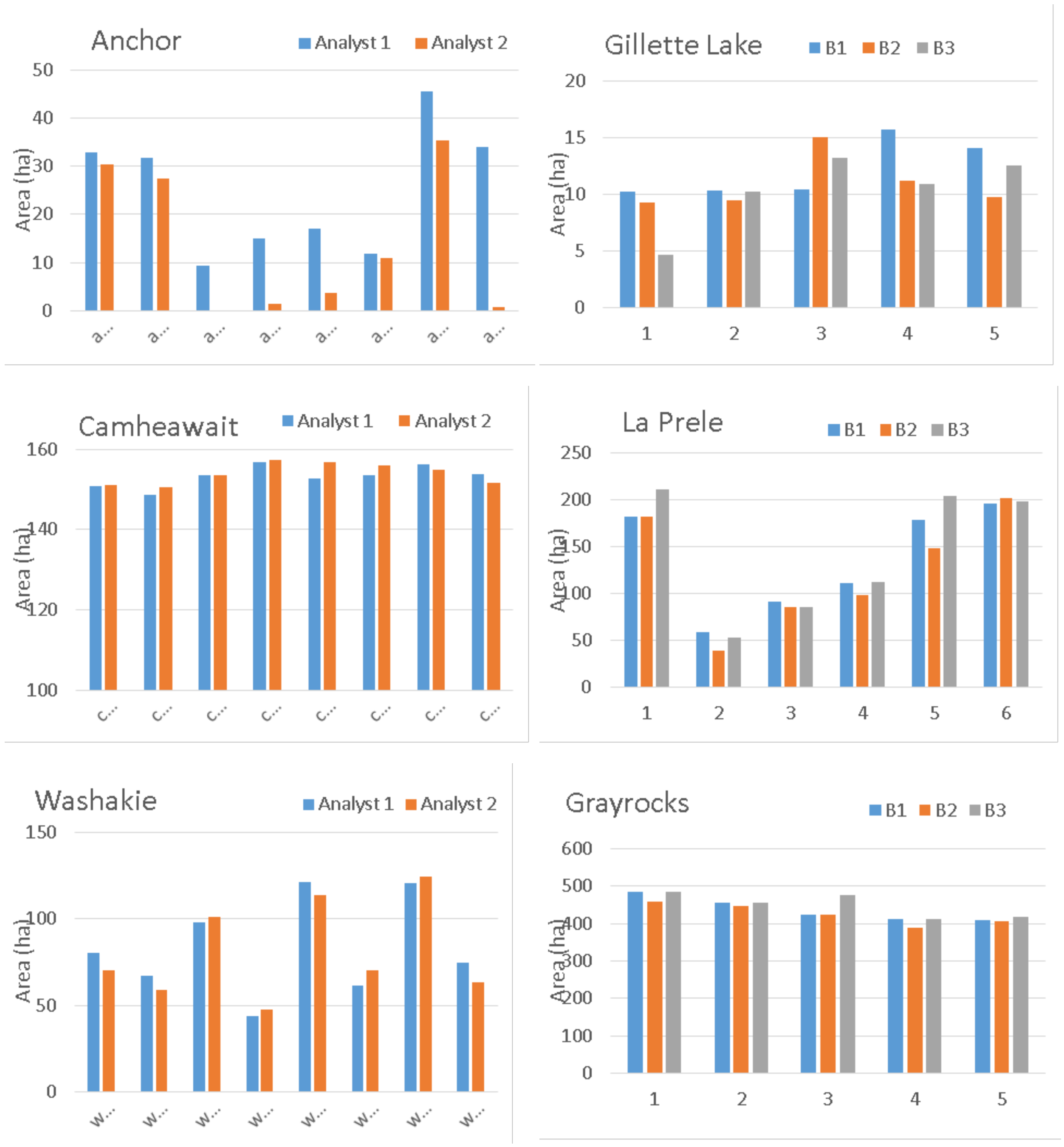

Figure 4.2: *Analyst bias in estimating water surface area of different reservoirs. Images of Anchor, Camheawait and Washakie reservoirs were mapped by two analysts (1 and 2), while Landsat images of Gillette, La Prele and Grayrocks reservoirs were mapped by three analysts (B1, B2 and B3). Area estimates of Anchor reservoir showed most differences between analysts.*

Analysts experience with image processing had a small influence in the area estimates they derived from each image. Analysts with 10+ years of experience combined some of the edge pixels with the main water body, however the analyst with least experience did not do so (Figure 4.3). This outcome might have to do with their level of familiarity with hydrological issues.

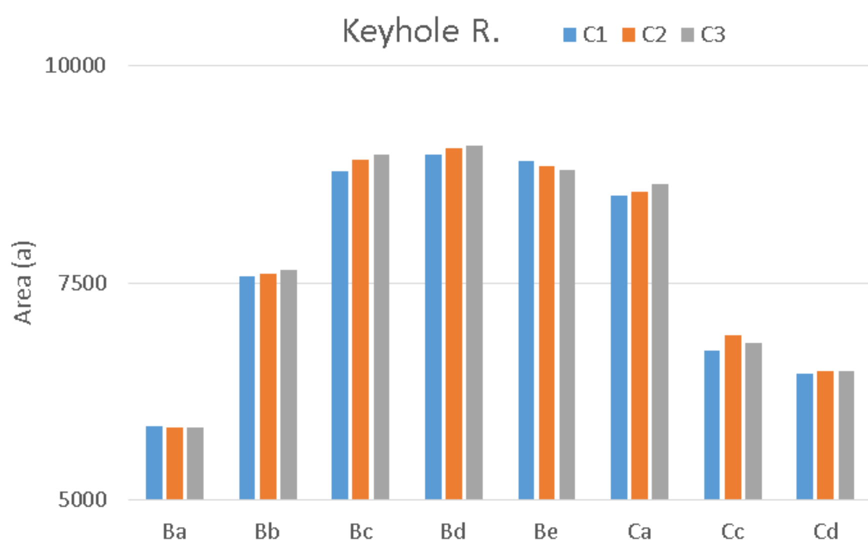

Figure 4.3: *Water surface area estimates derived from eight Landsat images by three analysts (C1, C2 and C3) who had one, ten and twenty plus years of image processing experience respectively.*

4.C. SURFACE AREA CHANGES

Based on the insights gained from the pilot studies we developed a set of image classification protocols for delineating water bodies from Landsat images and estimating their surface areas. Images were clipped close to the boundary of the reservoirs in order to minimize spectral confusion from Earth surface features outside the reservoir. Second, we decided to exclude the pixels representing shorelines and classified only those pixels that contained some water which was determined by their appearance in Landsat band combinations 4, 3 and 2. Finally analysts were required to classify several images in order to familiarize them to the unique characteristics of the landscape surrounding the reservoirs.

Surface area estimates of the reservoirs derived from Landsat images are displayed in Figures 4.4 – 4.10. For some reservoirs it was difficult to obtain cloud-free images in August, so we included images from September and in rare instances from July as well. However for some reservoirs (Bull Lake for example) it was difficult to obtain any cloud-free image from July through October. This resulted in data gaps in the time-series. Since there will be differences between seasons we did not use images from spring or summer to fill these data gap.

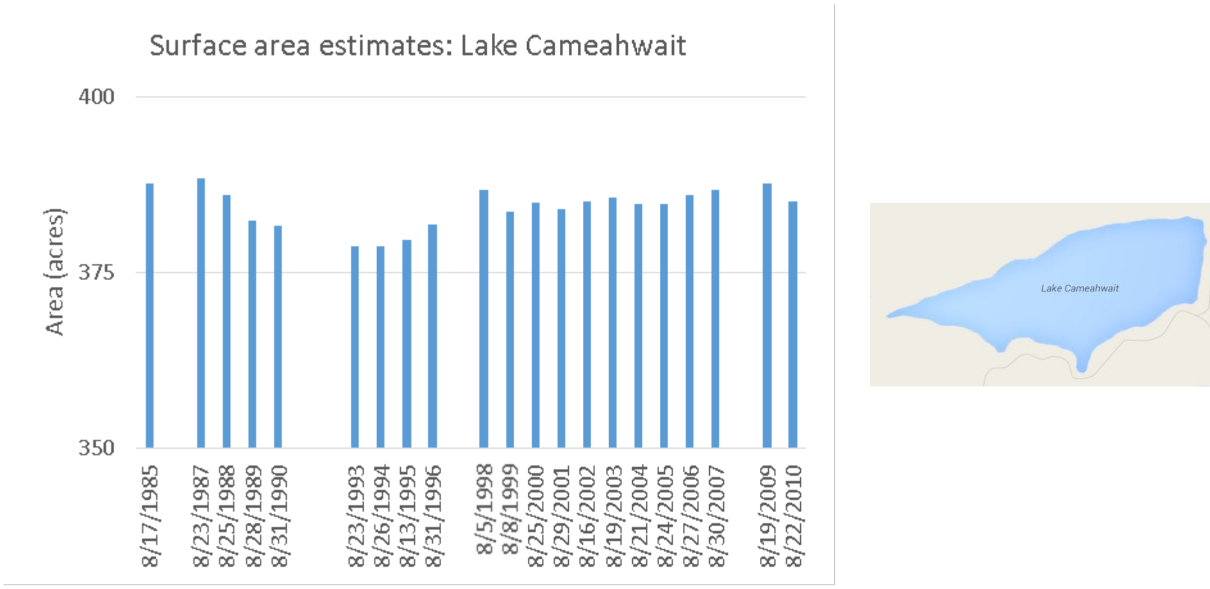

Figure 4.4: *Surface area estimates for Lake Cameahwait derived from Landsat 5 TM images acquired from 1985 through 2011 in the month of August.*

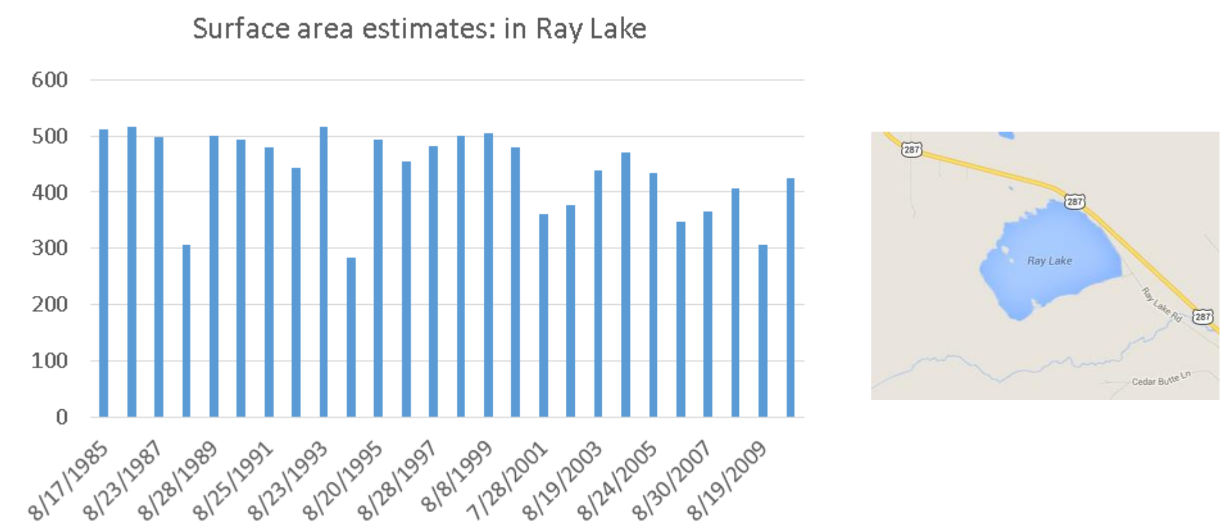

Figure 4.5: *Surface area estimates for Ray Lake derived from Landsat 5 TM images acquired from 1985 through 2011 in the month of August.*

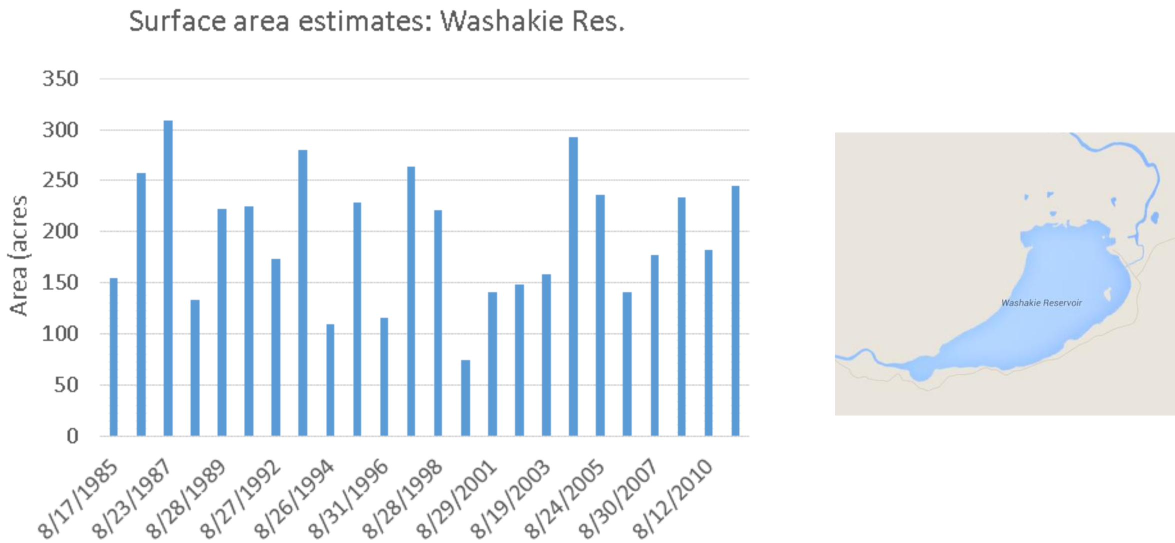

Figure 4.6: *Surface area estimates for Washakie Reservoir derived from Landsat 5 TM images acquired from 1985 through 2011 in the month of August.*

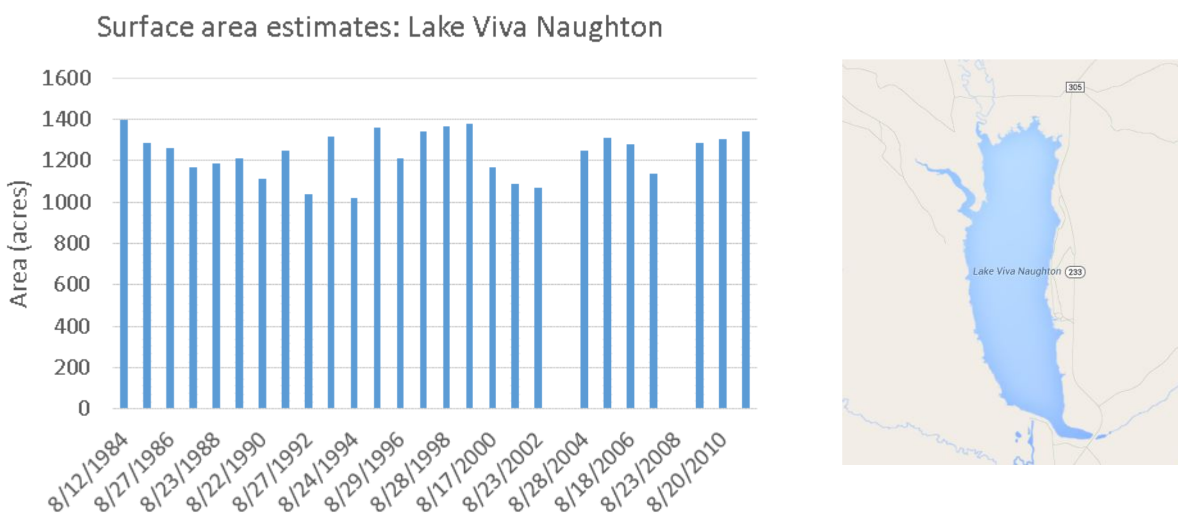

Figure 4.7: *Surface area estimates for Lake Viva Naughton derived from Landsat 5 TM images acquired from 1985 through 2011 in the month of August.*

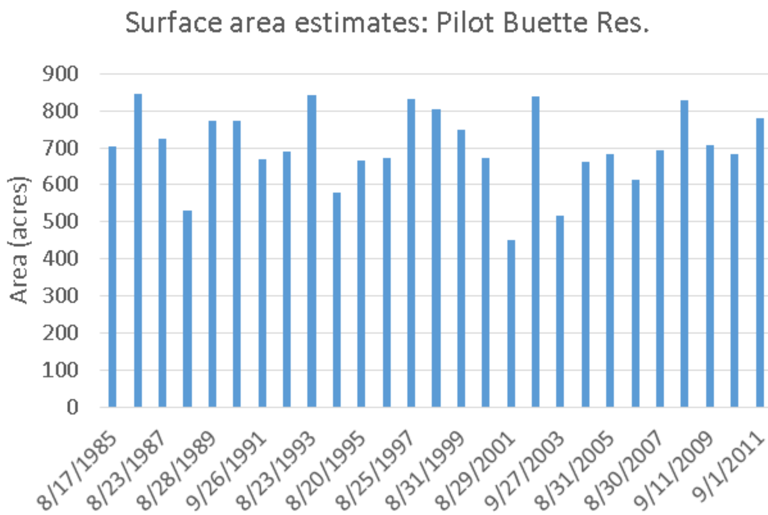

Figure 4.8: *Surface area estimates for Pilot Buette Reservoir derived from Landsat 5 TM images acquired from 1985 through 2011 mostly in the month of August. Four images were acquired in September, and one image was acquired in July.*

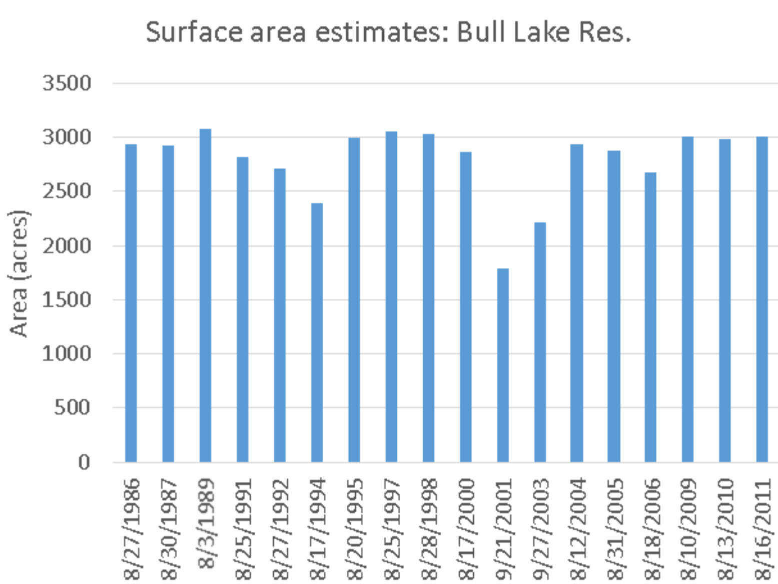

Figure 4.9: *Surface area estimates for Bull Lake Reservoir derived from Landsat 5 TM images acquired from 1986 through 2011 mostly in the month of August.*

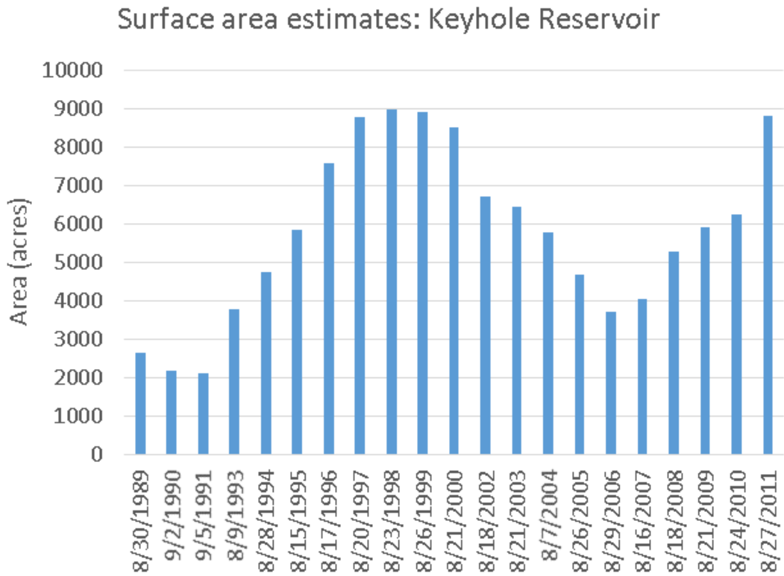

Figure 4.10: *Surface area estimates for Keyhole Reservoir derived from Landsat 5 TM images acquired from 1989 through 2011 mostly in the month of August.*

5. SIGNIFICANCE

This research project tested the utility of mapping surface area changes since 1984 in several small to medium sized reservoirs in Wyoming. Results obtained from this research suggest that Landsat data collected and distributed by the USGS can be used for estimating past surface area values of reservoirs in Wyoming. This information will be useful for those reservoirs that are gaged. Managers and policy makers can use this information to gain insights about how lake surface areas have changed since mid-1980s.

This study focused on creating a time-series consisting of late-summer, early-fall images. Since Landsat data were collected once in every 16 days it is possible to estimate surface area changes at that interval provided there are no clouds above the reservoir. Landsat data are provided at no-cost to users by the USGS.

Remotely sensed data used in this study was collected by Landsat 5 Thematic Mapper sensor which operated from 1984 through 2011. Landsat 7 (launched in 1999) continues to collect data however only 20% of each image is useful. The newest satellite in this series, Landsat 8 was launched in Feb 2013 and data are available from May 2013. Newly included spectral bands of Landsat 8 will improve the ability to water bodies.

Satellite derived surface areas of the reservoirs studied in this project and Ocean Lake (Gray and Sivanpillai 2010) will provide value valuable insights for mapping other reservoirs in Wyoming.

6. STUDENTS SUPPORTED & THEIR TESTIMONIALS

Total number of students supported in fall 2013: **8**

Total number of students supported in spring 2014: **1**

6.A. FALL 2013

Shane Black
BS, Rangeland Ecology and Watershed Management
Class: RNEW 4130 Applied Remote Sensing

I think that there is a bright future for studying water using remote sensing. I could see a lot of people using remote sensing and the correct software in the future for water identification. I do believe that there are limitations with measuring water using just unsupervised classification but with a combination of field work and unsupervised classification this can be a useful tool. I enjoyed taking part in this study it really helped me master some aspects of remote sensing.

Ryan Lermon
BS, Rangeland Ecology and Watershed Management
Class: RNEW 4130 Applied Remote Sensing

I found this water project to be very interesting, and it made me want to learn more about remote sensing. It is exciting that even though using satellite imagery for remote sensing has be around since the 1970's there is still much to learn. There are processes that still need to be refined or improved forty years later. It was somewhat difficult to find much research along the same lines that I was doing. To me this says that there is room for further study and improvement in this area of remote sensing.

Jimmy Schaffarzick
BS, Rangeland Ecology and Watershed Management
Class: RNEW 4130 Applied Remote Sensing

Throughout this experience, I have gained knowledge about both remote sensing and technological advancements that I never thought were possible. I have learned how to remotely sense water bodies, along with the challenges that arise with the process. I have learned how to use remotely sensed data to make management decisions in my future career. This project has greatly benefitted me, and I will use these many lessons for the rest of my life.

Zachariah Tuthill
BS, Rangeland Ecology and Watershed Management
Class: RNEW 4130 Applied Remote Sensing

This project broadened my knowledge of remote sensing and it applications. It also illustrated the impact of human bias and error, even in highly technological sciences like remote sensing. The need for accurate and reliable data about water is high, especially here in the west. Knowledge of how this data is collected and analyzed can only help me as I move forward toward a career in resource management.

Mary Harris
Undeclared graduate student
Class: BOT 4130 Applied Remote Sensing

My class project for BOT4130 was part of a larger study for the Wyoming Water Research Program. During this project I learned how to map reservoirs from Landsat5 satellite images, and I developed my own technique for assigning groups of pixels to specific landscape categories. Having my work be part of a larger study encouraged me to conduct my research on a professional level.

Elissa Paranto
BS, Biology Program
Class: BOT 4130 Applied Remote Sensing

I learned so much from this project, I do not know where to begin. This class was something I had no experience with in the past and was a challenge for me that I gladly accepted. This project took everything we learned all semester and applied it all into one huge lump sum. I have learned how to navigate excel and ERDAS with proficiency. I have also learned that mapping water's edge is a difficult feat to be had. Distinguishing water from the edge is a valuable measure of research to study for accurate readings of water levels for things like drought control and marine life. It is much more manageable then venturing out and doing ground work. I learned an immense amount and look forward to applying it in my future endeavors.

Ian Walker
BA Secondary Education/Social Studies
Class: BOT 4130 Applied Remote Sensing

I enjoyed working on this project because water management will be a consistent issue in the Western United States as future drought conditions are predicated. With so many lakes and reservoirs not regularly checked, water management is insufficient for this area. I learned that with the use of remote sensing and other techniques, it is possible to measure the amount of water, at a given location, and even be able to predict the water capacity during wet or dry years.

Erik Collier
B.S. Rangeland Ecology & Watershed Management
Class: BOT 4965 Undergraduate Research Remote Sensing

I previously completed an internship in remote sensing but with burn severity instead of mapping water. By mapping water I have gained another valuable skill to benefit my career. I will be working for the Bureau of Land Management and I feel mapping water can be useful in monitoring our allotments, by knowing how different areas are affected by drought. I am fortunate to have gained this skill set and can only see it benefiting my professional career. I would like to thank the Wyoming Water Research Program for the scholarship opportunity.

B. SPRING 2014

Zachariah Tuthill
BS, Rangeland Ecology and Watershed Management
Class: RNEW 4990 Digital Image Processing for Natural Resource Management

This Water Research Program internship helped me gain a deeper understanding of the utility and application of remote sensing in natural resource management. As management concerns grow especially as they pertain to water in the west, the knowledge to use and apply this kind of information is sure to be a benefit to me. Presenting my research at the Undergraduate Research Day helped develop my communication skills and my confidence.

7. PRESENTATIONS *(STUDENTS ARE ITALICIZED)*

Total number of conferences/events: **2**

Total number of students: **4**

Tuthill, Z, Sivanpillai, R. 2014. Mapping water bodies with Landsat imagery contaminated with thin layer-clouds. 2014 Wyoming Undergraduate Research Day, Laramie, WY. April 26.

McCollum, K, *Thoman, MJ*. 2013. Transferability of Landsat-derived NDWI Values across space and time. Geospatial Conference of the West 2013, Laramie, WY. Sept 16-19.

Terry, B. 2013. Characterizing analyst bias in unsupervised classification of Landsat images. Geospatial Conference of the West 2013, Laramie, WY. Sept 16-19.

8. CITATIONS

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Chander (2009) Remote Sensing of Environment 113:893–903
Chen L, Rau J (1998) Remote Sensing of Environment - 19:3383-3397
Elmore A, Guinn S (2010) Remote Sensing of Environment - 114:2384-2391
Gray WL, Sivanpillai R (2010) GIS in the Rockies – 2010 presentation. Loveland, CO
Jensen J (2000) Introductory Digital Image Processing: A Remote Sensing Perspective. Prentice-Hall, Englewood Cliffs, NJ