

**Glacial Surface Area change in
Grand Teton National Park**

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Introduction:

The Intergovernmental Panel on Climatic Change (IPCC) reported that a consensus exists among scientists and policy makers that "...the globally averaged net effect of human activities since 1750 has been one of warming..." (IPCC, 2007). The objective of the proposed research is to investigate glacial change in Grand Teton National Park (GTNP). Remote sensing data was obtained for the GTNP and a preliminary analysis of glacier area change was performed. Since the glaciated regions of GTNP have not been intensely studied in the past, it is essential to understand the past behaviors of the glaciers in the region. This study aims to create a database of quantitative information for the glaciers in GTNP such that future observations may be compared to past observations in an attempt to identify any long term trends of glacier behavior.

The research aimed to document glacial surface area change for selected glaciers in the Teton Mountain Range via analysis of aerial photographs (preliminary analysis). Aerial photographs were obtained from the USGS Earth Resources Observation & Science (EROS) Data Center in Sioux Falls, South Dakota.

Each image will be analyzed with a photogrammetric (the process of obtaining quantitative information from photographs) approach. The proposed approach involves digitizing and georeferencing each photo using ArcGIS. Once the georeferencing process is performed each glacier can be delineated using an unsupervised classification. Areas of snow and ice tend to have distinct reflectance values in aerial photographs, thus those areas can be delineated using an unsupervised classification. The resulting polygons (representing areas of snow and ice contained within the glacier boundaries) can be exported into geospatial software (ArcGIS) where the area of the resulting polygons can be digitally computed for each glacier at various different times. Since glaciated regions tend to hold fresh snow (from the year previous) until

late summer, each aerial photograph obtained shall be from the late summer months for each year analyzed, in an attempt to minimize the error and only compute the areas of perennial snow and ice coverage.

Methods:

USGS aerial photographs and Landsat images were utilized for comparison and verification purposes. The selected photos were from either August or September so as to minimize the effects of perennial snow cover.

The images were selected upon availability and providing valid and accurate documentation for every ten years. Five aerial photographs were obtained ranging from the year 1967 up to 2002. In addition to these, four images were selected for Landsat data ranging from 1994 to 2007.

Table 1:

Data Source:	Aerial Photographs	Landsat Imagery
Period of Record:	35 Years	13 Years
	August 17, 1967	August 24, 1994
	August 30, 1973	September 15, 1999
	September 15, 1983	August 17, 2003
	August 25, 1994	July 19, 2007
	August 18, 2002	

Upon obtaining the photographs it was found that the data from the 1973 aerial photographs could not be utilized due to the cloud coverage. This was not known until research had started on the photos and new photographs could not be ordered and analyzed in a timely matter to use for this research. It was also found that the 1999 Landsat image could not be used. This was not because of cloud cover, but due to a late snowfall in this year the photograph did not allow for an accurate reading for the watersheds.

Once the images were obtained analysis and comparison of the photos could be used to begin research. First, an unsupervised classification was used to group pixels representing glacier ice based upon each pixel's reflectance. An unsupervised classification is a method used to identify different materials on the surface based on their pixel value (reflectance). The resulting polygons would then be imported into a Geographical Information System (GIS) for further analysis.

In GIS the polygons that were defined as glacier ice would be set aside from the other polygons to be analyzed. In some cases cloud cover can have the same pixel value as the glaciers and it must be clipped out using ArcGIS. There are typically many polygons combined to create the glacier and they must be dissolved into one polygon to be measured. Finally, the areas of each polygon representing glacier ice were calculated in ArcGIS.

The methods used in analyzing the aerial photographs are similar to those of the Landsat images. The difference in the analysis is found when georeferencing and the digitizing of the photo. The Landsat data has spatial references when they are delivered and the aerial photographs are only a photo without any identifying dimensions or reference points to a geographical location.

The photographs were obtained through the United States Geological Survey (USGS) and imported into ArcGIS to be rectified. In most cases the spatial coordinates were given for the four corners of the photo which made it possible to match the photo to a geographic location. These photos were all rectified with a root mean squared error (RMSE) of three meters or less. Once these points were assigned, other points could be estimated for any point by determining the spatial coordinates of a known point. After this step was completed it was imported to the Leicos Erdas Imagine program to be classified and finished in the exact manner as the Landsat images.

Due to the lower resolution of the Landsat data, watersheds were developed for the main portions of the glacierized area to be studied. It was also optimal due to the 180 kilometer swath that the Landsat image displays. Two watersheds covering the area being studied were selected for analysis. For each year that Landsat data was obtained, the total area of glacial coverage was documented. This provided a large scale observation of the glaciers as a whole instead of a small selected area. Having a large scale observation will help to verify the results of the glaciers being analyzed.

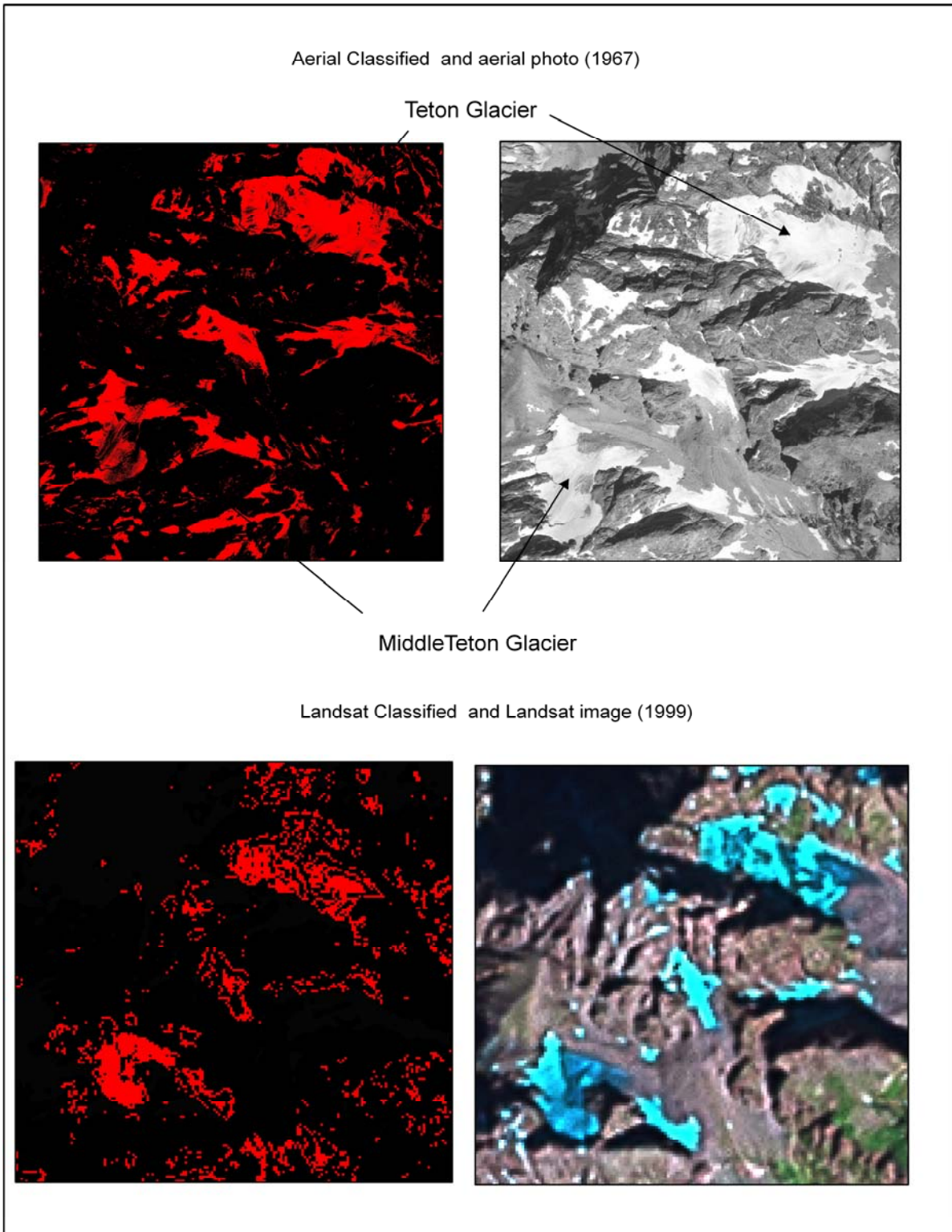


Figure 1: A display of a classified and actual image compared against a different year

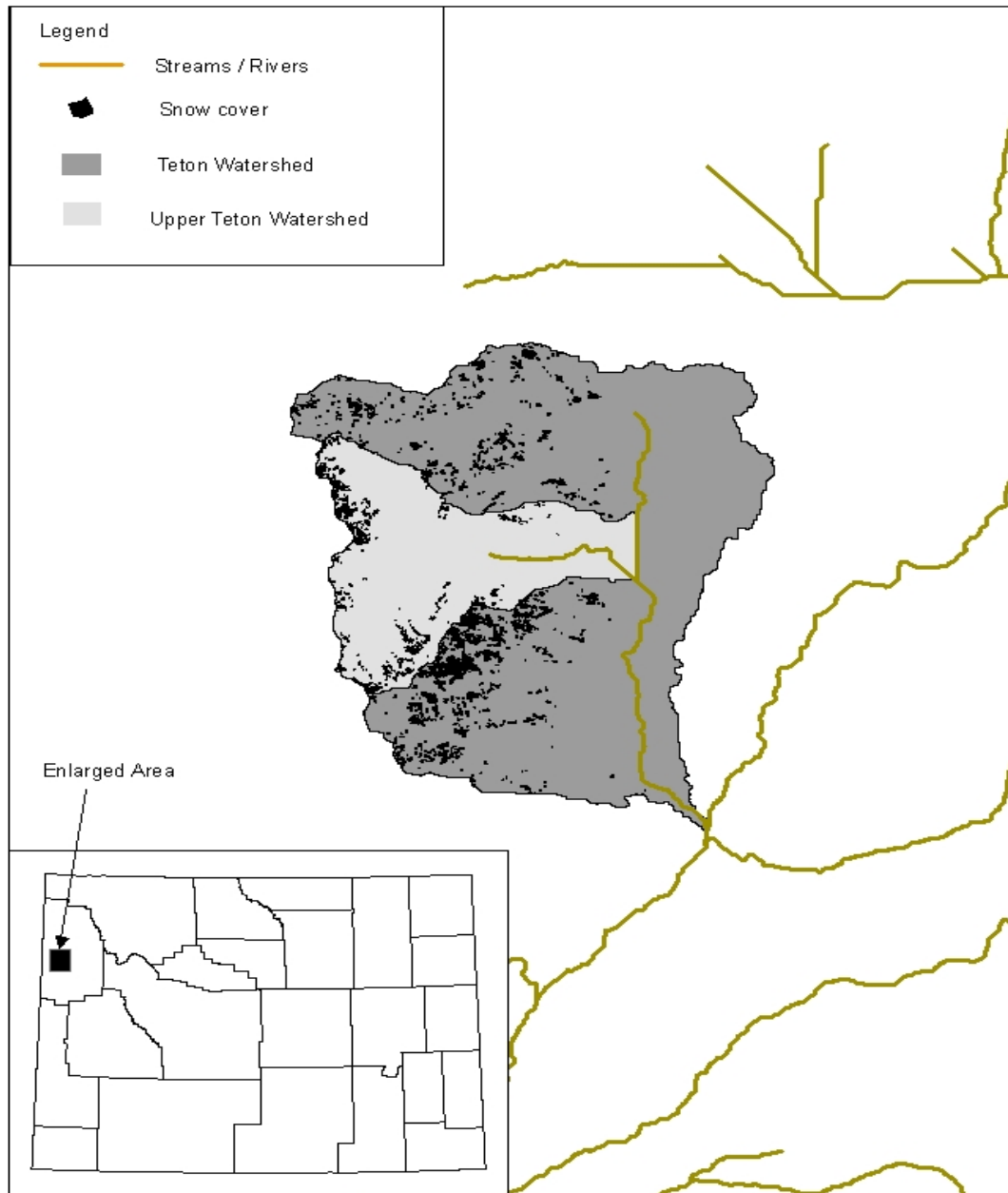


Figure 2: Selected watersheds showing geographic location

Results:

The area analyzed showed the watershed containing the two largest glaciers (Teton and Middle Teton) to have a size 55% of that in 1994 and the other watershed to have a size of 3% the size measured in 1994. In previous studies it has been found that smaller glaciers are more susceptible to change than larger ones (Granshaw and Fountain 2006). The glacerized watershed started with snow covering an area of $4.75 \pm 1.28 \text{ km}^2$ whereas the other watershed only had $2.18 \pm 0.57 \text{ km}^2$ of coverage. The loss of almost half its size in only thirteen years is alarming.

Table 2:

	Watershed Analysis using Landsat		
Date:	1994	2003	2007
	Glaciated Watershed		
Area (km ²):	4.747	4.128	2.617
% of 1994	--	86.96	55.13
	Non-Glaciaded Watershed		
Area (km ²):	2.187	0.621	0.147
% of 1994	--	13.09	3.09

The watershed that did not contain the two glaciers has much more variability than that of the non-glaciaded watershed. The more glaciaded watershed lost 45% of its area and the non-glaciaded watershed lost 97% of its area since 1994.

The two glaciers selected for study were analyzed using both Landsat data and Aerial photographs. The Landsat data overestimated the size of the glaciers due to the low resolution of 30 meters. The glaciers small size made it difficult for the Landsat data to accurately determine the size of the glacier.

Table 3:

Glacier Analysis using Landsat			
Date:	1994	2003	2007
Teton Galcier			
Area (km ²):	0.247	0.156	0.158
% of 1994	--	63.22	64.08
Middle Teton Glacier			
Area (km ²):	0.138	0.103	0.099
% of 1994	--	41.56	40.16

A common year was found between the two data sets and was compared to show the difference in size. The Landsat data was on average $38.85\% \pm 2\%$ larger than that of the aerial photographs.

Table 4:

Glacier Analysis using Aerial Photographs				
Date:	1967	1983	1994	2002
Teton Glacier				
Area (km ²):	0.268	0.156	0.101	0.092
% of 1967	--	58.25	37.67	34.38
Middle-Teton Glacier				
Area (km ²):	0.185	0.087	0.051	0.049
% of 1967	--	32.61	18.89	18.37

The results for the two methods vary greatly when looking at the numbers but by considering a graph and comparing the two a trend can be seen in both that looks similar and provide verification. The overestimate of the Landsat data may project a larger overall glacier size, but because overestimates the same on all images this data can still be utilized without concern of effecting the results.

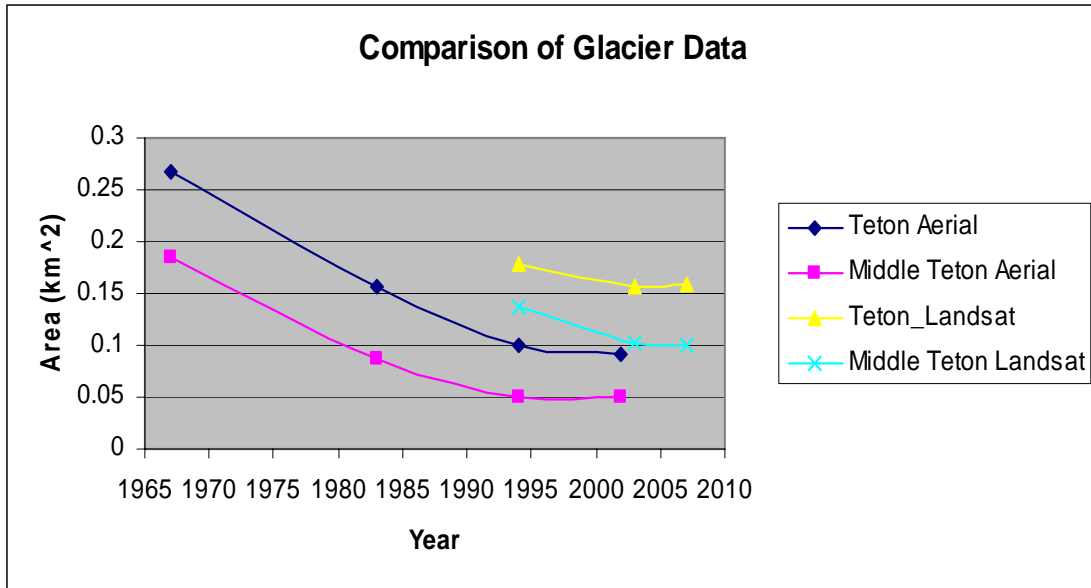


Figure 3: Landsat Glacier analysis compared against Aerial Photos for verification purposes.

The closeness and overall trend of the data can be used to verify the results of the other.

Conclusion:

Rivers and streams originating from glaciers exhibit unique stream flow patterns making them valuable for mid to late summer water supply needs, since glaciers typically reach their peak outflow during this time e.g. (Meier, 1969; Pochop et al., 1990). The change in glacier size is going to have a long term affect on agricultural needs, because it will have a large impact the amount of downstream water that can be used during this time.

During the late summer months precipitation can have high variability. Having a constant source of downstream flow provides a source of water for irrigation when precipitation is not available. The two glaciers studied have lost over half of their area since 1967. The loss of glacier area is going to have an effect on downstream flow. At some point the downstream flow will be so diminished it will not be available to be relied on for irrigation purposes.

The research has shown a loss in glacier size and snow cover for the selected area. The two watersheds that were utilized exhibited losses similar to that of the glaciers. This loss verifies the results

obtained for the glacier analysis. These results eliminate the chance of a particular glacier acting abnormally in a certain area.

This research will be useful not only to the people of the area but to the state of Wyoming as a whole. Agriculture is an important part to the state's economy and the importance of the glacier water is vital for irrigation purposes.

This study can be used as the beginning of a larger study by obtaining more photos and Landsat imagery and completing the gaps missing in the current data.

References:

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