An Examination of External Influences Imbedded in the Historical Snow Data of Utah

Randall P. Julander
Natural Resources Conservation Service, USDA

Michael Bricco
Natural Resources Conservation Service, USDA

AN EXAMINATION OF EXTERNAL INFLUENCES IMBEDDED IN THE HISTORICAL SNOW DATA OF UTAH

Randall P. Julander[1] Michael Bricco[2]

ABSTRACT

Snowpack data collection has a long and storied history in Utah as well as the western United States. Many researchers use historical snow course data for various applications ranging from water supply forecasting to climate change. These data are far from a perfect data set and data users should know the errors and limitations within them. In the current setting, only those collecting the data have access to the raw data and the site biographical information. In Utah, records extend back to at least 1912. Systematic measurements began in the mid 1920's with many long term snow courses established at that time. In an extremely fortuitous circumstance, Mr. George D. Clyde (former Governor of Utah) was responsible for the Snow Survey Program during the 1930's in Utah and had foresight to document each existing Snow Course in the year 1936. Each site was meticulously mapped, described and most important, photographed from several angles. Comparisons are made between the 1936 photographs, maps and descriptions and current conditions, specifically with regard to vegetation and sample point location. General conclusions are made regarding the impact that vegetation change has had on snow accumulation at each course. Changes in sampling technique and data processing are documented, particularly with regard to sample density and the re-sampling (or lack thereof in the record up to the 1950's) of individual sample points when density thresholds are exceeded. With the advent of weather modification programs, changes in snow accumulation could reasonably be expected. Utah began a relatively small test weather modification program in the 1950's in central Utah. The Utah cloud seeding act was passed in 1973 and the seeding program has continued since that time. Snow Courses affected by this program are identified and the potential impact on historical data. Finally, recommendations for individual snow course suitability for long term study based on consistency are made for each of the courses examined. SNOTEL sites, the automated version of the snow courses began to be installed in the late 1970's and early 1980's. These sites to a lesser degree due to the shorter historical time of data collection, have been impacted by vegetation change as well. They also have data impacted by sensor changes and weather modification. Because snow course data are often used to extrapolate the SNOTEL data set to a longer time frame, it is important that external influences in this data set are quantified as well.

INTRODUCTION

The Natural Resources Conservation Service (NRCS), United States Department of Agriculture (USDA) is charged with the task of measuring high elevation hydroclimatic data in the western United States. Snow water equivalent is the data parameter of primary interest with precipitation, temperature and other parameters also being measured. Snowpacks in Utah have been systematically measured to some extent since the mid-1920's. This is one of the best long-term databases of snow water equivalent (Soil Conservation Service 1979). These data provide a wealth of climate and runoff correlation data. The quantification of an average climatological condition as well as

---

Paper presented Western Snow Conference 2006

[1] Natural Resources Conservation Service, USDA

[2] Natural Resources Conservation Service, , USDA

the associated extremes has long had relevance in the categorization and characterization of various geographic regions. Recent events compared to both the historical observed data records as well as the inferred or synthetically generated geological climate record have led to a general conclusion of accelerated global climate change and a generally heightened interest in how climate at the local level may be impacted. Saunders and Maxwell state "in the most thorough review yet of changes in the West's snowpacks, an analysis of the records of 824 government snowpack-measurement sites across the West with records from 1950 to 1997 shows that snowpack levels have declined at most of those sites over that period". Cooley found in modeling studies of a Montana snowpack, that changes in temperature by 2 to 4 degrees C, could reduce snowpacks by as much as 80 percent. Gleick and Adams state that snow and ice cover are decreasing and melting earlier on average in the northern hemisphere. They state further, that field surveys show that snow cover over the northern hemisphere land surface since 1988 has been consistently below average over the last quarter century with an average decrease of about 10 percent, and that the changes have been linked to temperature. (Gleick and Adams, 2000). New research indicates that air pollution aerosols may suppress orographic precipitation by slowing down cloud drop coalescence and riming of ice precipitation, delaying the conversion of cloud water into precipitation. Mid level precipitation can be diminished by 15% to 25% of the annual total (Givati and Rosenfeld, 2004, Griffith, Solak and Yorty, 2005). As the global climate changes globally, climate changes in regional areas, such as the State of Utah, may or may not be impacted to the same degree. Thirty years is the World Meteorological Organization (WMO) standard time frame for calculating an average condition for snowpack snow water equivalent, precipitation, etc. These thirty-year averages are re-calculated and published every ten years. These climatic normals are then used to compare current observed parameters of snowpack, precipitation, to seasonal water supply and other analyses. This process then allows for a relatively consistent dataset to be used for water supply prediction.

Snowpack data are being consistently used as an indicator of global warming. It is essential that individuals using snowpack data to make historical comparisons and attribute any differences to a single cause, quantify as best they can, all influences imbedded in the data. Snow data may be impacted by site physical changes, vegetation changes, weather modification, pollution, sensor changes, changes in transportation or sampling date, comparisons of snow course to SNOTEL data, changes in measurement personnel or recreational and other factors. Another factor is a sensor that does not come back to zero at the end of the snow season.

In order to conclusively prove that global warming is impacting snowpacks in Utah using historical snow data, we believe that two criteria must be met: 1) current data must be significantly different than what has historically occurred using the longest period of record, and 2) other factors impacting the data must be ruled or factored out as a predominant cause, thus leaving climate change as the main or only factor. This does not imply that climate change is not happening in Utah but is simply an attempt to make sure that what is being seen in the data can be specifically attributed to a specific cause.

METHODS

Elements that impact the long term continuity of snow data collection in Utah were identified. A matrix of these elements was prepared for each snow data collection site. Each element was then graded based on the overall impact at that site. A range of expected impact was generated as well as an average or most likely effect on the site. These values were taken from published literature such as those documenting the impacts of vegetation on snow accumulation as well as those documenting the impacts of cloud seeding. Other impacts such as those associated with sensor change from steel to hypalon pillows were based on observed differences at sites that had both sensors simultaneously. Impacts from site physical changes, though rare were based on best estimation or simply noted as an impact and left un-quantified.

Vegetation changes at snow data sites can range from none at all to complete and dramatic. Trial Lake snow course is in a small meadow and the comparison of old photos to current conditions show little to no change in the forest canopy at this site over the 80 plus years of existence. Brian Head on the other hand used to be in a mature spruce forest that has since been beetle-killed and logged. From the complete canopy of huge spruce trees to an open campground, there has been a significant change in snow accumulation and ablation characteristics. Midway Valley Snotel is in the same condition. Sites like these are noted in the analysis to have zero impact from vegetation change because the change has happened in the past several years and thus to the point of recent impact, the historical data are free from the impact but current and future data will be impacted. Likewise Little Grassy and Lily Lake have had huge vegetation changes due to wildfire and will be significantly impacted, however the current historical record is free from the influence. This analysis of vegetative change is admittedly, subjective in nature, completed by multiple Snow Survey staff members and based on comparisons with old photos compared to current conditions where possible. Where older photos were not available, the state and type of current vegetation was used. For example, is the site located in a vigorously growing stand of aspens as opposed to a site in a mature Lodgepole forest. In the case of the aspens, the assumption is that this site will have vegetative change over a period of time. In the case of the mature Lodgepole forest, minimal vegetative change is expected. An arbitrary ranking system was used to classify the vegetative change using 4 categories: 1- no change, 2- minimal change, 3- moderate change and 4- major change during the sites existence. These categories were then converted to a range of percentage change based upon documented impacts on snow accumulation from other research. In this analysis, 23 of 134 sites were ranked as having had no significant vegetation change during their existence. An additional 68 were ranked as having only minor changes with little impact on snow accumulation or ablation. Thirty two sites had moderate changes and 11 were ranked as having major vegetative impacts. Thirty two percent of the total snow sites in Utah have had moderate to major vegetation impacts over their existence ranging from 5% to a conservative maximum of 30% decrease in snow accumulation due to vegetation changes. For the analysis of the 15 long term snow courses discussed later in this paper, the assumption was that these vegetative changes were in place for the 1971-2000 average period.

Weather modification has had impacts on precipitation accumulation in Utah. The first cloud seeding project began on the Wasatch Plateau of central Utah in the early 1950's. In 1973, the Utah Legislature passed the Utah Cloud Seeding Act which provided for licensing of cloud seeding operations by the Division of Water Resources. Since that time, cloud seeding had been tracked by year and county by the Division of Water Resources. The location of each weather modification site was plotted along with a 80.4 kilometer radius and the resulting chart revealed that only 4 snow data sites were not directly impacted within a 80.4 kilometer radius by weather modification: Camp Jackson, Buckboard Flat, Lasal Mountain Lower, Lasal Mountain SNOTEL and to a lesser extent, East Willow Creek (160.8 kilometer radius). Weather modification data were proportionately applied to the observed data based on the number of years of impact and assuming a constant impact of 14% as reported by Solak, Yorty and Griffith to be as conservative as possible. For analytical and comparative purposes, the data set is from 1973 (the beginning year of documented cloud seeding) to 2000, the ending year of the past 30 year averages. This gives a quantitative percentage of impact of cloud seeding on the current 1971-2000 April 1 Average to the analysis. Other researchers should include the years of 2001 to current conditions when making any other comparison.

Pollution impacts on precipitation are just now coming into view. Studies already referenced have documented 15% to 25% decreases in precipitation due to pollution. The assumption in this analysis is that pollution could impact all snow measurement sites immediately east of the major metropolitan areas of the Wasatch Front from Ogden in the North to Provo in the south. Griffith, Solak and Yorty tentatively demonstrate a decrease in precipitation as far as Trial Lake and Smith and Morehouse, thus these define the outer reaches of this impact. Other areas of Utah were assumed to have no impact due to pollution although there is potential for areas such as the Cache Valley (Logan) and the Cedar City area to have current and likely future impacts. The minimum impact of 15% was used in order to be conservative in the analysis. Because there is no current data suggesting at what level pollution impacts orographic precipitation, but according to the above cited study that it is impacting the Wasatch Front, we used an arbitrary assumption that these pollution impacts on the 1971-2000 averages began in mid course, in 1986 so these data were adjusted accordingly. More research needs to be done in this area to confirm the results of these studies.

Sensor changes can have an impact on snow measurement. In the early years of SNOTEL, (1978-circa 1990) all sites had steel pillows in either a 2, 3 or 4 pillow configuration. Post this time frame, most new installations as well as pillow replacements have been of hypalon type pillows. This is an area of research that has not yet had significant study and needs to be quantified. Cursory data analysis of sites in Utah and Idaho that have had both steel and hypalon pillows operated conjunctively, indicate a significant decrease (0% to 20%) in peak snow accumulation on the hypalon pillows versus the steel. There could be physical reasons for this observed phenomenon. Hypalon pillows contain far greater amounts of fluid than the steel pillows, 100 to 200 gallons versus 12 to 15 gallons per steel pillow. This fluid could retain more thermal energy later in the season and delay early snow accumulation. The hypalon is black and absorbs more energy than either the gravel covered steel pillows or the surrounding soil, again potentially delaying the early accumulation of snow. This black color could also hasten the melt process as the pillow melts out in the spring via absorption of short wave radiation and subsequent emitting of long wave radiation. Lower elevation sites seem to be far more prone to larger decreases than high elevation (3300 meters or higher) sites. This supports the theory that both the color and fluid may be impacting the thermal qualities of the site. At higher elevations, colder temperatures set in well before the convective precipitation seasons gives way to the frontal systems of fall and winter in Utah. This would allow the site to be well below freezing temperature prior to significant seasonal precipitation and would begin snow accumulation as the frontal storms move in. Lower elevation sites could still be warm enough to melt early season snows, delaying accumulation onset. At a very few sites, hypalon pillows collect more snow than their steel counterparts. Certainly more study of this observed phenomenon needs to be done to conclusively define the cause and extent of the discrepancy. Almost every steel pillow that has been changed to hypalon would show this inconsistency within the historical record. In Utah, we now cover the black surface of hypalon pillows with a white hypalon liner, which will introduce yet another source of discontinuity to the current historical record but, we feel this will yield more accurate data for the future. The process of covering all pillows will be long and tedious, as the cover is only currently added when a pillow fails or upon the installation of a new site. For this analysis, a constant 13% decrease was used because sites from 2200 meters to 3037 meters were very close to this number and sites above that were essentially neutral showing no difference between steel and hypalon. Fortunately, there are very few sites at or above the 3300 meter mark in Utah and none that have had pillow changes. The percentage change was applied to the data for the years since the actual pillow replacement.

Site physical changes, while somewhat rare (21 sites, 16% of total), still occur and can have significant impacts on snow data. These changes can be difficult to quantify. For example, some sites have to be moved such as Harris Flat, Beaver Dams and Panguitch Lake. Harris Flat was in a large open flat near an old cabin, long since gone that had four beautiful spruce trees in front. As it turns out, these trees had a significant impact on wind acceleration and deceleration across the pillow and hence the deposition and erosion of snowpack. The pillow was moved to a more neutral location and the data have since been stable. Beaver Dams was hit by a mud flow in 1983 and was subsequently moved from a young aspen stand to an open meadow, some 200 yards distant. Panguitch Lake, after 80 years of data collection, became lake-front development property and was moved about 1 kilometer to USFS property with some overlap in data collection. The most predominant site physical changes include things such as recreation - snowmobiles or skiers that compact snow courses. Tony Grove Ranger Station is one such site that has had impacts from the recreationists. Sample points 4 and 5 both are statistically getting less snow from 1984 to 2005 than from 1970 to 1983. Interestingly, sample 5 used to get more snow than sample 4 (1970 to 1983: 38.4 cm to 37.3cm) and is now getting less (1984-2005: 27.8 cm to 31.6 cm), by a significant margin. Both samples have been impacted by recreation and apparently sample 5 more than sample 4. This illustrates the difficult nature of trying to quantify the impact of recreationists removing snow from the course from others kinds of signatures in the snow data. Normally, one would expect that a snowmobile or skier would leave a track that would densify the underlaying snow, and that track would fill in with more snow leading to an increase in SWE. In this case, the samples are near the edge of the road and across the drainage ditch where apparently, snow is removed from the area. In another case, Burts Miller Ranch, the snow course is exactly as it was 70 plus years ago with the exception of the addition of two irrigation/recreation ponds a short distance above the course as well as an irrigation ditch immediately adjacent to the course. Also, along Mill Creek, there have been several beaver dams built in recent times. Immediately above the course there is an ephemeral stream and a cattle crossing that has been worn down through the years making a path directly along the course. Many of the snow notes from this course note standing water at the soil/snow interface. The property owner has stated to us that he used to be able to ride a horse across the meadow during late fall and early spring after melt-out but is no longer able to do so because the meadow is too wet and tends to pull the shoes off the horse as it bogs down. He states that the ponds, stream and beaver ponds are sub-irrigating the meadow in which the snow course is located throughout the late fall, winter and spring months. This course is statistically getting less snow from 1990-2005 than in previous years, about 20%, or about 3 centimeters less. This entire amount could easily be due to the transference of heat energy via sub-irrigation to the snowpack. The problem comes in determining if other sources play a role in the decrease and to what extent. Sample number 1 at the Fish Lake snow course is recently being impacted by road plowing. Stuart Ranger Station was discontinued because the nearby road plowing method was changed from blade to an auger that tossed huge amounts of snow on the course. Yankee Meadows had a stream rerouted for fish habitat directly through the snow course hitting sample point number 3 and sample point 5 gets flooded by the reservoir when it is full. The stream was subsequently re-routed to avoid the sample point, but still melts out earlier than what it used to. Brighton Snotel had a quad lift from the Brighton Ski Resort move in on both sides of the site, decreasing snow catch by some 10%.

Then there are the physical things that add sporadic errors to the data. When identified these errors are removed through a data editing process. The question is - how many of these errors are correctly identified anc corrected. Only the most extreme conditions, those greater than 10% deviation, are normally found. Most of this kind of error is in the form of snow creep or poorly performing sensors. Creep can add significant lateral stress and therefore weight to a pillow system (the Franklin Basin Problem, Julander et al). These situations typically occur with larger snowpack but can for that year, add up to 20% or more snowpack than what is really there. These errors are typically edited out of the historical data by comparing to manual ground truth samples and adjusting the data based on the long term relationship between the electronic and manual measurement. Snowbird is an example of this case where the pillow performs well up to about 100 Cm of SWE and then creep exerts lateral force increasing the apparent pillow SWE. Another type of physical error that gets edited out of the Snotel data is that of a pressure transducer (the device that weighs the pillow SWE) that does not come back to zero at the end of the snow ablation season. Most of them don't come back to exactly zero, but most of them come close, within plus or minus 1.5 centimeters. If the error is greater than that, and there has been a known problem or a replacement of the transducer or electronic component, then the data are edited to that known point and forced to zero. If not, and the cause is assumed to be some physical phenomenon such as frost heave, soil expansion, etc, then the sensor is simply set to zero and the data left as is. The reason for this is, where would one start the data edit, end the data edit, or factor by how much and how consistent through time would editing be applied? Without knowing what the actual problem is one cannot reasonably assume a start, end or the consistency of whatever process is happening. There are many questions and few answers.

Table 1. An example of historical offset adjustments to SWE data at various SNOTEL sites in centimeters.

Snow Water Equivalent Sensor Offset Adjustments at Various SNOTEL Sites

Trout Creek	Trial Lake	Timpanogos	Merchant Valley	Farnsworth Lake	Hayden Fork	Chalk Creek 1	Kimberly Mine
-0.3	-6.1	11.7	0.8	-0.3	1.3	0.3	0.5
-0.8	7.4	-8.1	0.3	6.9	0.8	-1.5	-0.3
0.5	2.5	5.3	1.0	2.0	-3.8	0.5	-1.3
0.3	-5.3	10.7	0.3	1.3	1.5	-2.5	1.3
0.5	-1.0	-2.0	1.0	1.5	-1.5	2.5	1.3
0.3	-1.3	-1.8	0.8	-3.8	-1.3	1.3	2.0
-2.3	1.8	-1.3	-5.8	-1.3	-1.3	5.3	4.1
-1.3	-1.3	-1.3	-1.3	-1.0	1.3	-2.0	3.3
1.5	-2.3	-1.3	2.3	-3.0	-1.3	2.0	1.0
1.5	-1.0	-1.0	1.8	-1.3	-1.0	-3.3	-3.0
-1.5	-1.5	-1.0	1.0	-2.3	1.8	2.8	-1.8
-0.5	1.0	1.5	4.3	-0.8	-1.0	-2.3	2.5

1.0	1.5	1.3	-1.5	-0.8	-1.0	1.0	-1.5
-0.8	1.8	1.3	-2.8	1.5	1.3	1.0	1.3
0.8		1.8	-1.0	3.6	-1.0	-1.3	-1.3
-1.3		1.0	-1.0	-1.8	1.3	-0.8	-1.5
1.0		2.0	-1.0	1.3	1.0	4.3	-1.3
0.8			-0.8	1.5	-1.3	-4.1	-1.0
-1.3			-2.5	0.8		0.8	-2.8
-2.3			-3.0	1.0		-0.5	1.8
0.8			-2.5	4.3			-0.8
-10.9			-4.6				-1.3
-1.0			-0.8				1.5
6.1							

The SNOTEL system was installed in the late 1970's and early 1980's. In order to generate a 30 year average estimate for each site, data from the SNOTEL sites were correlated to the concurrently measured snow course. These back estimated data are available for use but the user should be aware that they are estimates only. In most cases SNOTEL data between 1960 and about 1978 are estimates. Depending on the individual site, the R-Square for these relationships was generally 0.90 and above although in certain circumstances, the relationship could have been less. We do not recommend these data for long term climate comparisons.

Another physical impact is that of inconsistency of measurement technique and personnel. In the early days of snow data measurement, snow courses were laid out to try to capture a significant part of the terrain and as much geography as possible. These courses were often very long, in complex configurations and had up to 100 or more sample points. They ran through meadows and forest, up hills and down canyons. As the science matured, most courses have been standardized to between 5 and 10 sample points over a distance of about 50 to 100 feet. Sample points were reduced to those which best represented stable and replicatable measures best correlated to observed streamflow. These retained points were most often some sequential portion of the original set of points. All of the data currently used to calculate a specific snow course number for a given month use the original or edited data for that point. So, in that sense, snow course data are consistent through time. However, the sampling technique has changed over time, specifically with regard to sample quality. From the early 1900's until the mid 1950's *only one sample* was taken at each sample point and the average of all points used to calculate a snow course average. In the mid 50's with the advent of the Snow Survey Training School, standardized training became available to surveyors. The "Snow Survey Handbook" of 1955, USDA, SCS is also the first mention of comparing densities of various sample points to make sure an accurate sample was obtained. In later versions, a sample point density range of no more than 5% was recommended. In reducing the number of sample points from 50 to 5, if a data point were encountered that had an obvious bad reading as judged by the density of the sample, then those data were edited to reflect a value in line with the densities of adjacent samples. If one were to use the original data, there would likely be less SWE in those early years than that currently reflected in the historical data base. Also in the early days of snow course measurement, individual sample points were defined on a map and the end or ends of the snow course marked. Measurements were taken using the map and a measuring device - a tape measure or using the snow tube as a tape. Currently, each sample point is marked with a steel and PVC pole and the 3 samples are taken at a distance of 91 cm (March 1), 61 cm (April 1) and 30 cm (May 1) from that physically marked spot. The early samples on any given snow course, could have been taken at any point along the course depending on the individual sampler and how conscientious they were in their duties. Also, the accuracy of any individual measurement is 1.27 Cm or 0.5 inch. In the 15 long term snow courses used in this study, that ranges from 2.1% to 12.2% of the April 1 average snowpack. Obviously as a percentage, the lower accumulation sites stand out and the higher accumulation sites have the lower percentages. All of the lower elevation sites range from 8% to 12.2% and given this high measurement error, an increase or decrease of 5% to 10% is within the accuracy of the measurement technique.

The absolute comparison of April 1 SNOTEL data to snow course data have an inherit discrepancy in the sense that SNOTEL data are actually measured on April 1 and snow course data are most likely measured at some point prior to that date. If relative comparisons are made then the difference is not important. If however, one is referencing the absolute value then the difference between the 2 data sets ranges from 0.6% to 3.9% with an average of 1.7% of the April 1 value which in actual SWE is 0.2 to 1.6 centimeters of SWE with an average of 0.7 centimeters. This reflects the amount that would need to be added on average to the snow course data set to make it comparable to the SNOTEL data set (Julander, 2005), although each specific site would be different.

Table 2 gives an overview of each site and an estimate in percent of the various individual impacts and the total of ***only the major impacts*** on the site 1971-2000 average calculation. Admittedly, this is a crude estimate of the many complex interactions going on at each location but it at least gives some quantification to known processes that are occurring and a general magnitude of those interrelated impacts. Specifically with regard to vegetation changes, if these were estimated to be none or minor, a zero value was assigned and moderate to major were ranked according to the magnitude of change between 5% and a maximum of 30%. These are very conservative estimates as almost all long term sites would have some impact from vegetation encroachment. Minor impact could be assessed at 5% or less which would dramatically alter Table 1. Researchers can use this table to get a *relative estimate* of the total impact or at a minimum be aware of various influences in the data when making comparisons between the historic and current data (2005). Cloud seeding is a negative impact in that one must subtract that influence from the observed data and impacts that decrease observed snow accumulation just as most vegetation changes must be added back to the data.

Table 2. A summary of estimates of influences imbedded in Utah's historic snowpack data relative to the 1971-2000 average.

Potential Impact on the 1971-2000 AVG	**Vegetation**	**Physical**	**Cloud Seeding**	**Pollution**	**Pillow Change**	**Total**
AGUA CANYON SNOTEL	0%		-4%	none	0%	-4%
ALTA CENTRAL	0%		-5%	7%		2%
BEAVER DAMS SNOTEL	0%	moved	-9%	none	steel	-9%
BEAVER DIVIDE SNOTEL	0%		-3%	none	4%	1%

BEN LOMOND PK SNT	0%		-2%	7%	3%	9%
BEN LOMOND TR SNT	15%		-2%	7%	4%	25%
BEVAN'S CABIN	15%	buildings	-8%	none		7%
BIG FLAT SNOTEL	0%		-10%	none	3%	-7%
BIRCH CROSSING	15%		-9%	none		6%
BLACK FLAT-U.M. CK SNT	0%		-11%	none	steel	-11%
BLACK'S FORK GS-EF	0%	snowmobiles	-4%	none		-4%
BLACK'S FORK JUNCTN	0%	snowmobiles	-4%	none		-4%
BOX CREEK SNOTEL	10%		-8%	none	4%	7%
BRIAN HEAD	30%		-9%	none		21%
BRIGHTON SNOTEL	10%	10%	-4%	7%	0%	24%
BRIGHTON CABIN	0%	cabins	-5%	7%		2%
BROWN DUCK SNOTEL	0%		-1%	none	steel	-1%
BRYCE CANYON	0%		-13%	none		-13%
BUCK FLAT SNOTEL	0%		-9%	none	0%	-9%
BUCK PASTURE SNT	0%		-6%	none		-6%
BUCKBOARD FLAT	30%		0%	none		30%
BUG LAKE SNOTEL	15%		-8%	none	steel	8%
BURT'S-MILLER RANCH	0%	20%	-4%	none		17%
CAMP JACKSON SNOTEL	15%		0%	none	steel	15%
CASTLE VALLEY SNOTEL	0%		-7%	none	steel	-7%
CHALK CK #1 SNOTEL	0%		-3%	none	5%	2%
CHALK CK #2 SNOTEL	15%		-3%	7%	steel	19%
CHALK CREEK #3	0%		-4%	7%		4%
CHEPETA SNOTEL	0%		-1%	none	steel	-1%
CLEAR CK RIDG #1 SNT	15%		0%	7%	steel	22%
CLEAR CK RIDG #2 SNT	0%		0%	7%	steel	7%
CORRAL	15%		-4%	none		12%
CURRANT CREEK SNT	0%		-1%	none	steel	-1%
DANIELS-STRAWBERRY	0%		-3%	none	steel	-3%
DILL'S CAMP SNOTEL	15%		-4%	none	steel	11%
DONKEY RESERVOIR SN	15%		-9%	none	steel	7%
DRY BREAD POND SNT	0%	snowmobiles	-2%	7%	3%	9%
DRY FORK SNOTEL	0%		-3%	none	0%	-3%
EAST WILLOW CREEK SN	0%		0%	none	steel	0%
FARMINGTON U. SNOTEL	0%	snowmobiles	0%	7%	steel	7%
FARMINGTON LOWER SC	15%	snowmobiles	0%	7%		22%
FARNSWORTH LK SNT	20%		-8%	none	steel	13%
FISH LAKE	0%	road plowing	-10%	none		-10%
FIVE POINTS LAKE SNT	0%		-1%	none	steel	-1%
G.B.R.C. HEADQUARTER	15%		-12%	none		4%
G.B.R.C. MEADOWS	0%	snowmobiles	-10%	none		-10%
GARDEN CITY SUMMIT	30%		-8%	none		23%
GEORGE CREEK	0%		-6%	none		-6%
GOOSEBERRY R.S.	0%		-10%	none		-10%
GOOSEBERRY R.S. SNT	0%		-8%	none	3%	-5%

HARDSCRABBLE SNT	0%		0%	7%	0%	7%
HARRIS FLAT SNOTEL	5%	pillow move	-11%	none	3%	-3%
HAYDEN FORK SNOTEL	0%		-3%	none	5%	2%
HENRY'S FORK	0%		-1%	none		-1%
HEWINTA SNOTEL	0%		-3%	none	steel	-3%
HICKERSON PARK SNTL	0%		-3%	none	steel	-3%
HOBBLE CREEK SUMMIT	0%		-1%	7%		7%
HOLE-IN-ROCK SNOTEL	0%		-1%	none	steel	-1%
HORSE RIDGE SNOTEL	0%		-6%	7%	steel	1%
HUNTINGTON-HORSESH	0%	snowmobiles	-12%	none		-12%
INDIAN CANYON SNOTEL	0%		-3%	none	3%	0%
JOHNSON VALLEY	0%		-10%	none		-10%
JONES CORRAL G.S.	0%		-10%	none		-10%
KILFOIL CREEK	15%		-8%	7%		15%
KILLYON CANYON	0%		-5%	7%		2%
KIMBERLY MINE SNOTEL	15%		-9%	none	steel	7%
KING'S CABIN SNOTEL	0%		-1%	none	3%	3%
KLONDIKE NARROWS	15%	snowmobiles	-8%	none		8%
KOLOB SNOTEL	15%		-11%	none	4%	9%
LAKEFORK #1 SNOTEL	0%		-1%	none	steel	-1%
LAKEFORK BASIN SNTL	0%		-1%	none	s/h	-1%
LAKEFORK MOUNTAIN #3	10%		-1%	none		10%
LAMBS CANYON	10%		-5%	7%		12%
LASAL MOUNTAIN LOWER	20%		0%	none		20%
LASAL MOUNTAIN SNTL	0%		0%	none	4%	4%
LILY LAKE SNOTEL	0%		-3%	none	steel	-3%
LITTLE BEAR LOWER	15%		-8%	none		8%
LITTLE BEAR SNOTEL	15%		-6%	none	4%	13%
LITTLE GRASSY SNOTEL	0%		0%	none	3%	3%
LONG FLAT SNOTEL	0%		-7%	none	steel	-7%
LONG VALLEY JCT. SNT	0%		-6%	none	3%	-3%
LOOKOUT PEAK SNOTEL	10%		-5%	7%	0%	13%
LOST CREEK RES	0%		-2%	7%		5%
MAMMOTH-COTTONWD	0%		-9%	none	steel	-9%
MERCHANT VALLEY SNT	10%		-8%	none	steel	2%
MIDDLE CANYON	0%	recreation	-8%	none		-8%
MIDWAY VALLEY SNT	0%		-6%	none	steel	-6%
MILL CREEK	0%		-5%	7%		2%
MILL-D NORTH SNOTEL	0%		-5%	7%	0%	3%
MILL-D SOUTH FORK	0%		-5%	7%		2%
MINING FORK SNOTEL	0%		-4%	none	steel	-4%
MONTE CRISTO SNOTEL	0%		-2%	7%	steel	6%
MOSBY MTN. SNOTEL	0%		-1%	none	steel	-1%
MT.BALDY R.S.	0%	snowmobiles	-12%	none		-12%
MUD CREEK #2	15%		-12%	none		4%

OAK CREEK	10%		-11%	none		-1%
PANGUITCH LAKE R.S.	0%	moved	-8%	none		-8%
PARLEY'S CANYON SNTL	0%		-5%	7%	s/h	3%
PAYSON R.S. SNOTEL	0%		0%	7%	3%	10%
PICKLE KEG SNOTEL	15%		-9%	none	steel	6%
PINE CREEK SNOTEL	0%		-6%	none	steel	-6%
RED PINE RIDGE SNTL	0%		-9%	none	4%	-5%
REDDEN MINE LOWER	30%		-3%	7%		34%
REES'S FLAT	15%		-8%	none		7%
ROCK CREEK SNOTEL	0%		-1%	none	steel	-1%
ROCKY BN-SETTLEMT SN	0%		-6%	none	0%	-6%
SEELEY CREEK SNOTEL	0%		-8%	none	4%	-4%
SMITH MOREHOUSE SNT	0%		-3%	7%	steel	4%
SNOWBIRD SNOTEL	0%	creep	-4%	7%	0%	3%
SPIRIT LAKE	0%		-2%	none		-2%
SQUAW SPRINGS	0%		-10%	none		-10%
STEEL CREEK PARK SNT	0%		-3%	none	steel	-3%
STILLWATER CAMP	0%		-4%	none		-4%
STRAWBERRY DIVIDE SN	15%		0%	none	steel	15%
SUSC RANCH	0%		-9%	none		-9%
TALL POLES	0%		-9%	none		-9%
THAYNES CANYON SNTL	0%		-5%	7%	steel	3%
THISTLE FLAT	0%		-12%	none		-12%
TIMBERLINE	-25%		-4%	none		-29%
TIMPANOGOS DIVIDE SN	0%		0%	7%	steel	7%
TONY GROVE LK SNT	15%		-6%	none	steel	9%
TONY GROVE R.S.	0%	recreation	-7%	none		-7%
TRIAL LAKE	0%		-4%	7%		4%
TRIAL LAKE SNOTEL	0%		-3%	7%	s/h	4%
TROUT CREEK SNOTEL	0%		-1%	none	steel	-1%
UPPER JOES VALLEY	0%		-12%	none		-12%
VERNON CREEK SNOTEL	0%		0%	none	steel	0%
VIPONT	0%		-6%	none		-6%
WEBSTER FLAT SNOTEL	15%		-10%	none	4%	9%
WHITE RIVER #1 SNT	0%		0%	none	steel	0%
WHITE RIVER #3	0%		-1%	none		-1%
WIDTSOE #3 SNOTEL	15%	creep	-6%	none	steel	10%
WRIGLEY CREEK	0%		-12%	none		-12%
YANKEE RESERVOIR	0%	stream, reservoir	-9%	none		-9%

We realize that the adjustments to the data in table 2 are arbitrary and indefensible with regard to each specific site based on personal evaluation. There are likely multiple interrelated micro and macro factors impacting snowpack characteristics at any given site and their absolute separation and quantification is likely impossible. The adjustments are within a range of context from literally hundreds of studies on the impacts of vegetation and other impacts on snow accumulation/ablation characteristics. Individual quantification of impacts at each course has not been accomplished and will likely not be given serious consideration given the impossible nature of the task, current resources and the fact that this is precisely why we use a 30 year average as the context for snow and other meteorological parameter quantification in relation to water supply forecasting. When researchers are using these data for other comparative functions, they must know of the range of other potential impacts affecting snow characteristics at various sites prior to concluding that this or that is the single cause for observed differences in these characteristics.

The next part of this analysis deals with the "so what" issue. There are 15 long term snow courses with data records extending back to the early 1930's that we use to compare current conditions with historic. We adjust the observed individual years of data with the calculated impacts based on vegetation, weather modification, pollution, etc and then test the adjusted data against the early period to see if there are statistically significant differences that we can attribute to the lone remaining un-quantified impact in the snowpack data, global warming.

Table 3. Comparison of the 1990-2005 average to historical periods using observed, non-adjusted data.

Station	Period	T-Stat	T-Critical	Mean Change	Significant
Burts Miller Ranch	37-50	1.82	1.71	-1.5	yes
Buckboard Flat	56-70	0.3	1.7	-0.6	no
Fish Lake	59-70	-0.74	1.71	0.9	no
GBRC Meadows	61-72	0.6	1.71	-1.1	no
Gooseberry RS	30-40	-0.77	1.71	0.7	no
Hobble Creek	59-72	0.63	1.7	-1.1	no
Garden City Summit	39-48	0.77	1.71	-1.5	no
Huntington Horseshoe	54-77	0.65	1.69	-1.2	no
Mill D South	35-50	2.09	1.7	-3.5	yes
Lasal Mountain Lower	31-47	-0.04	1.7	0	no
Parleys Summit	54-77	0.28	1.69	-0.4	no
Redden Mine	60-81	1.21	1.69	-1.8	no
Trial Lake	58-77	0.64	1.69	-1.4	no
Panguitch Lake	57-81	-0.28	1.69	0.4	no
Bryce Canyon	53-72	-0.82	1.69	1.1	no

In table 3, the data used are the actual observed snow data with no adjustments made. In the Mean Change column, the reference is from the 1990-2005 to the early period, thus all but 4 sites declined in overall SWE. We find that only 2 sites show a statistically significant difference with both the Burts Miller Ranch site and the Mill D South site receiving less snow than at any time in the historical record. Both of these sites have physical conditions that could lead to decreased snow accumulations. Burts Miller Ranch has the sub-irrigation problem and Mill D South could be impacted by pollution.

Table 4. Comparison of the 1990-2005 average to historical periods using adjusted data.

Station	Period	T-Stat	T-Critical	Mean Change	Significant
Burts Miller Ranch	37-50	1.00	1.70	-0.74	no
Buckboard Flat	56-70	-1.07	1.70	2.47	no
Fish Lake	59-70	0.71	1.69	-0.93	no
GBRC Meadows	61-72	2.61	1.70	-4.52	yes
Gooseberry RS	30-40	0.87	1.71	-0.74	no
Hobble Creek	59-72	0.67	1.70	-1.13	no
Garden City Summit	34-47	0.49	1.70	-1.09	no
Huntington Horseshoe	54-77	2.59	1.68	-4.52	yes
Mill D South	35-50	1.38	1.70	-2.41	no
Lasal Mountain Lower	31-47	-1.07	1.70	1.47	no
Parleys Summit	54-70	-1.31	1.70	2.20	no
Redden Mine	60-78	-1.75	1.68	2.91	yes
Trial Lake	58-77	-0.68	1.68	1.47	no
Panguitch Lake	55-62	-0.26	1.70	0.32	no
Bryce Canyon	53-72	-0.52	1.69	0.67	no

In table 4, these data have been adjusted for changes in vegetation, weather modification, pollution, and physical site changes. Burts Miller Ranch and Mill D South are no longer statistically different, but 3 new sites have become significant, GBRC Meadows, Huntington Horseshoe (lower snowpacks) and Redden Mine (higher accumulation). Eight of the 15 sites have 1990-2005 averages that are lower than historical periods and seven have historical averages that are greater than the 1990-2005 average, close to a 50/50 split. When analyzing the potential impact of Global Warming on snowpacks, theoretically the impacts would show up first at the lower latitudes and the lower elevations first, progressing toward the higher latitudes and higher elevations. Thus southern Utah snow courses and lower elevation sites should have greater impacts early on than higher elevation and more northern latitudes. Thus in this analysis the southern most and lowest elevation sites, Panguitch Lake (2500 meters), Buckboard Flat (2744 meters), Gooseberry (2561 meters), Fish Lake (2652 meters) and Bryce Canyon (2440 meters) should be impacted first and this is not the case, either in the adjusted or in the non-adjusted data. The sites that show up as having been negatively impacted (GBRC Meadows 3049 meters and Huntington Horseshoe 2988 meters) are further north and at substantially higher elevations than the sites that theoretically should be impacted first. The only data adjustments at these two sites were for weather modification as there were no physical or vegetative changes at either site. This is a general indication that things do not add up. It is likely that the weather modification impacts have been over estimated for these two sites. The coarse nature of these data adjustment on all categories (vegetation, physical and weather modification) certainly contributes to the results but we did not want to bias the outcome by over analysis or trying to adjust past what one could reasonably apply or justify. When you look at sites that have increased snowpack in the 1990-2005 period, all but one, Bryce Canyon have substantial vegetation, pollution or physical impacts indicating that the these impacts might have been overestimated as well. The difference between a 15% and a 30% impact could be the difference between statistical significance or non - significance. This also illustrates the difficulty of trying to isolate the impacts of Global Warming in these data and given there is no clear pattern that conforms to the expected theoretical impacts we conclude that the impacts present in the current snowpack data (1990-2005), are not yet detectable or statistically prove-able using the methods employed here.

Table 5. Recommended sites for long term snowpack comparison

Station	Elevation - Meters	Latitude	Longitude
Fish Lake	2652	38.50	111.77
GBRC Meadows	3049	39.30	111.45
Gooseberry RS	2561	38.78	111.45
Hobble Creek	2262	40.18	111.38
Huntington Horseshoe	2988	39.61	111.30
Trial Lake	3037	40.68	110.95
Panguitch Lake	2500	37.70	112.65
Bryce Canyon	2440	37.63	112.17

Table 5 gives our recommendations for the most stable snowpack sites in Utah for long term study. These sites have the smallest signature from vegetation, physical, and pollution impacts. Almost all sites in Utah now and in the future will continue to be impacted by weather modification. These sites are not without reservations as well - Panguitch Lake has been physically moved from the original location to a site some distance away. During the time that there were concurrent measurements, the two courses were essentially equal but there is not sufficient time or conditions to replicate high, low and average snowpack conditions represented in that sample. Trial Lake could also be impacted by pollution. The other seven long term snow courses of the 15 analyzed here have been significantly impacted by vegetation change and other factors.

CONCLUSIONS

Fifteen long-term snow courses in Utah representing complete elevational and geographic coverage of the dominant snowpacks within the state were analyzed and adjusted for the major known site conditions impacting the data. These impacts were: physical, vegetative, pollution and weather modification. The adjusted data (1990-2005) were then compared to earlier portions of the historic record to determine if there were statistically significant differences in snow pack characteristics, particularly those that could indicate the impacts of Global

Warming. The period of 1990-2005 had 2 significant droughts, the latter of which lasted 6 years and could have been one of the most severe in the past 100 years and possibly the recent 400 plus years (USGS, 2004, Woodhouse, 2003). The comparison of these extremely low snowpack years to the previous historical record would be the most likely to have statistical significance. Two sites showed up as getting less snow than historically (Burts Miller Ranch and Mill D South) when using only the observed unadjusted data. Both of these sites have known data impacts that could account for the reduction. Using the adjusted data, these sites were no longer significant but three new sites became statistically significant. Two sites along the Wasatch Plateau in central Utah (Huntington Horseshoe and GBRC Meadows) are now getting less snowpack than at any time in the historical record and one site, east of the Wasatch Front near Salt Lake City (Redden Mine) is getting more snow. The two Wasatch Plateau sites are at relatively high elevation and have only one factor adjusted out of the historical record, weather modification. Both have a very long and continuous record of this modification, from 1973 to 1983 and from 1988 to the present. Thus 15% was factored out of the historical record from 1990-2005 for comparison to earlier records. In the case of Redden Mine, there was far less weather modification in the record, 1990-1996 and far more in the way of vegetative and pollution impacts. This site has had major vegetative changes and the data were accordingly adjusted by 30% as well as for pollution impacts of 15%. These adjustments were likely far greater than what has actually occurred. When looking at the general trend using the adjusted data, there are 7 sites with increased snowpack and 8 with decreased accumulations. Six of the seven sites with increases have significant vegetative or physical conditions leading us to believe that the impacts associated with this analysis are overstated, especially when considering that the comparative period should have less snowpack due to the duration and severe nature of the drought. The one increased site (Bryce Canyon) with only weather modification impacts removed was still higher than the previous low period. This is likely due to the extremely variable nature of this site and the near record snowpack of 2005. When looking at those sites that are accumulating less snow in the adjusted data and those that would theoretically show the impacts of global warming first (Fish Lake, Panguitch Lake, Buckboard Flat, Gooseberry and Bryce Canyon) none are statistically different either in the adjusted data or the non-adjusted data version. This leads us to conclude that any signature of Global Warming currently present in the snowpack data of Utah is not yet at a level of statistical significance using the methods employed here and will likely be very difficult to isolate from other causes of snowpack decline compared to the historic data.

REFERENCES

Cooley, K.R., 1989. "Assessing the Effects of Climatic Changes on Snowpack and Streamflow", Proceedings 57th Western Snow Conference, April 18-20, 1989, Fort Collins, CO, pp. 118-121.

Givati, A. and D. Rosenfeld, 2004. "Quantifying Precipitation Supression Due to Air Pollution", Journal of Applied Meteorology, 43, 1038-1056.

Gleick, Peter H. ; Adams, P. Briane. "Water: the Potential Consequences of Climate Variability and Change for the Water Resources of the United States", The report of the water sector assessment team of the national assessment of the potential consequences of climate variability and change. Pg 8, 38. For the U.S. Global Change Research Program. Septempter 2000.

Griffith, Don A., Mark E. Solak, and David P. Yorty. "Is air pollution impacting winter orographic precipitation in Utah?", North American Weather Consultants, Inc. Published Report, 2005. Sandy Utah, USA.

Hawkins, Richard H. "Runoff curve numbers from partial area watersheds". American Society of Civil Engineers, Journal of the Irrigation and Drainage Division. 105(IR4): 375-389, 1979

Julander, Randall P., G. Ray Wilson, and Robert Nault. "The Franklin Basin Problem". Proceedings of the Western Snow Conference, 1998. 153-156.

Julander, Randall P. "An analysis of the timing of snow course measurement and the potential error compared to April 1 measurement in Utah". Proceedings of the Western Snow Conference, 2005. 131-137.

Moore, C.A. and W.W. McCaughey, 1997, "Snow Accumulation Under Various Forest Stand Densities at Tenderfoot Creek Experimental Forest, Montana, USA", Proceedings 65th Western/54th Eastern Snow Conference, May 4-8, Banff, Alberta, Canada, pp. 42-51.

Pankey, Jan M.; Hawkins, Richard H. "Stormflow as a function of watershed impervious areas". In: Hydrology and water resources in Arizona and the Southwest: Proceedings of the 1981 meetings of the Arizona Section, American Water Resources Association, and the Hydrology Section, Arizona-Nevada Academy of Science; 1981 May 1-2; Tucson, AZ.

Powell, D.R., 1987. "Observation of Consistency and Reliability of Field Data in Snow Survey Measurements", Proceedings 55th Western Snow Conference, April 14-16, 1987, Vancouver, British Columbia, pp. 69-77.

Saunders, Stephen, Maxwell, Maureen. "Less Snow, Less Water: Climate Disruption in the West" Rocky Mountain Climate Organization, September, 2005.

Solak, Mark E., David P. Yorty and Don A. Griffith. "Estimations of downwind cloud seeding effects in Utah". North American Weather Consultants, Inc. Published Report, 2005, Sandy Utah, USA

Soil Conservation Service, US Department of Agriculture. "Summary of Snow Survey Measurements for Utah". 1979

Toews, D. A. A. and D.R. Gluns, 1986. "Snow Accumulation and Ablation on Adjacent Forested and Clearcut Sites in Southeastern British Columbia", Proceedings 54th Western Snow Conference, April 15-17, 1986, Phoenix, AZ, pp. 101-111.

USGS, 6/2004. "Climatic Fluctuations, Drought, and Flow in the Colorado River". USGS Fact Sheet 3062-04.

Woodhouse, Connie A. "A 431-year Reconstruction of Western Colorado Snowpack from Tree Rings". Journal of Climate, May, 2003. Volume 16. 1551-1561.