A HISTORICAL COMPARISON OF SNOWPACK AVERAGES IN UTAH

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ABSTRACT

Snowpack data collection began in an organized fashion in Utah during the late 1920's and the first 30-year average was calculated in the late 1950's. Individual sites are used to calculate moving 30-year averages each year in this continuous record up to current data. Snowpacks are analyzed over this time period by site, region and elevation to determine any significant changes. Snowpacks in southern areas are compared to those in northern Utah as well as low elevation sites to the higher elevations to ascertain potential trends or differences. SNOTEL is a telemetering system providing daily snow water equivalent, precipitation and temperature data. Installed in the late 1970's and early 1980's, it provides accurate data on site specific melt out dates. SNOTEL provides far greater data than the manual snow course system does, but has a much shorter period of record, limiting it's statistical relevance. Given the statistical limitations of a 25 year period of record, snowpack melt-out dates are examined statewide to determine if there are definable trends.

INTRODUCTION

The Natural Resources Conservation Service, United States Department of Agriculture is charged with the task of measuring high elevation hydroclimatic data in the western United States. Snowpack snow water equivalent is the data parameter of primary interest with precipitation, temperature and other parameters also being measured. Snowpacks in Utah have been measured to some extent since the mid-1920's and has 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 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. 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). As the global climate changes, climate changes in regional areas, such as the State of Utah, may or may not be impacted to the same degree. In Utah, the vast majority of streamflow is generated from the melting of snowpacks, (Hawkins, 1979, Hawkins and Pankey, 1981). In fact, even the majority of baseflow throughout the summer and fall seasons is snowpack derived. Any change of climate that could impact the amount or duration of snowpack could have a significant impact on the economy and other facets of life within the state. Since temperature can impact the accumulation and ablation of snowpacks, any change in this parameter has the potential to affect the total amount of snow available for melt within the state of Utah. Even if the overall average amount of snowpack remained stable, variability extremes could pose equally difficult management problems for water supplies. Currently, the state is in the fourth year of below normal snowpack accumulation and runoff. Estimates of the impact in the current 2002 water year are up to 80 million dollars in agricultural damages and the loss of 3900 jobs. Record low April 1 snowpacks were recorded on the Sevier and Virgin River Basins with other areas of southern and eastern Utah in the bottom 2 or 3 years of record.

Thirty years is the standard time frame for calculating an average condition for snowpack snow water equivalent. 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, etc for water supply and other analyses.

Latitude and elevation play an important role in snowpack accumulation and ablation. Southern latitudes generally melt out faster than do northern latitudes of equal elevation, aspect and vegetative cover. Similarly, lower

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elevations melt out faster, and do not accumulate as much snow as do higher elevations of similar characteristics. Regional and elevational differences in average snow water equivalents are examined to determine if there are changes based on these characteristics.

Snotel is an automated hydroclimatic data collection system run by the Natural Resources Conservation Service, USDA. Daily and at times, hourly data on snow water equivalent, precipitation, temperature and other parameters are available. One side parameter that is available from this system that is not available from snow course data collection is the Julian date of snowpack melt-out at individual sites. This parameter, would be sensitive to any kind of climate change that impacts the accumulation or ablation of snowpack, especially temperature related changes. There are other factors that could influence melt-out dates, namely changes in total snow or solar radiation. Significantly greater snowpacks take longer to melt and shallow snowpacks require less time for the same amount of energy. A major factor in a significant change in the amount of solar radiation impacting the snowpack would be cloud cover. Increased cloud cover would be typically inferentially linked to greater precipitation and, thus to a larger snowpack already mentioned. The SNOTEL system has a very short period of record (circa 20 years) for analyses and thus the first 10-year period is compared to the last 10-year period for all sites in Utah. This short period of record compromises the statistical validity of the comparisons to a certain extent.

METHODS

The sites selected for Snow Water Equivalent analysis, were determined based on the station period of record, the record continuity and whether the station is still currently measured. An alteration in the way a parameter is measured can dramatically impact record continuity and we wanted to analyze the best possible data available without having to do any data alteration or adjustment to compensate for technique or measurement changes. Given these criteria, 14 snow course stations were selected, all of which were initiated in the late 1920's or early 1930's. These sites were systematically measured on or near April 1 for each year. Later on in the record period, systematic measures are available for May 1 data as well. The May 1 data record is not nearly as extensive as the April 1 data record is, but nonetheless provides an excellent opportunity to analyze the temporal extent of snowpacks within the state. All of these early sites were systematically laid out to geographically cover the entire state and they reflect an excellent elevation distribution as well. The primary purpose of these sites was to provide water supply forecasts based on site-specific snow water equivalent. Table 1 gives the elevation and location of the snow courses used in this study, geographically from north to south.

Table 1: Snow Courses used in the study

Station	Elevation	Latitude	Longitude
Garden City Summit	7600	41.92	111.47
Burts Miller Ranch	7900	41.00	110.87
Parleys Summit	7500	40.77	111.62
Trial Lake	9960	40.68	110.95
Redden Mine	8500	40.68	111.22
Mill D South Fork	7400	40.65	111.65
Hobble Creek	7420	40.18	111.38
GBRC Meadows	10000	39.30	111.45
Hunitington Horseshoe	9800	39.61	111.30
Gooseberry	8400	38.78	111.68
Fish Lake	8700	38.50	111.77
Lasal Mountian	9850	38.48	109.27
Buckboard Flat	9000	37.87	109.45
Panguitch Lake	8200	37.70	112.65

The first 30-year averages (about 1930-1959) from these stations were compared to the current 1971-2000 average using a standard T-Test to determine if there was a statistical difference between the two time periods. The same data set and time period was used to compare the sites to determine if there is a difference in variability. A standard F-Test was use to determine statistical significance. To determine if there is a geographic or an elevation component, sites were arranged in a north to south pattern as well as by elevation.

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All SNOTEL sites in Utah were compared to determine if there was a difference in melt-out dates. There are approximately 85 SNOTEL sites in Utah and giving a complete listing in this paper is impractical. These data as well as various site characteristics are available from the Natural Resources Conservation Service. Most SNOTEL sites are located at and correlated with snow courses that were eventually discontinued. These data would comprise another source of excellent high elevation climatic data for analyses as far as snow water equivalent and precipitation is concerned. The snow water equivalent data from SNOTEL were specifically excluded in favor of long term consistency of data measurement techniques, (snow courses) which should lead to a more rigorous data set. The first 10-year average melt-out data from SNOTEL were compared to the 1991-2000 average melt-out data for differences using a standard T-Test.

Results

Chart 1 shows the overall results of the T-Test analysis. None of the sites show a statistically significant difference between the first April 1 30-Year average and the current 1971-2000 average at the alpha 0.05 level. Some sites are getting close to statistical significance.

Chart 1

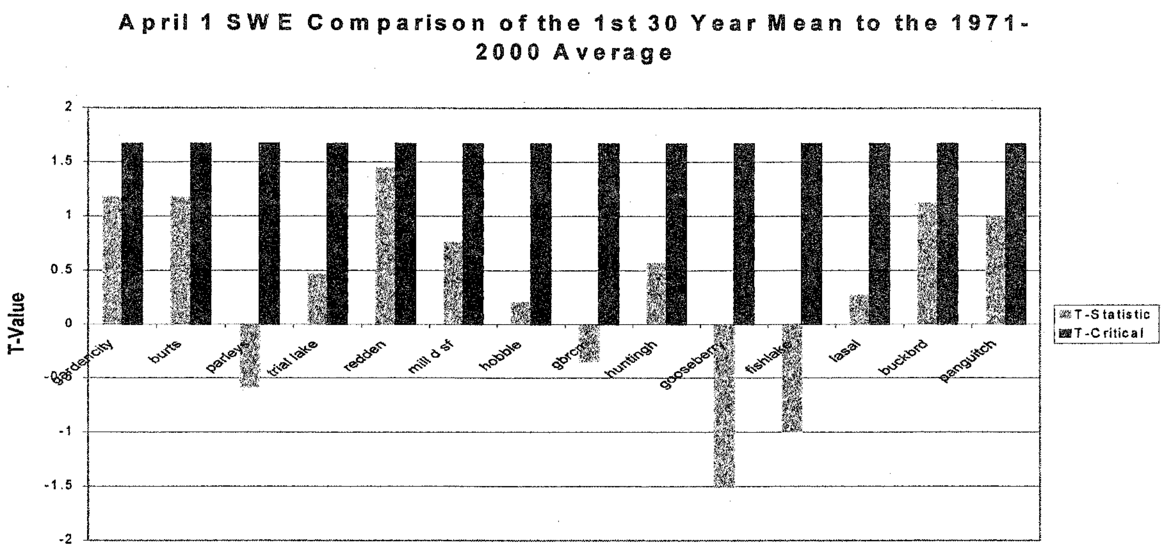


Chart 2 show the same information for the May 1 snow water equivalent data. Again, none of the sites show a statistically significant difference.

Chart 2

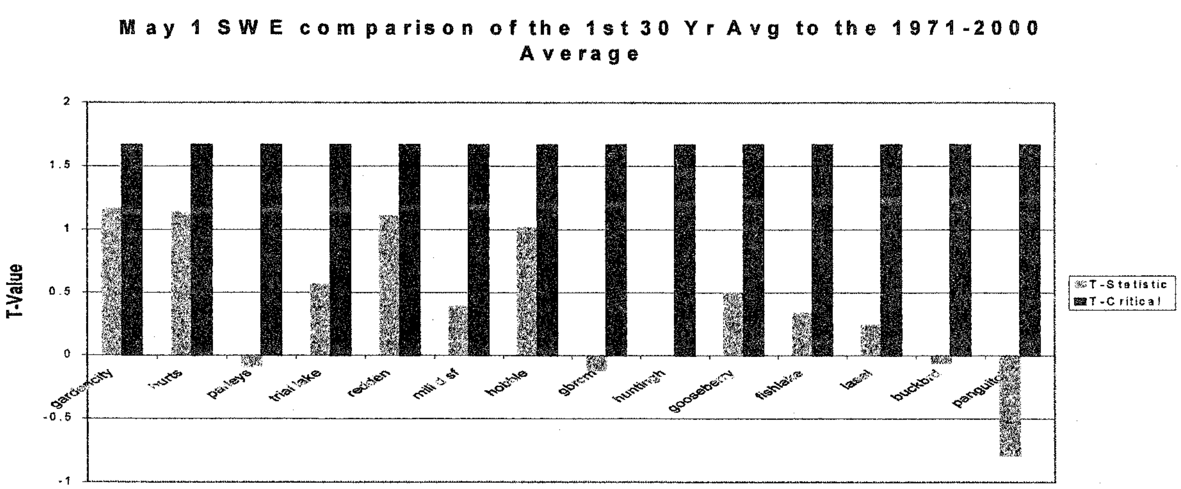


Chart 3 shows the averages from the 1st 30 year period, generally 1930-1959 to the current 1971-2000, April 1 snow water equivalent averages for the 14 selected sites arranged geographically from north to south.

Chart 3

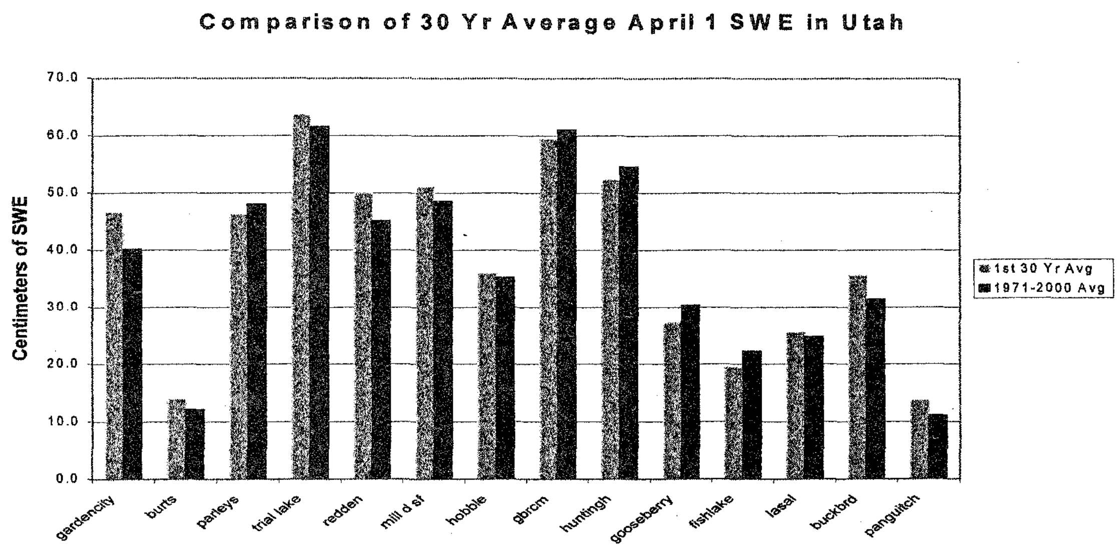
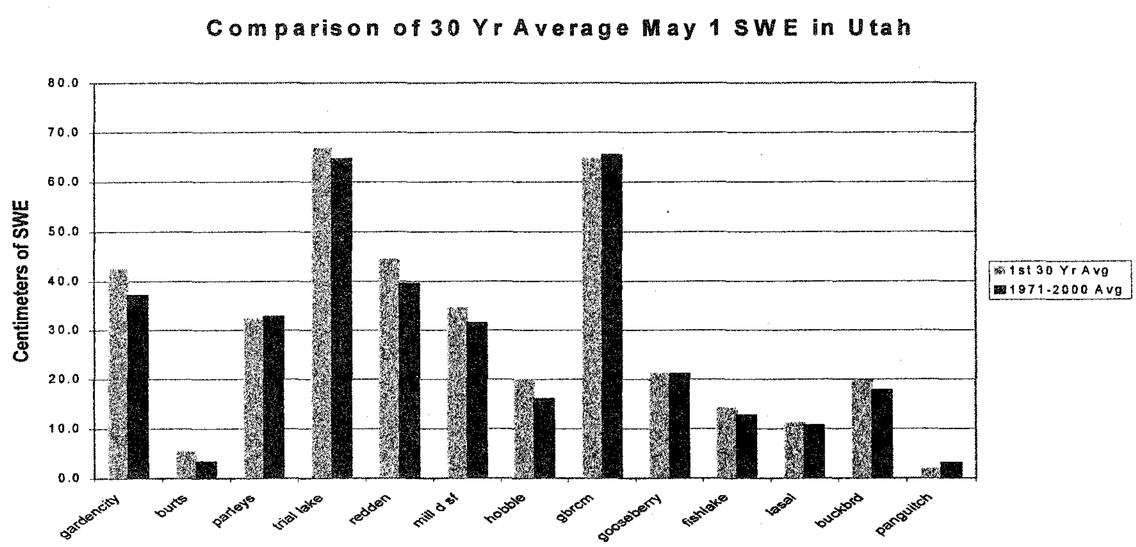


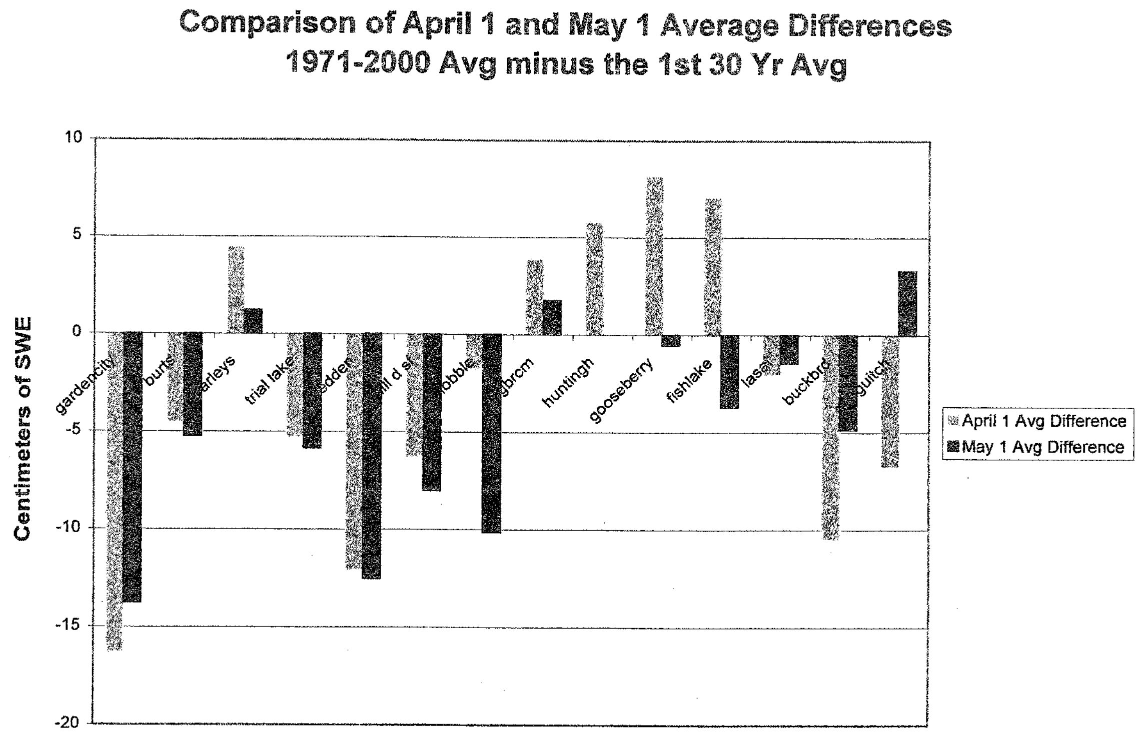
Chart 4 shows the averages from the 1st thirty year period compared to the current 1971-2000 May 1 snow water equivalent averages, again arranged geographically from north to south.

Chart 4



Looking at these two graphs produces no startling results, as expected from the statistical analysis. Both the April 1 and the May 1 comparisons are very similar. The current averages are very similar to the historical averages at most sites. Chart 5 shows the April 1 and the May 1 differences between the current 1971-2000 average and the first 30-year average. This was done by subtracting the original average from the current 1971-2000 average. Thus bars that are below the axis line have decreased amounts of snowpack compared to the original average and those above the axis are now receiving more snow within the bounds of normal variability, than originally.

Chart 5



An interesting pattern emerges from these geographically arranged sites. Only one station in northern Utah has more snow while 6 have less. In central Utah, there are some mixed signals. All sites in central Utah have more snow on April 1, but 2 have less in May. In southern Utah, most stations have less snow on April and May 1, but one, Panguitch Lake, has more snow on May 1. Again, all stations having more/less snow are within the bounds of normal variability and show no statistically significant difference in accumulation or ablation. It appears that overall, the north seems to be getting less snow, the central section more snow and the extreme south, again, a little less snow than originally. All snowpack change is within the normal range of individual site variability.

An F-Test was conducted on the data from the first 30 years versus the current 1971-2000 years to determine if variability is increasing within individual sites. The results of those tests were exactly the same as the results of the T-Tests: no significant difference in variability from the current data to those measured early on. This despite the fact, that both the record high and low snowpacks in all areas of the state have been recorded within the last 30 year period.

Given the fact that some sites seem to be approaching statistical significance between means, we decided to investigate those sites further to determine if there were other potential causes or influences that might be affecting the site. Garden City Summit and Redden Mine in northern Utah were potential sites. Comparing photos from the mid 30's to current conditions revealed that the site at Garden City Summit has had dramatic changes in the coniferous vegetation supplanting the aspens that originally dominated the site. These conifers have grown large enough that melt rings under the trees have been affecting the sample sites. The conifers themselves, through interception processes have been gradually decreasing the amount of snowpack at this site, as has been documented through numerous studies (Toew, D.A.A. and D. R. Gluns, 1986, Moore, C.A. and W. W. McCaughey, 1997). This coupled with the impacts of long wave radiation from the tree bowl have combined to decrease the snowpack at this site. How much of the total decrease is due to normal climatic variation and what is due to the impacts of physical site change is non-determinable. Photo number 1 is looking southwest at the Garden City Summit Snow Course in 1936 and Photo number 2 is the same Snow Course in 2000. Notice how the conifers have filled in and basically forced most of the aspen complex out. Melt rings surrounding the conifers had been impacting sample points at this course.

Another site that is approaching significance is at Redden Mine. At this site, snowpacks appear to be decreasing as well, similar to Garden City Summit. Again, comparing photos from the mid 30's to current conditions, reveals significant vegetative changes. In this case, however, the vegetation is completely aspens. In the earlier pictures, there is an open meadow where several of the sample points are located. We have analyzed each of the individual sample points for this snow course and determined that there are 2 points, samples 3 and 4 that are statistically different than the original 30-year average for those points. These sample points, numbers 3 and 4, are where the small meadow originally was and is now enclosed by aspens. We have found no research that indicates aspen type vegetation has significant impacts on snow accumulation, positive or negative. Given that the 2 samples most

Photo 1

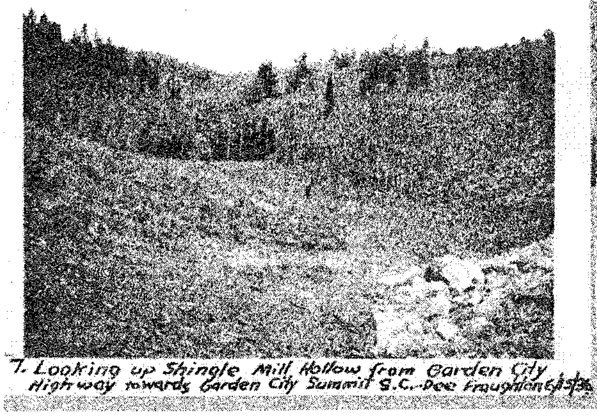


Photo 2

Photo 3

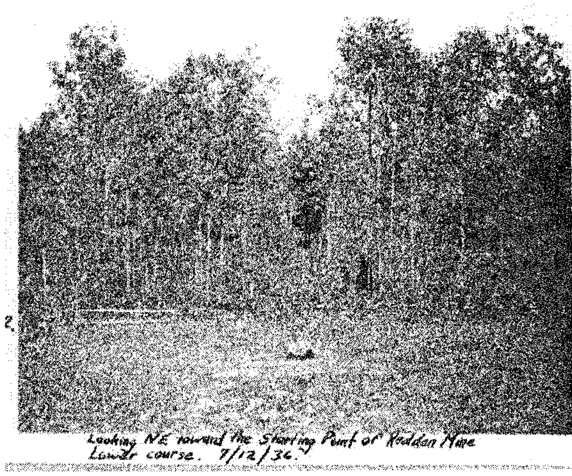


Photo 4

impacted by the encroachment of the aspens are significantly different and the other sample points, 1, 2 and 5 are not significantly different may suggest that aspens may have some affect. It appears, at least in this case, that some portion of the decrease in snowpack accumulation at Redden Mine may be attributable to site physical changes. The above 2 photos show the 1936 Redden Mine and the 2000 Redden Mine. The clearing in the original photo has filled in significantly with aspen trees. Notice the conifer at dead center in both photos for a reference point.

The snow course at Fish Lake also showed some interesting trends. The April 1 SWE has been increasing since 1984 and the May 1 SWE has been decreasing slightly. After a review of the records, we found that during this time frame, there was a personnel change at this site. The NRCS Data Collection Office began the measurement of all snow courses in Utah during this time via helicopter instead of having contractors or local Field Office Personnel conduct the measurements. The snow course at Fish Lake is in an open area where the dominant vegetation is sage brush. It is extremely cold, wind swept and prone to temperature gradient snowpacks. Generally a 5 to 10 centimeter dense crust overlays an extremely weak layer of temperature gradient/faceted snow and makes the sampling on this course extremely difficult. The crust tends to plug the snow sampler, forcing the weak, granular faceted snow out and around the sample tube leading to under-sampling of the snowpack. Powell (1987) found many similar personnel and physical problems in the continuity of snow sampling. More experienced personnel sampling the snow course seem to be getting more complete and accurate samples leading to a perceived increase in the long term mean. As to the slight decrease in the May 1 average, it is also consistent with the change in personnel. The May 1 sample is generally not affected by the temperature gradient snowpack because by this time, the snowpack has gone isothermal, sintering is advanced and the faceted snowpack is now one single layer of pretty much homogenous density. This type of snowpack is reasonably easy to measure and there is far less chance of an under-sample as is the case on the April 1 survey. Thus the May 1 record is most likely more consistent throughout the period of record. Chart number 6 shows the trend of 30 year averages for the Fish Lake snow course.

Chart 6

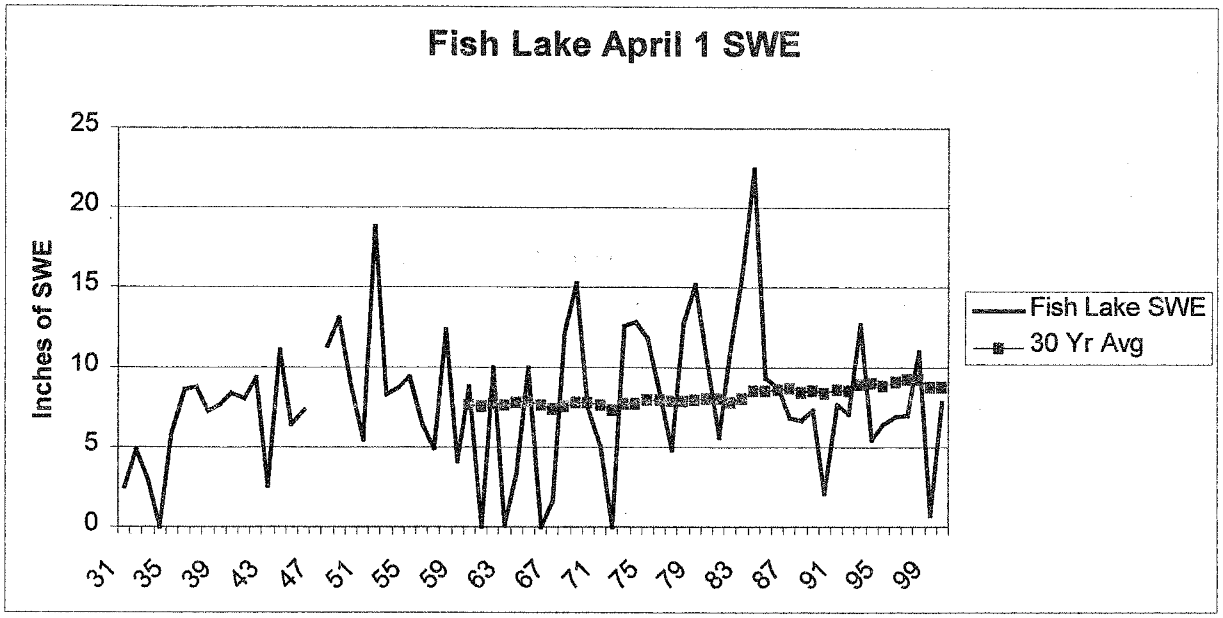
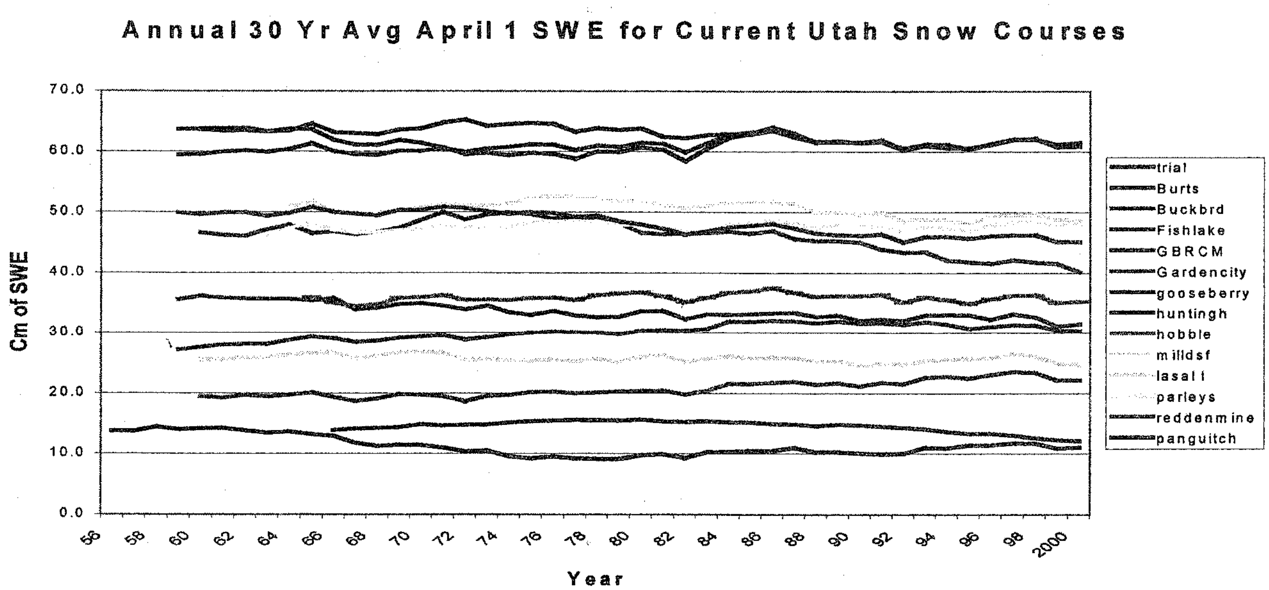


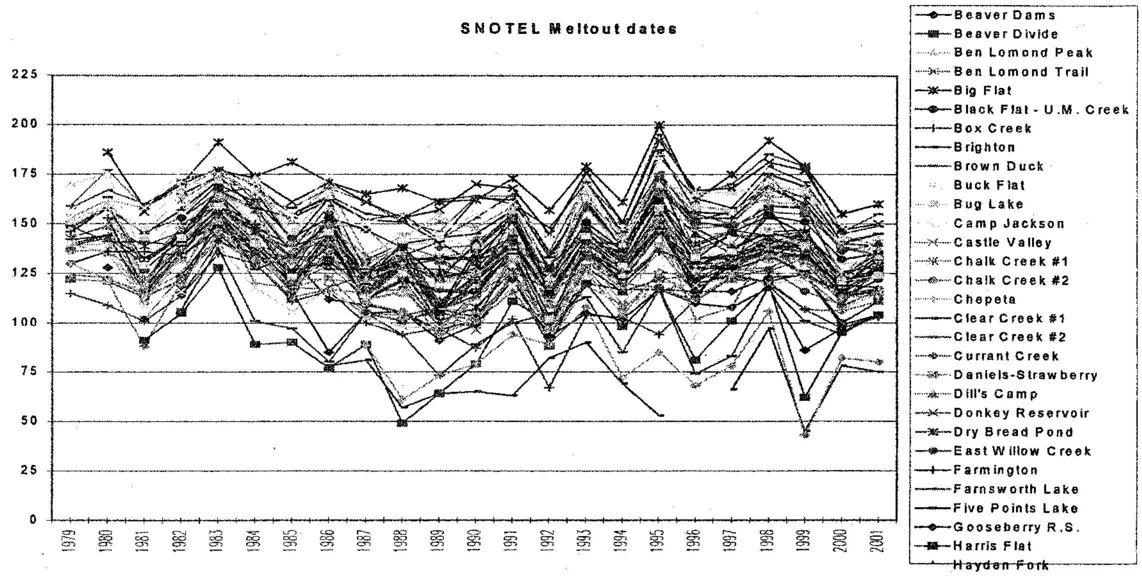
Chart 7 shows the 30-year average curves for all sites tested as a general reference.

Chart 7



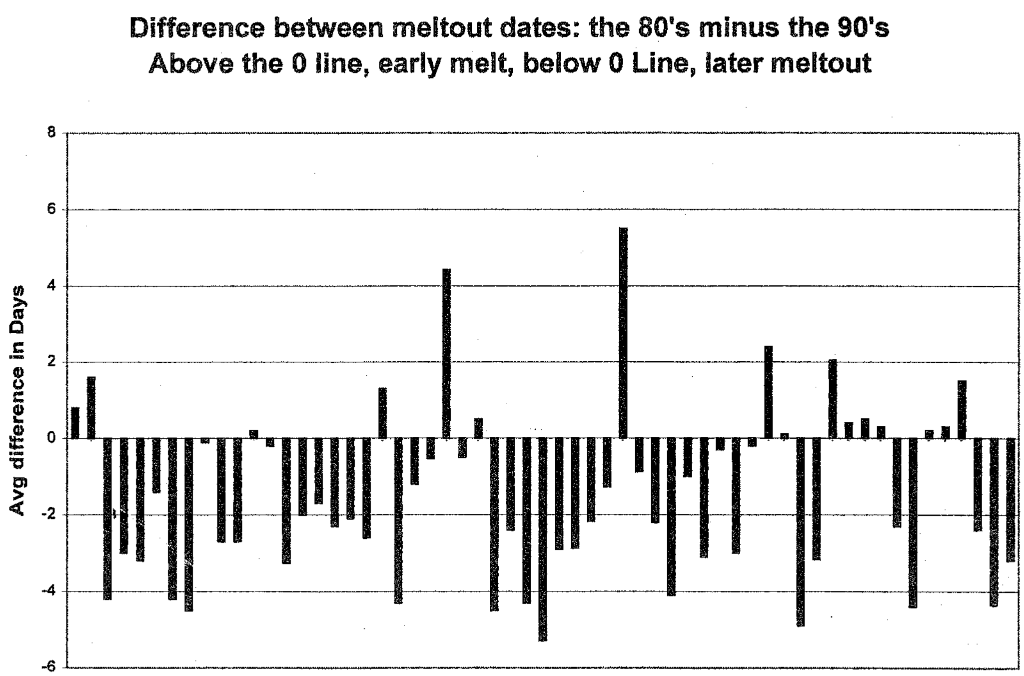
The comparison of SNOTEL site Julian melt-out dates simply reveals normal climatic variability with no statistically significant deviations. The late 80's and early 90's were very low snowpack years and hence, had a tendency for early melt-out dates. Chart 8 shows a combination of all SNOTEL site melt-out dates and the general climatic pattern as well as the yearly variability.

Chart 8



Overall, from 1987 through 1992, there were relatively low snowpacks across the state and consequently, a large dip in melt-out dates. From 93 through the late 90's brought some larger snowpacks and the melt-out dates commensurately increased. We examined those stations that had the greatest difference between the 1980's and the 1990's mean melt-out dates and tested for statistical significance. No station tested show statistical significance. Chart number 8 shows the results of the melt out dates for some 60 stations.

Chart 8



CONCLUSIONS

Fourteen long-term snow courses in Utah representing complete elevational and geographic coverage of the dominant snowpacks within state were analyzed for differences in means as well as variability. No statistical differences were found suggesting that, as a climatic indicator, snowpacks across the state are neither decreasing nor increasing. This means that some of the predicted affects of global climate change such as lower snow water equivalent, early melt and greater variability have not yet occurred from a statistical standpoint relative to snowpack in Utah. Some sites that were approaching statistical significance were examined further and differences, both increasing and decreasing were partially explained by physical site changes. This should serve as a cautionary note to climate researchers that when dealing with data sets involving snowpack as an indicator, minor site changes can cause data impacts. These data changes could be easily misinterpreted as climate change, when in fact, it is not. Julian melt-out dates for a shorter period were also analyzed and again, no statistical differences were found. Snowpacks were not melting earlier or later in the season indicating only normal climatic variability. In this case, the shorter period of record compromises meaningful results, but as the period of record increases, this could be an indicator of potential changes in climate.

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