THE DOCUMENTATION OF EXTREME EVENTS: TWO CASE STUDIES IN UTAH, WATER YEAR 2005

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ABSTRACT

The Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service, has monitored mountain snowpack and precipitation in the Western United States since 1934. The automation of measurement sites began in the late 1970s and now over 700 SNOw TELemetry (SNOTEL) sites are installed, most reporting hourly. The established length of record and hourly records now make it possible to evaluate and document extreme hydrometeorlogical events. Two recent events in Utah brought attention to the current lack of protocol for documenting extreme events. During October 20 - 22, 2004 the twenty four hour precipitation intensities for six Utah sites exceeded the National Weather Service estimated 100-year average return interval, and eleven of seventy seven Utah sites with 15 years or longer record, measured the maximum twenty four hour precipitation intensity of record. A second event Jan 8th to 12th hit SW Utah with high intensity rains and snow leading to the flooding of the Santa Clara River and the destruction of over twenty homes. The Utah NRCS Snow Survey office is working towards a Snow Survey system wide protocol for the documentation of extreme events recorded by SNOTEL stations that will provide validation and documentation of extreme events, easily accessed by current and future data users.

INTRODUCTION

In response to the Dust Bowl of the 1930s, the Soil Conservation Service (SCS) was mandated to measure mountain snowpack in the Western U.S and to forecast the water supply for this region. The SCS has since been renamed the Natural Resources Conservation Service, and since the late 1970s has automated nearly 700 of its manual snow courses with automated hydrometeorlogical stations called SNOTEL for SNOw TELemetry. These stations consist of snow pillow to measure the snow water equivalent of the snowpack, and a precipitation gage, as well as air temperature, and in many cases snow depth, and soil moisture. Most SNOTEL sites and all sites maintained by the Utah Data Collection Office (DCO) are now measured hourly. The Utah DCO includes Utah, Nevada, and portions of eastern draining California. The SNOTEL network represents the largest network of near real-time hydrometeorlogical stations in the mountains regions of the Western U.S. As such, data from the SNOTEL system are used for a large variety of operational, research, and recreational applications. These data users need to have confidence that an event that seems questionable has been validated, and is not simply a "glitch" in the data set. These "outlier" events should hopefully be found by DCO staff during normal data quality assurance work, and investigated as soon as possible after the event. Two such events were apparent during the first third of the 2005 water year in Utah, and are the motivation for this paper. They are the events of October 17 to October 22, 2004, and January 8 to January 11, 2005. The October event will be presented first, followed by the January event.

OCTOBER 2004

A very significant storm system impacted most of the state of Utah starting between late October 17 and early Oct 18, 2004 and tapering off between Oct 21st and 23rd. Storm totals for October 17th through 22nd ranged between 31.5cm and 2cm with an average of 88 sites being 12.7cm (Figure 1). This storm was followed by another significant, but lower intensity storm with little or no gap at many sites before the beginning of November. Of the 77 SNOTEL sites with a period of record of 15 years or greater, 51 had the cumulative October precipitation of record, and two tied the record. A breakdown of record October precipitation by basin is represented in (Table 1.) The period of maximum precipitation intensity was on the 20th or early 21st at most sites, with the notable exceptions of the north slope of the Uintas, The Wasatch Plateau and South Eastern sites which were approximately one day later. Twenty-four hour precipitation intensity frequency analysis revealed 12 of 86 sites (two missing) in

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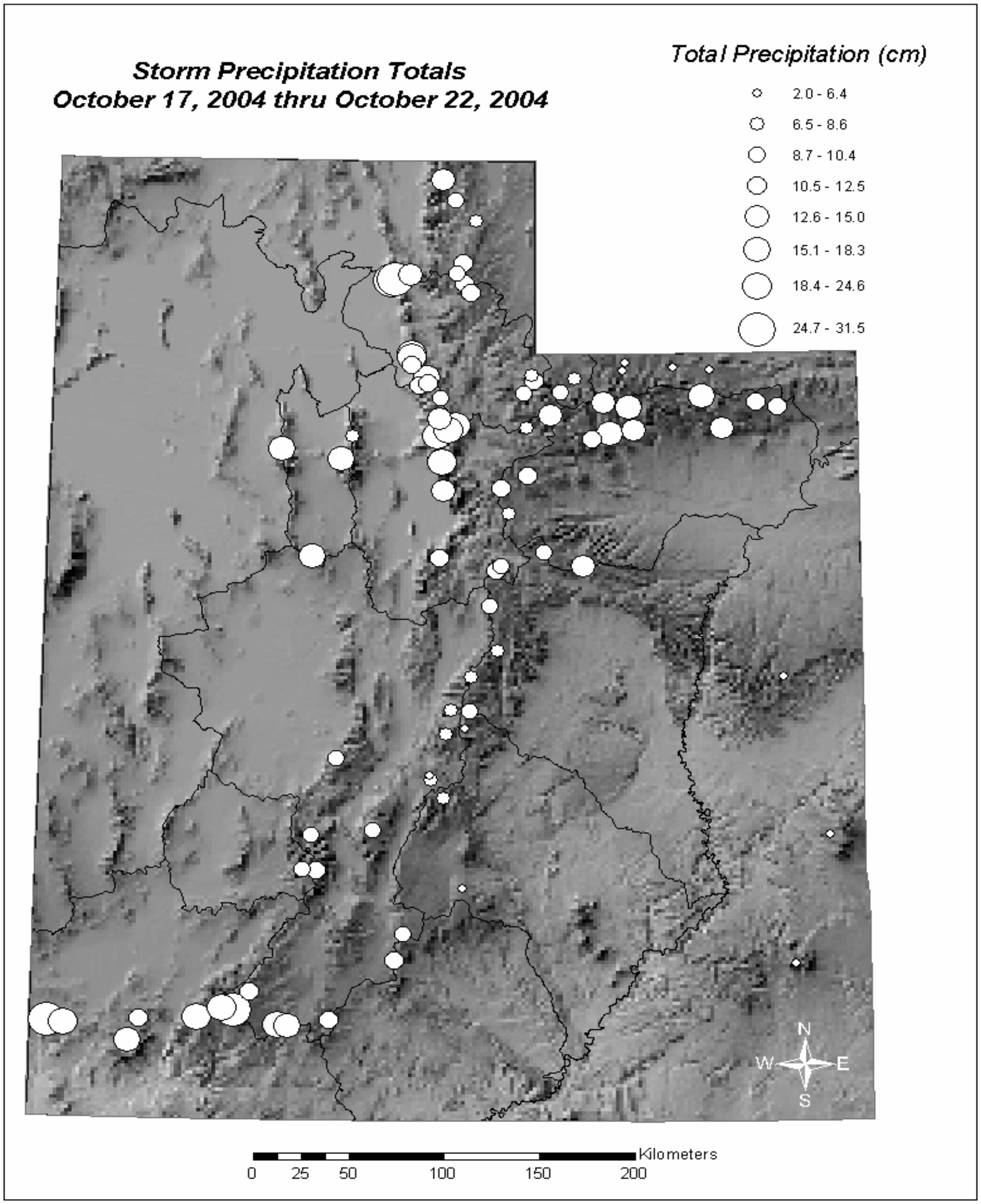

Figure 1. Storm total accumulated precipitation in centimeter for 88 Utah SNOTEL sites from October 17th through October 22nd 2004.

excess of 25 year return intervals with 6 of those sites exceeding 100 year return intervals. Five of the six highest intensity sites were in the South West region of Utah.

Basin	# of Records	# of Sites
Bear River	7	8
Weber-Ogden Rivers	10	14
Provo R.-Utah Lake-Jordan R.	8	11
Toole Valley-Vernon Creek	3	3
Green River	2	6
Duchesne River	11	12
Price-San Rafael	2	5
Dirty Devil	1	3
South Eastern Utah	1	3
Sevier River	8	15
Beaver River	2	2
Escalante River	0	2
Virgin River	7	7

Table 1. Cumulative October precipitation records per basin.

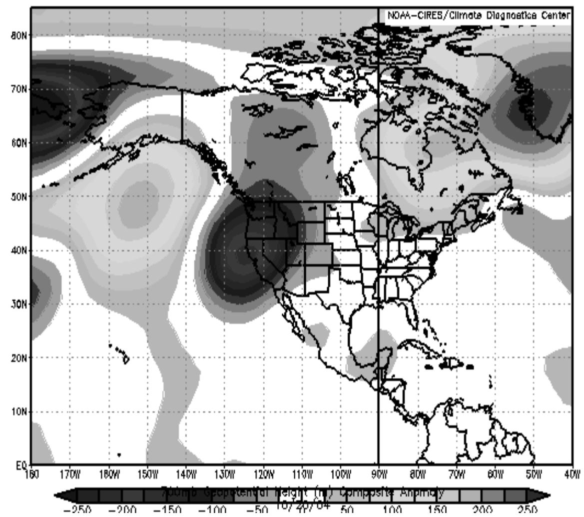

Figure 2. 700mb Geopotential height anomalies for 10/20/2004, scale is in meters and anomalies based on date from 1968 to 1996. Image provided by NOAA-CIRES/Climate Diagnostic Center

Storm Analysis

A very deep and slow moving low pressure system centered over the SW U.S. brought warm moist air over Utah for the days of this event. Highest intensities precipitation mostly occurred on October 20th, while Utah was at the leading edge of the trough and with the greatest instability (Figure 2). Most SNOTEL sites in Utah showed this event occurred mostly as rain. Significant local variations occurred, but in general sites above approximately 2900 meters showed the majority of precipitation as snow, while sites below this elevation showed a mix of rain and snow with rain dominating. Most sites below approximately 2200 meters collected all rain.

A feature of this storm that appeared to be unique in addition to the total precipitation was the precipitation intensity. Analysis of the return frequency of the maximum 24-hour intensities was performed for all sites with continuous hourly records for the storm period. Two methods were used to evaluate the 24-hour intensities. First, the National Weather Service produces a Precipitation Frequency Data Server (NOAA Frequency 2005, http://hdsc.nws.noaa.gov/hdsc/pfds/sa/ut_pfds.html). This site uses historic precipitation stations to calculate the average return interval for storms of various durations. When a SNOTEL site has a record of 15 years or more, the site creates a frequency analysis for that point. The product also interpolates values for areas where no gage has existed, or a gage has insufficient data. Each SNOTEL site was evaluated on this webpage to determine the return interval of the maximum 24-hour intensity. The results of this analysis are displayed in Figure 3. The greatest return interval is for the newly installed Gutz Peak in the Santa Clara drainage with greater than a 1000 year estimated return interval. An additional simple analysis compared the maximum 24-hour intensity to the record 24-hour intensity of all sites with a 15 year or greater record. There were 12 sites indicating a 24-hour intensity record from this analysis, half of which were located in southwest Utah.

Stream Response

In general stream response was relatively benign for the majority of the state with the exception of the South West Corner of the state. Outside of this area most streams and rivers showed moderate increases in flow. The most notable exception was the Virgin River and its tributaries which showed increase in flow on the order of 100 fold. The Paria and Escalante, and Upper Sevier also showed similar scale increases, but these flows were still well below flood stage, and low reservoir levels allowed much of this water to be captured.

Data Quality Assurance

Standard data quality assurance for SNOTEL measurements evaluates only the midnight reading. In order to evaluate the maximum 24 hour intensities it was necessary to evaluate the quality of hourly measurements. Data from each site were evaluated individually to determine the reliability of the site during this event. These hourly

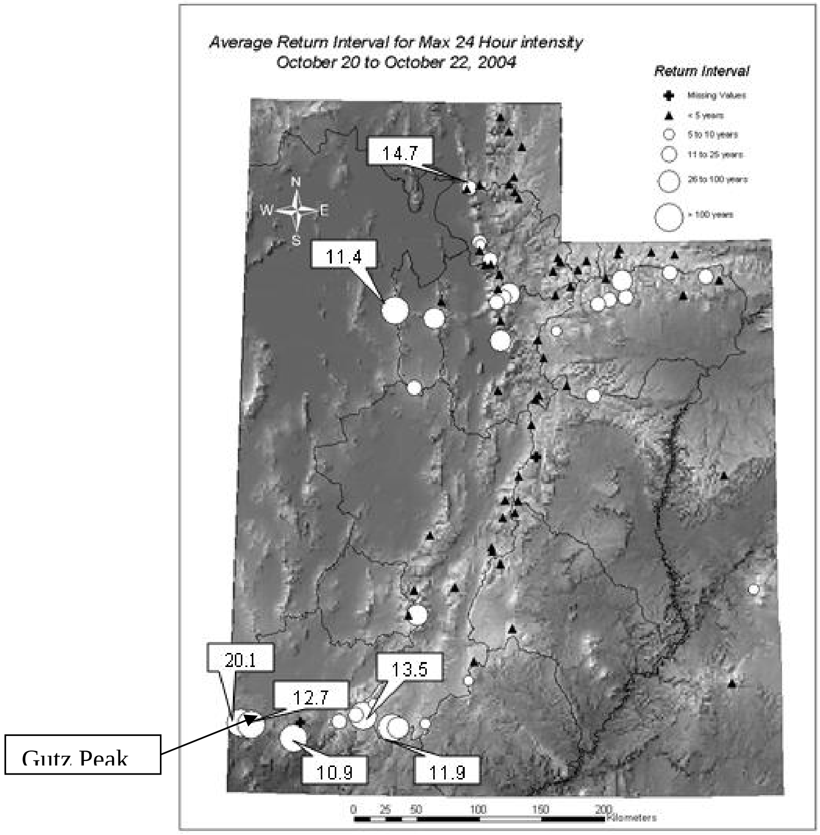

Figure 3. Average return interval in years for maximum 24 hour precipitation intensity for 10/20 to 10/22/2004 derived from NOAA/NWS (http://hdsc.nws.noaa.gov/hdsc/pfds/sa/ut_pfds.html. Selected sites are labeled with 24hour maximum precipitation in centimeters.

measurements often show significant temperature induced instability during dry periods; however the vast majority of sites demonstrated reasonable stability during this relatively short and intense period of precipitation. Where hourly data were not of suitable quality, the intensities were either labeled as missing, or conservatively estimated, where possible from stable values. In addition to electronic data analysis, ground verification measurements were taken at several sites. The centimeters of precipitation, and centimeters of snow water equivalent (SWE) were measured at each site with a pressure transducer, and can be verified by a manual manometer reading. Since this event was dominated by rain, and most of the sites visited had very little snow on the ground only precipitation readings are summarized. During and shortly after this storm eight sites were visited and ground verification collected. Seven of the eight ground measurements of cumulative precipitation to date compared very well with telemetry data, exhibiting a difference of 4 % or less. The only exception to this is for the Little Grassy site. While it is possible that the transducer at Little Grassy was over measuring during this event, the site showed no signs of instability and compares well with neighboring sites (Figure 4). Additionally, later in the water year, the Little Grassy pressure transducer was thoroughly tested for calibration, and proved to be highly accurate. Given this information, it is likely the manometer was either misread or the manometer valve was not fully open.

JANUARY 2005

A second large rain and snow event impacted Utah between January 8th and 11th 2005. This storm accumulated large precipitation totals throughout the state, but again focused its highest intensities on the on the South Western portion of the state. As expected this storm was colder than the October event, building the snowpack at higher elevations, and a mix of rain and snow at lower elevation mountain sites. The intensity of snow accumulation and the mixture of rain and snow forced a different approach to evaluating this storm versus the October storm. This

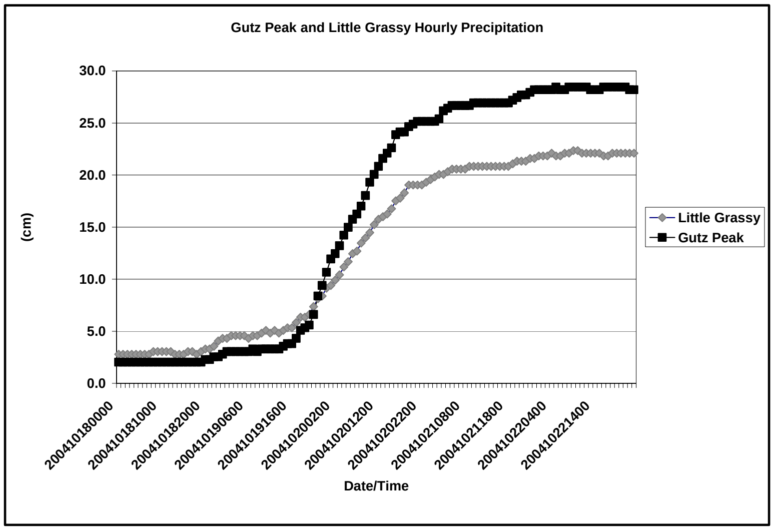

Figure 4. Gutz Peak and Little Grassy SNOTEL hourly precipitation accumulation 10/18 through 10/21/2004. These are the western two most sites in South Western Utah (see figure 1.)

storm also caused flooding on the Virgin and Santa Clara rivers destroying over twenty homes and causing an estimated 150 to 180 million dollars of damage (Utah Flood Relief, 2005).

Storm Analysis

The atmospheric circulation creating the January event was very similar to that of the October event. Another very deep and slow moving low pressure system centered over the NW U.S. brought warm moist air over Utah for the days of this event. (Figure 5) The timing of this storm was from January 8th to 11th 2005. Similar to the

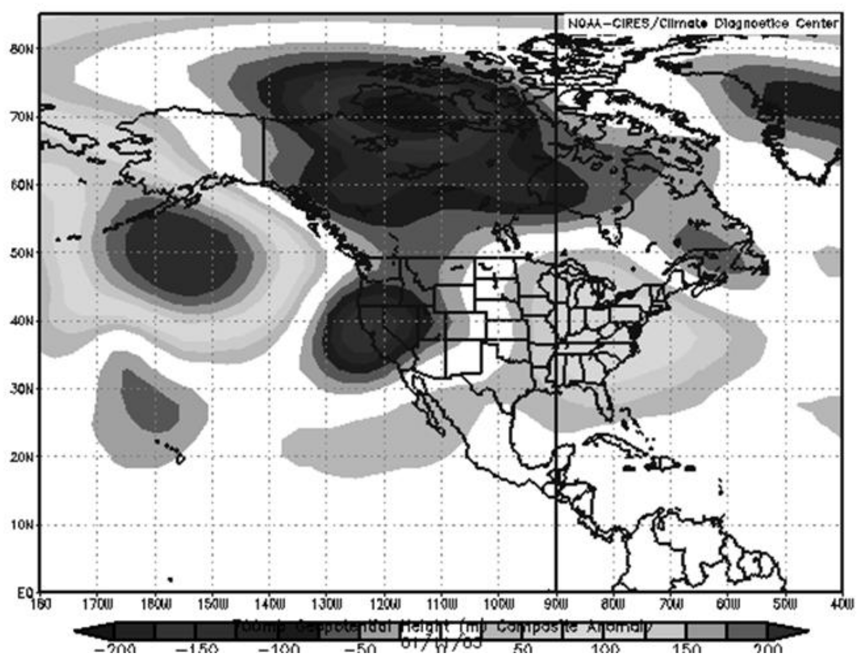

Figure 5. 700mb Geopotential height anomalies for 1/11/2005, scale is in meters and anomalies based on date from 1968 to 1996. Image provided by NOAA-CIRES/Climate Diagnostic Center

October event, this storm impacted most of the state of Utah, but accumulation in all but the South Western portion of the state were moderated as nearly all of these areas experience almost exclusively snow. Portions of SW Utah collected a mixture of rain and snow, and had greater accumulation than other part of the state. Basin average accumulated precipitation and snow water equivalent (SWE) for the entire state is displayed in Figure 6. A closer look at accumulation in the South Western region of the state can be found in Figure 7. The Little Grassy SNOTEL is the lowest elevation SNOTEL site in the Virgin Basin at 1830 meters. This site showed little net change in SWE during the event, and indicated mostly rain fell at this elevation, but it passed through the snowpack without causing significant melt. SNOTEL sites above approximately 2130 meters in this region collected nearly all precipitation as SWE and therefore did not represent a winter flooding risk. There is however a very large area that is not adequately represented by any measurement network in the 1525-to-1830 meter range that had a significant snowpack before this event, and lost most if not all of it in addition to very high rain accumulation.

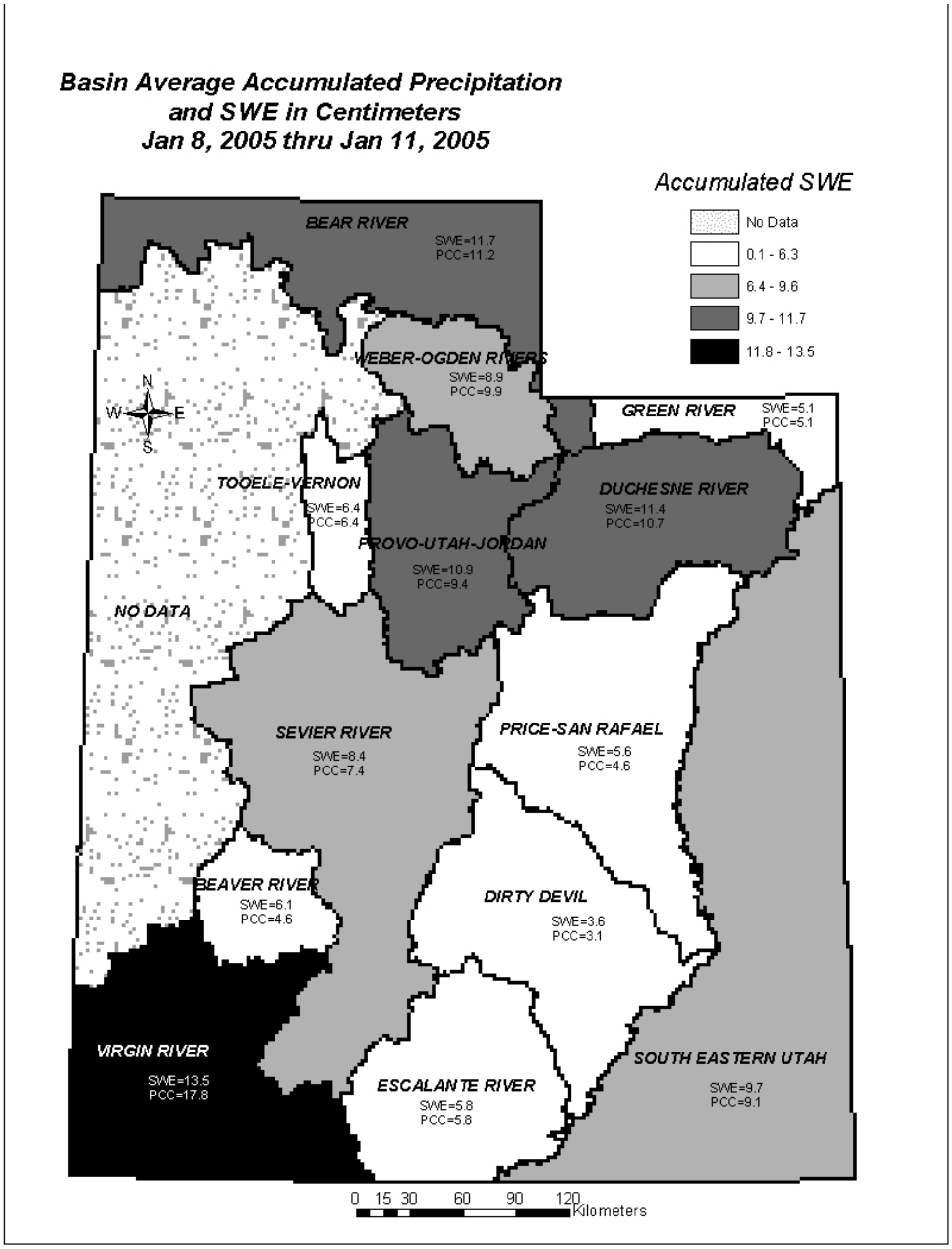

Figure 6. Average accumulated Precipitation and snow water equivalence (SWE) in Centimeters at SNOTEL sites within each basin. January 8 through 11, 2005. Accumulated SWE includes gains and losses.

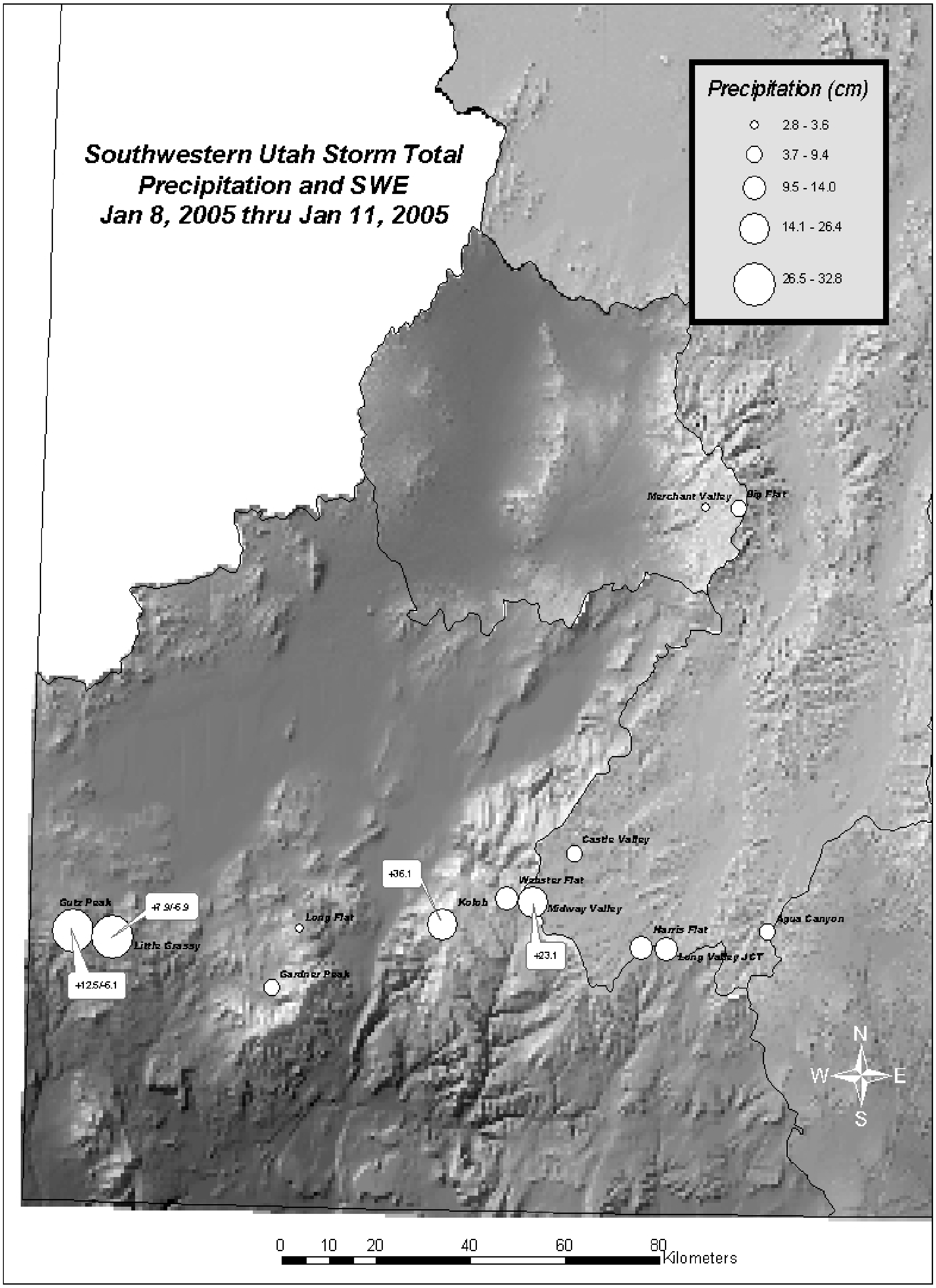

Figure 7. The South Western region of Utah, including the Virgin, Beaver, and portions of the Sevier, and Escalante Basins. Circles indicate the total precipitation at the area SNOTEL sites from January 8th through 11th 20005. Selected sites indicate changes of SWE during the same period. Sites with two numbers indicate an accumulation, then ablation of SWE during the event.

Stream Response

The stream response to the rain, rain on snow, and snowmelt event of January 8th to 11th 2005 was enormous, but very difficult to quantify. Runoff conditions were greatly enhanced by wet soil moisture conditions left behind by the October event, leading to unusually high runoff efficiency (Figure 8). Most of the USGS stream gages in the heaviest hit drainages of the Virgin, Santa Clara, and their tributaries were significantly compromised. The USGS has estimated flows and return intervals for the stations in the area, but only stations in less severely impacted areas have continuous real time records that include the peak flow. Many stations had estimated recurrence intervals near and in excess of 100 years (USGS, 2005a; USGS, 2005b). Stream channels were very significantly altered and had an enormous impact on adjacent property and infrastructure (Figures 9 – 13).

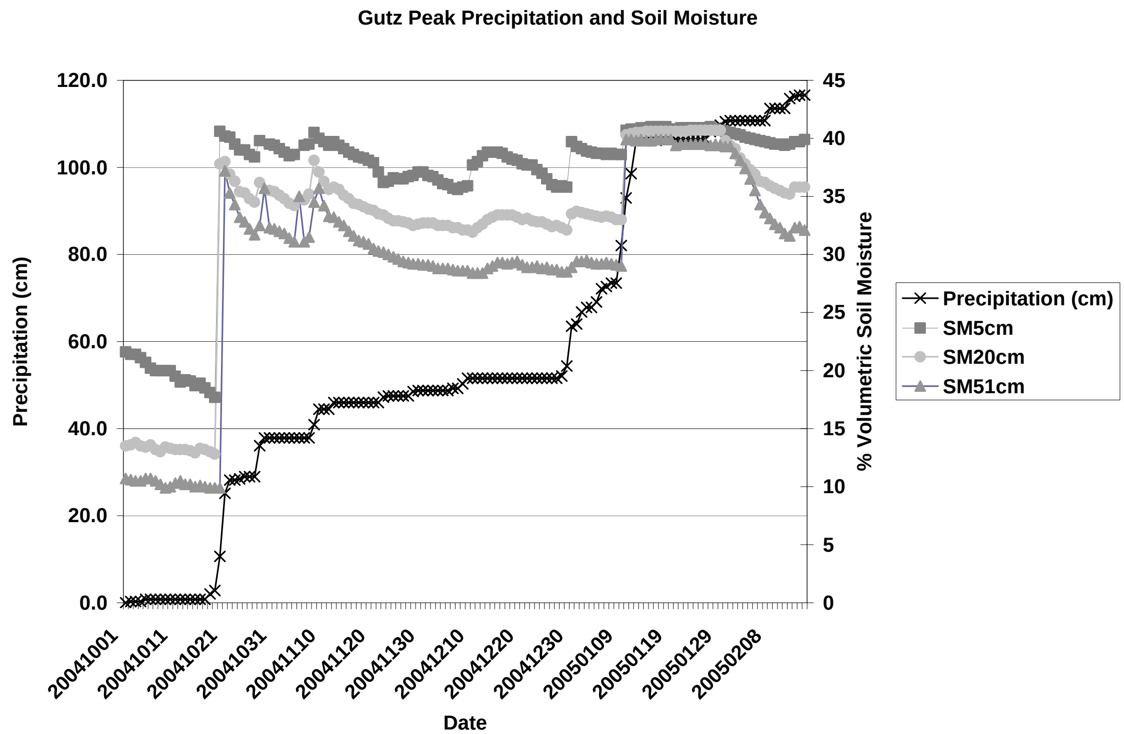

Figure 8. Gutz Peak SNOTEL site precipitation and volumetric soil moisture, October 1, 2004 to February 15, 2005. Note rapid increase in soil moisture corresponding to mid-October event and return to saturation with the January event.

Figure 9. One of several homes completely lost to the Santa Clara River January 11, 2005 Photo

Figure 10. Lower Enterprise Reservoir overtopping. This reservoir continued to overtop for several weeks after the January event.

Figure 11. Looking down stream from the Santa Clara at Saint George stream gage March 27, 2002. Photo USGS

Figure 12. Looking down stream from Santa Clara at Saint George stream gage January 13, 2005. Photo USGS

Figure 13. New channel around bridge in photos 10 and 11. Photo USGS

Figure 14. A plugged 3.7 meter precipitation gage at Kolob SNOTEL January 19, 2005. The height of this gage was extended 3.2meters on the same day

Data Quality Assurance

The nature of a very intense winter storm with relatively warm air temperatures creates many difficulties for automated measuring stations. A primary problem in these conditions precipitation gages have a tendency to become plugged with snow, apparently stopping snow accumulation. The type of storage gage used by the NRCS has a 30cm diameter orifice, with a gage height a minimum of 1.2 meters above the expected maximum snow accumulation. A propylene glycol antifreeze mix melts the snow that is then measured with a pressure transducer. A snow plug can form in the gage above the antifreeze mix. It is very rare for any of the precipitation to be lost from the gage, but timing of the event is delayed until the plug melts, or is manually mixed into the gage (Figure 14). This problem makes the frequency analysis of the October event impossible in this case. A comparison of SWE measurements, snow depth measurements, and nearest neighbors can be used to estimate the timing of precipitation when a gage is plugged, with final totals based on the unplugged precipitation. Six high accumulation sites were visited shortly after the January event, and ground measurements of SWE and precipitation corresponded closely with telemetered values. At several of these sites, the plugged precipitation gage was manually cleared by breaking up the snow plug. Two of these sites had such deep snow packs that the gage heights needed to be extended by 1.2 meters. These challenges made it impossible to report hourly incremental precipitation and swe, but storm totals were able to be estimated with a reasonable degree of accuracy.

SUMMARY

The Storms of October 17th through 22nd, 2004 and January 8th through 11th 2005 had a very significant impact on immediate hydrologic conditions in the state of Utah as well as on the water year as a whole. Combined precipitation totals from these two events were near the average water year total for several sites in the Southwestern region of the state. The extreme nature of these events will draw additional interest in hydrometeorlogical data from these time periods. These data users will have access to an event summary report through the Utah data collection office or its web page.

ACKNOWLEDGEMENTS

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REFERENCES

NOAA Frequency (U.S. Department of Commerce, National Oceanic and Atmospheric Administration). 2005. NOAA's National Weather Service Hydrometeorological Design Studies Center, Precipitation Frequency Data Server. (Web page); http://hdsc.nws.noaa.gov/hdsc/pfds/sa/ut_pfds.html. (Accessed September 12, 2005)

Utah Flood Relief. 2005. Virgin River/Santa Clara River Flood Relief Inc, Foundation. [web page]; http://www.utahfloodrelief.com/need.html. (Accessed September 12, 2005)

U.S. Geological Survey. 2005a. Flood in the Virgin River Basin, Southwestern Utah, January 9-11, 2005. (Web page); http://ut.water.usgs.gov/FLOODING/Virgin_flood.html. (Accessed September 12, 2005)

U.S. Geological Survey. 2005b. Daily Water Data for Utah. (Web page); http://waterdata.usgs.gov/ut/nwis/dv. (Accessed September 12, 2005)