Defining Large Precipitation Events in the Upper Colorado River Basin and the Contributions to Lake Powell Inflow

JOHNATHAN P. KIRK[1] AND THOMAS W. SCHMIDLIN[1]

EXTENDED ABSTRACT

Keywords: Colorado River Basin, SNOTEL, large precipitation events

BACKGROUND

Declining annual mountain snowpack across the western United States is placing unprecedented strains on regional water supplies. Further complicating seasonal water supply forecasting is the emerging prospect that interannual variation in alpine snow conditions is greatly influenced by the occurrence and characteristics of large precipitation events each year, rather than more frequent, but less intense events. The occurrence of these large precipitation events can dictate whether a year produces above or below average runoff, underscoring the need for more targeted investigation. Using observational data recorded at a sample of snow telemetry (SNOTEL) monitoring stations located among headwater regions of the Upper Colorado River Basin (UCRB) in Colorado and Wyoming, this exploratory study seeks to define a "large precipitation event" and examine its relative influence on yearly water supply. Average annual precipitation yields and frequencies of large precipitation events observed at the SNOTEL sites in the UCRB are assessed from 1981-2014 and statistically related to inflow at Lake Powell.

DATA & METHODS

For this exploratory study, 15 SNOTEL sites were selected to represent headwater regions for major tributaries in the UCRB (Table 1). For operational purposes, the sites represent drainage areas which reliably produce substantial runoff each year, as measured at local river gages (Colorado Basin River Forecast Center [CBRFC], personal communication). Figure 1 depicts the locations and distributions of these SNOTEL sites.

Daily snow-adjusted precipitation increments (referred to here as "precipitation increments") were collected for water years 1981 (or the earliest complete reporting year for newer stations) to 2014 at each of the selected SNOTEL sites, using online Natural Resource Conservation Service (NRCS) databases. The NRCS defines "snow-adjusted precipitation" as the daily positive increment in precipitation accumulation or SWE, whichever is larger, as observed by SNOTEL instrumentation. This is done to address known instrument undercatch scenarios (e.g. Serreze et al., 1999, 2001; Fassnacht, 2004; Meyer et al., 2012). The precipitation increments at the basin headwaters are linked to streamflow as represented by inflow at Lake Powell, the basin's outlet, over the same timeframe. Unregulated reservoir inflow data were collected from online United States Bureau of Reclamation (USBR) databases.

---

[1] Department of Geography, Kent State University (jkirk9@kent.edu).

Table 1. List of selected SNOTEL sites. The Reporting Since column lists the earliest full water year of reporting in each station's period of record. The period of study in this paper is defined as water year 1981 (or the first full water year of reporting as listed in the table, whichever is later) through 2014.

SNOTEL ID	Site Name	Latitude	Longitude	Reporting Since	Elevation (m)	LPE Threshold (mm)
386	Cascade	37.65083	-107.80602	1979	3090	10.2
387	Cascade #2	37.65800	-107.80268	1991	3104	10.2
780	Spud Mountain	37.69866	-107.77715	1987	3710	12.7
632	Molas Lake	37.74932	-107.68866	1987	3654	10.2
629	Mineral Lake	37.84747	-107.72657	1979	3494	10.2
713	Red Mountain Pass	37.89180	-107.71342	1981	3898	12.7
380	Butte	38.89433	-106.95300	1981	3536	7.6
737	Schofield Pass	39.01522	-107.04877	1986	3724	12.7
669	North Lost Trail	39.07813	-107.14389	1986	3202	10.2
618	McClure Pass	39.12897	-107.28806	1981	3306	10.2
940	Elk River	40.81588	-106.74835	1999	3243	10.2
467	Lost Dog	40.84781	-106.96871	1979	3028	10.2
597	Loomis Park	43.17387	-110.14007	1981	2868	10.2
555	Kendall RS	43.24930	-110.01662	1986	2694	7.6
944	Gunsight Pass	43.38000	-109.88000	1999	3417	7.6
AVERAGE					3331	10.2

The daily precipitation increment data were used to define thresholds for "large precipitation events" (LPEs) at each SNOTEL site. After examining various absolute and relative thresholds, the 80th percentile of daily precipitation increments was selected as the threshold for defining LPEs. This threshold translates from 7.6 to 12.7 mm (0.3 to 0.5 inches) at each station, as depicted in Table 1. The thresholds defined here align with similar definitions and findings used in other studies examining precipitation and/or SNOTEL data across Western North America (e.g. Cowie and McKee, 1986; Serreze et al., 2001; Bolinger et al., 2014; Lute and Abatzoglou, 2014). A single LPE can continue over multiple days, as long as the daily LPE precipitation increment threshold for that station is met on each subsequent day. As such, LPEs persisted for as long as 12 days, but 91.3% of all precipitation included in LPEs occurred during 3-day or shorter LPEs.

Various precipitation statistics were calculated for each SNOTEL site, including annual total precipitation, annual LPE precipitation, annual LPE counts, and the average LPE magnitude (precipitation yield per LPE). These statistics were then associated with streamflow at Lake Powell via Pearson's bivariate correlations, as an exploratory assessment of how interannual variability in precipitation conditions at basin headwater regions relates to streamflow variability at the basin outlet.

RESULTS & DISCUSSION

By defining LPEs as days when observed precipitation was equal to or greater than the threshold for that station defined by the 80th percentile (all days $\geq$ 7.6 – 12.7 mm), an average of 24.4% of all precipitation days across all selected SNOTEL sites were classified as LPE days. Overall, LPE days capture 47.1 – 63.4% of all precipitation recorded at each site, with an average of 55.5% across all sites (Table 2). Therefore, roughly the top 25% wettest days account for approximately 56% of the total precipitation at the selected sites. This indicates that precipitation does not accumulate evenly throughout the year at the selected sites; rather the majority of precipitation occurs during (mainly cool season) LPEs, as defined here among headwater regions of UCRB tributaries.

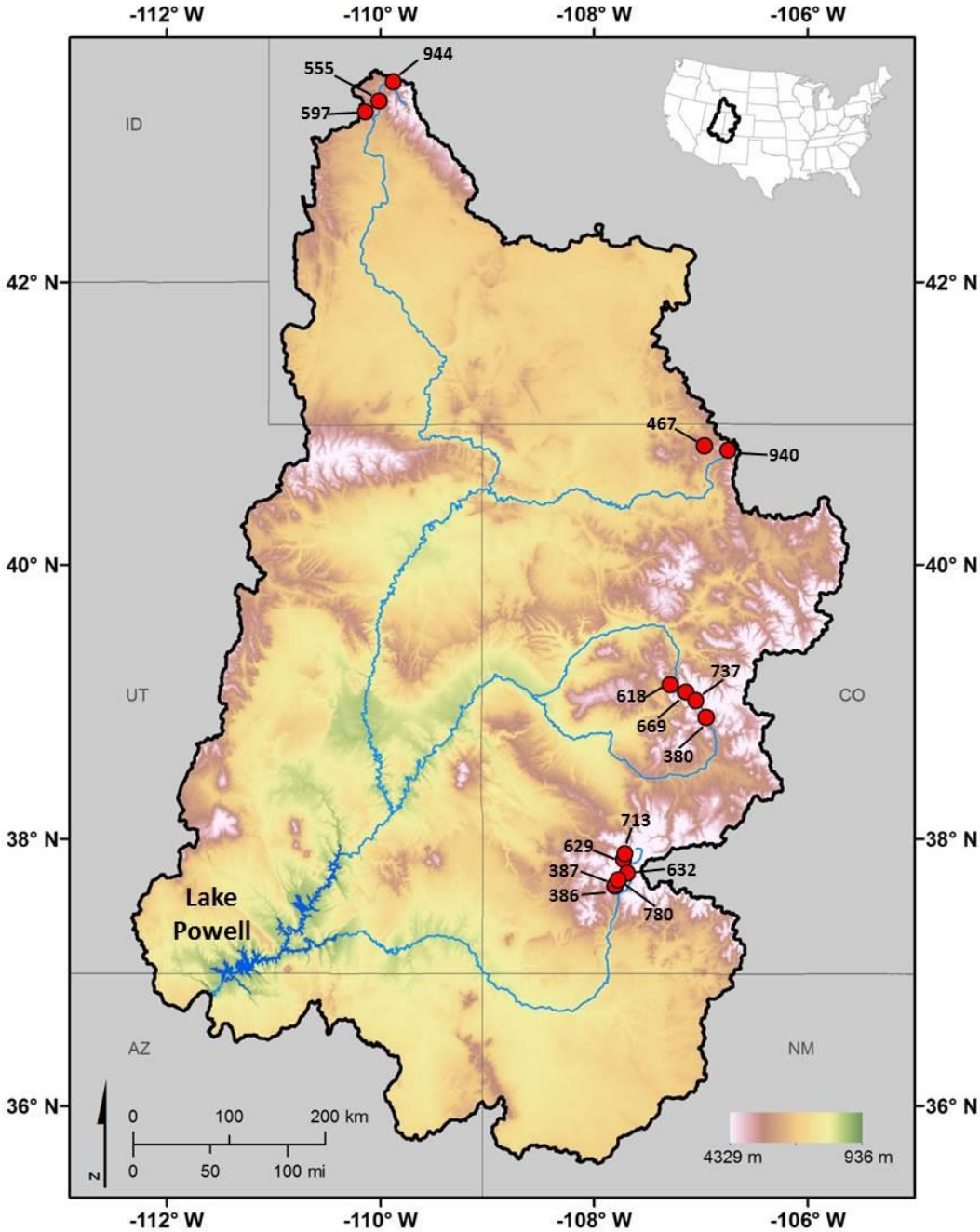

Figure 1. Map of the UCRB depicting the selected SNOTEL sites and Lake Powell, along with elevation and some of the major basin tributaries.

The average annual LPE precipitation totals by SNOTEL site are listed in Table 2. On average across all stations, 58.2 cm of precipitation accumulates annually from LPEs, accounting for the previously referenced 55.5% of annual total precipitation. The average annual LPE precipitation observed at each station does not exhibit a clear relationship with station elevation, but the drier stations overall tend to be located the farthest north, particularly the Wyoming stations in the Wind River Range. Similarly, no clear relationship exists between elevation and the proportion of total precipitation accounted for by LPEs, though the higher proportions tend to occur at stations located farther south in the San Juan Mountains.

Table 2. Average annual LPE precipitation, LPE count, and average LPE magnitude by SNOTEL site. Correlations are also presented of the interannual variability for each metric to Lake Powell unregulated inflow. Results denoted in bold and with * are significant at α = 0.05.

SNOTEL ID	Ave. Annual LPE Precipitation (cm) [% of Annual Total Precip]	Correlation LPE Precip to Lake Powell Inflow	Ave. Annual LPE Count	Correlation Annual LPE Count to Lake Powell Inflow	Ave. LPE Magnitude (mm)	Correlation Annual LPE Magnitude to Lake Powell Inflow
386	61.2 [60.0]	**0.62***	23.4	**0.52***	25.4	0.24
387	58.2 [61.4]	**0.73***	22.1	**0.62***	25.4	**0.57***
780	86.9 [63.4]	**0.77***	23.4	**0.49***	38.1	**0.67***
632	65.0 [58.8]	**0.71***	25.6	**0.58***	25.4	**0.48***
629	48.5 [49.5]	**0.74***	22.9	**0.77***	20.3	0.25
713	66.3 [50.1]	**0.85***	24.0	**0.70***	27.9	**0.69***
380	48.0 [59.4]	**0.78***	27.7	**0.61***	17.8	**0.60***
737	91.7 [57.3]	**0.81***	27.3	**0.52***	33.0	**0.63***
669	57.7 [53.8]	**0.77***	26.2	**0.67***	22.9	**0.49***
618	60.2 [56.8]	**0.84***	26.2	**0.74***	22.9	**0.56***
940	67.3 [56.3]	**0.78***	29.2	**0.67***	22.9	**0.54***
467	51.1 [47.1]	**0.54***	25.7	**0.48***	20.3	**0.41***
597	38.6 [48.8]	**0.56***	19.6	**0.56***	20.3	0.26
555	38.4 [60.2]	**0.61***	23.1	**0.47***	17.8	**0.38***
944	34.3 [50.1]	**0.56***	22.6	0.49	15.2	0.35
AVERAGE	58.2 [55.5]		24.6		23.7	

The interannual variability in total LPE precipitation is strongly correlated to Lake Powell inflow at every SNOTEL site (r = 0.54 to 0.85). While the relationship is significant at every site, the coefficients tend to be lower for the Wyoming sites, perhaps a manifestation of their distance from Lake Powell in comparison to the other SNOTEL sites. These results suggest that the selected SNOTEL sites represent headwater regions which produce significant streamflow each spring and are viable data sources for analyzing basin hydrology.

Given the importance of LPEs to yearly precipitation totals overall, the average annual count of LPEs and the average LPE magnitude (precipitation yield per event) at each SNOTEL site are also presented in Table 2. On average, about 25 LPEs occur at the SNOTEL sites each year, yielding an average of 23.7 mm of precipitation per event. LPE magnitudes tend to be higher at higher elevations and LPEs are slightly more common at the sites in the central and northern mountains of Colorado, as opposed to the southernmost or northernmost selected sites overall.

Correlations for the interannual variability in LPE count is statistically significant at all but one of the sites (r = 0.47 to 0.77), suggesting that years with a higher (lower) frequency of LPEs tend to coincide with wet (dry) years, reinforcing similar observations made in Bolinger et al. (2014). For interannual LPE magnitude variability, 11 of the 15 sites exhibit significant correlations to Lake Powell inflow (r = 0.38 to 0.69). Years with wetter (drier) LPEs tend to coincide with wet (dry) years, but the differing correlation results between neighboring stations indicates that other, perhaps highly localized, factors can strongly influence LPE magnitude.

CONCLUSION

This exploratory study characterizes the influence of large precipitation events (LPEs) observed at SNOTEL sites representing the headwater regions of the Upper Colorado River Basin on streamflow at Lake Powell, the basin's outlet. As defined in this study, LPEs on average, account for the majority of annual precipitation across the selected sites, producing interannual variability

in total LPE precipitation that is significantly correlated to Lake Powell inflow. Similarly, variability in the frequency and magnitude of LPEs is strongly correlated to inflow variability. These results suggest that wet/dry years in the basin may be characterized by the number of large events, the average precipitation yield per event each year, and the annual total precipitation from LPEs. While the general precipitation conditions observed at headwater SNOTEL sites are well known to be representative of the inflow variability at the basin outlet, stakeholders should also consider the importance of LPEs, as a smaller and impactful subset of all precipitation days, at these sites in producing basin water supply. Based on the current drought, evidence presented here suggests that a year with fewer and drier LPEs may coincide with a drier year overall; indicators which deserve further study and may aid stakeholders in decision making.

REFERENCES

Bolinger RA, Kummerow CD, and Doesken, NJ. 2014. Attribution and characteristics of wet and dry seasons in the upper Colorado River Basin. *Journal of Climate* **27:** 8661-8673.

Cowie JR, and McKee TB. 1986. Colorado precipitation event and variability analysis (Atmospheric Science Paper No. 400 Climatology Report No. 86-3). Fort Collins, CO: Department of Atmospheric Science, Colorado State University.

Fassnacht SR. 2004. Estimating Alter-shielded gauge snowfall undercatch, snowpack sublimation, and blowing snow transport at six sites in the conterminous USA. *Hydrological Processes* **18:** 3481-3492.

Lute AC, and Abatzoglou, JT. 2014. Role of extreme snowfall events in interannual variability of snowfall accumulation in the western United States. *Water Resources Research* **50:** 2874-2888.

Meyer JDD, Jin J, and Wang S. 2012. Systematic patterns of the inconsistency between snow water equivalent and accumulated precipitation as reported by the snowpack telemetry network. *Journal of Hydrometeorology* **13:** 1970-1976.

Serreze MC, Clark MP, Armstrong RL, McGinnis DA, and Pulwarty RS. 1999. Characteristics of the western United States snowpack from snowpack telemetry (SNOTEL) data. *Water Resources Research* **35:** 2145-2160.

Serreze MC, Clark MP, and Frei A. 2001. Characteristics of large snowfall events in the montane western United States as examined using snowpack telemetry (SNOTEL) data. *Water Resources Research* **37:** 675-688.