# Meteorological Patterns and Parameters Associated with Flash Flood Events for the Elko County Warning Area

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## 1) Introduction:

The Great Basin experiences flash flooding throughout the warm season during strong Monsoonal moisture surges from Arizona, which affects the lives and property of Nevadans. The Elko County Warning Area (CWA) is very rural, consisting of mountainous terrain, barren alkali flats, uninhabited desert areas, and limited population. Due to the sparsely populated nature of central and northern Nevada, flash flood events are rarely reported.

Forecasting flash flooding across the Elko CWA is challenging due to a variety of physical and demographic delimitations. First, like so many regions of the Inter-Mountain West, the radar beam is blocked by a number of high mountain peaks. To compensate and alleviate for some of the blocking issues, the KLRX radome sits at an elevation of 6,858 feet above mean sea level (MSL). Although this eliminates some of the beam blocking issues, it also exasperates beam overshooting and causes poor sampling of storm bases at distances greater than 80 miles from the radome. Second, high quality automated rain gauges are limited, separated by great distances between sites (on average 831 square miles). Third, the population density is very low at roughly 1.5 people per square mile, which leads to a very sparse spotter network with some portions of the CWA having no certified spotters for 75 miles or more. Finally, radar data from neighboring offices is of limited use due to beam overshooting, causing poor sampling of the lower portions of thunderstorms. For a visual representation of how poor the radar coverage below 10,000 feet above ground level (AGL) is across the CWA, see Figure 1. One can see that much of northern Nye, White Pine, northwest portions of Humboldt, and extreme eastern Elko counties have no radar coverage below 10,000 feet AGL. Due to this, radar precipitation estimates do not exist across large portions of the CWA.

Due to the aforementioned challenges, forecasters cannot rely on empirical data only to issue flash flood warnings. Forecasters must also be able to identify patterns that support flash flooding, be knowledgeable of local terrain and water basin flow, and use meteorological parameters associated with flash flooding to aid in their decision making process. This paper will expand upon previous research completed by Brong (2006) for the Reno CWA and provide guidance on recognizing flash flood patterns, parameters, and other factors within the Elko CWA to help us build a Weather Ready Nation.

## 2) Data and Methods:

According to storm reports from the National Climatic Data Center (NCDC) Storm Event Search Engine (NCDC, 2014), the Elko CWA reported 51 flash flooding events from 1995 to 2013. Several of these reports occurred on the same day with 43 total flash flood days reported. Two of these flash flood events occurred in the Las Vegas CWA, but were within 20 miles of Elko

CWA's southern boundary. Therefore, they were included here to increase the dataset collected for this study.

The flash flood events were analyzed using 500 hPa synoptic charts of geopotential height collected from the Storm Prediction Center (SPC) archived upper air charts. Each case was examined and then grouped into one of four 500 hPa geopotential height patterns which will be discussed in detail later in this paper. Once the events were all grouped together, 500 hPa geopotential height composite maps were created for the four pre-identified synoptic patterns using the NCEP NARR (Mesinger et al. 2006) derived data provided by NOAA/OAR/ESRL PSD, Boulder, Colorado, USA from their website at (http://www.esrl.noaa.gov/psd/data/narr/).

To calculate precipitable water (PW), lifted condensation level (LCL), storm motion, and warm cloud thickness, upper air observations were used from the Elko sounding. For each flash flood event occurrence in northern Nevada, the 00 UTC or 12 UTC Elko sounding was used depending on the event time. Due to the large geographical distances in the Elko CWA, sounding data could be unrepresentative across central Nevada. Due to this issue, different data sources were used for events that occurred across central Nevada. To differentiate between northern Nevada and central Nevada flash flood events, a blue line was drawn in Figure 2 depicting this separation. To calculate PW across central Nevada, scalar upper air maps were used from the Plymouth State Weather Center upper air products archive (http://vortex.plymouth.edu/u-make.html). Values were estimated using the scalar upper air maps at the location of the reported flash flood. To estimate storm motion and warm cloud thickness for central Nevada flash flood events, an average was computed between the Elko and Las Vegas sounding using either the 12 UTC or 00 UTC sounding depending on event time. To estimate LCL heights for central Nevada flash flood events, the SPC hourly mesoscale analysis daily archive directory (http://www.spc.noaa.gov/exper/ma_archive/) was used. Values were estimated in a similar method as calculating the PW values using the Plymouth State Weather Center maps. Dewpoint temperatures were determined by finding the archived MESOWEST surface observation that was closest to the reported time and location of the flash flood event.

To assess antecedent rainfall conditions, rainfall measurements from ASOS, AWOS and/or NWS cooperative observers located within a 25 mile radius of the event were used, if applicable. Additionally, archived level 3 NCDC storm total precipitation radar data was used for 48 hours before the flash flood event. The radar data was only used for those cases that fell within the NEXRAD coverage below 10,000 feet AGL.

## 3) Analysis:

### *a. Local Factors that Influence Thunderstorm Initiation and Flash Flood Potential*

Topographically, the Elko CWA has several north-south oriented mountain ranges separated by valleys and basins which create localized areas of convergence due to upslope winds during daytime heating. In addition to the normal terrain features for convective initiation, the Elko CWA has a locally named Great Basin Convergence Zone (GBCZ). It is a persistent, year-round, quasi-stationary surface to 700 hPa confluence zone tied to topography. Although this feature has been recognized by forecasters for years, little research has been done to examine the mechanisms responsible for the GBCZ. West and Steenburgh (2010) were the first to officially study this phenomenon, but their research concentrated on lee side cyclogenesis during the winter months. This confluence zone occurs frequently near the US Highway 50 corridor from Ely to Eureka, extending westward towards Austin (Figure 3). This is a natural convergence zone caused by a relatively high plateau greater than 6,000 feet MSL, surrounded by lower elevation basins of 4,000 to 5,000 feet MSL. The GBCZ is strongest during the summer months due to stronger solar insolation, which provides a focus for thunderstorm development and flash flooding in this area. Unfortunately, the predominant location of the GBCZ coincides with one of the lowest population densities in the CONUS. The number of documented flash flood events in this region is most likely underestimated. Even so, the GBCZ allows storms to initiate south of Interstate 80 and steer into relatively higher populated areas of the Humboldt River Valley.

### *b. Terrain and Soil Types that Impact Flash Flooding*

Terrain plays an important role in the Great Basin when flash flooding occurs. The steep canyons and dry washes cause runoff to flow towards roads, towns, and ranches throughout the CWA, making these areas prone to flash flooding. The high resolution topographical map of the CWA (Figure 2) shows the terrain in detail, with the numbers indicating locations where flash flooding was reported. Some towns like Montello in northeastern Nevada and Manhattan in central Nevada have a higher frequency of reported flash flooding, but almost any town in the CWA can experience flash flooding. Many roadways, including state route 376 in northern Nye County, state route 278 in Eureka County, and state route 318 in Eureka and Nye County (Figure 4) frequently experience flash flooding as they are situated near mountain washes or along basin floors. The rocky, alkali soils and sparse vegetation also enhance the potential for flash flooding by increasing runoff rates. Urbanization does not play a significant role in causing flash flooding in the Elko CWA, with a few exceptions being the larger towns of Elko, Winnemucca, and Ely. Burn scars are also a large concern as fires plague the CWA during the summer season and can enhance the possibility of flash flooding and debris flow.

### *c. Monthly Distribution of Flash Flood Events*

Although heavy precipitation is rare across the Elko CWA, it can occur and is most common in the summer months of July and August when surges of sub-tropical moisture push north from Arizona or the Gulf of California region. There have been reports of flash flooding in the spring and early fall months, but these occurrences are rare. The distribution of documented flash floods by month (Figure 5) was compiled with the majority of flash flood events occurring in July and August. September had the third highest report of flash flood events; however this chart does not tell the whole story. Half of the September flash flood reports occurred in just one year, which was caused by a major monsoon push in 2013. The early and late season events in May, June, and September are usually due to slow moving upper level lows or troughs.

### *d. Synoptic Flash Flood Patterns Across the Western Great Basin*

Brong (2006) identified three dominant synoptic patterns associated with flash flooding across the western Great Basin. These include the Four Corners High (FCH), which is a common feature across the southwestern United States during the summer. The Great Basin High (GBH) was a second pattern identified by Brong, where high pressure is centered over Nevada or Utah but can be elongated or ill defined. The third pattern is the Upper Low (UL), where a 500 hPa trough is located near western Nevada, northern California or just off the California coast. In addition to these three patterns, a fourth FCH/UL hybrid pattern will be presented that was a prevalent pattern for the Elko CWA.

Extensive research of the 51 reported flash flood events revealed that a majority of these events (31 of the 51) were categorized as UL flash flood events associated with an upper level low or trough either in Nevada or California. A 500 hPa composite map from the NOAA/ESRL PSD website was developed using these UL flash flood event days (Figure 6). The analysis shows a broad high over New Mexico and west Texas with southwesterly flow over the Elko CWA. The mean trough was centered near the coast of California. The second highest number of flash flood events occurred with an FCH/UL hybrid pattern, with nine documented cases. Events considered in the FCH/UL hybrid pattern occurred when the FCH was in place for at least 24 hours prior to the flash flood event, but before a 500 hPa shortwave trough moved through northern California and Nevada (Figure 7). This pattern is well known in fire weather forecasting and is called the break-down of the Four-Corners High. The third most prevalent flash flood pattern is the FCH with six events. This is different from Brong's (2006) findings in the Reno CWA, where this pattern was the most common cause of flash flood events. These events showed an area of strong high pressure centered near the Four-Corner region with south to southwest flow across the CWA and a weak upper level trough near the California coast (Figure 8). The GBH pattern (Figure 9) accounted for five events and was the least common of the four patterns. This pattern featured an elongated area of high pressure centered over the Great Basin with a trough typically located to the south in Arizona and southern California. It is interesting to note in three of the five GBH events, a 500 hPa vorticity maxima or weak shortwave trough embedded in the flow was most likely the catalyst for the convection (Figure 10).

It is interesting to note that the "normal" monsoonal flow pattern of the FCH was the least prevalent flash flood pattern of the 4 patterns and the UL pattern was responsible for 57% of the events. This shows that enhanced dynamics, most likely due to increased shear and storm-top divergence from stronger upper level jet features, is a key component to stronger storms and flash flood potential in the Elko CWA.

### *e. Meteorological Parameters Associated with Flash Flood Events*

Local studies suggest the best parameters for assessing the potential for flash flooding is precipitable water (PW). PW values of 0.8" to 1.0" favor a heightened potential for flash flooding, while values greater than 1.0" suggest an extreme potential for flash flooding. The average PW values were 0.97" for all reported flash flood events for the Elko CWA, thus verifying the previous in-house studies. During the GBH flash flood events the PW's ranged from 0.75" to 1.1" with an average of 0.91", which was the lowest PW average of all the 4 patterns. This was expected as a drier air mass resided over the Elko CWA during the GBH pattern. The FCH and FCH/UL patterns had the highest average PW at 1.1", due to south to southwesterly flow in low and mid-levels of the atmosphere advecting monsoonal moisture north into the CWA. The UL pattern PW average was 0.95" with a wide range of values from 0.60" to 1.20". This wide distribution was due to a variety of reasons, including early season upper level lows which typically have lower PW values due to lower heights. The distribution of precipitable water was analyzed (Figure 11) during these events with 40 of the 51 events (78%)

showing PW values of 0.9” or greater when flash flooding was reported. The climatology of PW values for the CWA is shown in Figure 12. As one can see, when flash flooding occurs in July and August, the PW values are roughly 2 standard deviations higher than average and near the 99$^{th}$ percentile or higher in some events.

Dewpoint temperatures are above 45 degrees (Figure 13) when flash flooding occurs, except for one outlier event, which occurred in the late spring when the surface dewpoint was below 45 degrees. It should be noted that the dewpoint temperature can change rapidly in the desert environment. It is not uncommon to see dew points in the 30s and 40s and increase rapidly by 10 to 20 degrees when convective outflow winds occur or rainfall begins to saturate the drier air near the surface. In many flash flood cases, it was noted that dew points increased during or just prior to the flash flood event. It is important to realize that antecedent dewpoint temperatures might not always be greater than 45 degrees during the pre-storm meteorological analysis.

Storm motion is very important as it controls how long any one storm can deposit precipitation over an area. Storm motions showed great variability, ranging from 5 knots to 25 knots; however the average value was 12 knots for all flash flood events. The GBH pattern exhibited the slowest storm motion, with an average of 7 knots for all the events, while the UL pattern had the highest average storm motion at 14 knots. The FCH pattern averaged 11 knots, while the FCH/UL pattern averaged 13 knots. Around 76% of the flash flood events occurred with storm motions of 15 knots or less (Figure 14). 17 events occurred when storm motions were less than 10 knots and another 22 events occurred with storm motions of 10 to 15 knots. Only 12 events had storm motions above 15 knots. These latter events most likely occurred with very intense rainfall occurring in a short period of time and there may also have been training of storms, however this study does not investigate that possibility.

Lifted condensation level (LCL) heights are important as lower cloud bases decrease the amount of sub-cloud evaporation. Past local studies suggest that heights less than 5,000 feet AGL are associated with a higher potential for flash flooding. This research indicates that 42 of 51 events occur with LCL heights below 7,000 feet AGL (Figure 15) with 25 of the events occurring with LCL heights below 5,000 feet AGL. Only 9 events occurred with LCLs greater than 7,000 feet AGL. The GBH pattern showed the highest average LCL heights at 7,400 feet AGL, while the FCH/UL pattern was the lowest with an average LCL height at 4,650 feet AGL. Lastly, the UL and FCH patterns averaged 5,255 and 5,820 feet AGL, respectively.

Warm cloud thickness may also play an important role based on local rules of thumb. There was a large variance in warm cloud thickness between the 4 identified patterns with an average value of 3,210 feet. The GBH pattern showed the smallest warm cloud thickness average at 1,763 feet, with the other three patterns averaging between 3,000 to 4,000 feet; however the research was inconclusive about the usefulness of this parameter due to the highly variable values that were observed for each event. What this study does show is the 10,000 foot warm layer thickness rule of thumb developed east of the Rockies doesn’t work across the semi-arid high elevations of the Great Basin.

Antecedent moisture played a role in some flash flood events for this study. To determine if antecedent moisture was a factor for a flash flood event, greater than 0.25” of rain measured within a 24 hour period or 0.50” of rain measured within a 48 hour period was used. Lesser amounts were considered insignificant due to evaporation and infiltration into the ground. Many events showed heavy, short duration rainfall fell during the flash flooding events ranging from 0.50” to near 2.00”. Two of the flash flood events in northern Nye and White Pine counties did not have useful data with no nearby observations and the radar beam overshooting the base of the storms to confirm antecedent precipitation. Data in 39 of the 49 events indicated no significant antecedent moisture had fallen within 48 hours of the event with the 2 events previously mentioned not included, while 10 of the events showed antecedent moisture prior to flash flooding. Although antecedent moisture can elevate the risk of flash flooding, it is not needed to cause flooding across the Elko CWA.

**4) Summary:**

There are many challenges that forecasters encounter regarding flash flooding in the Elko CWA and this paper illustrates some important meteorological patterns and parameters forecasters can use to improve flash flood forecasting across the forecast area. Flash flooding occurs most frequently during the months of July and August, but can occur in the late spring and early fall months. The UL pattern is the most common pattern experienced when documented flash flooding occurred, the FCH/UL is the second, the GBH is the third, and the FCH is the rarest pattern observed. Terrain, along with rainfall rates and rainfall duration, partially influenced by storm motion, appear to be the most important factors influencing flash flooding in the CWA. The quasi-stationary GBCZ is a focal point for thunderstorm initiation in central NV. Due to a south-north steering flow, these storms move over the relatively higher populated areas of the Humboldt River Valley. Several meteorological parameters were examined with PW, storm motion, and LCL heights showing the best correlation with reported flash flood events. However, other parameters such as dew points can be useful in forecasting flash flooding events.

**5) Acknowledgements:**

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**6) References:**

Brong, Brian (2006): Synoptic Patterns Associated with Flash Floods in Eastern California and Western Nevada. Western Region Technical Attachment Lite No. 06-15. [Available online at http://www.wrh.noaa.gov/media/wrh/online_publications/talite/talite0615.pdf]

Mesinger, Fedor, and Coauthors, 2006: North American Regional Reanalysis. *Bull. Amer. Meteor. Soc.*, **87**, 343–360.

National Climatic Data Center (2014). Storm Event Search Engine. [Available online at http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms]

West, Gregory L., W. James Steenburgh, (2010): Life Cycle and Mesoscale Frontal Structure of an Intermountain Cyclone. *Mon. Wea. Rev.*, **138**, 2528–2545. [Available online at http://www.inscc.utah.edu/~steenburgh/papers/tds.pdf]

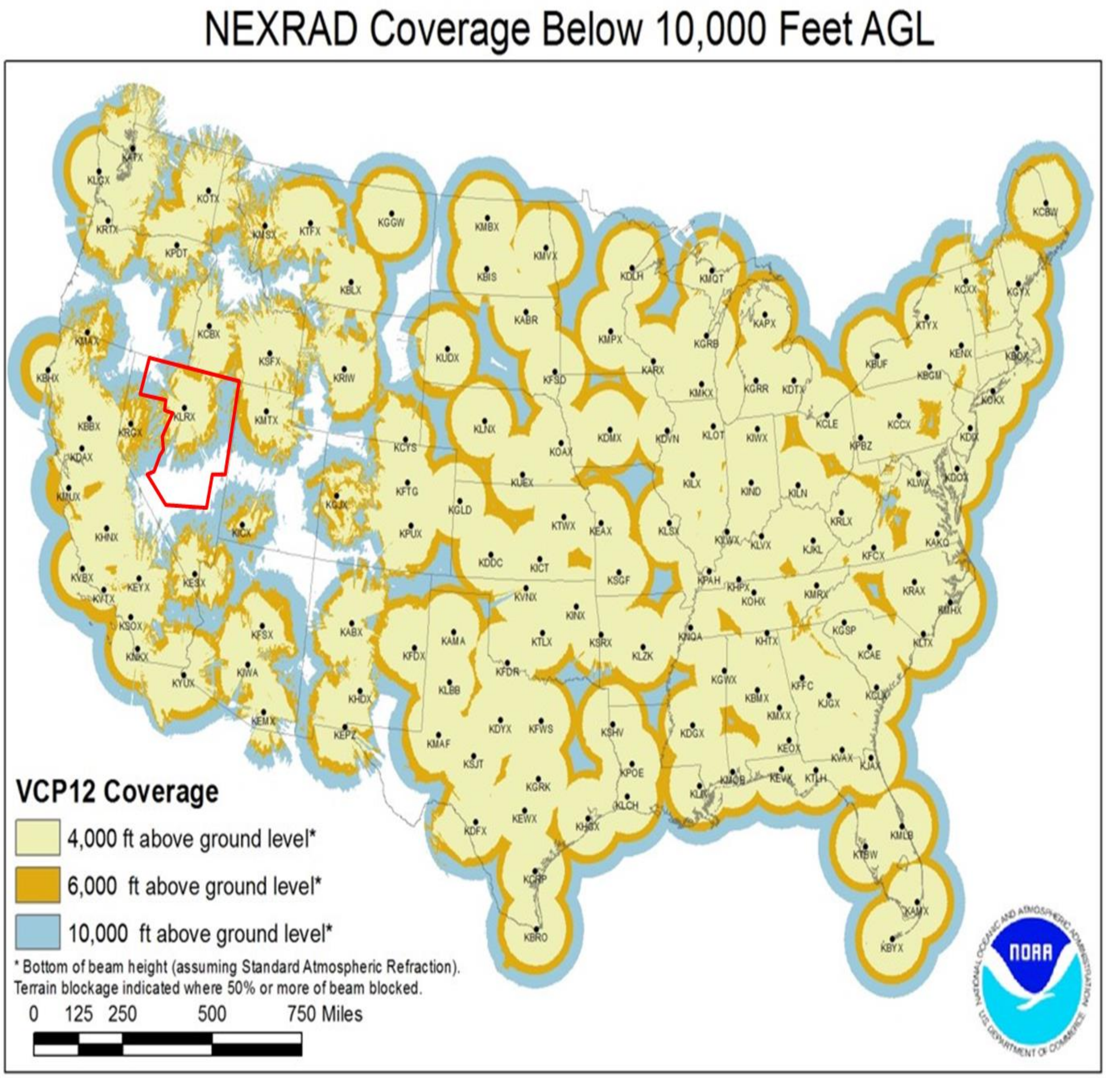


**Figure 1: NEXRAD coverage of the CONUS below 10,000 Feet AGL. The red area shows the approximate area of the Elko CWA with large swaths (white area) of the CWA with no coverage below this altitude.**

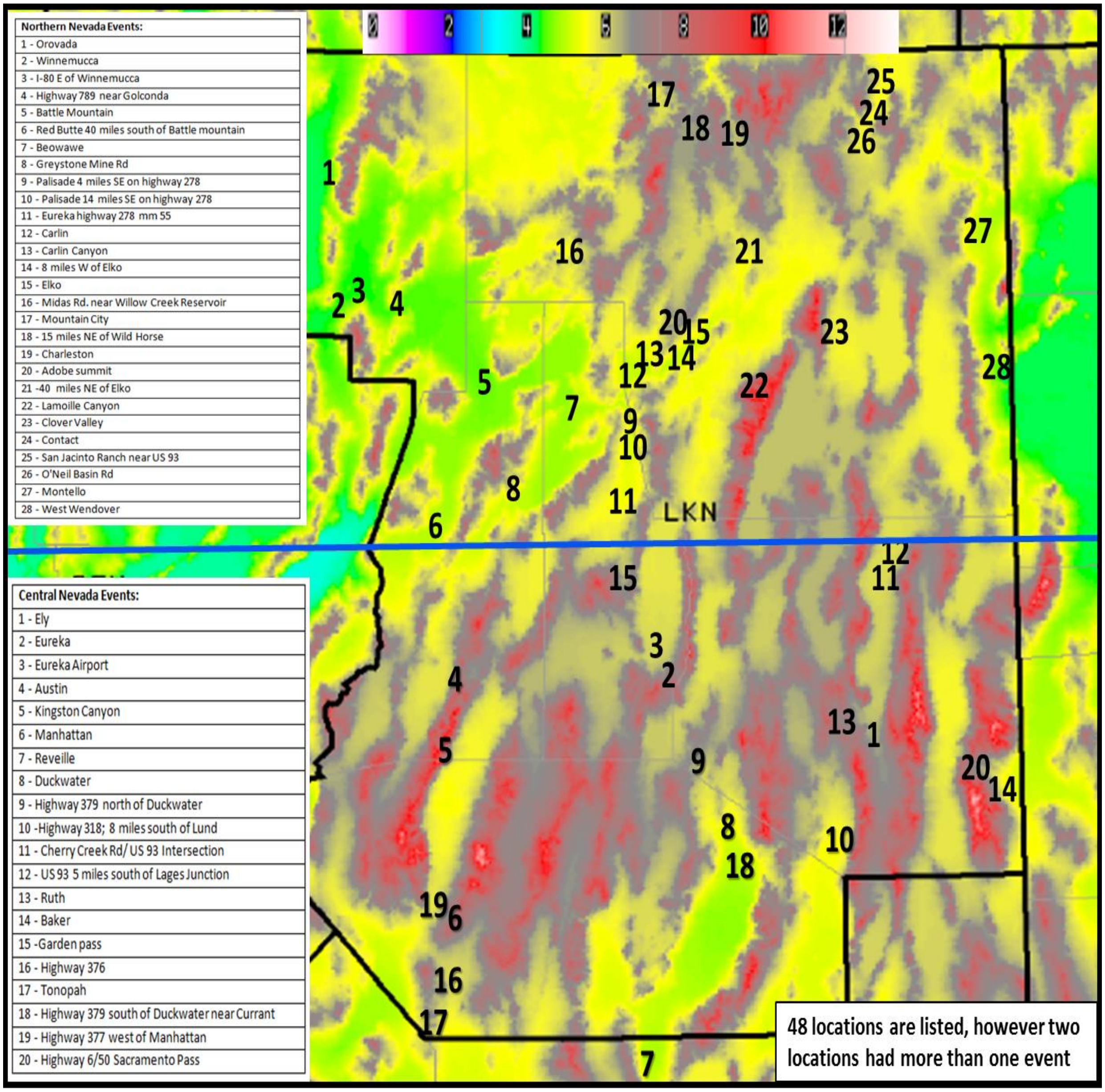


**Figure 2: High resolution topographical (warm colors represent higher elevations) map showing the boundary of the Elko CWA (black line). The numbers represent locations where flash flooding has been reported from 1995-2013. The blue line depicts the separation between northern and central Nevada flash flood events. The locations of northern Nevada flash flood events are in the text box on the upper left and for central Nevada flash flood events in the text box on the lower left. Two locations had reports of flash flooding on different days, which accounts for the total of 51 recorded events.**

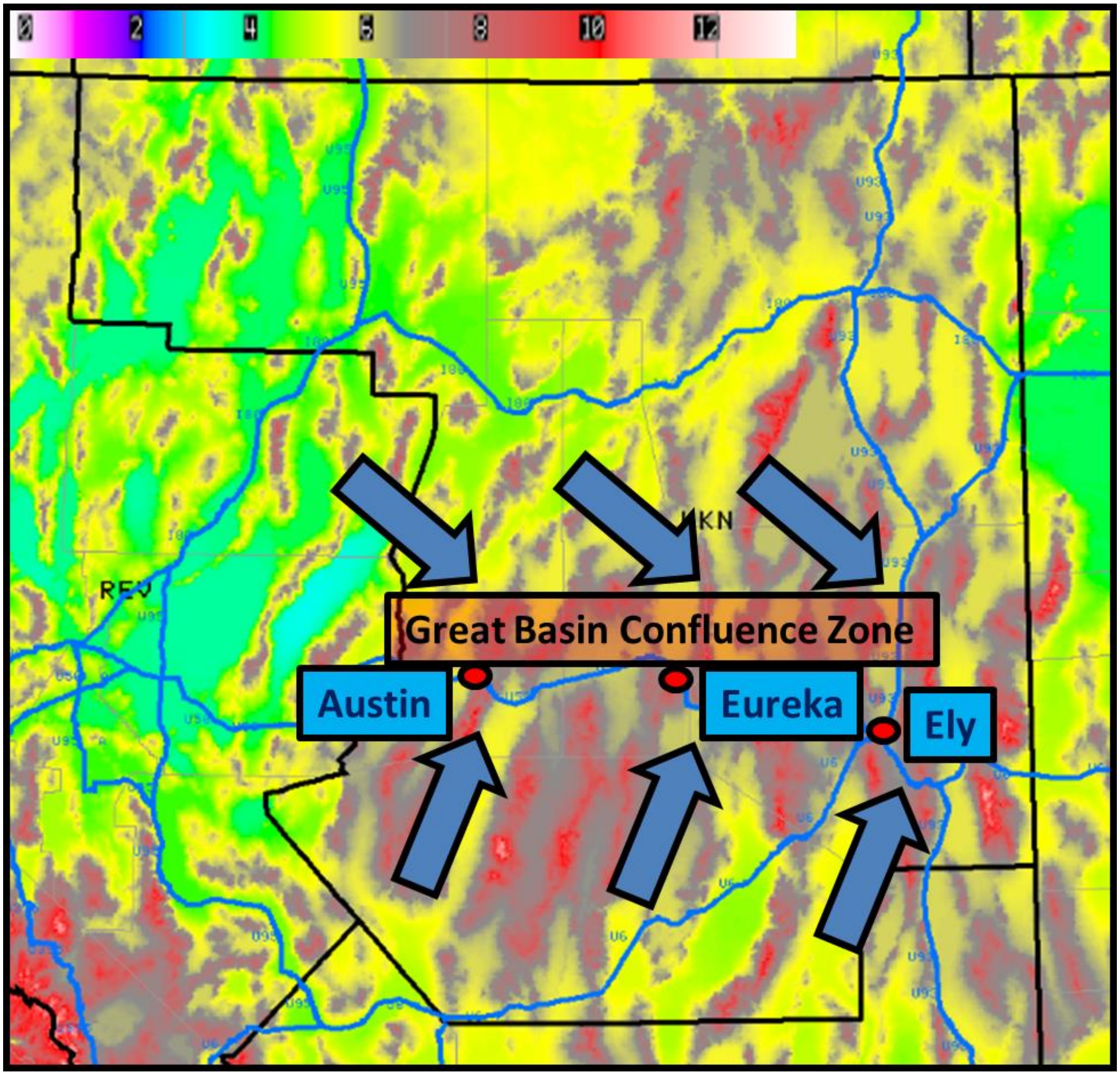


**Figure 3: High resolution topographical (warm colors represent higher elevations) map showing the boundary of the Elko CWA (black line). Large red dots show locations of towns near the Great Basin Confluence Zone. Large blue arrows simulate the near surface airflow around the confluence zone.**

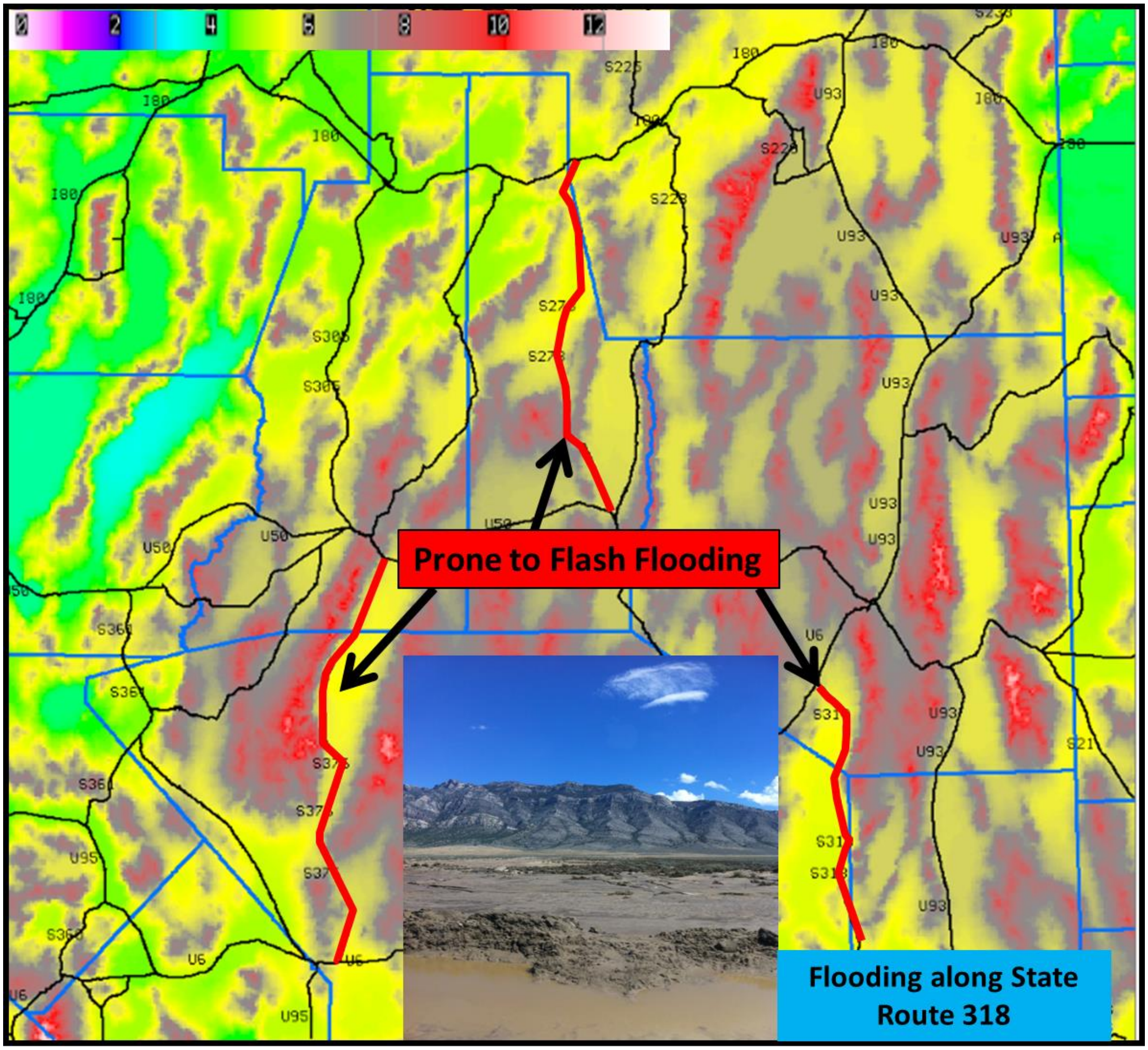


**Figure 4: High resolution topographical (warm colors represent higher elevations) map showing the Elko CWA (blue line). County boundaries are outlined in blue, while state routes 278, 318, and 376 are highlighted in red, depicting known roadways that are prone to flash flooding. Embedded image shows a documented debris flow along state route 318 during the summer of 2013.**

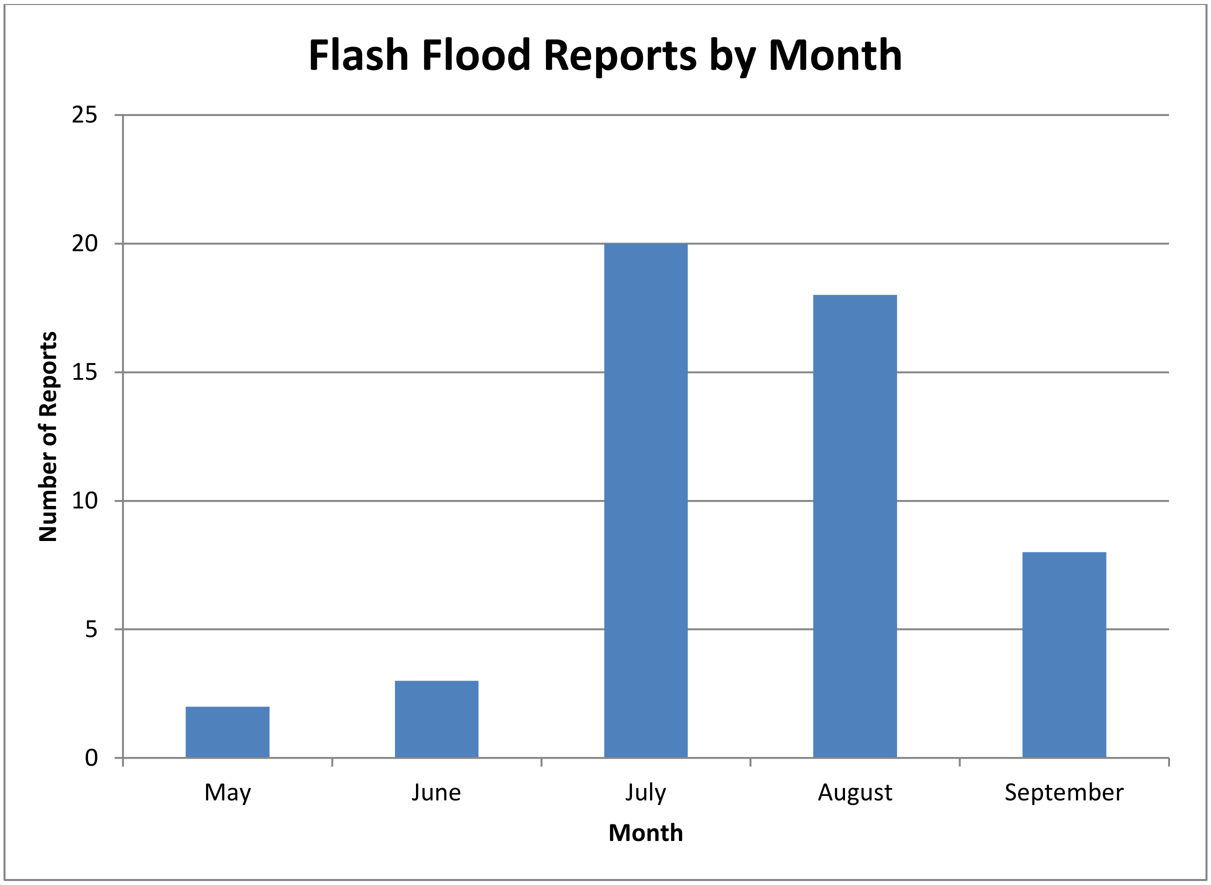


**Figure 5: Distribution of flash flood events by month for the Elko CWA. July and August have the most recorded flash flood cases for the Elko CWA.**

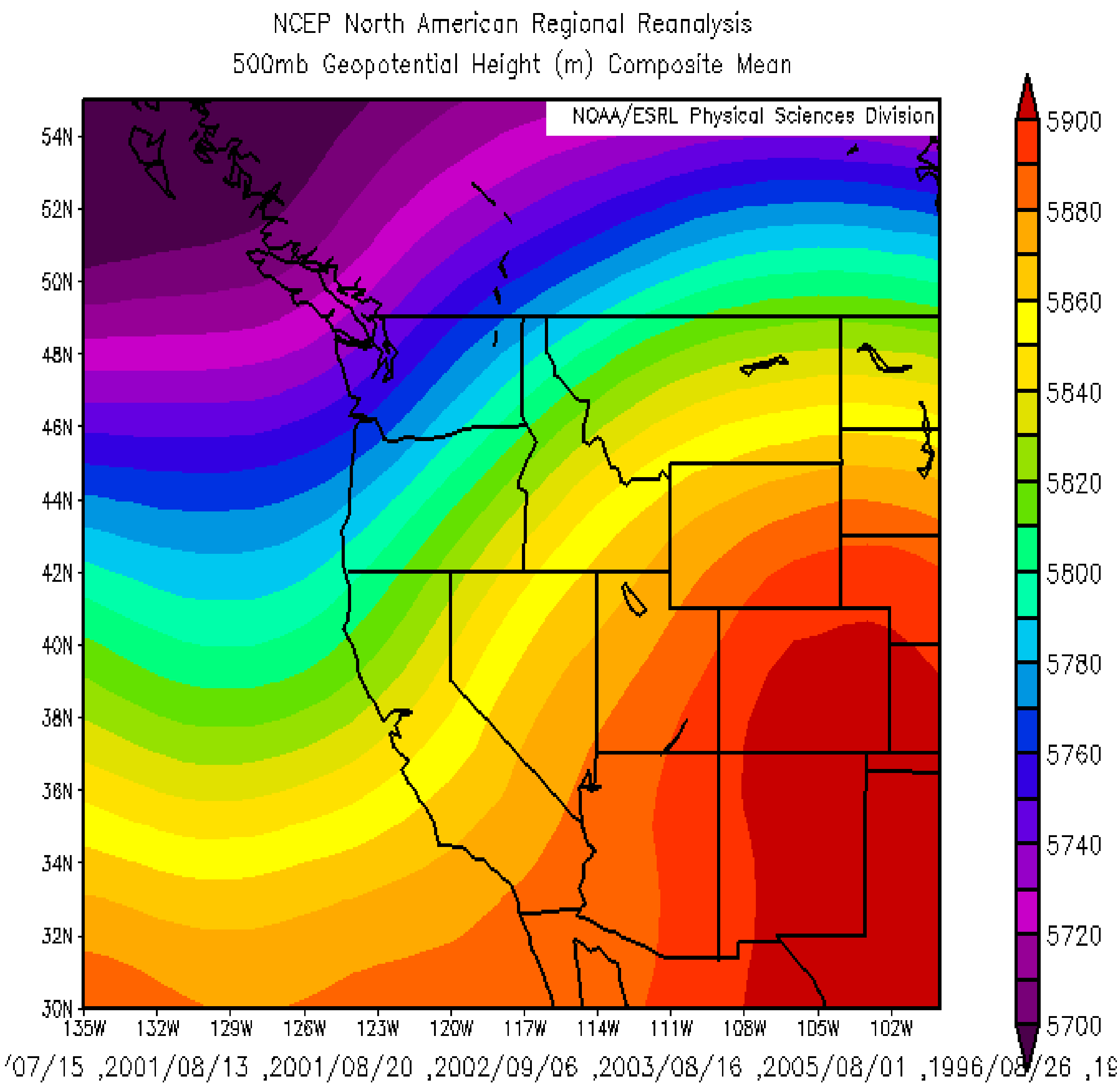


**Figure 6: NCEP North American Regional Reanalysis daily 500hPa mean composite for UL pattern flash flood events from 1995-2013 (warmer colors represent higher heights).**

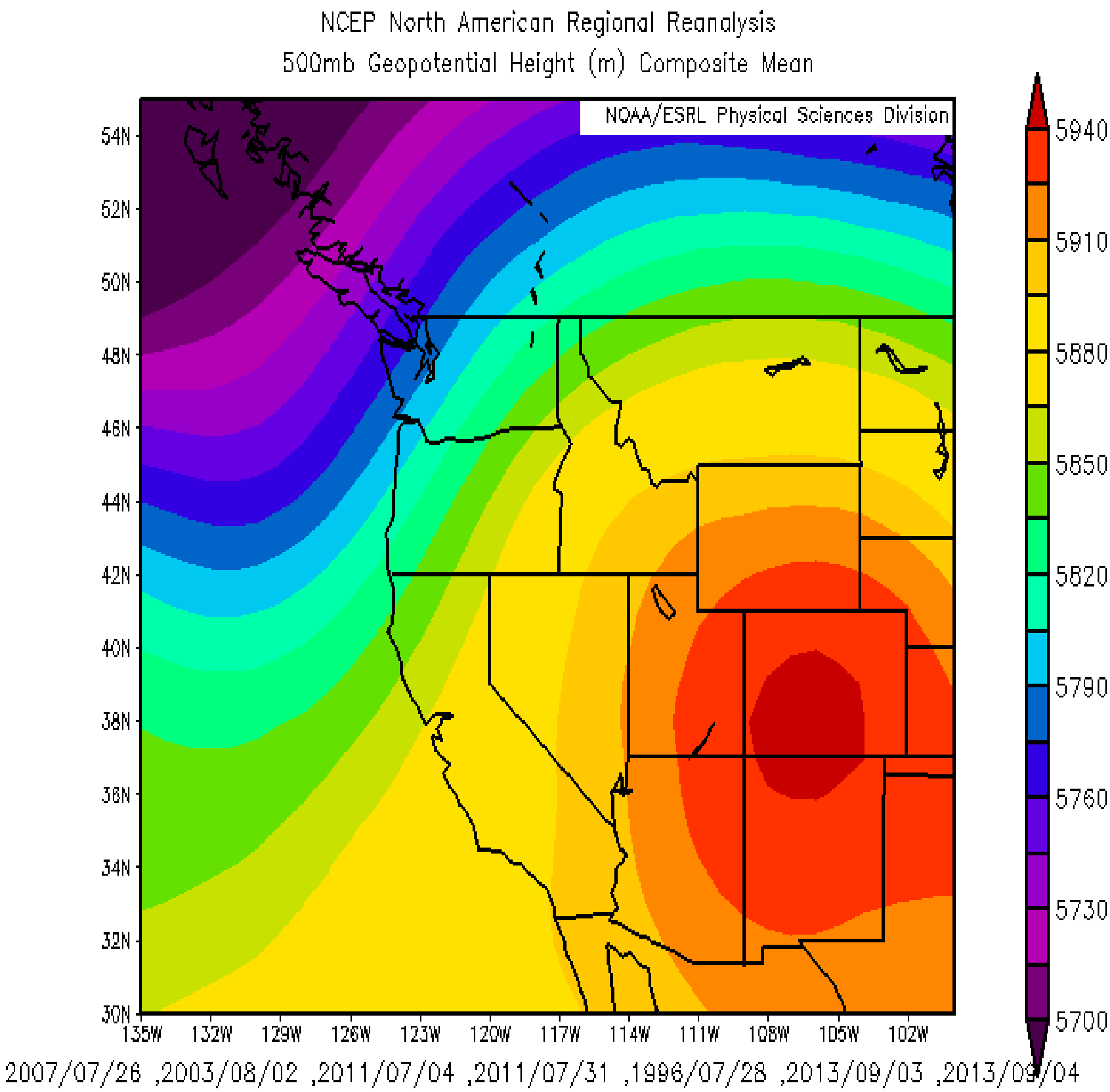


**Figure 7: NCEP North American Regional Reanalysis 500hPa daily mean composite for FCH / UL hybrid pattern flash flood events from 1995-2013 (warmer colors represent higher heights).**

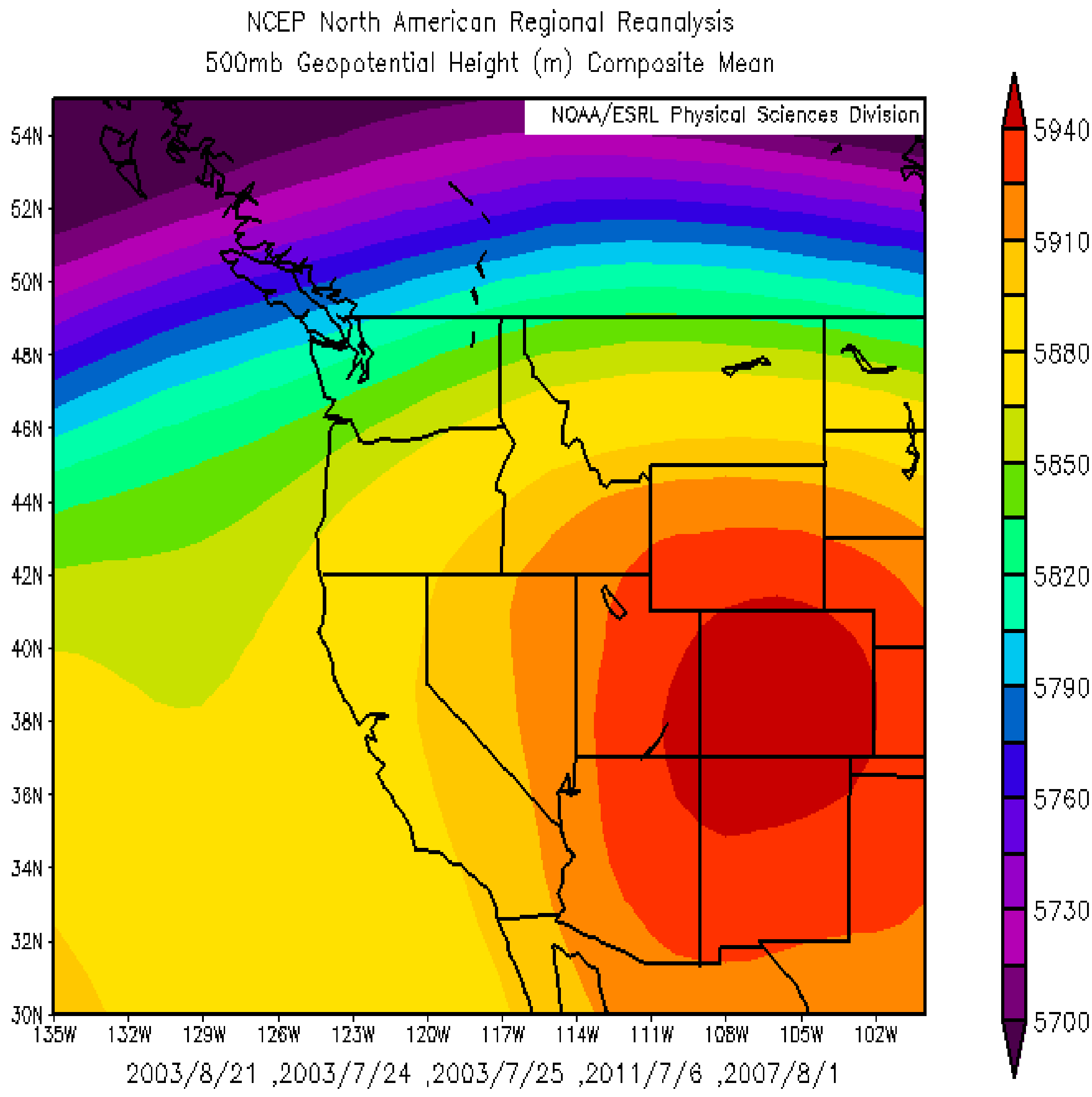


**Figure 8: NCEP North American Regional Reanalysis 500hPa daily mean composite for the FCH pattern flash flood events from 1995-2013 (warmer colors represent higher heights).**

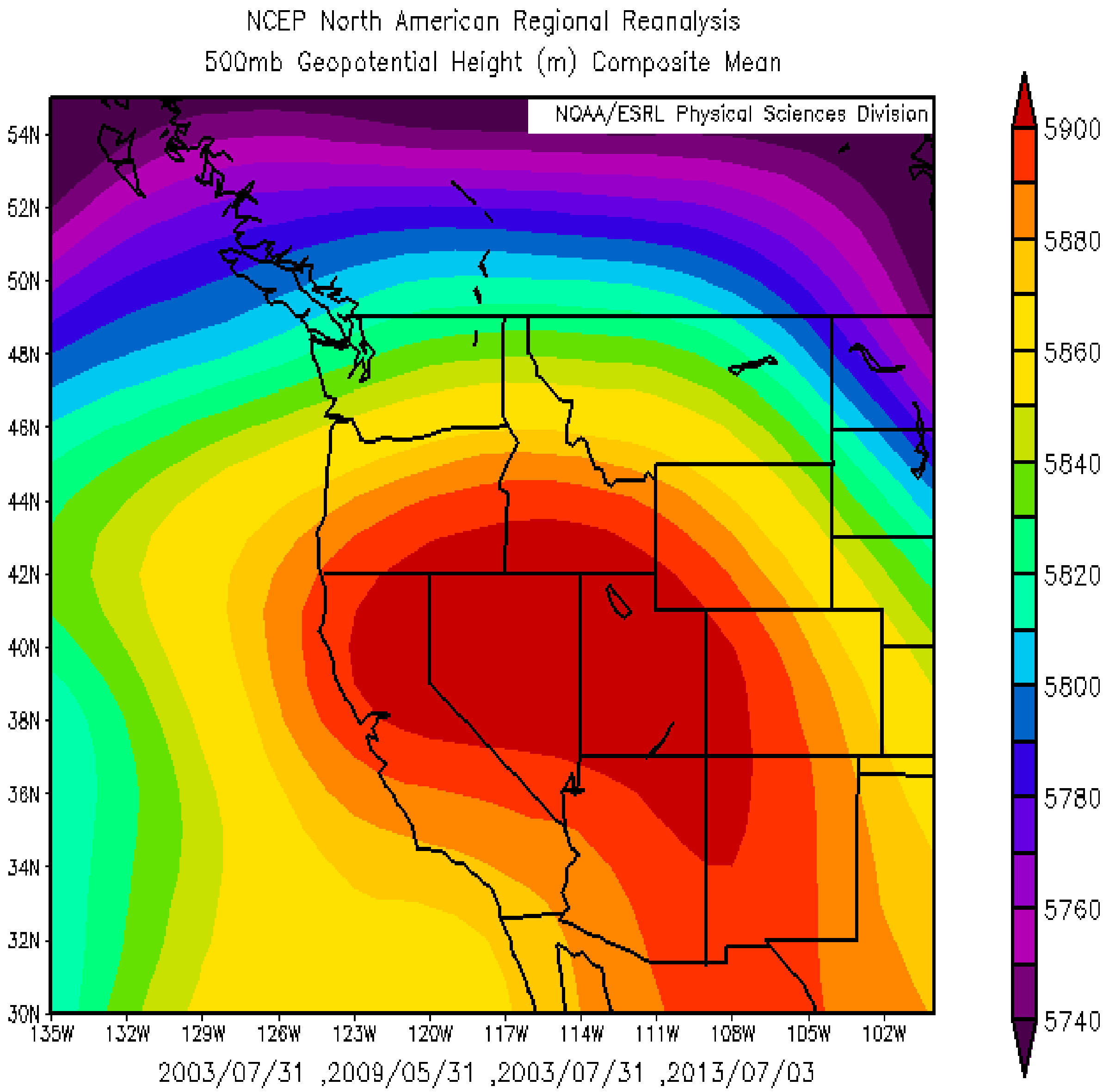


**Figure 9: NCEP North American Regional Reanalysis 500hPa daily mean composite for the GBH pattern flash flood events from 1995-2013 (warmer colors represent higher heights).**

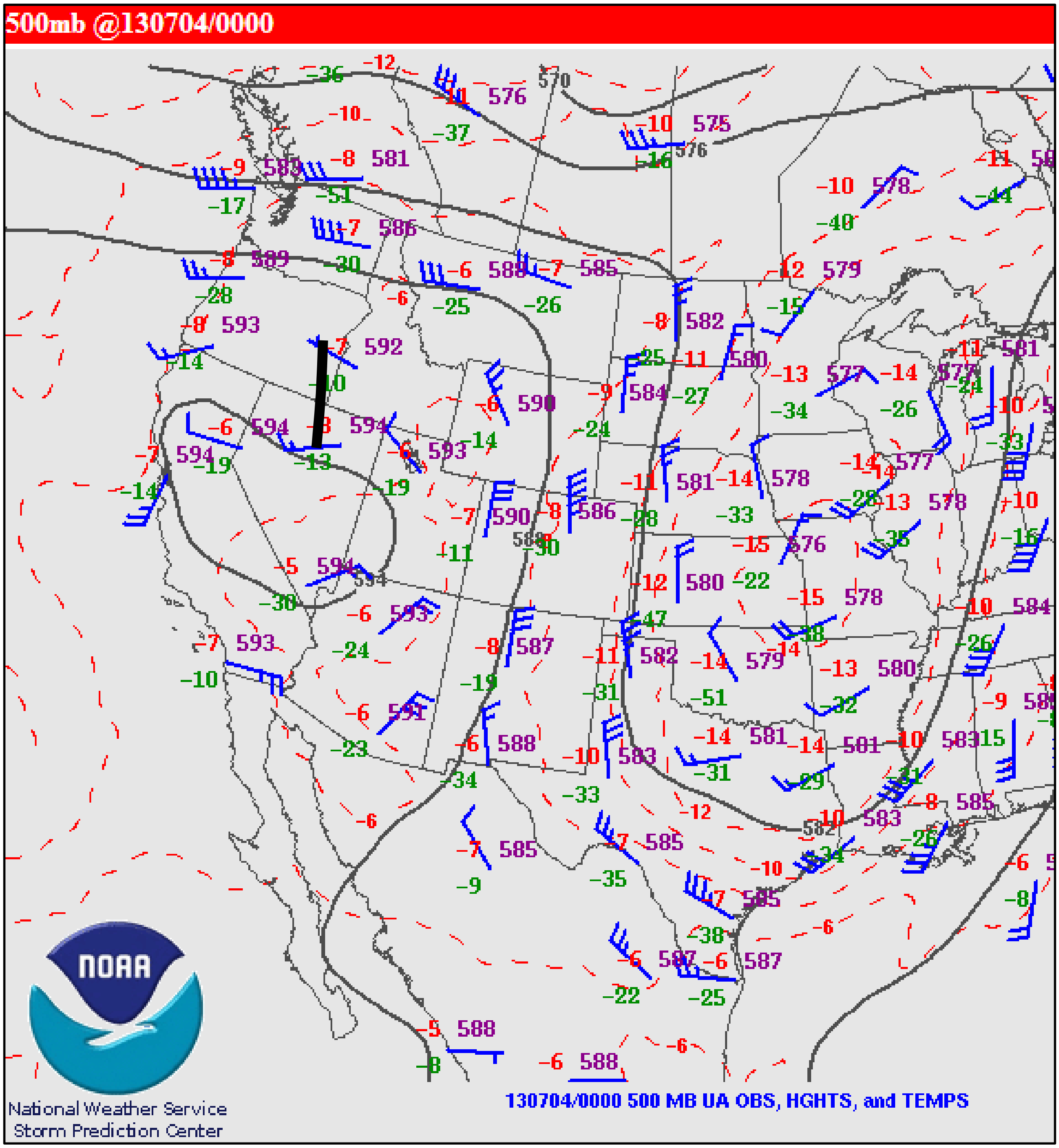


**Figure 10: 500 hPa analysis from 4 July 2013 at 0000 UTC. This is a recent example of a GBH event with a weak upper level trough progressing through the Elko CWA. Black line represents the approximate location of the mid-level short-wave trough.**

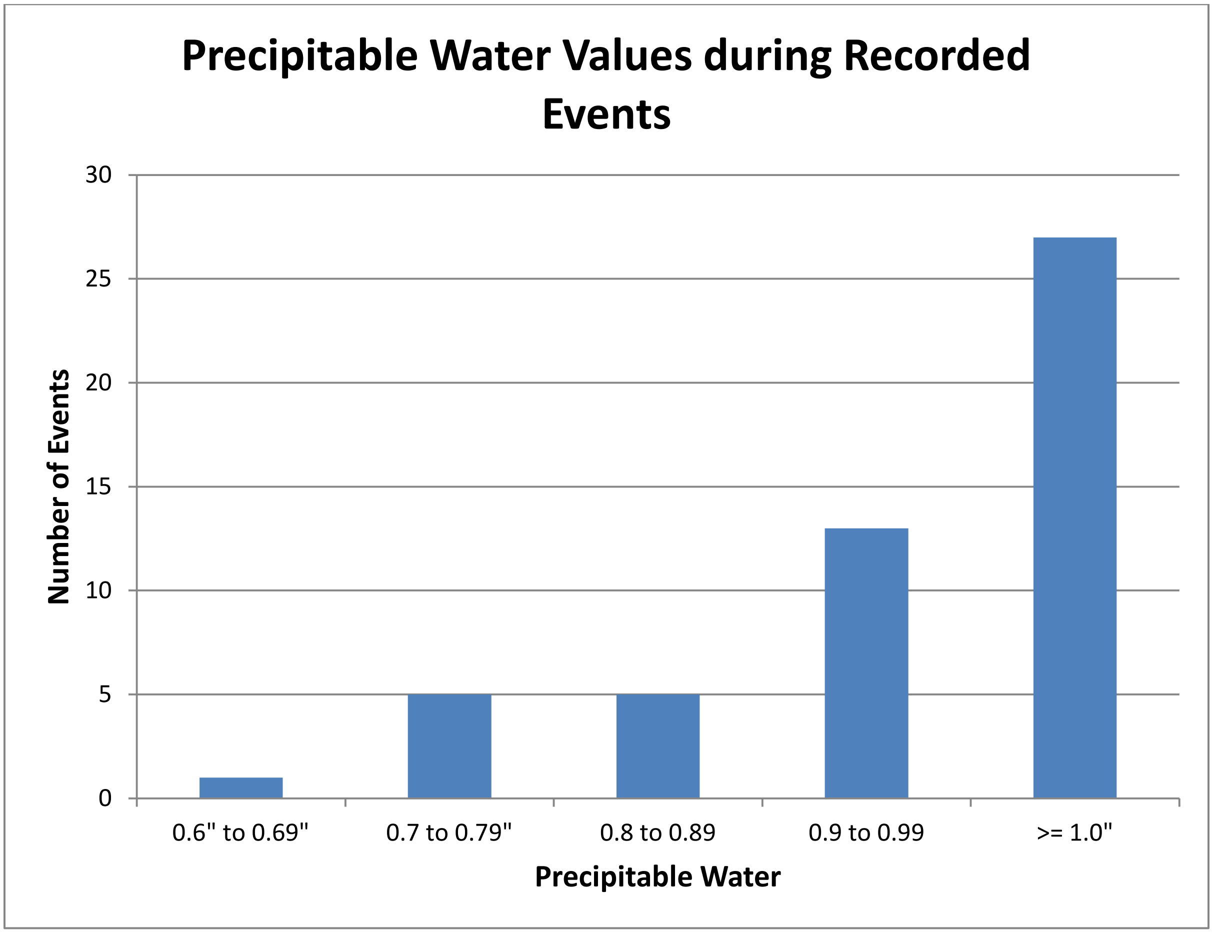


**Figure 11: Distribution of flash flood events by precipitable water values (in inches) for the Elko CWA.**

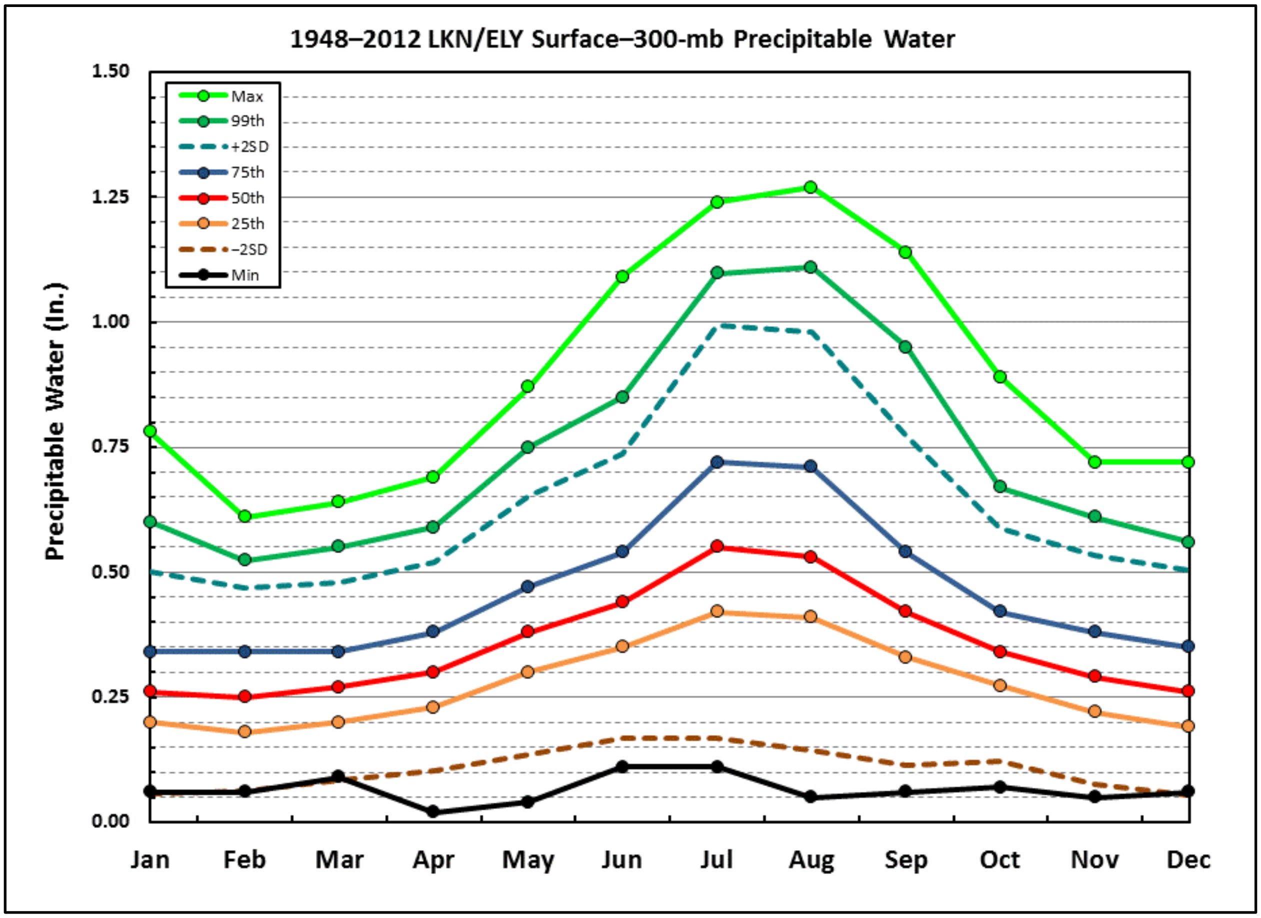


**Figure 12: Elko/Ely threaded precipitable water (in inches) climatology (surface to 300 hPa) from 1948 to 2012. +2 Standard deviations during July and August occur with PWAT values of 1". Graph taken from [http://www.crh.noaa.gov/unr/include/pw.php?sid=LKN.](http://www.crh.noaa.gov/unr/include/pw.php?sid=LKN)**

| Surface Dewpoint Values | # of Flash Flood Events |
|---|---|
| >50 F | 31 |
| 45-50 F | 19 |
| <45 F | 1 |

**Figure 13: Distribution of flash flood events by dewpoint temperature (in degrees F) for Elko CWA.**

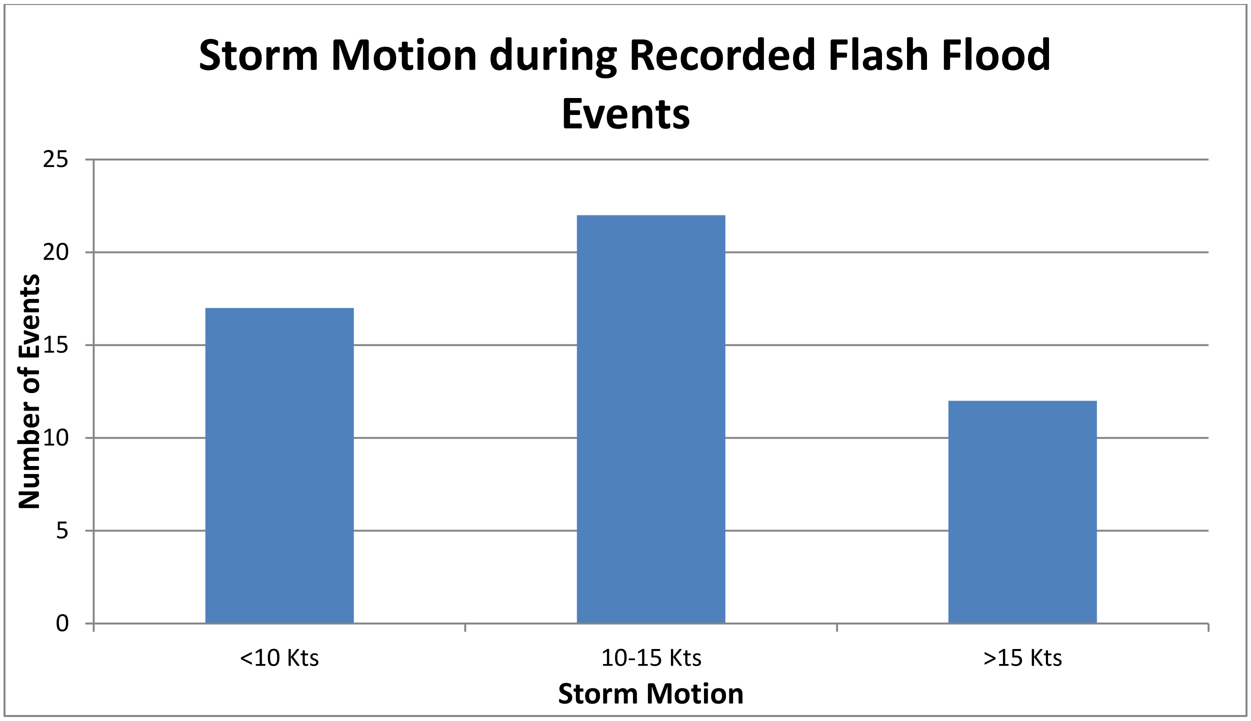


**Figure 14: Distribution of flash flood events by storm motion (in knots) for the Elko CWA.**

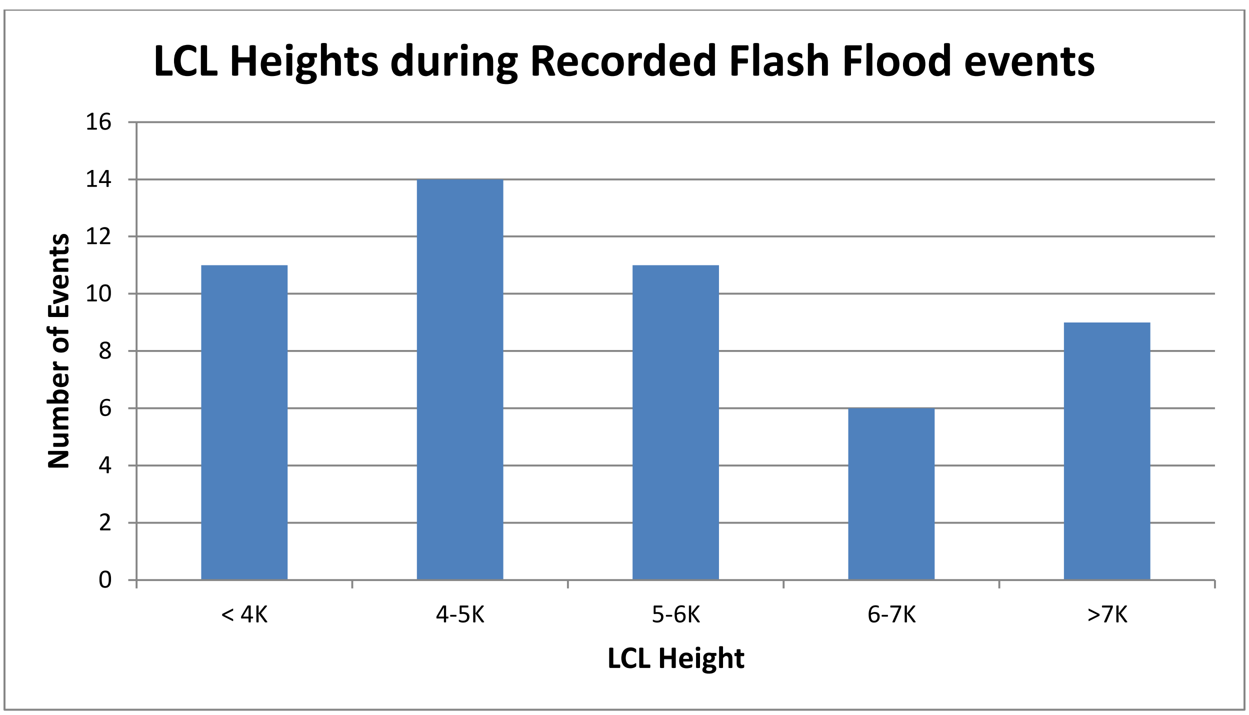


**Figure 15: Distribution of flash flood events by lifted condensation level (LCL) height in feet above ground level (AGL) for the Elko CWA.**