860 Decision Support Services and Impacts of the Flash Flood and Debris Flow in Mount Charleston, Nevada, 28 July 2014

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1. INTRODUCTION

A destructive flash flood and debris flow occurred on 28 July 2014 within the town of Mount Charleston, Nevada. Mount Charleston is located in the Spring Mountains approximately 40 km (25 miles) northwest of Las Vegas (Fig. 1) and at an elevation of approximately 2286 meters (7,500 feet) mean sea level (MSL). An increase in monsoonal moisture over several days combined with an approaching upper-level shortwave trough provided the necessary ingredients for thunderstorm development across the region, particularly over the higher elevations of the Spring Mountains.

Of greater importance was the antecedent ground conditions for portions of Mount Charleston, as heavy rain of two inches fell in less than two hours on the Carpenter 1 wildfire burn scar. The result of such heavy rain on a nearly impermeable, sloped surface caused flash flooding and a debris flow on 28 July 2014. This resulted in more than $2 million USD in damages to Clark County infrastructure and residential property in the Rainbow Canyon Subdivision.

This case study provides a brief meteorological overview of the 28 July 2014 event, discusses the decision support services provided by the National Weather Service (NWS) in Las Vegas, and highlights the societal and economic impacts. Section 2 provides brief background information on the Carpenter 1 wildfire burn scar. Section 3 discusses the meteorological overview of the flash flood event as well as radar analysis and rainfall estimation. Section 4 provides an overview of NWS Las Vegas products and services. Section 5 highlights the societal and economic impacts, while section 6 discusses conclusions that can be made from this event.

2. CARPENTER 1 WILDFIRE BURN SCAR

The Carpenter 1 wildfire was a large wildfire in the Spring Mountains of Clark County in southern Nevada. The fire was started by lightning on 1 July 2013 and consumed 27,881 acres between the elevations of 1524 through 3352.8 meters (5,000-11,000 feet) MSL by the time it was fully contained on 17 September 2013 (National Interagency Fire Center 2013). The fire burned with moderate to severe intensity resulting in hydrophobic soils over much of the burn scar. The main populated location impacted was Mount Charleston, Nevada. Figure 2 illustrates the size of the burn scar and a few key locations throughout Mount Charleston.

3. METEOROLOGICAL ANALYSIS

The meteorological analysis will consist of two sections, 3.1 Synoptic Analysis and 3.2 Radar Analysis. Section 3.1 will discuss overall atmospheric conditions, while Section 3.2 will discuss storm structure characteristics from radar analyses.

3.1 *Synoptic Analysis*

The North American monsoon pattern (Adams and Comrie 1997) had been established several days prior to the high impact flash flood and debris flow of 28 July

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2014. Precipitable water values surged to record numbers by the evening of 27 July 2014, which are visible in the 00 UTC 28 July 2014 NWS Las Vegas (KVEF) sounding (Fig. 3) and the Storm Prediction Center's (SPC) sounding climatology (Fig. 4). These anomalously high moisture values remained in place through 28 July, as noted in the KVEF 18 UTC 28 and 00 UTC 29 soundings (Figs. 5 and 6). The SPC sounding climatology also shows the precipitable water value for the 00 UTC 29th sounding was a daily maximum as well (Fig. 7). All soundings also indicate relatively deep warm cloud layers, with lifted condensation levels (LCLs) just above 1828 meters (6,000 feet) MSL and freezing levels around 3962.4 meters (13,000 feet) MSL.

Investigating the instability values associated with the 18 UTC 28 July 2014 sounding (Fig. 5) shows nearly 850 J/kg of convective available potential energy (CAPE) from the surface-based parcel (SBCAPE), which is also the CAPE for the most unstable parcel (MUCAPE). Diurnal heating played a large role in the destabilization process and subsequent thunderstorm development. Additionally, the convective temperature was much lower than indicated by the sounding due to the elevation of roughly 2286 meters (7,500 feet) MSL for Mount Charleston when compared to the elevation of the sounding location of nearly 670.6 meters (2,200 feet) MSL. This atmospheric profile for an elevation of approximately 2286 meters (7,500 feet) MSL would only need temperatures to reach the middle teens degrees Celsius (lower 60s degrees Fahrenheit) for thunderstorm development near Mount Charleston. Diurnal heating was not the only forcing mechanism at play. The approach of a trough of low pressure, or potential vorticity advection (Fig. 8), also provided large-scale lift to the region (Bosart et al. 2010).

Once convection developed near Mount Charleston and over the Carpenter 1 burn scar, individual cells continued to develop over nearly the same location producing 50.8 mm (two inches) of rain in 1.5 hours. Individual cell motion was only about 4-5 m/s (10-12 mph), visible in Fig. 9 as well as the surface-6 km and surface-8 km mean wind on the 18 UTC sounding (Fig. 5). Thus, once thunderstorm cells developed, they exhibited quasi-stationary back building characteristics outlined by Schumacher and Johnson (2005) within that 1.5 hour time period.

3.2 *Radar Analysis*

Convection along the Spring Mountains of Clark County, Nevada, particularly the Mount Charleston area began at 1718 UTC and continued until 1845 UTC. As mentioned in Section 3.1, thunderstorm cell motion was only about 10 knots and redevelopment was over nearly the same location within that 1.5 hours. Slow storm motions combined with quasi-stationary back-building convection are a few ingredients necessary for the production of flash flooding (Doswell et al. 1996 and Schumacher and Johnson 2005). Estimated rainfall amounts using a 3-hour accumulation from the quantitative precipitation estimation (Q3 QPE; Zhang et al. 2014) illustrates 50.8 mm (two inches) of rain fell across portions of the Mount Charleston area (Fig. 10). A backyard rain gauge from a Rainbow Canyon resident validated that radar estimate. This area receiving two inches of rainfall in less than 2 hours gives this event at least an average recurrence interval of 10 years (Fig. 11). Factoring in the antecedent ground conditions makes it worse.

These thunderstorms also featured low-echo centroids (LECs), which is a type of convective cell where most of the reflectivity is located within the warm portion of the cloud bearing layer. This allows for rainfall produced from collision-coalescence (Vitale and Ryan 2012). Vitale and Ryan indicated several consistent features found in LEC storms, which include: radar reflectivity ≤60 dBZ within a storm cell, a long-lived steady state reflectivity of 45-55 dBZ, and increasing reflectivity with decreasing height within a storm cell due to the physical properties of the collision-coalescence process. Additionally, excessive rainfall events produced from collision-coalescence processes typically require a deep warm-cloud layer, weak and/or shallow updrafts, limited cloud layer wind shear, and high relative humidity through a deep layer (Davis 2001). The synoptic analysis discussed in Section 3.1, depicts an atmosphere that contains the necessary ingredients for heavy rainfall, as shown by Davis (2001).

The storms over Mount Charleston exhibited quasi-stationary back building characteristics (Figs. 12a and 12c) outlined by Schumacher and Johnson (2005), with each LEC thunderstorm training over the Carpenter 1 burn scar and Rainbow Canyon Subdivision of Mount Charleston within a 1.5 hour period. Cross sectional (Fig. 12b) and three-dimensional (Fig. 12d) analyses of the storms at 1742 UTC and 1818 UTC, respectively, revealed shallow updrafts with the highest reflectivities within the warm cloud layer. It is within this layer of the cloud where collision-coalescence processes can occur, provided that all water remains in liquid phase (Vitale and Ryan 2012). The shallow nature of the updrafts is one indication that storm relative vertical velocities were weak enough for collision-coalescence to effectively occur, along with the relatively thin CAPE profile from the 18 UTC KVEF observed sounding (Fig. 5) on 28 July 2014 (Zipser and LeMone 1980). The combination of environmental and storm-relative ingredients created excessive rainfall producing thunderstorms. This resulted in major flash flooding and debris flow across the Mount Charleston area, particularly in Rainbow Canyon.

4. NWS LAS VEGAS PRODUCTS AND SERVICES

NWS Las Vegas began issuing daily email briefings to core partners on 25 July 2014 to indicate a more active period of thunderstorms would be possible 27-29 July 2014, with 28 July being the primary day of concern. This concern arose due to the forecast of an approaching shortwave trough or inverted trough, which could increase areal coverage and perhaps the development of more organized thunderstorms as large-scale forcing increased (Bosart et al. 2010).

Given the potential of more widespread and potentially organized convection within an anomalously moist atmosphere, the NWS Las Vegas Forecast Office issued a flash flood watch during the early morning hours on 28 July 2014, valid for the entire day (Fig. 13). The town of Mount Charleston was included in the flash flood watch. Each email briefing contained a specialized table to heighten awareness of potential flash flooding on local burn scars. The table within the email briefing on the morning of 28 July 2014 indicated NWS Las Vegas believed there would be an 80 percent chance of a flash flood threat over the Carpenter 1 burn scar (Fig. 14).

The first flash flood warning issued for the Mount Charleston area was at 10:46 AM PDT. NWS Las Vegas utilized a phone notification list to inform the Rainbow Canyon neighborhood watch of the heavy rain and potential for debris flow if heavy rain continued. Heavy rain did continue and NWS Las Vegas received a call from the neighborhood watch that flooding was occurring and a debris flow was beginning. A flash flood emergency was quickly issued by NWS Las Vegas at 11:30 AM PDT. Recognizing extreme events as they unfold and providing severity-based product wording, such as *flash flood emergency*, has been highlighted by several NWS service assessments (NWS 1999, 2010, 2011).

The news of a devastating flash flood and debris flow came from the Clark County Office of Emergency Management. NWS Las Vegas began creating weather-specific talking points that both the NWS and Clark County officials could use for media inquiries. NWS Las Vegas participated in conference calls with the Clark County Office of Emergency Management to discuss weather associated with the flash flood and debris flow, but also to discuss current and forecast weather conditions, as they pertain to cleanup operations. During the conference calls, NWS Las Vegas also discussed the possibility of a damage survey the following day, 29 July 2014. A damage survey was scheduled and the necessary equipment prepared. NWS Las Vegas daily email briefings to core partners continued through 3 August as cleanup operations were ongoing, but also to highlight the potential for another active period of showers and thunderstorms. Luckily, the next round of thunderstorms on 3 August did not cause additional flooding or debris flows for Mount Charleston.

In early August the United States Army Corps of Engineers (USACE) were tasked with designing and constructing a diversion channel and berm to temporarily protect the Rainbow Canyon subdivision from future flash flooding and debris flows. The USACE utilized NOAA Atlas 14 (Bonnin et al. 2011) data as well as NWS Las Vegas local knowledge of the typical rainfall amounts and patterns for the Mount Charleston area. By the beginning of September, the USACE had prepared their design document for the diversion channel and berm, with construction scheduled to begin shortly thereafter. The project was scheduled for completion before spring 2015. Pictures taken by NWS Las Vegas in April 2015 show the completed diversion channel and berm (Figs. 15 and 16).

5. IMPACTS AND DAMAGE

Impacts and damage to the Rainbow Canyon subdivision in Mount Charleston were extensive, with more than $2 million USD in damages to Clark County infrastructure and residential property:

- Highway 157, a major arterial road for Mount Charleston, was closed for nearly 24 hours.
- Power was lost at a nearby substation, affecting 402 customers.
- Deep erosion caused substantial damage to area roadways including Rainbow Canyon Blvd, which is the main street through the subdivision (Fig. 17a).
- The deep erosion also substantially damaged water supply and waste water pipes to many of the homes (Figs. 17b and 17c).
- Landline telephone service was lost during the event, restored the following day.
- Numerous propane tanks and connections were inspected and fixed where necessary.
- Approximately 12 homes were damaged, with two containing severe damage and were not inhabitable (Figs. 18 and 19).
- Shelters were established by the American Red Cross at a nearby hotel and school for impacted residents.
- Within 48 hours, Clark County cleared tons of debris and water, power, and fuel services were restored.

6. CONCLUSIONS

The destructive flash flood and debris flow that occurred on 28 July 2014 in the town of Mount Charleston resulted from the combination of daily record monsoonal moisture, destabilization via diurnal heating, and increased large-scale forcing from an approaching upper-level trough of low pressure. Anomalous moisture, deep warm cloud layers, and slow storm motions created a favorable environment for highly efficient precipitation. Storms moving over nearly the same locations produced two inches of rainfall in a 1.5 hour period, which has an average recurrence interval of at least 10 years. Of greater importance was that this rain fell on the Carpenter 1 wildfire burn scar. The resultant flash flood and debris flow caused more than $2 million USD in damages to Clark County infrastructure and residential property in the Rainbow Canyon Subdivision.

NWS Las Vegas highlighted the potential for flash flooding, particularly on 28 July 2014, by issuing a flash flood watch and included a flash flood threat index table for area burn scars within an email briefing sent to core partners. Once convection was ongoing across Mount Charleston and information of a potential debris flow was received, NWS Las

Vegas issued a flash flood emergency highlighting the severity of a debris flow. NWS Las Vegas also assisted the Clark County Office of Emergency Management by producing talking points and fact sheets for the event. After the event, a damage survey was conducted to learn more about the impacts. NWS Las Vegas assisted the USACE as they designed a temporary diversion channel and berm to reduce future flash flooding and debris flows.

7. REFERENCES

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8. FIGURES

Figure 1. Google Earth image showing the location of Mount Charleston, Nevada, with respect to Las Vegas, Nevada. Mount Charleston is approximately 40 km (25 miles) northwest of Las Vegas and at an elevation of roughly 2286 meters (7,500 feet) MSL within the Spring Mountains of Clark County. The location of the KESX WSR-88D radar is also noted in the lower right-hand corner, which is approximately 91.73 km (57 miles) southeast of Mount Charleston.

Figure 2. The maroon area outlined in white depicts the Carpenter 1 wildfire burn scar, 27,881 acres. The area outlined in red is Rainbow Canyon, which contains the heavily damaged Rainbow Canyon subdivision during this event.

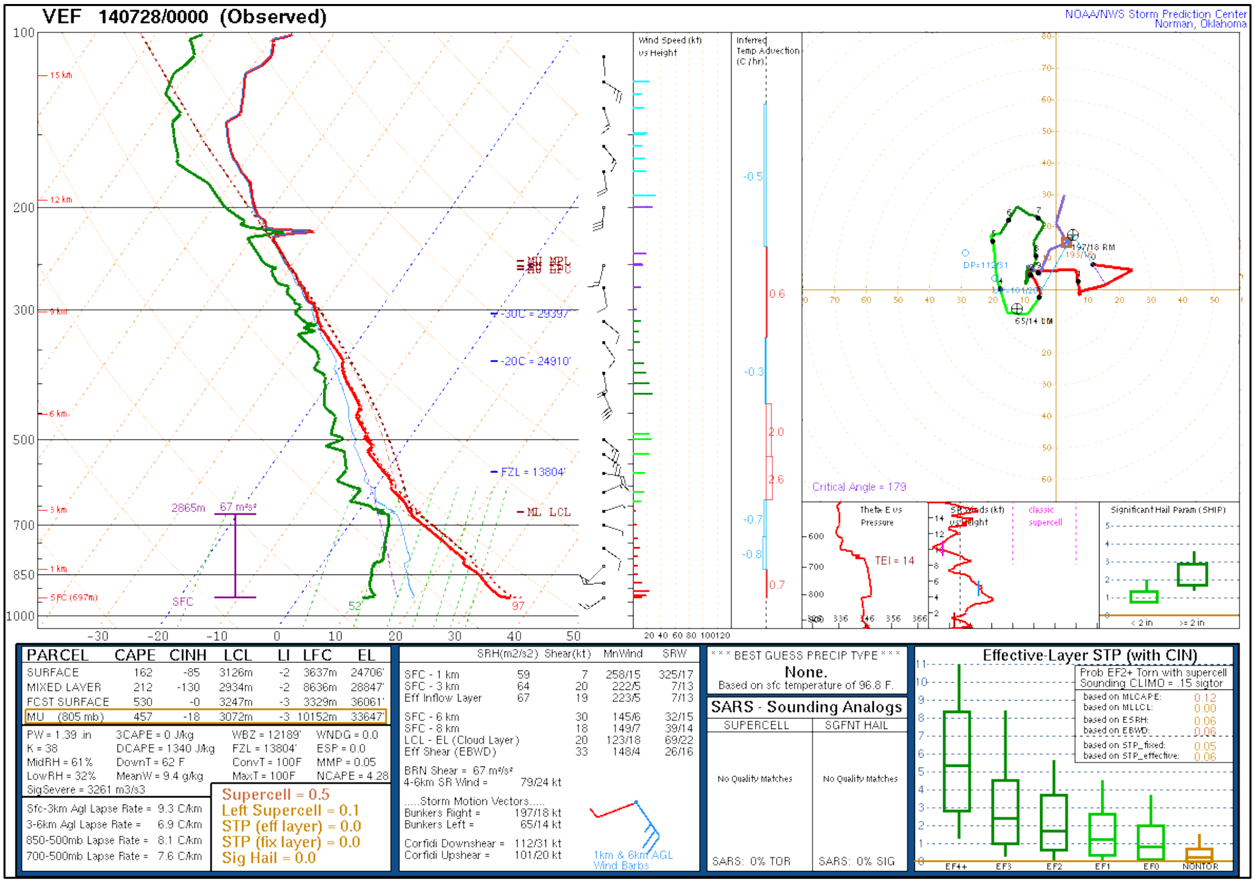

Figure 3. The 00 UTC 28 July 2014 KVEF observed sounding illustrates the anomalous moisture across the area, with a precipitable water value of 35.3 mm (1.39 inches). This precipitable water value is a daily record for the 00 UTC sounding on this date, which is also illustrated in Figure 4.

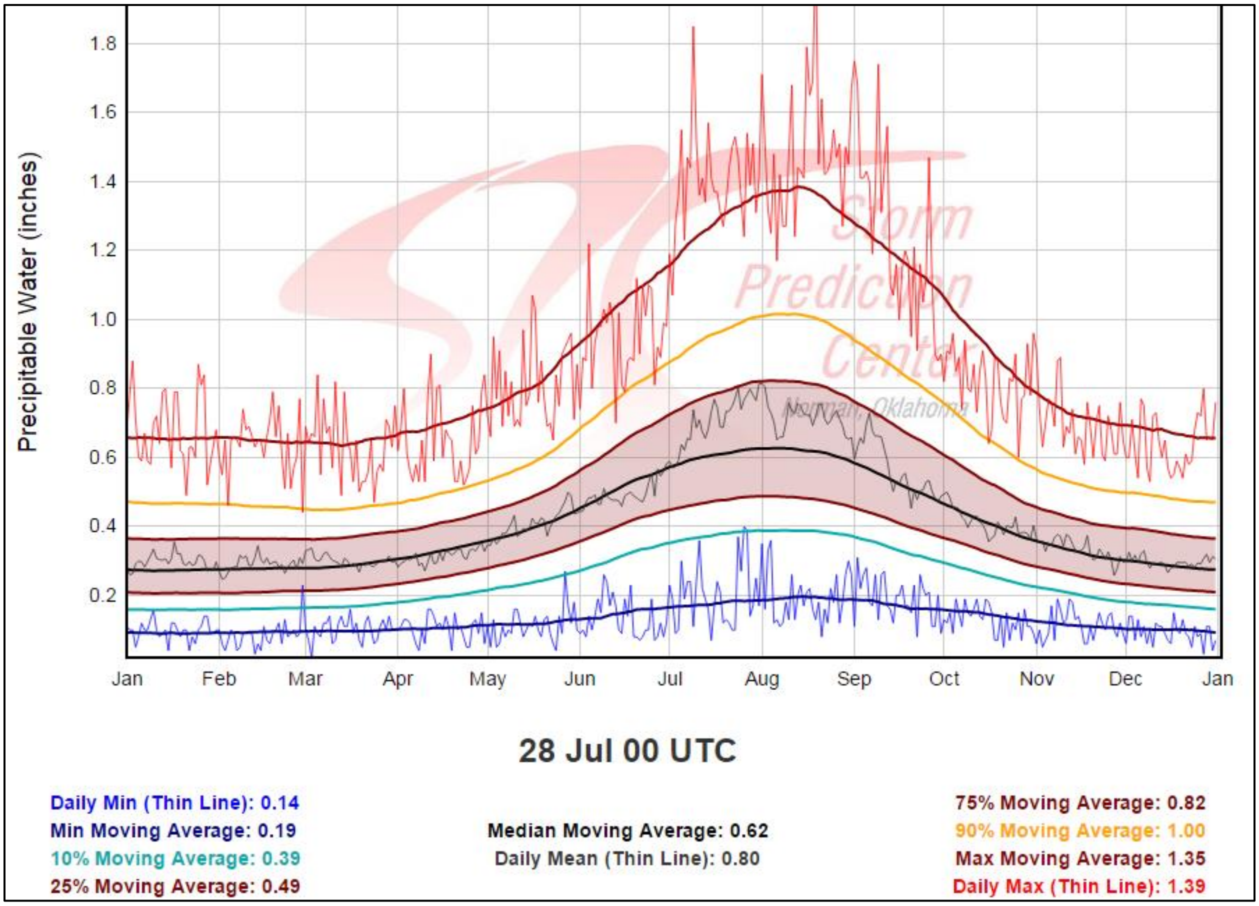

Figure 4. Sounding climatology from the Storm Prediction Center for the KVEF sounding at 00 UTC 28 July 2014. The daily precipitable water value of 35.3 mm (1.39 inches) for a 00 UTC sounding on this date was a record. Note the daily max value in the lower right corner matches the precipitable water value from the observed sounding that day (Fig. 3).

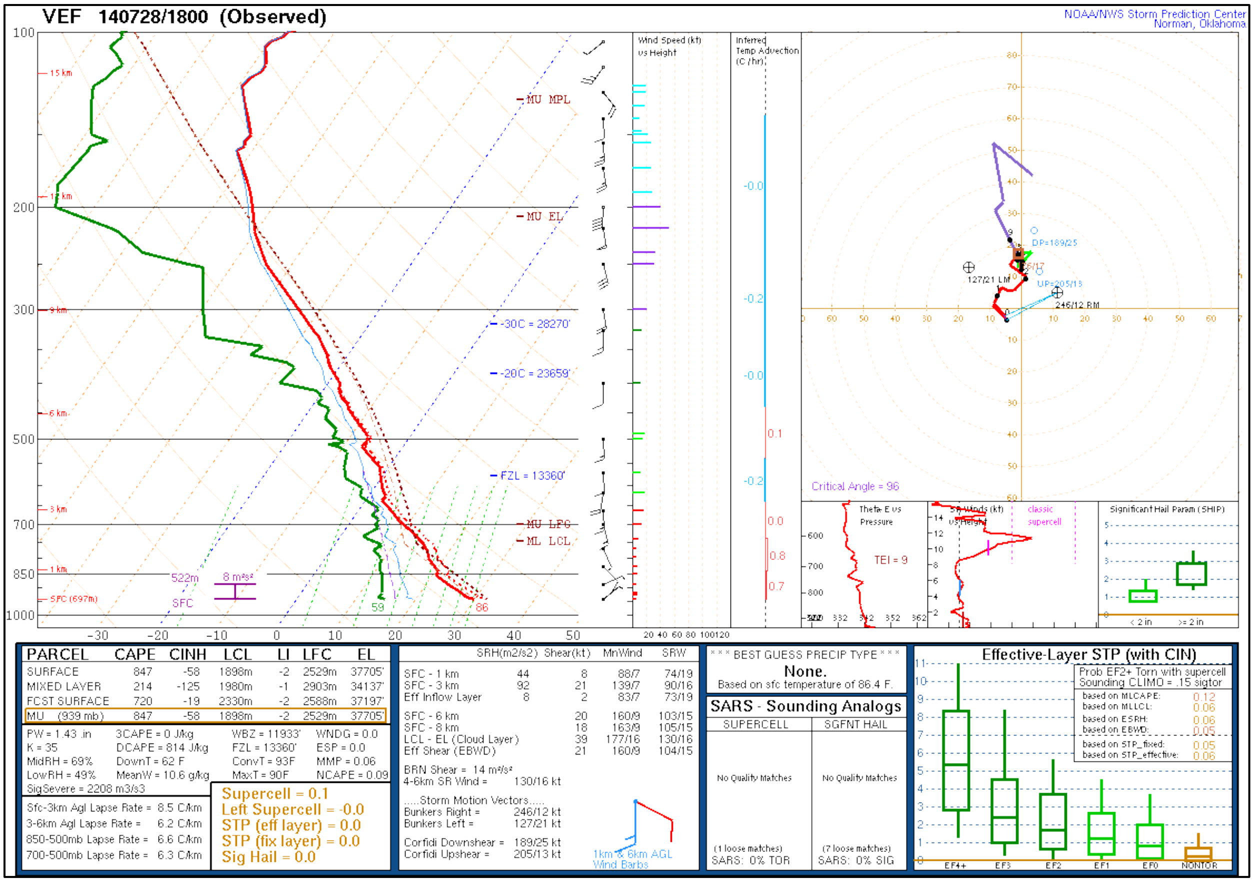

Figure 5. Same as Figure 3, except for 18 UTC 28 July 2014. This sounding illustrates an increase in anomalous moisture across the area, with a precipitable water value of 36.3 mm (1.43 inches). The tall and narrow CAPE profile provides a MUCAPE value of 847 J/kg, which would be achieved via diurnal heating.

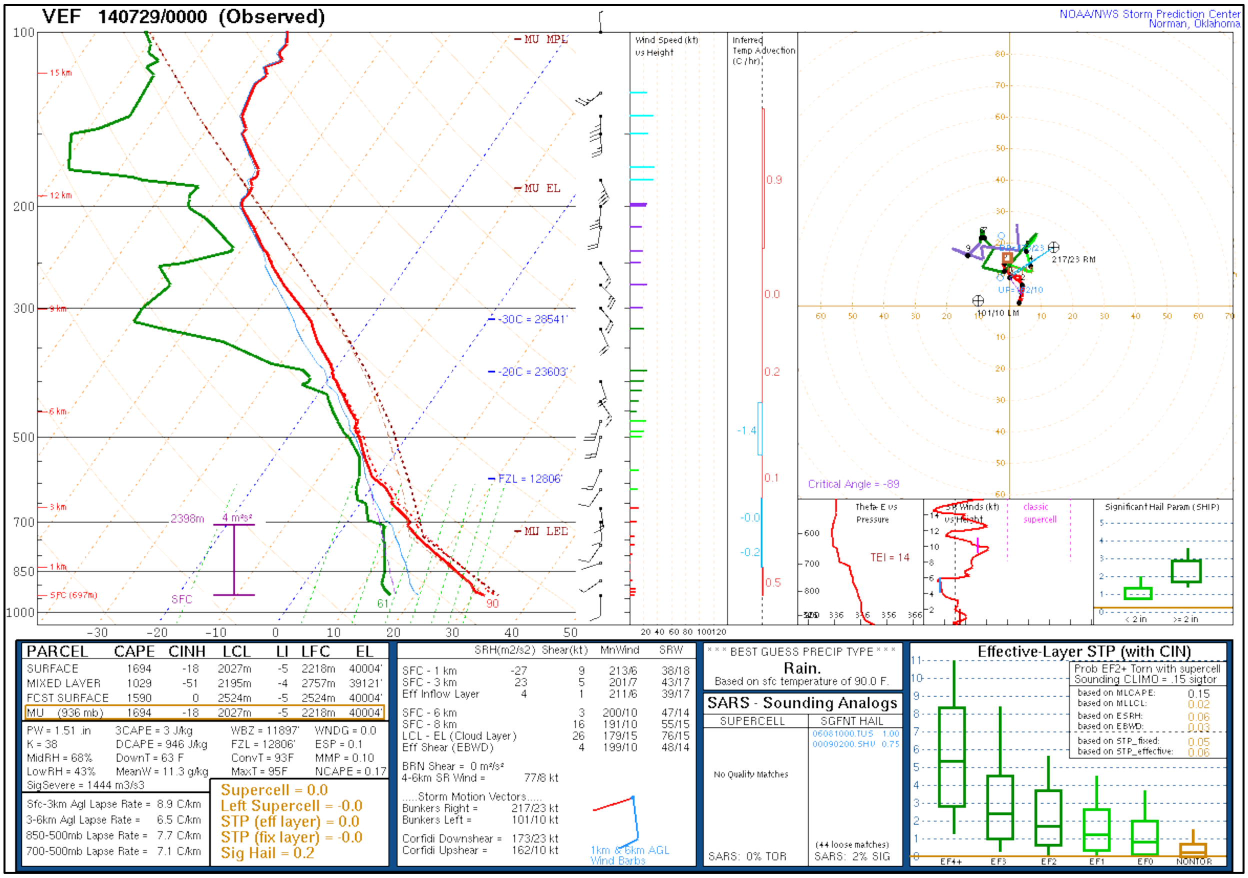

Figure 6. Same as [Figures 3] and [5], except for 00 UTC 29 July 2014. This sounding illustrates a daily record precipitable water value of 38.4 mm (1.51 inches), which is also illustrated in [Figure 7]. By this time MUCAPE values increased to 1694 J/kg, but convection was already finished and the atmosphere over Mount Charleston stabilized.

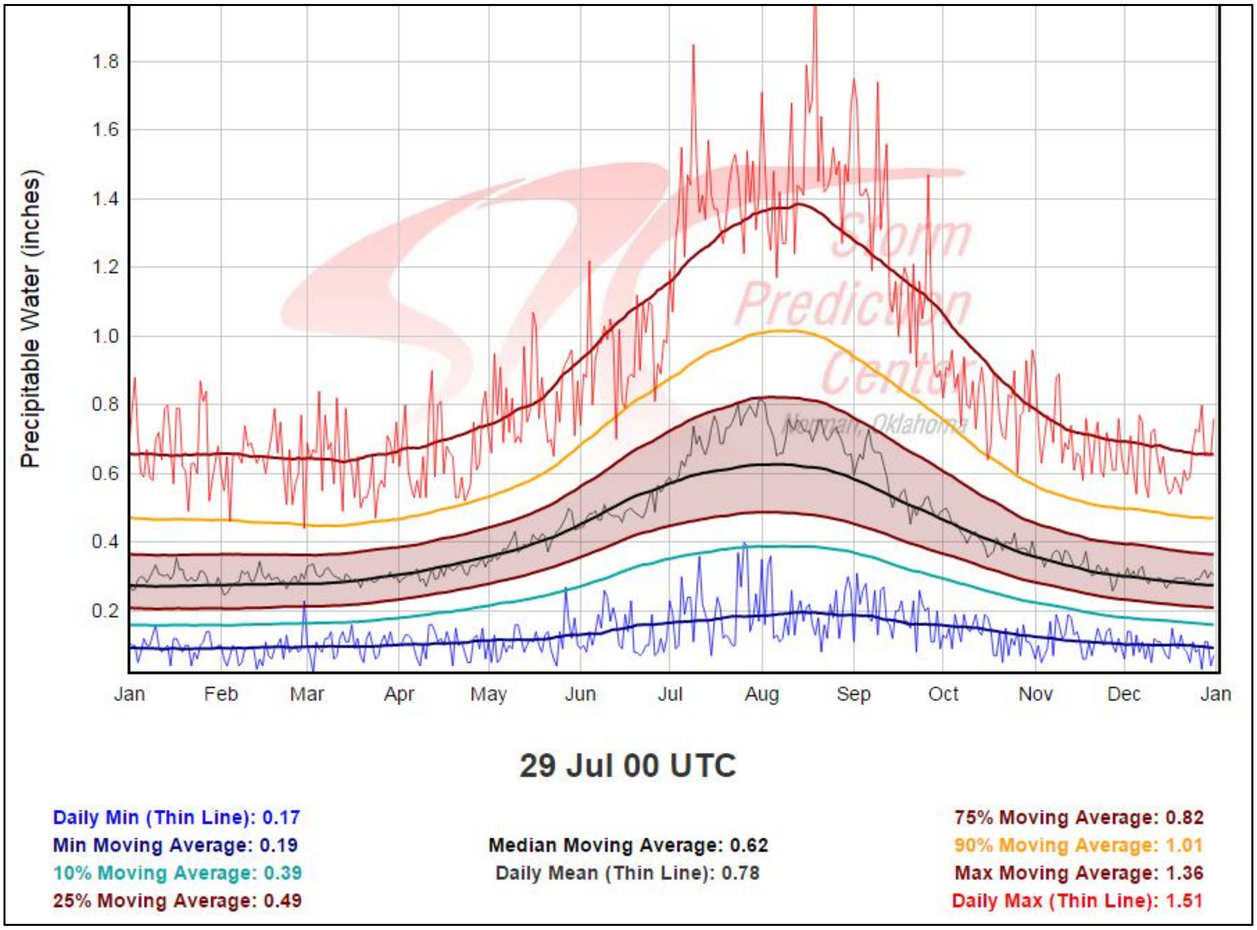

Figure 7. Same as Figure 4, except for 00 UTC 29 July 2014. The daily precipitable water value of 38.4 mm (1.51 inches) for a 00 UTC sounding on this date was a record. Note the daily max value in the lower right corner matches the precipitable water value from the observed sounding that day (Fig. 6).

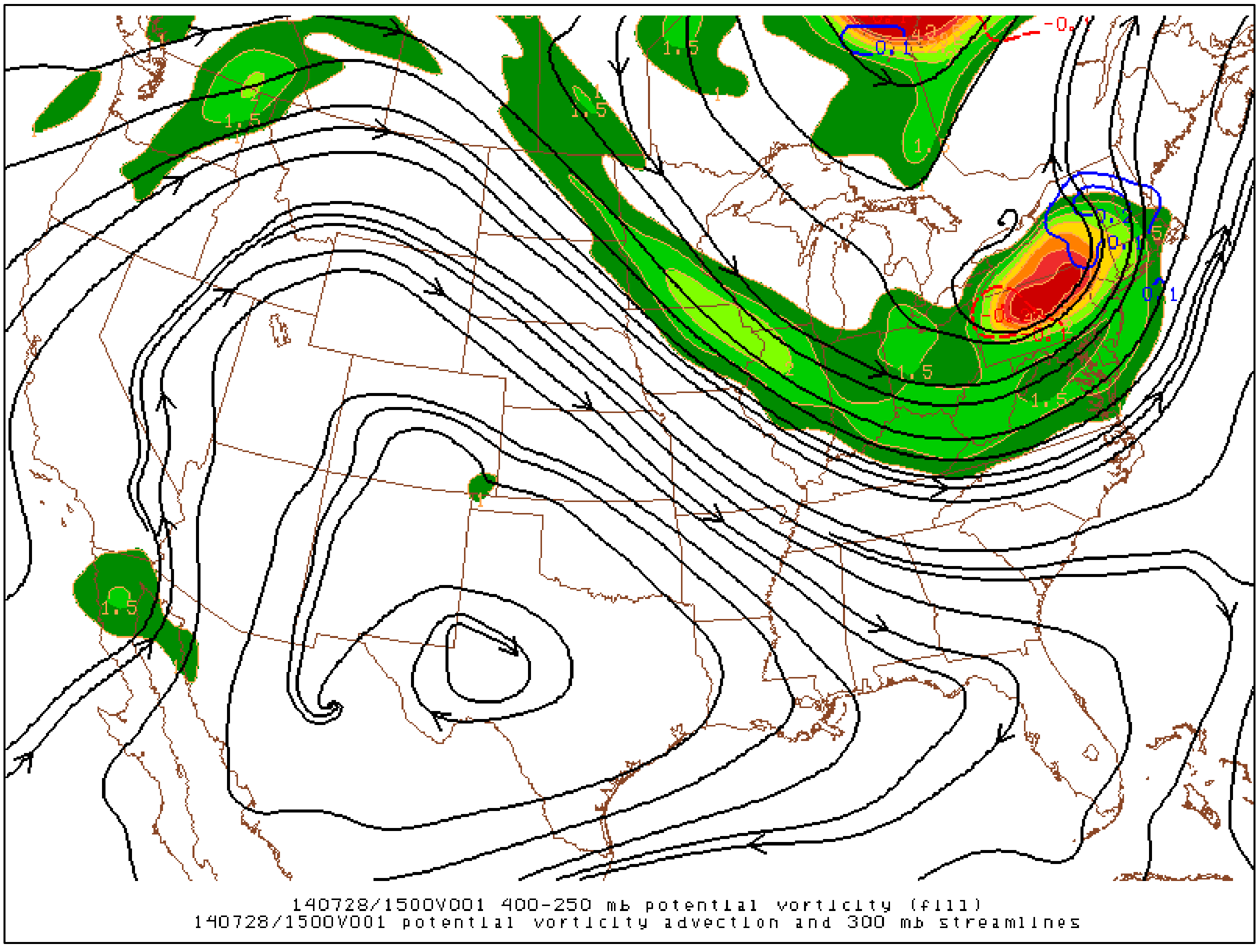

Figure 8. The Storm Prediction Center mesoanalysis of 400-250 hPa potential vorticity (shaded) over northern Baja California associated with a trough of low pressure advecting north (streamlines) toward southern Nevada at 15 UTC on 28 July 2014.

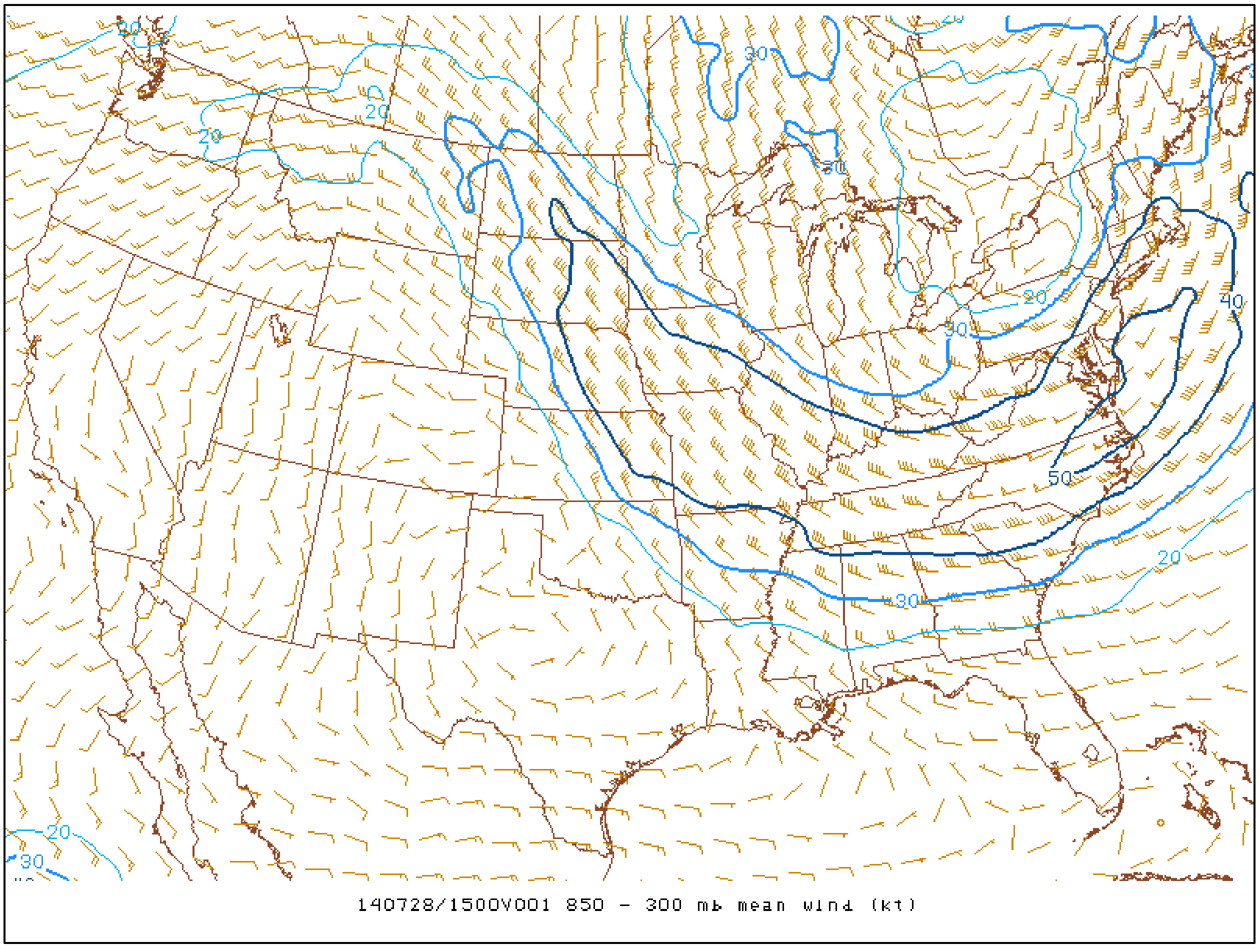

Figure 9. The Storm Prediction Center mesoanalysis of 850-300 hPa mean wind (knots) at 15 UTC on 28 July 2014, with generally 4-5 m/s (9-10 knots or 10-12 mph) of southerly flow indicating a slower storm motion across southern Nevada.

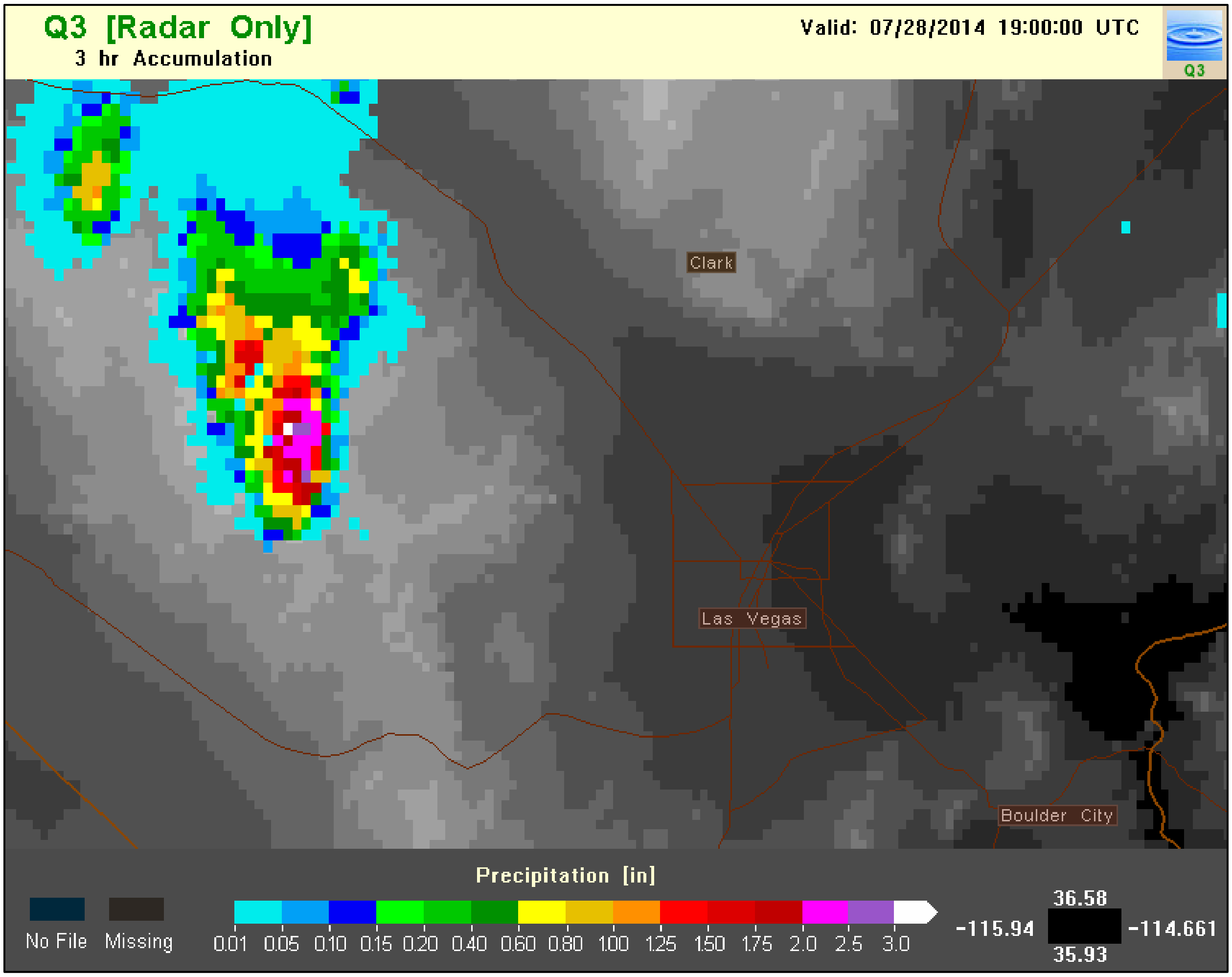

Figure 10. The 3-hour accumulation ending at 19 UTC 28 July 2014 from the Q3 QPE (Radar Only) illustrates an area of 50.8 mm (two inches) of rainfall is estimated to have occurred across portions of Mount Charleston.

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.239 (0.197-0.280)	0.318 (0.260-0.375)	0.448 (0.364-0.526)	0.548 (0.443-0.648)	0.685 (0.555-0.822)	0.795 (0.643-0.964)	0.917 (0.736-1.13)	1.05 (0.836-1.33)	1.26 (0.990-1.65)	1.46 (1.12-1.99)
10-min	0.363 (0.300-0.426)	0.484 (0.396-0.572)	0.681 (0.555-0.800)	0.833 (0.674-0.985)	1.04 (0.845-1.25)	1.21 (0.978-1.47)	1.40 (1.12-1.73)	1.60 (1.27-2.02)	1.92 (1.51-2.52)	2.23 (1.71-3.02)
15-min	0.450 (0.371-0.529)	0.600 (0.491-0.708)	0.845 (0.688-0.991)	1.03 (0.836-1.22)	1.29 (1.05-1.55)	1.50 (1.21-1.82)	1.73 (1.39-2.14)	1.98 (1.58-2.51)	2.38 (1.87-3.12)	2.76 (2.12-3.75)
30-min	0.607 (0.501-0.712)	0.808 (0.661-0.954)	1.14 (0.927-1.33)	1.39 (1.13-1.65)	1.74 (1.41-2.09)	2.02 (1.63-2.45)	2.33 (1.87-2.88)	2.67 (2.13-3.38)	3.20 (2.52-4.20)	3.71 (2.85-5.04)
60-min	0.751 (0.619-0.882)	1.00 (0.819-1.18)	1.41 (1.15-1.65)	1.72 (1.39-2.04)	2.16 (1.75-2.59)	2.50 (2.02-3.03)	2.88 (2.31-3.57)	3.31 (2.63-4.18)	3.97 (3.11-5.20)	4.60 (3.53-6.24)
2-hr	0.845 (0.710-1.01)	1.11 (0.936-1.33)	1.54 (1.29-1.86)	1.90 (1.57-2.29)	2.43 (1.99-2.93)	2.88 (2.33-3.48)	3.39 (2.71-4.12)	3.97 (3.11-4.85)	4.85 (3.71-6.01)	5.65 (4.21-7.10)

Figure 11. Precipitation Frequency Estimates from NOAA Atlas 14 produced for the Rainbow Canyon portion of Mount Charleston shows that this area receiving 50.8 mm (two inches) of rainfall in less than two hours has at least an average recurrence interval of 10 years, outlined in red.

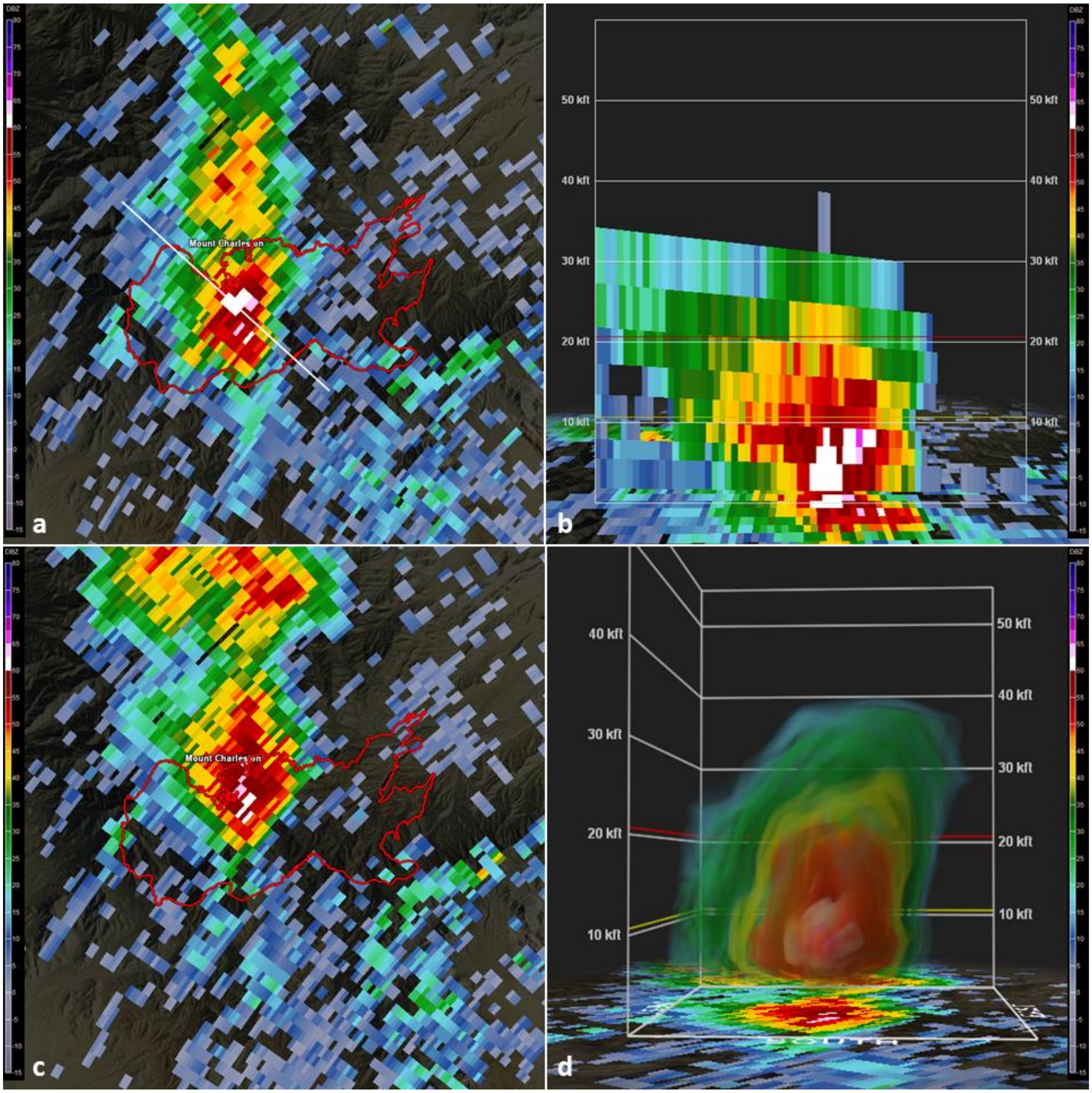

Figure 12. Reflectivity using Gibson Ridge Software from KESX radar of (a) a storm at 1742 UTC on 28 July 2014 over Mount Charleston and Carpenter 1 burn scar, (b) a cross section through the 1742 UTC storm, (c) another storm cell at 1818 UTC, and (d) a three dimensional view of the 1818 UTC storm. Both (a) and (c) show the redevelopment of convection over practically the same area of Mount Charleston. These were not the only cells that developed, but a good snapshot of the types of storms and locations of redevelopment, particularly over the Carpenter 1 burn scar outlined in red. Both (b) and (d) show the low-echo nature and heavy rain potential of the storms, with the highest reflectivity below the freezing level of approximately 3962 meters (13,000 feet) MSL. *Disclaimer: Reference to any commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its recommendation or favoring by the United States Government or NOAA/National Weather Service. Use of information from this publication shall not be used for advertising or product endorsement purposes.*

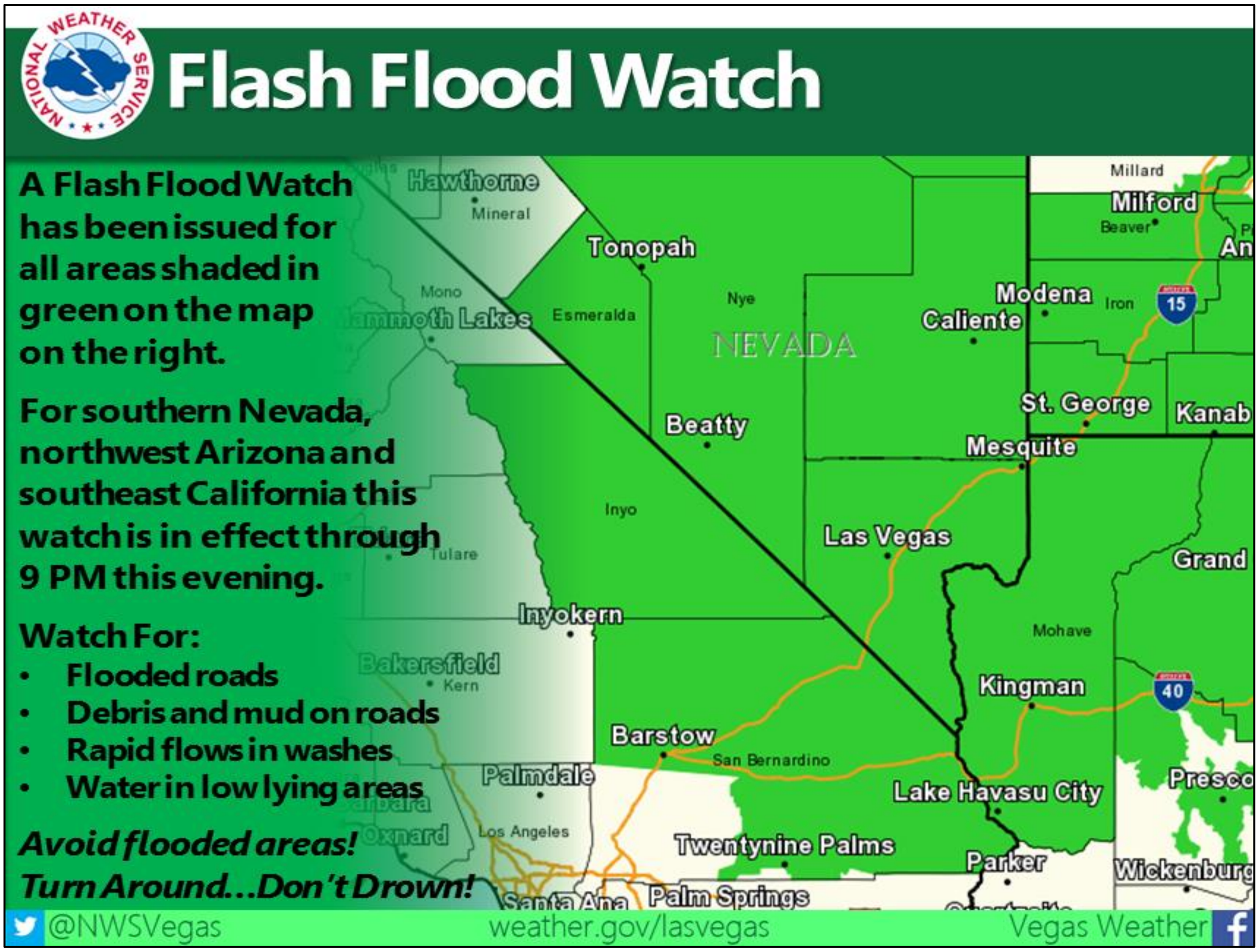

Figure 13. NWS Las Vegas Facebook post showing the Flash Flood Watch issued for southern Nevada and surrounding areas for 28 July 2014.

FLASH FLOOD THREAT INDEX

	Burn Scar	Mon 7/28	Tue 7/29	Wed 7/30	Thu 7/31	Fri 8/1	Sat 8/2	Sun 8/3
T-storm/Flash Flood Threat Index	Carpenter 1	80	20	20	10	10	40	50
	Dean Peak	60	30	30	20	20	40	40

*Index numbers represent the threat of flash flooding over the burn area. Numbers run from 0-100. Values over 50 indicate that a Flash Flood Watch is possible, while lower numbers mean conditions are marginal. These numbers DO NOT indicate flash flood severity.

Figure 14. NWS Las Vegas Flash Flood Threat Index table used for burn scars and other flash flood prone areas. This table is placed in weather briefings sent via email to core partners. This example is from the morning of 28 July 2014 that indicates NWS Las Vegas felt there was an 80% chance of flash flooding over the Carpenter 1 burn scar.

Figure 15. NWS Las Vegas picture showing the berm and diversion channel built by the United States Army Corps of Engineers to protect the Rainbow Canyon portion of Mount Charleston from additional flash flooding and debris flows. The Subdivision is off the picture on the right-hand side. The burn scar area remains visible across the higher terrain toward the top of the picture.

Figure 16. Same as Figure 15, except facing downhill toward the Rainbow Canyon Subdivision.

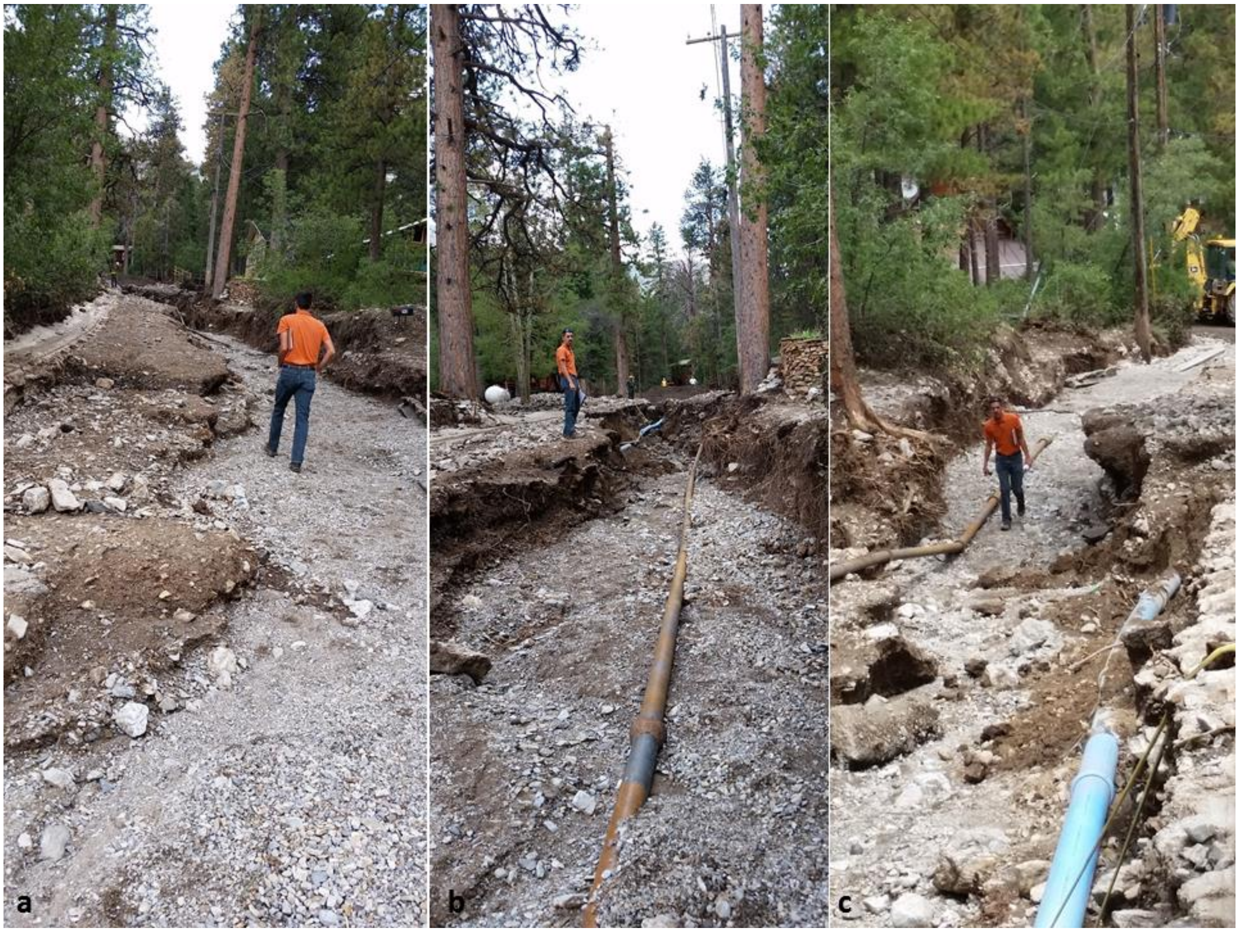

Figure 17. NWS Las Vegas damage survey pictures showing deep erosion from the flash flood and debris flow caused substantial damage to area roadways as well as water supply and sewer pipes. Rainbow Canyon Blvd, pictured above, is the main street through the subdivision and was extensively damaged, with some places being eroded six feet deep.

Figure 18. NWS Las Vegas damage survey picture showing substantial damage to one house, where debris broke through the front glass doors and rushed into the house. The debris piled to a height of three feet in several rooms of the house.

Figure 19. NWS Las Vegas damage survey picture showing damage to the lower level of another house. The debris, mud, and water height during the event is noticeable on the house, but more so on the children's play house and swing set.