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UDFCD Flash Flood Prediction Program –F2P2 XXVIII

**Final Project Report
Urban Drainage & Flood Control District
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Executive Summary

Urban Drainage & Flood Control District (UDFCD or District) has funded a Flash Flood Prediction Program (F2P2) since May 1979. The F2P2 was established as a community response to the disastrous Big Thompson Flash Flood of July 31, 1976 in Larimer County. The District contracts the unique, basin/storm-specific weather prediction services of a Private Meteorological Service (PMS) to augment the traditional forecast and warning services of the National Weather Service (NWS) for the seven-county District area. The services and products provided by the PMS are not produced or provided by NWS. HDR Engineering, Inc. of Denver, Colorado was the PMS for the 2006 F2P2 operational season. 2006 was the 28th operational year for the F2P2.

The District includes over 60 percent of Colorado's population. The primary support area for response agencies is about 1600 square miles in size. F2P2 products are issued to emergency response agencies within this area. The forecast area of responsibility is an area of about 3,000 square miles that includes the headwater basins of streams that flow into the District.

The F2P2's purpose is to predict the daily flash flood and flood potential for the Denver metro area's emergency response agencies. The predictions are communicated by daily Heavy Precipitation Outlooks, Messages indicating County flooding potential and expert-to-user telephone communications before, during and after flooding events.

The 2006 F2P2 produced several notable achievements and an unusual weather pattern that provided only limited flooding opportunities. Key highlights are listed below:

1. Thirty-seven Message days were predicted and twenty-eight Message days were observed. The annual average number of observed Message days is twenty-eight. 2006 was the first average year after four consecutive years of below average Message day observance.
2. Weather forecasting accuracy for Message days was 76 percent for the District-wide area or 8 percent below the annual average for the program.
3. No lives were lost due to flash flooding.
4. On Message days 43 percent of the county-specific Messages verified with a heavy rain and flooding event observed in the predicted county area. Arapahoe County Message verification rates were better than 50 percent.

After four quiet summers of below average thunderstorm occurrence, the summer of 2006 boomed at a slightly above average rate. Blanket Messages (all counties) were issued on about 75 percent of the days as a reflection of the general instability that affected the District on most Message days.

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1.0 Introduction

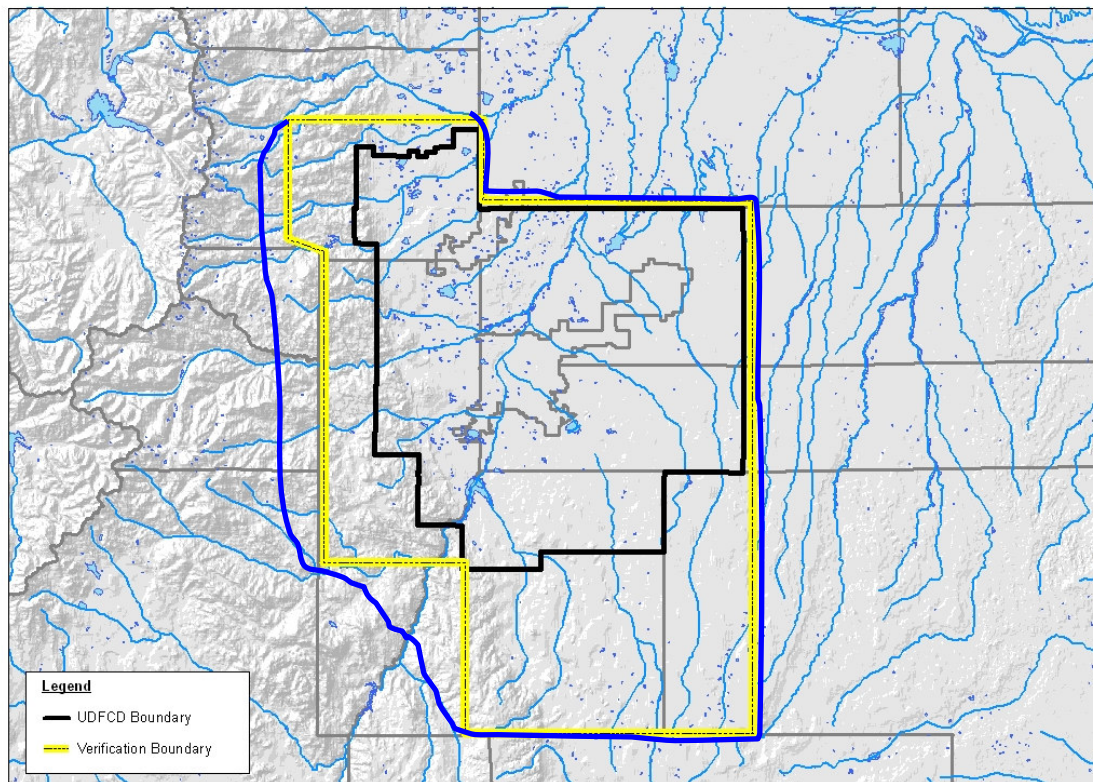
Urban Drainage & Flood Control District (UDFCD or District) has funded a Flash Flood Prediction Program (F2P2) since May 1979 and 2006 was the 28th operational year for the F2P2. The F2P2 was established as a community response to the disastrous and deadly Big Thompson Flash Flood of July 31, 1976 in Larimer County.

The F2P2's purpose is to predict the daily flash flood potential for the Denver metro area's emergency response agencies. In addition to the response agencies, Denver media, school districts and transportation agencies use the information. The District contracts the prediction services of a Private Meteorological Service (PMS) to augment the traditional forecast and warning services of the National Weather Service (NWS) for the seven-county District area. The F2P2's operational season extends from 15 April to 15 September.

2.0 F2P2 primary support and forecast areas

The District is located within the black colored line in **Figure 1** and includes over 60 percent of Colorado's population and is about 1600 square miles in size. The District comprises the **primary support area** for response agencies. F2P2 products are issued to emergency response agencies for either heavy rainfall events or flooding runoff events that occur within this area.

Figure 1 UDFCD District (black) and Forecast area (Yellow) boundaries.



The **forecast area of responsibility** is an area of about 3,000 square miles within the solid blue boundary. The forecast area includes the headwater basins of streams that flow into the District. Experience has shown that many of the streams with headwaters in the foothills of Boulder, Jefferson, Douglas and Elbert County terminate or merge into areas within the District. Heavy rainfall over these headwater areas is capable of producing a flooding runoff within the District even when skies are clear over the District. Thus it has been practice to provide both forecasts products for these headwater areas for well over a decade.

In 2006 the District began an internal verification program to evaluate the services provided by the PMS. The District based its verification in 2006 on the occurrence of heavy rainfall or flooding events within the solid yellow area noted on **Figure 1**. Except for the portions of Clear Creek and Gilpin Counties the areas are almost identical. HDR has embraced the District-proposed area shown in **Figure 1** and recommends it be used in all future verification efforts.

Terrain in the forecast area varies from the rolling populated prairies of Arapahoe, Adams and Broomfield Counties to highly urbanized Denver County to the rugged plains-foothills-mountain interfaces of Jefferson, Boulder and Douglas Counties. The population in this area has increased dramatically over the last ten years within the city of Aurora, Douglas County and, recently, Adams County.

3.0 HDR – the 2006 Private Meteorological Service (PMS).

HDR Engineering in Denver was selected as the 2006 F2P2 PMS. HDR maintains a full-service, 24/7(as needed) Weather Center at its offices at 303 East 17th Avenue. The F2P2 services were provided by HDR meteorologists William Badini, Robert Rahrs and John Henz. In addition, HDR employed three graduate meteorologists, Nathan Clements (Texas A&M), Daniel Henz (University of Wisconsin-Madison) and Shawn Jacobs (South Dakota School of Mines & Technology) to augment forecast services from May 15 to August 15 as part of a HDR Meteorologist Internship Program. The 2006 F2P2 season is HDR's sixth year as the PMS. HDR meteorologists are experienced in flash flood prediction, flood response plan development, water supply prediction and quantitative precipitation forecasting.

Mr. Henz has been involved actively in the F2P2 since it was developed in 1979. He has participated in 28 F2P2 seasons. Mr. Henz was the project manager of the 2006 F2P2 program. Mr. Badini has seven years of F2P2 experience and Robert Rahrs has five years of F2P2 experience. Their 41 combined years of F2P2 experience provided continuity, creativity, insight and decision-making expertise.

HDR offered five PMS forecast services not offered by the NWS to the emergency response agencies. The special services are listed below:

1. Basin-specific probabilistic **Quantitative Precipitation Forecasts (QPPF)** that forecast the hourly rain rates and event total precipitation for each of the critical District basins.
2. Daily **Heavy Precipitation Outlooks** which identify the county flash flood and flooding threat, probabilistic peak rain rates and prime time for storm activity.

3. **StormTrak** provides storm-specific movement, speed and areal coverage of thunderstorm systems capable of producing flash flood and flooding rains in the District. This product remains one of the most popular F2P2 products.
4. **Messages** describing county/city flash flood and flood potential are issued by direct expert-to-user phone communications to local emergency response agencies before, during and after flood and flash flooding events.
5. Direct support to the seven flood warning plans developed by the District for high threat urban and foothills streams. These plans link basin hydrologic support to determination of historical flooding and evacuation concerns.

The District Flood Warning Plans (FWP) are identified below:

1. **Boulder Creek Flood Warning Plan:** supports Boulder/South Boulder Creeks in the City of Boulder and south Boulder County.
2. **Ralston Creek Flood Warning Plan:** supports the lower Ralston/Van Bibber/Leyden Creeks basins as they impact northern Jefferson County and the City of Arvada.
3. **Lena Gulch Flood Warning Plan:** supports the Lena Gulch basin which impacts Jefferson County, the Cities of Golden, Lakewood and Wheat Ridge and Consolidated Mutual Water.
4. **Bear Creek Flood Warning Plan:** supports the Bear Creek basins in Jefferson County and the Cities of Morrison and Lakewood. Numerous small foothills communities located along Bear Creek and its tributaries are supported by this plan.
5. **Harvard/Goldsmith Gulch Flood Warning Plan:** supports south-central Denver and south-east Denver and the Denver Technical Center. This basin is prone to urban and street flash flooding events almost annually.
6. **Westerly Creek Flood Warning Plan:** supports eastern Denver and western Aurora. This FWP is multi-jurisdictional and requires effective communication.
7. **Toll Gate Creek Flood Warning Plan:** supports central and southeastern Aurora. Both of these basins are capable of producing significant flooding events within highly urbanized areas of Aurora.

Examples of the PMS forecast services can be found on the District web page. Provision of the PMS services is funded by the UDFCD. HDR provided all F2P2 forecast products to the National Weather Service in Boulder, Colorado. The cooperation between the NWS and PMS was excellent during the 2006 F2P2 season.

The provision of these services to users and sharing of the products with NWS assists in coordination and communication between the agencies and eliminates confusion for the user community. Basins without FWP are supported as effectively on an event basis.

4.0 2006 Operational Season – An overview

The 2006 F2P2 season can best be characterized as a “Return of the El Nino monsoon summer” that produced a series of significant thunderstorm outbreaks. The F2P2 operational season runs from 15 April through 15 September. In all, 28 Message days were observed during the 2006 F2P2 season or right at the 28-year average.

4.1 April-June 2006

Below average precipitation and above normal temperatures were observed from April into June. Only two Message days were observed through the end of May compared to an average of 15 during this period. This period continued a warm, dry period that had begun in late winter.

June 2006 was the 3rd hottest and 4th driest June on record as 90F or higher maximum temperatures were observed on 19 days setting a monthly record. DIA recorded only 7 thunderstorm days compared to an average of 11 thunderstorm days. Messages were issued on only 3 days in June making it the third fewest number of June Messages since the F2P2 began.

On June 24 the F2P2 season started to become active as a severe thunderstorm dropped hail up to 1.5 inches in diameter in a three mile wide swath from the City of Boulder across Lakewood into northwestern Douglas County. Over 2.00 inches of rain was dropped in less than 30 minutes at the Boulder County Justice Center with amounts from 0.75 inches to over 1.00 inches in less than 30 minutes observed along the remaining portion of the storm’s path.

In summary, five Message days were observed from April 15 to June 30: May 22 and 31 and June 21, 24, and 25. Normally the F2P2 experiences about twice as many Message days in this period of time. However, the hot, dry start to the summer may have reduced the number of Message days.

4.2 July-September 2006

The Colorado monsoon season usually begins 5-7 days after the onset of the Arizona monsoon and 2006 was no exception. The Arizona monsoon started June 28 or about a week earlier than the normal July 3rd start. This year’s Arizona monsoon was the wettest on record since 1983 in Tucson, Arizona and much of eastern Arizona. The early start to the Arizona monsoon significantly increased the number of northward intrusions of sub-tropical moisture into Colorado from New Mexico and Arizona. The 2006 F2P2 was by contrast an earlier starting and more intense monsoon than those observed over the past five years.

The F2P2 monsoon season started with a bang as nine consecutive Message days were noted from July 2 to July 10 with 15 Message days for the month. Two extreme precipitation events occurred in early July with the first event a 7 inch plus flash flood rainfall on July 2 in Castlewood Canyon in southeastern Douglas County. Five days later on July 7 a flash flood raged down West Creek near the fire-burn scars of southwestern Douglas County producing over \$10 million dollars of damage.

Message days were noted on eight of the first fifteen days of August. Significant urban flooding events were noted on August 13, 14 and 19 in the City of Denver. The August 14 event flooded Colfax Avenue from Broadway to Colorado Boulevard during the height of the evening rush hour. Thirteen Message days were observed or seven above average for the month of August.

In contrast to the rest of the summer of 2006, September was the seventh coldest on record. Four Message days were observed in September or two above average. The most significant thunderstorm event occurred in Parker on September 10 when 1.96 inches of rain fell in less than an hour. This event was the last one to record over 1.00 inches of rain for the 2006 F2P2 season.

5.0 Significant Storms of 2006

HDR meteorologists had numerous choices for significant storms of the 2006 F2P2 year. Three storm events were chosen as the most intense or most important to F2P2 operations. A description of the causes, rainfall and photos of each event follows.

5.1 June 24, 2006

The severe thunderstorm of June 24, 2006 maximized its flooding potential over the City of Boulder. The Boulder County Justice Center's gage recorded over 2.00 inches of rain in less than 20 minutes. The NWS issued a Severe Thunderstorm Watch for June 24 at 230PM for most of northeastern Colorado including the District. Severe thunderstorms were observed over Weld and Larimer Counties between 3PM and 5PM. (**Figure 7**) However rainfall with these storms was less than 0.50 inches in 15-30 minutes. Rainfall in District gages in the St. Vrain watershed was less than Message criteria through 15 minutes of the storm arriving in the City of Boulder.

Figure 2 June 24, 2006 Severe thunderstorm complex over eastern Larimer County about 500PM as taken from SE Longmont.



The Lafayette/Louisville District weather station indicated dew points in the low 40's while a dew point of 52F was needed for heavy rain. The 500PM hourly NOAA-ERL weather station in Boulder showed a dew point of 47 degrees. No problems were anticipated at this point. However, the 600PM hourly NOAA-ERL dew point climbed to 53F. This observation was available just minutes before the storm exploded but too late to influence Message issuance.

HDR meteorologist Nate Clements had pre-prepared Message 1's for Boulder, Jefferson, western Adams and Denver Counties as the approach of a severe thunderstorm was monitored on radar. The storm exploded over the City of Boulder prompting an "after the fact" Message 1 issuance within minutes of 0.50 inches of rain being observed in the Boulder gage. Nonetheless this event was a miss for the City of Boulder. Message 1s were also issued for counties within the StormTrak issued and over 45 minute lead-times were attained in each of the downstream counties.

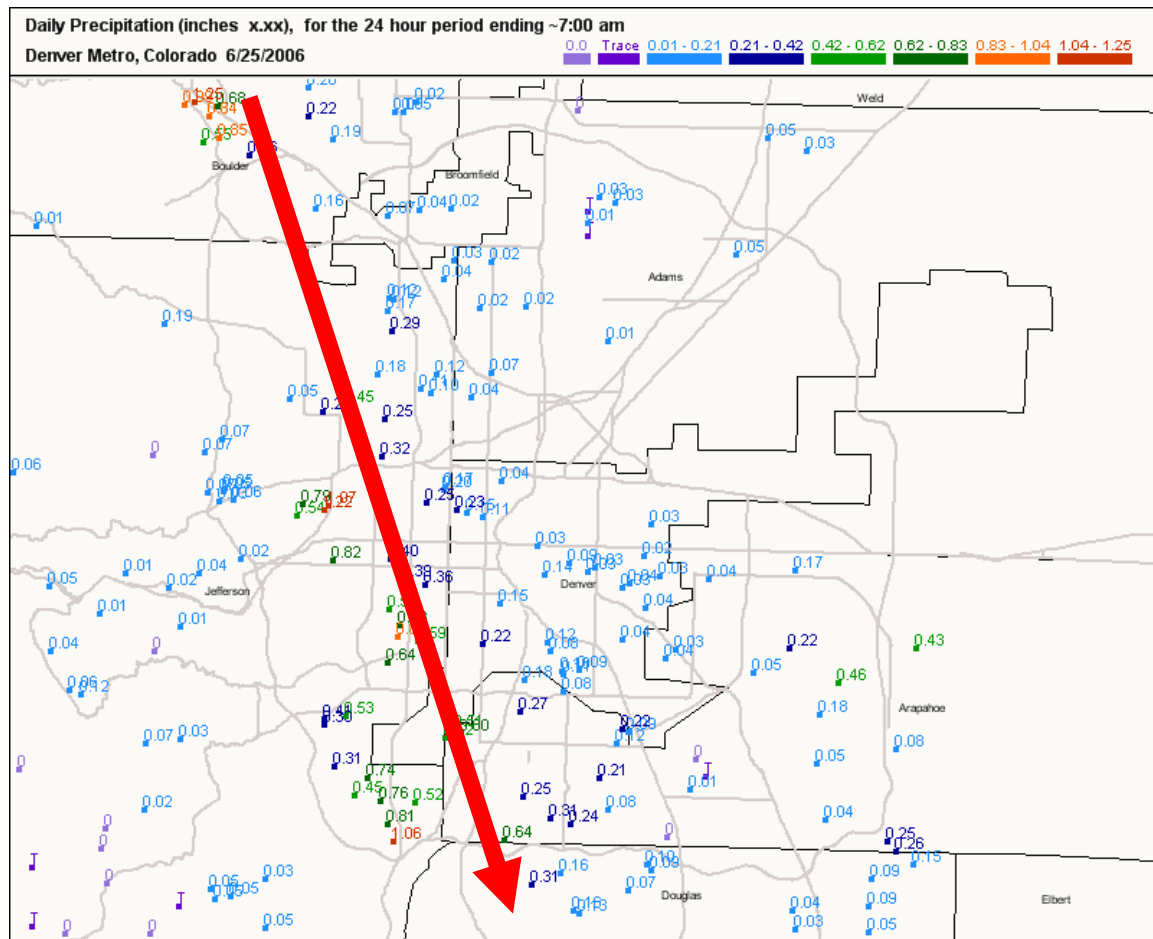
By 630PM the storm system encountered a moist flow of air from the east over Lakewood as shown in **Figure 8** and developed into a severe-right moving thunderstorm that pushed south-southeastward across the entire District into El Paso County before dissipating (**Figure 9**). The rapid intensification of this storm supports the recommendation that whenever the Storm Prediction Center in Norman OK issues a Severe Thunderstorm Watch before July 15 and storm steering winds are from the northwest it would be prudent to issue Message 1's for Boulder, Adams, Broomfield and Jefferson Counties as a precaution.

A review of similar situations from 1990 to 2006 indicated that if Messages were issued at the same time as the Severe Thunderstorm Watch that in about 75 percent of the cases one or more Messages would verify somewhere in the District with a hour lead-time or more. However, in each case, response agencies would be afforded at least an hour of needed lead-time unlike the unpleasant surprise of the June 24, 2006 storm.

Figure 3 Severe thunderstorm on June 24, 2006 over Lakewood



Figure 4 CoCoRaHS 24-hr precipitation for the June 24, 2006 severe thunderstorm. Red arrow denotes storm path.



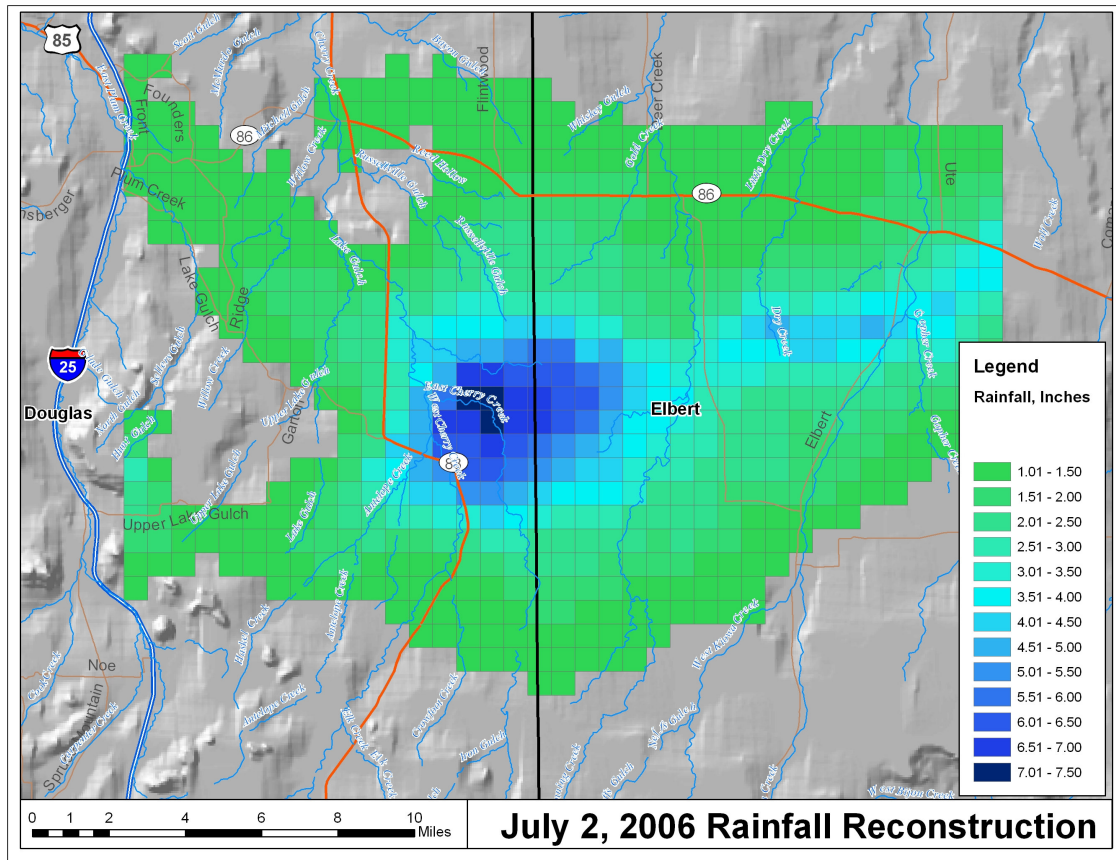
5.2 July 2, 2006 – The Castlewood Canyon Flash Flood

The Castlewood Canyon flash flood was the first extreme precipitation event (>7.00 inches in less than 6 hrs estimated by radar) that has occurred in the District in at least the past ten years. The threat of local flooding rainfall was predicted by meteorologist William Badini early in the day and Message 1's were issued for the entire District between 130PM and 300PM. While no Flash Flood Watches were issued by the National Weather Service, the District was ready for its first heavy storms of the season.

HDR performed a radar-reconstruction of the July 2 event for Colorado Water Conservation Board (CWCB) and Douglas County Public Works. The radar-estimated rainfall pattern is presented in **Figure 10**. Note that the storm center is rather small and covered about 25 square miles. The area of rainfall over 5.00 inches is about 5 square miles. The thunderstorm produced between 6.00 and 7.50 inches of rain in less than three hours. A small but significant flash flood caused a rise on East Cherry Creek from a few inches to over 9 feet in less than 15 minutes according to Bob Jarrett of the USGS (personal communication). Several bridges were washed out with a few miles of

Castlewood Canyon. In addition to this thunderstorm, other storms produced significant urban flooding was reported throughout western Arapahoe County, Aurora and Douglas Counties.

Figure 5 Radar-rainfall estimated for July 2, 2006 by HDR Engineering.



5.3 July 7, 2006 – The West Creek Flash Flood

The June 7 flash flood in West Creek was largely contained within the fire-scarred portions of southwestern Douglas County. This area has been slow to recover from the Hayman fire of 2002 and suffers enhanced runoff as vegetation has been slow to recover. HDR meteorologists issued Message 1's for foothills areas as storms developed rapidly during the heat of the day. The flooding and damage observed in West Creek appears to have been the product of moderate thunderstorm activity occurring over a fire-scarred watershed that enhanced runoff into West Creek.

No fatalities or injuries were reported but damage estimated totaled in the millions to public roads and facilities in Douglas County. Road repairs were slowly accomplished as additional rainfall fell for the better part of ten days over the watershed. **Figure 11** shows the radar-rainfall reconstruction done by HDR for CWCB and Douglas County Public Works. Peak storm rainfall may have reached about 2.50 inches to 3.00 inches of rain in about 90 minutes. **Figure 12** shows some of the damage to Douglas County roads along West Creek by the raging waters.

Figure 6 Radar-rainfall estimated for July 7, 2006 by HDR Engineering.

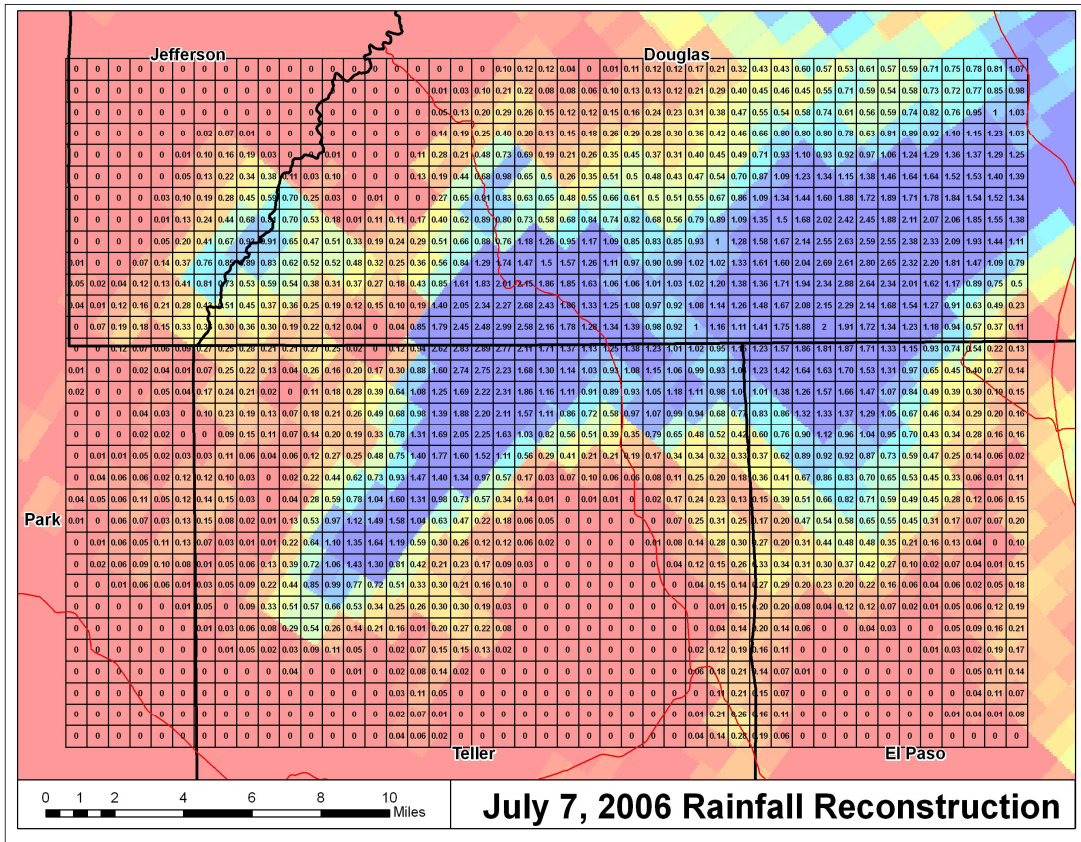


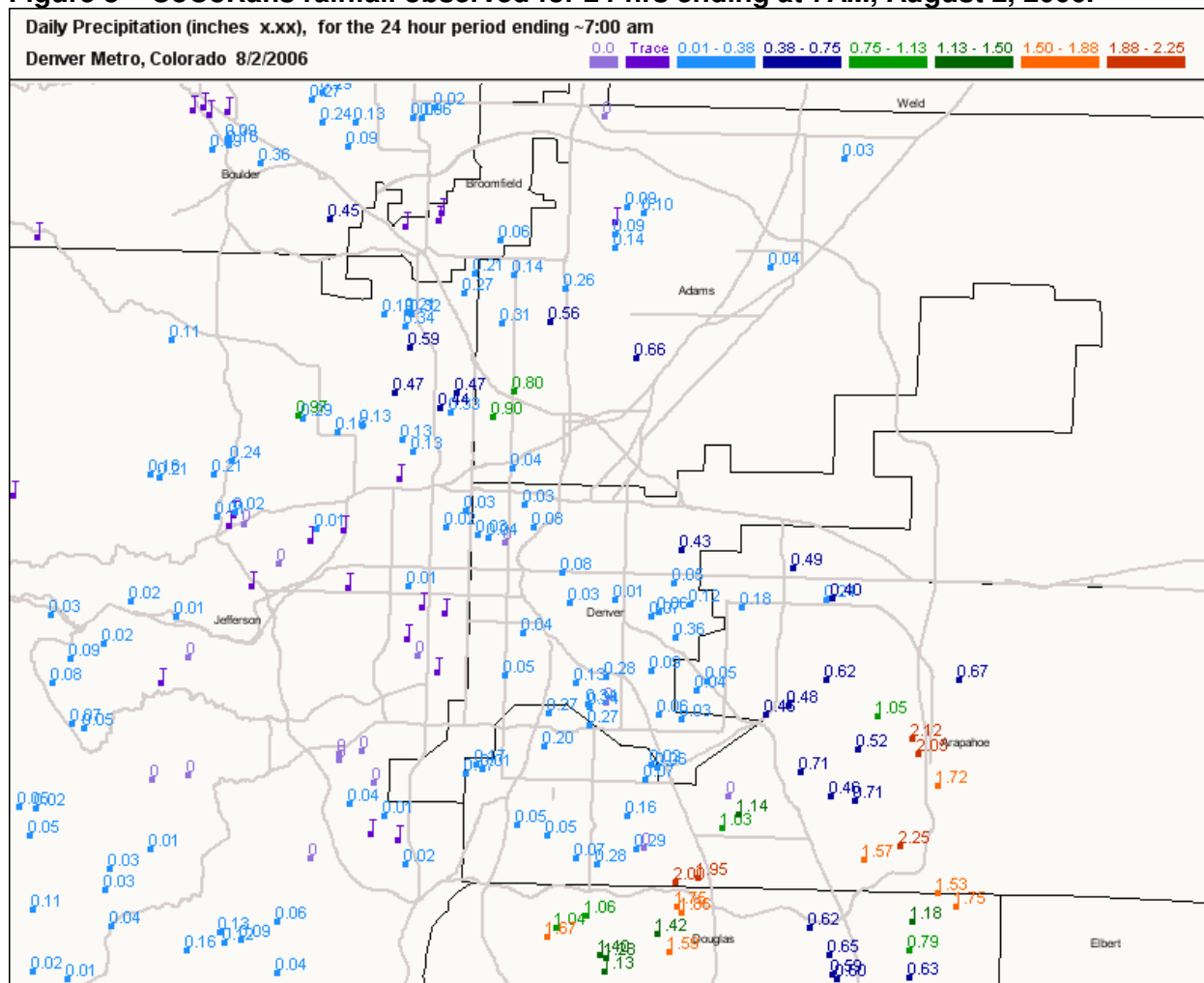
Figure 7 West Creek flood damage reported by Denver Channel 7 News.



5.4 August 1, 2006: Southeast District urban flash flooder

The August 1, 2006 urban flooding event is the final extraordinary flash flooding event of 2006. Messages were issued for the entire District at 1130AM for the period from Noon to Midnight. The heaviest rainfalls reached from 1.00 to 2.50 inches in a swath from Highlands Ranch into eastern Aurora along the E-470 beltline. (**Figure 13**)

Figure 8 CoCoRaHS rainfall observed for 24-hrs ending at 7AM, August 2, 2006.



A series of storms formed along a Denver Convergence line that stretched across portions of Aurora, Arapahoe County and Douglas County. Storms fired up rapidly and reached maximum rainfall production in less than 30 minutes. Each of the key storms demonstrated stationary movement during periods of heaviest rainfall production. Flooding spread into planned floodways in Saddle Rock in Aurora (**Figure 13**) and in Highlands Ranch (**Figure 14**) in Douglas County.