NOAA Technical Memorandum NWS WR-279

Effects of Wildfire in the Mountainous Terrain of Southeast Arizona: An Empirical Formula to Estimate 5-Year Peak Discharge from Small Post-Burn Watersheds

William B. Reed[1] and Mike Schaffner[2]
June 2007

[1]NOAA National Weather Service, Colorado Basin River Forecast Center, Salt Lake City, UT
[2]NOAA National Weather Service, Weather Forecast Office, Tucson, AZ

United States
Department of Commerce
Carlos M. Gutierrez, Secretary

National Oceanic and
Atmospheric Administration
VADM C. Lautenbacher
Under Secretary

National Weather Service
MaryGlackin, Acting Assistant Administrator
for Weather Services

And is approved for publication by
Scientific Services Division
Western Region

Andy. Edman, Chief
Scientific Services Division
Salt Lake City, UT


Coauthor Mike Schaffner viewing a boulder deposit in Marijilda Canyon (photo courtesy of USGS).

Effects of Wildfire in the Mountainous Terrain of Southeast Arizona: An Empirical Formula to Estimate 5-Year Peak Discharge from Small Post-Burn Watersheds

William B. Reed[1] and Mike Schaffner[2]

[1]NOAA National Weather Service, Colorado Basin River Forecast Center, Salt Lake City, UT
[2]NOAA National Weather Service, Weather Forecast Office, Tucson, AZ

Abstract. This paper presents the new fundamental concept of the ***hyper-effective drainage area***, the area of the high severity burn plus the area of the moderate severity burn, and provides an empirical formula to estimate the 5-year peak discharge from small post-burn watersheds to demonstrate the use of the concept. The equation uses the documented hydrologic response within the first two years after the occurrence of wildfire of ten watersheds in Southeast Arizona. These watersheds are within the forested steep terrain of the Santa Catalina, Santa Rita, and Pinaleno Mountains. After the burns, frequent flash floods and occasional debris flows have occurred. A few of the flash floods were particularly severe resulting in one fatality, several evacuations of flood prone areas, and the destruction of four stream gaging sites. To predict the "likely" peak flow that can be expected before a given burned watershed is back to conditions that resemble pre-burn hydrology, an empirical equation was devised to estimate the post-burn 5-year peak flow. The developed equation works reasonably well (cross validation adjusted coefficient of determination of 0.90) for the documented watersheds. Its ability to deal with topographic and geomorphologic diversity lies in the use of a multivariate runoff index that utilizes the hyper-effective drainage area (determined from burn severity), average basin elevation, and an objective modified channel relief ratio.

Additional keywords: Arizona; Post-Burn Hydrology; Forest Hydrology; Peak Flows; Flash Floods; Modified Channel Relief Ratio; Hyper-Effective Drainage Area.

Introduction

Southeast Arizona has recently been impacted by several wildfires. These include the Oracle Hill Fire (2002), Bullock Fire (2002), and Aspen Fire (2003) in the Santa Catalina Mountains; the Nuttall Fire (2004) in the Pinaleno Mountains; and the Florida Fire (2005) in the Santa Rita Mountains (Figure 1). After these wildfires, significantly increased runoff from the burn areas has occurred. Rainfall amounts and intensities, which normally would have caused little if any, flooding, have produced dangerous flash floods during watershed recovery.

Often the National Weather Service is faced with predicting post-burn peak flows shortly after a fire, and sometimes, while the fire is still burning. This urgency for forecasts does not allow for the use of the tools currently available to Burned Area Emergency Rehabilitation (BAER) teams for post-burn hydrologic analysis because these methods are either too data intensive, or too time consumptive, for use in a real-time operational setting. Although burn severity information is usually not available in near real time, for operational purposes, a worst-case scenario could be assumed until the data became available. The outlet of the basin would be selected based upon potential damage to life or property, e.g., a bridge crossing or nearby housing.

This study presents the new fundamental concept of *hyper-effective drainage area*, the area of the high severity burn plus the area of the moderate severity burn, and provides an empirical formula to estimate the 5-year peak discharge (Q_5) from small watersheds, watersheds less than 15 square miles (38.8 square kilometers), during post-burn recovery to demonstrate the use of the concept. Determining the 5-year return interval has proven an effective approach for similar burn studies (Reed 2002). This is perhaps because research conducted on burned watersheds throughout the Rocky Mountains indicates hydrologic recovery to near pre-burn conditions within 3 to 5 years (Morris and Moses 1987, Martin and Moody 2001).

A series of equations for different return intervals (e.g., 2-year and 10-year) also could be developed but was beyond the scope of this paper. The 5-year peak discharge equation was developed by evaluating the hydrologic response within the first two years after the occurrence of wildfire of ten watersheds in Southeast Arizona: Frye Canyon, Deadman Canyon, Marijilda Canyon, Noon Creek, Wet Canyon, Upper Campo Bonito, Sabino Creek near Mount Lemmon, Alder Canyon at Ventana Windmill, (these first eight documented in Schaffner and Reed 2005a), Madera Canyon (described below), and Romero Canyon (also described below). Additionally the information for Upper Campo Bonito was updated in Schaffner and Reed (2005b). The methodology used to determine the 5-year post-burn flow for all ten basins was similar. Pertinent data are presented in Figures 2, 3, and 4.

Cañada del Oro near Coronado Camp documented in Schaffner and Reed (2005a) was not used because it was a second year event likely preceded by undocumented first year events of larger magnitude. Additionally, this basin at 21.6 square miles (55.9 square kilometers) is perhaps too large for the methodology used. A cursory examination of the data for the downstream gage, Cañada del Oro at Rancho Solano, suggests that post-burn runoff from basins of this size (21.6 square miles) and larger may be better modeled using a technique that considers maximum rainfall rates rather than basin averages. Another approach that may be worth evaluating is to use only the basin average for the hyper-effective drainage area.

Eight of the ten basins are smaller than 10 square miles (25.9 square kilometers). When considering only the hyper-effective drainage area, eight of the ten basins are smaller than 2.5 square miles (6.5 kilometers). Therefore, the spatial distributions of the entire storms were not generally considered important to this analysis. However, what may have been important was for the storm core to have moved over at least a portion of the hyper-effective drainage area. This was common to all ten events. Additionally, the importance of storm motion is evaluated.

Burn areas yield an increase in debris and sediment as compared to pre-burn conditions (Robichuad 2000). This study and its associated discharge measurements do not take into account added bulking of the flow due to debris or changes in sediment transport.

Role of Mountainous Terrain

Factors in peak discharge generation from burn areas, such as burn severity, basin size, terrain, rainfall amount, and storm intensity, can all play a key role. In this study, an objective Southeast Arizona specific modified channel relief ratio[1] was selected as an important indicator

---

[1] The modified channel relief ratio was defined by the authors so as not to include the relief from the upper most area of the mountainous terrain of Southeast Arizona, which often is void of well defined channels. The modified channel relief ratio is an objective measurement unlike the traditional channel relief ratio. Additionally, the authors defined the modified channel relief ratio so as to include the channel relief in the vicinity of the basin outlet where flooding occurred.

of topographic diversity in the mountainous terrains evaluated. The *modified channel relief ratio* is the average slope of the basin along the first order channel measured from 1,250 feet (381 meters) below the ridge to the basin outlet. For small impervious areas, peak discharge will tend to increase as channel slope increases. An increase in channel slope can result in decreased time of concentration and less infiltration. This may be especially true for areas recently denuded or with new hydrophobic soils. Post-burn flows originating from the Pinaleno Mountains had greater increases in runoff than those observed in the Santa Catalina Mountains. This was initially believed by the authors to be due to significant differences in the channel relief. However, the Santa Rita Mountains with modified channel relief ratio similar to the Pinaleno Mountains had an increase in runoff similar to the Santa Catalina Mountains. But the actual channel slope through the slope conveyance cross-section measured for the Santa Rita flood is similar to the modified channel relief of the Santa Catalina Mountains. Therefore future studies may want to evaluate using channel slope through flooded reach rather than the modified channel relief ratio. Modified channel relief ratio and other basin values are presented in Figure 3. Average basin elevation was also selected as an important variable for mountainous terrain. The *average basin elevation* is the average altitude above mean sea level using the elevation of the highest point of the basin and the elevation of the basin outlet. In addition to being an indicator of rainfall variability and local climate, average basin elevation in mountainous terrain is indirectly an indication of vegetation coverage and type (Brown 1982); and perhaps to a lesser degree, indirectly an indicator of soil depth and predominant soil characteristics (Hendricks 1985). Initially, the authors thought the usefulness of the average basin elevation could also be because the higher organic matter in the higher elevation soils (in contrast to lower elevation soils with less organic matter) played a key role in the likelihood of the higher elevation soils developing hydrophobic conditions. Yet for very high elevations there may be: 1) more exposed bedrock, 2) no channel development, 3) less natural vegetation, and 4) where soils occur they may tend to be shallow; such conditions would likely result in an inverse relationship between elevation and increased post-burn runoff. Simply put if you burn rock it is still rock, resulting in very little—if any—change in hydrologic response. Other indicators evaluated by the authors but not selected included the traditional channel relief ratio, main channel slope index, basin relief ratio, average channel elevation, mean main channel elevation, and traditional drainage area.

Methodology

The methodology used to determine the 5-year post-burn flow for all ten basins was similar. The details for Frye Creek, Deadman Canyon, Marijilda Canyon, Noon Creek, Wet Canyon, Upper Campo Bonito, Sabino Creek near Mount Lemmon, and Alder Canyon at Ventana Windmill are documented in Schaffner and Reed (2005a). The information for Upper Campo Bonito was updated in Schaffner and Reed (2005b). The details for Madera Canyon and Romero Canyon are provided below.

To create the empirical formula the first step was to determine the 5-year post-burn flow for the basins. The steps required were 1) calculate the basin average precipitation for events known to have caused floods from the burned basins (an attempt was made to use the first major flush after a burn) and document storm duration, 2) determine the return period of these rain events, 3) determine the peak flow of the flood event, 4) calculate the pre-burn peak flow for the corresponding return period of the precipitation event, 5) calculate the pre-burn 5-year peak flow, 6) calculate the ratio of pre-burn peak flow to post-burn peak flow[2], and 7) multiply the pre-burn 5-year peak flow for a basin (determined in step 5) by the corresponding ratio (determined in step 6). For the two cases, Marijilda and Alder, where the return period of the precipitation event was a 5-year event, steps 4 through 7 were not necessary but were done for consistency and display purposes. Results of steps 1 through 4 are presented in Figure 2. Results of step 5 are presented in Figure 4. Results of Steps 6 and 7 are presented in Figure 3.

The t-year rainfall is commonly used in applied hydrology to calculate a t-year flood, for example this is a major input of the rational method, as well as the model TR55 (Natural Resources Conservation Service, 1986) commonly used by the Forest Service to estimate post-burn runoff response. For the rational method a rainfall intensity for a duration equal to the time of concentration is used. For TR55 a rainfall with a duration of 24-hours is used with a rainfall time distribution designed to contain the intensity of any duration of rainfall for the frequency of the event chosen. Or as stated by Natural Resources Conservation Service (1986): "That is, if the 10-year frequency, 24-hour rainfall is used, the most intense hour will approximate the 10-year, 1-hour rainfall volume."

For this paper, it was assumed that a short-term thunderstorm with a duration approximately equal to or greater than the time of concentration for the burned basin, of a particular frequency, produces a peak flood discharge of the same frequency. Whereas this may be an oversimplification, it will always be a conservative one that overestimates the t-year flow for relatively impervious burned basins in the mountainous terrain of Southeast Arizona. In the United States, it is a common assumption made by land management agencies when trying to calculate t-year flows for ungaged basins in arid and semi-arid regions.

Time of concentration for the ten studied basins range from 0.3 to 1.2 hours (Figure 2). Duration of the event storms ranged from 0.5 to 1 hours (Figure 2). For all but one case, the duration of the flood-causing storm was approximately (within 0.2 hours) equal to or greater than the time of concentration. The exception was Romero Canyon. For Romero Canyon, the duration of the storm was approximately 0.5 hours while time of concentration is 1.1 hours. Therefore, the post-burn 5-year peak flow may have been slightly underestimated for this basin. However, it has also been observed that time to peak can be shorter for burned basins (Neary and others, 2003), if so, even Romero Canyon's case study storm duration could have been approximately equal to the time of concentration for the then existing post-burn watershed conditions.

Another possible oversimplification of this paper was the use of the same ratio of pre-burn to post-burn flow for return intervals different than the 5-year storm (e.g. 2-year) to calculate post-burn 5-year flow from the corresponding pre-burn 5-year flow. The authors felt that this assumption was acceptable because half of the events were close to a five-year event, i.e., five of the ten events were 2-year, 3-year or 5-year events. Additionally, of the remaining five events, three had return intervals less than the 2-year event (they were approximately 1-year events) and two had return intervals greater than the 5-year event (both were 10-year events). Whereas the ratios likely are different for smaller events than larger events, it was felt that this clustered "balanced" distribution would reasonably offset the tendency for an unacceptable over-or-under estimation.

Another way to look at the relationship of pre-burn to post-burn flows (resulting in the same values as above) is to assume that the ratio of the magnitude of the pre-burn t-year event to the magnitude of pre-burn 5-year event would remain essentially the same for post-burn events

[2] This ratio is calculated by dividing the result of step 3 by the result of step 4.

of the same respective return intervals. Once again, this seems a reasonable approach when return intervals equal to or less than the 10-year return interval are used.

Madera Canyon

Madera Canyon is a 4.00 square mile (10.35 square kilometers) watershed. On August 8, 2005, 0.70 inches (17.78 millimeters) fell in about 45 minutes. The basin average precipitation frequency for Madera Canyon event was less than a 1-year event using NOAA Atlas 14 Volume 1 (Bonnin and others, 2004). On January 23, 2006, the authors conducted a field survey of the high water mark and associated channel geometry for Madera Creek near the U.S. Forest Service amphitheater. The high water mark was 7 feet (2.13 meters) above the channel thalweg. The cross section perpendicular to the direction of the flood flow was trapezoidal with a top width of 38.2 feet (11.64 meters) and a base of 15 feet (4.57 meters) resulting in a cross sectional area of 186.2 square feet (17.3 square meters). Channel slope through this cross section was 0.094 feet/feet (0.094 meters/meters). Manning's "n" was estimated at 0.15. The velocity of the peak flow was calculated to be 8.20 feet/sec (2.50 meters/sec). The peak flow was calculated as 1526 cfs (43.22 cubic meters per second) +/- 10 percent. Such a flow would be in the range of a 20-year pre-burn flow (Figure 5). This is a post-burn peak discharge increase of at least 6.8 times greater than pre-burn peak discharge. The 5-year post-burn flood is therefore estimated using this ratio to be greater than 4,476 cfs (126.76 cubic meters per second).

Romero Canyon

Romero Canyon is a 7.25 square mile (18.78 square kilometers) basin located on the southwest side of the Santa Catalina Mountains. At 6:00 PM MST of July 24, 2003, a north-south line of thunderstorms developed in the San Pedro River Valley to the east and pushed westward over the Santa Catalina Mountains at 15 mph (24.14 kilometers per hour). Rain fell on the Romero Canyon basin from about 6:30 to 7:30 PM. Tucson's KEMX WSR-88D radar as well as five Pima County Flood Control rain gages sampled the thunderstorms. Storm motion during the event was generally up to down-stream over Romero Canyon. This likely added to the magnitude of the peak; perhaps resulting in a peak flow up to 3.0 times greater than other storm motions.

A basin average rainfall value was obtained for the Romero Canyon event by averaging radar bins that fell within the basin from the one-hour precipitation product. A basin average 1-hour rainfall value of 2.35 inches (59.69 millimeters) was obtained. Since radar rainfall can be overestimated in the desert southwest due to hail contamination and dry air at the low levels, it is desirable to adjust the radar values if there is significant variation from rain gage totals. While no rain gages are located within the Romero Canyon basin, two are located within 2 miles (3.22 kilometers) of the basin boundary. These two gages show that only 63 percent of the radar indicated rainfall reached the ground.

Satellite imagery, radar, and lightning data remained consistent as the storm progressed from east to west across the Santa Catalina Mountains. As a result, there is confidence to use a regional approach to determine the best possible radar correction factor to compute an adjusted basin average rainfall. Using the above-mentioned rain gages, a radar correction factor of 0.85

was obtained. As a result, 2.00 inches (50.8 millimeters) was the adjusted basin average 1-hour rainfall.

Because the majority of rainfall from summer convective storms tends to fall in a timeframe less than an hour, it is advantageous to examine precipitation frequency with respect to peak rainfall. The five rain gages showed 80 percent of the rain fell within 30 minutes. Values ranged from 78 – 83 percent of rain fell within 30 minutes. Due to the narrow range of values between individual gages, the regional approach is once again valid. Thus 80 percent of the adjusted basin average 1-hour rainfall yields a 1.60 inches (40.64 millimeters) adjusted basin average 30-minute rainfall. According to NOAA Atlas 14 Volume 1, this amounts to a 10-year 30-minute basin average precipitation frequency.

Ann Youberg of the Arizona Geological Survey estimated the resultant flash flood at 9,500 cfs (269.04 cubic meters per second) +/- 15 percent. This estimate was derived by Ann Youberg using the HEC-RAS step backwater model with 5 cross sections. Such a flow would be greater than a 500-year pre-burn flow (Figure 6). This is a post-burn peak discharge increase of 6.7 times greater than pre-burn peak discharge. The 5-year post-burn flood is therefore estimated using this ratio to be 6,035 cfs (170.90 cubic meters per second).

Frye Creek Multiple Events Considered

The multiple events for Frye Creek documented in Schaffner and Reed (2005a) and presented in Figure 7 can be used to demonstrate the importance of using the first major hydrologic flush from the basin after the burn for calculating the maximum likely post-burn 5-year response. If the post-burn response calculated for each subsequent event were used, the calculated post-burn 5-year peak flow would be approximately half of the post-burn 5-year peak flow calculated using the preceding event (see Figure 8). Therefore an attempt was made to use only the first hydrologic flush from the ten basins after the burns to determine the maximum likely 5-year post-burn peak flow. Therefore, for Frye Creek, July 27, 2004 is used.

General Basin Response

The basin response differences between individual basins and between mountain ranges are illustrated in Figure 4. The Santa Catalina Mountains have an average post-burn basin response 3.8 times greater than pre-burn conditions. The Santa Rita Mountains have a post-burn basin response 6.8 times greater than pre-burn condition. The Pinaleno Mountains have an average post-burn basin response 106.6 times greater than pre-burn conditions. The Santa Catalina and Santa Rita Mountains have values similar to those reported by Reed (2002), NOAA National Weather Service for the White Mountains in Arizona and the Pinaleno Mountains have values similar to those reported by Veenhuis (2002), U.S. Geological Survey for the Jemez Mountains in New Mexico.

An Empirical Formula to Estimate 5-Year Peak Discharge from Small Post-Burn Watersheds

Because it takes 3-5 years or in some cases longer (Livingston, R. K. and others, 2005) for a watershed to recover from high and moderate severity burns, an empirical equation for predicting post-burn runoff for the 5-year return interval is presented here (Figure 9). The presented equations (envelope curve and best-fit) are representative of the conditions prevalent during the first two years of recovery; and therefore, are expected to be useful for initial burn recovery planning as well as operational forecasting. These equations use a multivariate runoff index defined as

$$x = 1000(\alpha\psi)^{0.54}\beta^{2}\phi^{-1.28} \quad (1)$$

where

x = multivariate runoff index

α = high severity burn + moderate severity burn as a fraction of total watershed (square miles/square miles);

ψ = total drainage area (square miles);

β = modified channel relief ratio (feet/feet); and

ϕ = average basin elevation above mean sea level (thousands of feet).

The envelope curve equation is

$$Q_5 = 4114(x)^{0.65} \quad (2)$$

and the best-fit equation is

$$Q_5 = 1993x \quad (3)$$

where

Q_5 = post-burn runoff for the 5-year return interval (cfs).

The adjusted R-square value for the best-fit curve is 0.96. The envelope curve was developed by adding 25% (the largest reported flow measurement error) to the values for Deadman, Romero, and Marijilda Canyons; and then fitting a power curve to these data points. A power function was used to insure the curve went through the origin, (0,0).

These equations are for small watersheds less than 15 square miles (38.8 square kilometers); and include sites with average basin elevations from 5500 to 8100 feet (1676.4 to 2469 meters) above msl. After several tries to fit the data, the authors found that weighing the burned area heavily, in this case using the high and moderate burn area as the only contributing area[3], using modified channel relief ratio as an indicator of basin steepness, and using average basin elevation as an indicator of predominant vegetation and soil characteristics, provided a reasonable fit. The best-fit equation neither significantly overestimates nor significantly underestimates the post-burn runoff for any watershed.

Storm Motion Considered

To evaluate the possible influence of storm motion, Romero Canyon, the only storm that moved from upstream to downstream (see Figure 2), was temporarily removed. The new envelope curve equation for the remaining 9 data points is

$$Q_5 = 5293(x)^{0.56} \quad (4)$$

and the corresponding best-fit equation is

$$Q_5 = 1949x \quad (5)$$

where

Q_5 = post-burn runoff for the 5-year return interval (cfs).

---

[3] The hyper-effective drainage area, α times ψ in the first equation or the area of the high severity burn (square miles) plus the area of the moderate severity burn (square miles).

The adjusted R-square value for the new best-fit curve is 0.97. The new envelope curve was developed by adding 25% (the largest reported flow measurement error) to the values for Noon and Deadman Canyons; and then fitting a power curve to these data points. As can be seen, equations 3 and 5 are essentially the same. The relationship between envelope equations is

$$y = 0.1963(x)^{1.1605} \qquad (6)$$

where

y = equation 2; and

x = equation 4.

Equations 4 and 5 are presented here for comparison with equations 2 and 3 only. To allow direct comparison the definition of the multivariate runoff index has been held constant. Since the best-fit equations are essentially the same, and the difference between envelope curves is within the reported error of observations, the continued use of equations 2 and 3 are recommended.

Validation of Equation

The leave-one-out cross validation technique was used to test the regression equation ability to predict Q_5. This technique allows each data point to be treated, one at a time, as independent data (Wilks 2006, see page 215 for a more detailed description of this method). Using this process a cross validation adjusted R-square value of 0.81 was obtained with a corresponding cross validation standard error of 1757 cfs (49.8 cubic meters per second). This yields a cross validation adjusted coefficient of determination (adjusted correlation coefficient) of 0.90. This is considered by the authors to represent an acceptable forecast precision, and therefore, the authors feel confident in the use of the equations operationally to predict the “likely” peak flow that can be expected before a given burned watershed is back to conditions that resemble pre-burn hydrology. However, as more data becomes available, these equations should be updated and their usefulness further tested.

Discussion

The USGS equations for estimating flood-frequency relations in USGS Water-Supply Paper 2433 (Thomas 1997) specifically the relationships for the 5-year event in Southeast Arizona do not use an elevation measurement for Region 13 (this region includes the Santa Catalina and Santa Rita Mountains); and uses an inverse relationship for elevation for Region 14 (this region includes the Pinaleno Mountains). In order to have a reasonable data set for post burn events, we had to evaluate these regions lumped together. An analysis of the data separated into these regions hints that an inverse relationship for average basin elevation would be significant for the post-burn Region 13 basins but perhaps not for the post-burn Region 14 basins. This is likely because all the basins had a relatively high average basin elevation regardless of what region they were in, and perhaps because neither region had enough data for a more rigorous analysis. An equation using just the hyper-effective drainage area and the modified channel relief ratio, i.e., an equation that does not use an elevation measurement, was found to have an adjusted R-square value of 0.93. Therefore, a bivariate equation could be developed with essentially the same success as the multivariate approach. However, average basin elevation was considered useful to help discern between different mountain ranges and was retained. As more data becomes available it may become possible to develop separate equations for these regions. At that time it may be that a multivariate approach will work best for post-burn Region 13 and a bivariate approach will work best for post-burn Region 14.

It is interesting to note that the USGS equations do not use a relief ratio or other measurement of slope for these regions. Also as would be expected for pre-burn equations, the USGS equations use the entire drainage basin (not a portion of the basin, i.e., hyper-effective drainage area). Perhaps these differences between the pre-burn equations and those presented here underscores that post-burn hydrology can be significantly different from normal conditions.

The direct relationship between 5-year peak flow and basin size does not necessarily pertain to burned watersheds (Figure 10). Noon Creek, with the largest value for the Post-Burn runoff, has neither the steepest modified channel relief ratio nor the highest average basin elevation; neither the largest burned area nor the largest basin size. Yet Noon Creek does have the highest multivariate runoff index. As can be seen in Figure 10, the best-fit equation value (light blue/fourth bar) underestimates (although not significantly) the target post-burn value[4] (blue/third bar) for Wet, Frye, Romero, and Alder Canyons. However, as intentionally developed, the envelope curve values (burgundy/fifth bar) are greater than target post-burn values for all ten sites. Additionally, the envelope curve begins to "flatten" faster than the best-fit curve (Figure 9), and thus displays the curve shape expected for larger basins (generally larger index values). Therefore, for conservatively estimating 5-year post-burn runoff in Southeast Arizona watersheds, the envelope curve (equation 2) should be used. For situations where post-burn hydrology is not significantly different than normal conditions (when the hyper-effective drainage area is a small portion of the total drainage area) the results of the post-burn envelope curve and a pre-burn 5-year equation should be compared and the higher result used.

Conclusions

Common rainfall events can cause large peak flows in basins recently burned. Peak flows from post-burn mountainous terrain may be several orders of magnitude greater than what they would have been for pre-burn conditions. This was observed for various watersheds in the Santa Catalina, Santa Rita, and Pinaleno Mountains. Since 3 to 5 years is a reasonable rule of thumb for recovery of burned watersheds, a 5-year rainfall event should be expected during the recovery period. The probability of occurrence of one or more events equal to or greater than the 5-year event in 5 years is 67%. In order to evaluate the minimum peak flow that can be expected before a given burned watershed is back to conditions that resemble pre-burn hydrology, an empirical equation was devised to predict the 5-year peak flow. This equation works reasonably well for the recently burned watersheds of the Santa Catalina, Santa Rita, and Pinaleno Mountains. Its ability to deal with such topographic and geomorphologic diversity lies in the use of a multivariate runoff index that utilizes the hyper-effective drainage area (determined from burn severity), average basin elevation, and an objective (Southeast Arizona specific) modified channel relief ratio. The hyper-effective drainage area approach may be representative of two contrasting runoff conditions: 1) significant runoff from burn areas with hydrophobic soils, under such circumstances all rainfall can essentially be considered in excess of soil moisture needs; and 2) little runoff from dry non-burned areas where there may have been little if any excess.

[4] The target values are those values determined by Schaffner and Reed (2005a) and were updated as shown in furthest right column of Figure 3.

In light of the difficulty in estimating increased peak flow from burned areas, empirical equations represent a significant tool for estimating peak flow. Several flow events from various watersheds are required for the geographic area in question. If a different probability of occurrence is desired, a curve could be developed for a different return interval using the methods described above. However, for return intervals greater than the 10-year return interval, the method to calculate post-burn peak flow would have to be modified to take into account that the ratio of pre-burn to post-burn would not be the same for large magnitude events.

Acknowledgements

The authors thank Chris Smith, Dan Evans, and Saeid Tadayon of the U.S. Geological Survey for conducting a slope-area measurement of Marijilda Canyon, their sound advice, and field assistance; thank Barry Scott of Arizona Division of Emergency Management for the GIS analysis of the various watersheds in the Pinaleno Mountains and Santa Catalina Mountains; thank Robert Lefevre of U.S. Forest Service for providing burn severity shapefiles for the Nuttall Fire and burn severity estimates for the Sabino Creek near Mount Lemmon watershed; and thank Ann Youberg of the Arizona Geological Survey for providing a HEC-RAS step backwater model analysis for Romero Canyon. The authors also thank Kevin Werner and Erik Pytlak of NOAA National Weather Service for their helpful reviews of the early drafts of this paper.

A Few Words Regarding the Cover Photograph

This boulder levee is an interesting feature of our studies. Such levees are characteristic of debris flows. From USGS Open File Report 97-136 by Susan H. Cannon: "Debris-flow deposits are characterized by significant relief and sharp, well-defined flow boundaries. Levees lining the flow path, or a veneer of mud coating the channel sidewalls, as well as steep, lobate deposits of matrix-supported material at the path terminus are characteristic of this flow process." We tend to believe that the levee was the result of a debris flow prior to a water flow and that the peak flow was a water flow that did over topped the levee as evidenced by the "debris" against the tree and the lack of mud stained walls. So a possible order of the events is 1) debris flow, 2) levee deposited, 3) frontal lobe of debris / hyperconcentrated flow, 4) overtopping of levee by water flow with floating debris, 5) wrapping of floating debris against tree, 6) peak flow, 7) retreat of water flow to channel during falling limb of hydrograph. Note: steps 1-5 would occur during rising limb of hydrograph. Perhaps steps 1 and 2 would be considered a separate geo-hazard event, followed by a second hydrological event consisting of steps 3 through 7. Of course this is all conjecture. Finally it seems to us that the levee was washed clean of any mud coating due to the overtopping by water or perhaps subsequent rain.

References

Bonnin, G. M., D. Todd, B. Lin, T. Parzybok, M. Yekta, and D. Riley, 2004. NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 1: Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico, Utah). Available online: http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_docs.html#volume1.

Brown, D. E., editor, 1982. Biotic Communities of the American Southwest--United States and Mexico. *Desert Plants* **4**, 1-4.

Crippen, J. and C. Bue. 1977. Maximum Flood flows in the Conterminous United States. USGS Water Supply Paper 1887.

Hendricks, D. M., 1985. Arizona Soils. Available online: http://southwest.library.arizona.edu/azso/index.html.

Livingston, R. K., T. A. Earles, and K. R. Wright, 2005. Los Alamos Post-Fire Watershed Recovery: A Curve-Number-Based Evaluation, ASCE Conf. Proc. 178, 41.

Martin, D. A., and J. A. Moody, 2001. Comparison of soil infiltration rates in burned and unburned mountainous watersheds. Hydrological Processes 15:2893-2903.

Morris, S. E., and T. A. Moses, 1987. Forest fire and the natural soil erosion regime in the Colorado Front Range. Association of American Geographers 77: 245– 254.

Natural Resources Conservation Service, 1986. Urban Hydrology for Small Watersheds, Technical Release 55. Available online: ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

Neary, D. G., K. C. Ryan, and L. F. DeBano, eds., 2005. Wildland fire in ecosystems: effects of fire on soils and water. Gen. Tech. Rep. RMRS-GTR-42-vol.4. Available online: http://www.fs.fed.us/rm/pubs/rmrs_gtr042_4.pdf.

Reed, W., 2002. Rodeo-Chediski Fire: December 16, 2002 Hydrology Meeting. Available online: http://www.cbrfc.noaa.gov/report/wbr_hydrofinal.pdf.

Ries, K.G., III, and M. Y. Crouse, 2002. The National Flood Frequency Program, Version 3: A Computer Program for Estimating Magnitude and Frequency of Floods for Ungaged Sites, 2002: U.S. Geological Survey Water-Resources Investigations Report 02-4168, 42 p. Available online: http://pubs.usgs.gov/wri/wri024168/.

Robichuad, P. R., 2000. Forest fire effects on hillslope erosion: what we know. Watershed Management Council Networker 9(1): Winter 2000. Available online: http://watershed.org/news/win_00/2_hillslope_fire.htm.

Schaffner, M. and W. Reed, 2005a. Effects of Wildfire in the Mountainous Terrain of Southeast Arizona: Post-Burn Hydrologic Response of Nine Watersheds. NOAA National Weather Service Western Region Technical Attachment 05-01. Available online: http://www.wrh.noaa.gov/wrh/05TAs/ta0501.pdf.

Schaffner, M. and W. Reed, 2005b. Evaluation of Post-Burn Hydrologic Recovery of a Small Mountainous Watershed: Upper Campo Bonito Wash in Southern Arizona. NOAA National Weather Service Western Region Technical Attachment 05-06. Available online: http://www.wrh.noaa.gov/wrh/05TAs/ta0506.pdf.

Tadayon, S., 2004. Peak Flow Estimate at Marijilda Wash near Safford (09458050), AZ, by the Slope-Area Method using SAX Program: Flood of August 17, 2004. U.S. Geological Survey, Arizona Water Resources Division, Unpublished Slope-Area Report.

Thomas, B., et. al., 1997. Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States. USGS Water-Supply Paper 2433. Available online: http://pubs.er.usgs.gov/pubs/wsp/wsp2433#viewdoc.

Veenhuis, J., 2002. Effects Of Wildfire On The Hydrology Of Capulin and Rito de los Frijoles Canyons, Bandelier National Monument, New Mexico. USGS Water-Resources Investigations Report 02-4152.2. Available online: http://nm.water.usgs.gov/publications/abstracts/wrir02-4152.pdf.

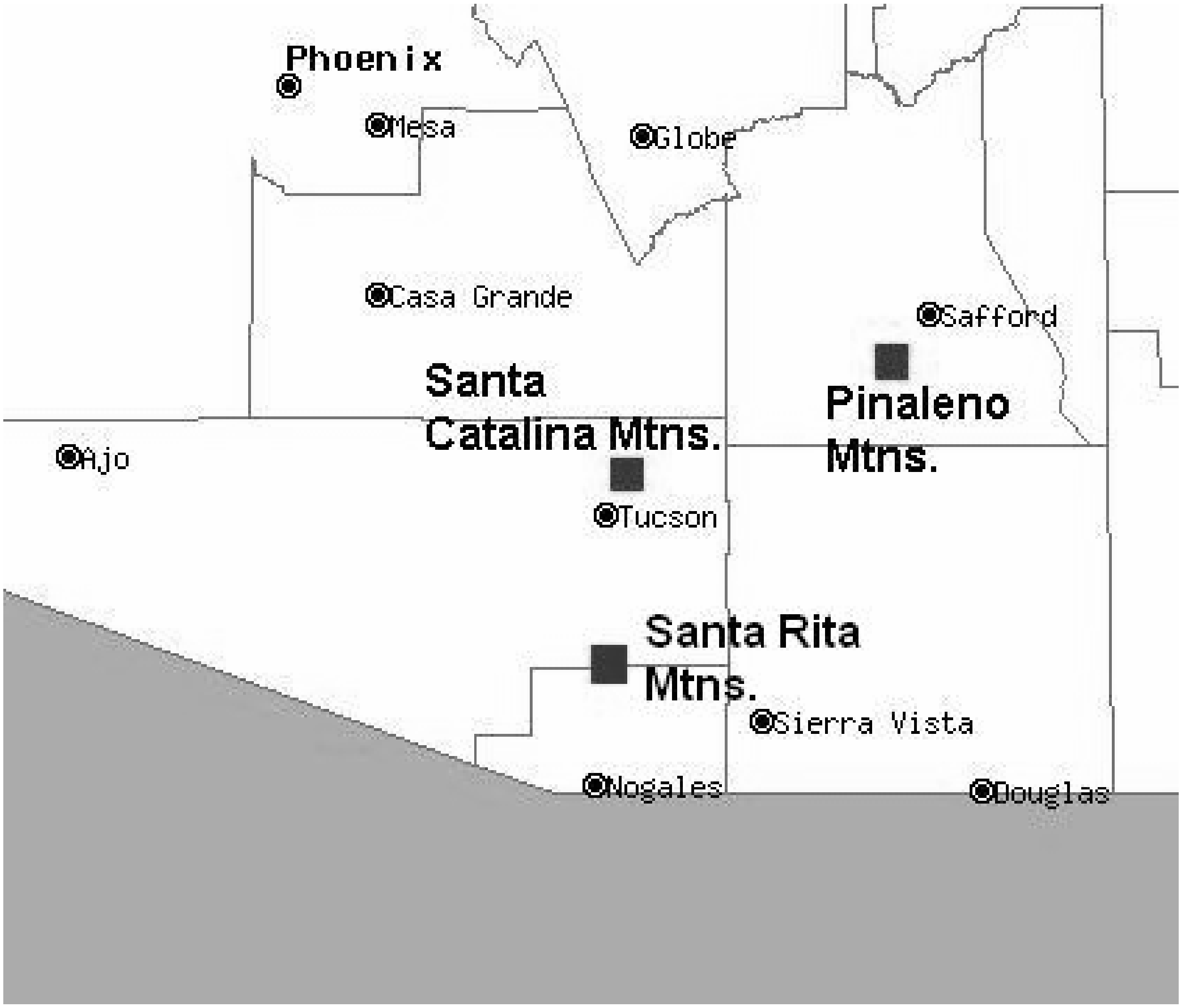


Figure 1: Map displaying locations of Santa Catalina, Santa Rita, and Pinaleno Mountains in southeast Arizona.

SOUTHEAST ARIZONA POST-BURN FLOOD DATABASE FOR TEN BASINS							
Watershed	Basin Average Precipitation (inches)	Storm Duration (hours)	General Storm Motion	Time of Concentration (hours)	Rainfall Return Interval (t-years)	Peak Flow of Flood (cfs)	Pre-Burn Peak Flow of Rainfall Return Interval (cfs)
Frye Creek	0.40	0.5	across	0.6	< 1-year	1400~	18.5
Deadman Canyon	1.00	0.5	across	0.5	3-year	5500	67.2
Marijilda Canyon	1.25	0.7	across	0.8	5-year	8470♦	313
Noon Creek	0.94	0.4	across	0.4	2-year	2684#	19
Wet Canyon	0.8	0.7	across	0.3	1-year	1490	7.2
Upper Campo Bonito	1.51	0.5	stationary	0.3	10-year	1900	586
Sabino Creek near Mount Lemmon	1.25	1	stationary	0.6	2-year	350	119
Alder Canyon at Ventana Windmill	1.60	1	down to up	1.2	5-year	3103	1260
Madera Canyon	0.70	0.75	stationary	0.4	< 1-year	1526	224
Romero Canyon	1.60	0.5	up to down	1.1	10-year	9500	1420

Figure 2: Southeast Arizona post-burn flood database for ten basins.

~ July 27, 2004.

♦ Value updated based upon October 6, 2004 written communication from USGS (Tadayon, 2004) providing a new peak flow estimate for the flood of August 17, 2004.

Value updated based upon January 24, 2006 survey of high water marks by authors and subsequent slope conveyance.

ADDITIONAL SELECTED BASIN VALUES							
Watershed	Location	Modified channel relief ratio (ft/ft)	High severity burn + Moderate severity burn (%)	Average basin elevation above mean sea level (ft/1000)	Drainage area (sq mi)	Pre-burn 5-year peak discharge (cfs)	Post-burn 5-year discharge (cfs)
Frye Creek	Pinaleno Mountains	0.19	61	8.1	4.02	116	8778
Deadman Canyon	Pinaleno Mountains	0.22	51	7.7	4.78	137	11213
Marijilda Canyon	Pinaleno Mountains	0.15	59	7.1	11	313	8470♦
Noon Creek	Pinaleno Mountains	0.24	77	7.7	2.99	86	12149#
Wet Canyon	Pinaleno Mountains	0.26	44	8.1	1.58	45.5	9416*
Upper Campo Bonito	Santa Catalina Mountains	0.07	80	5.5	1.5	376	1219**
Sabino Creek near Mount Lemmon	Santa Catalina Mountains	0.07	55	8.2	3.4	278	818
Alder Canyon at Ventana Windmill	Santa Catalina Mountains	0.08	35	6.1	14	1260	3103***
Madera Canyon	Santa Rita Mountains	0.22	15	7.2	4	657	4476
Romero Canyon	Santa Catalina Mountains	0.12	34	5.7	7.25	902	6035

Figure 3: Additional selected basin values for study watersheds in the Pinaleno, Santa Catalina, and Santa Rita Mountains. Note: Madera and Romero Canyons recently added and documented in this paper.

♦ Value updated based upon October 6, 2004 written communication from USGS (Tadayon, 2004) providing a new peak flow estimate for the flood of August 17, 2004.

Value updated based upon January 24, 2006 survey of high water marks by authors and subsequent slope conveyance.

* This value corrected to reflect that event storm was actually a 1-year event.

** This value corrected to reflect Region 13.

*** This value corrected to reflect that event storm was actually a 5-year event.

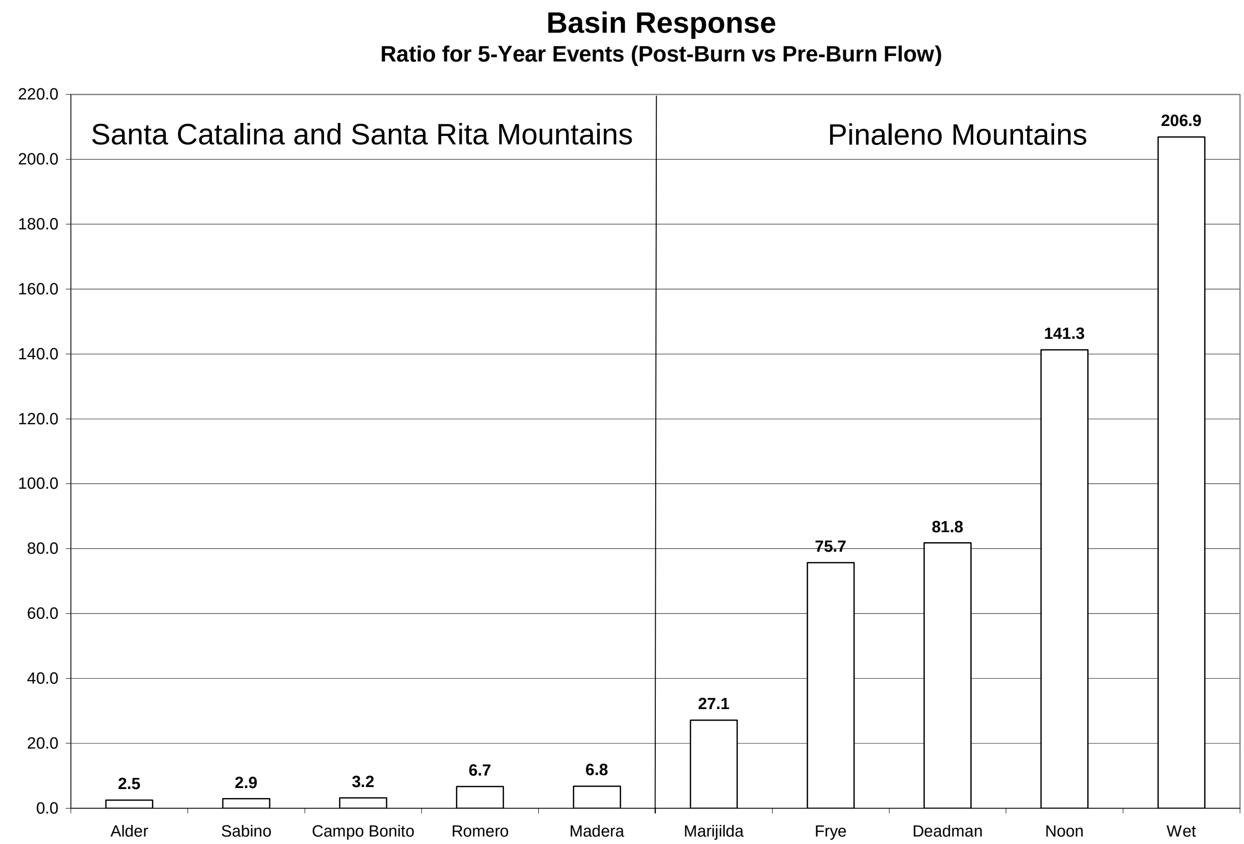


Figure 4: Basin Response under burn conditions for various watersheds in the Santa Catalina, Campo Bonito, Sabino, Alder, and Romero), Santa Rita (Madera), and Pinaleno Mountains (Marijilda, Frye, Noon, Deadman, and Wet).

Madera Creek		
Return Period	Pre-Burn Flow	Post-Burn Flow
2-year	271 cfs (7.67 m^3/sec)	1846 cfs (52.25 m^3/sec)
5-year	657 cfs (18.61 m^3/sec)	4476 cfs (126.67 m^3/sec)
10-year	1030 cfs (29.17 m^3/sec)	7017 cfs (198.59 m^3/sec)
25-year	1660 cfs (47.01 m^3/sec)	11310 cfs (320.06 m^3/sec)
50-year	2220 cfs (62.87 m^3/sec)	15125 cfs (428.03 m^3/sec)
100-year	2960 cfs (83.83 m^3/sec)	20166 cfs (570.71 m^3/sec)
500-year	5040 cfs (142.73 m^3/sec)	34338 cfs (971.75 m^3/sec)

Figure 5: Peak flows for Madera Creek. The pre-burn flows were calculated using the National Flood Frequency (NFF) method for Southern Arizona Region 13 (Ries and Crouse, 2002). The maximum flow calculated from Crippen and Bue (1977) method is 30,300 cfs (858.10 m^3/sec). Note: The Post-Burn Flow values for events greater than the 10-year event are not considered as reliable as those for the return intervals equal to or less than the 10-year event. These less reliable values were not used in the development of the empirical equation.

Romero Canyon		
Return Period	Pre-Burn Flow	Post-Burn Flow
2-year	372 cfs (10.54 m^3/sec)	2490 cfs (70.52 m^3/sec)
5-year	902 cfs (25.54 m^3/sec)	6035 cfs (170.90 m^3/sec)
10-year	1420 cfs (40.21 m^3/sec)	9515 cfs (269.46 m^3/sec)
25-year	2290 cfs (64.85 m^3/sec)	15340 cfs (434.43 m^3/sec)
50-year	3070 cfs (86.94 m^3/sec)	20600 cfs (583.39 m^3/sec)
100-year	4090 cfs (115.83 m^3/sec)	27400 cfs (775.97 m^3/sec)
500-year	7020 cfs (198.81 m^3/sec)	47000 cfs (1331.04 m^3/sec)

Figure 6: Peak flows for Romero Canyon. The pre-burn flows were calculated using the National Flood Frequency (NFF) method for Southern Arizona Region 13 (Ries and Crouse, 2002). The maximum flow calculated from Crippen and Bue (1977) method is 49,200 cfs (1393.34 m^3/sec). Note: The Post-Burn Flow values for events greater than the 10-year event are not considered as reliable as those for the return intervals equal to or less than the 10-year event. These less reliable values were not used in the development of the empirical equation.

FRYE CREEK MULTIPLE EVENTS								
Date 2004	Basin Average Precipitation Step 1 (inches)	Storm Duration Step 1 (hours)	Rainfall Return Interval Step 2 (t-years)	Peak Flow of Flood Step 3 (cfs)	Pre-Burn Peak Flow of Rainfall Return Interval Step 4 (cfs)	Ratio Step 5 (cfs/cfs)	Pre-burn 5-year peak discharge Step 6 (cfs)	Post-burn 5-year discharge Step 7 (cfs)
July 27	0.40	0.5	< 1-year	1400	18.5	75.7	116	8778
August 4	1.00	1.0	2-year	1040	26	40	116	4640
August 17	1.30	0.5	5-year	2260	116	19.5	116	2260

Figure 7: Multiple Events For Frye Creek.

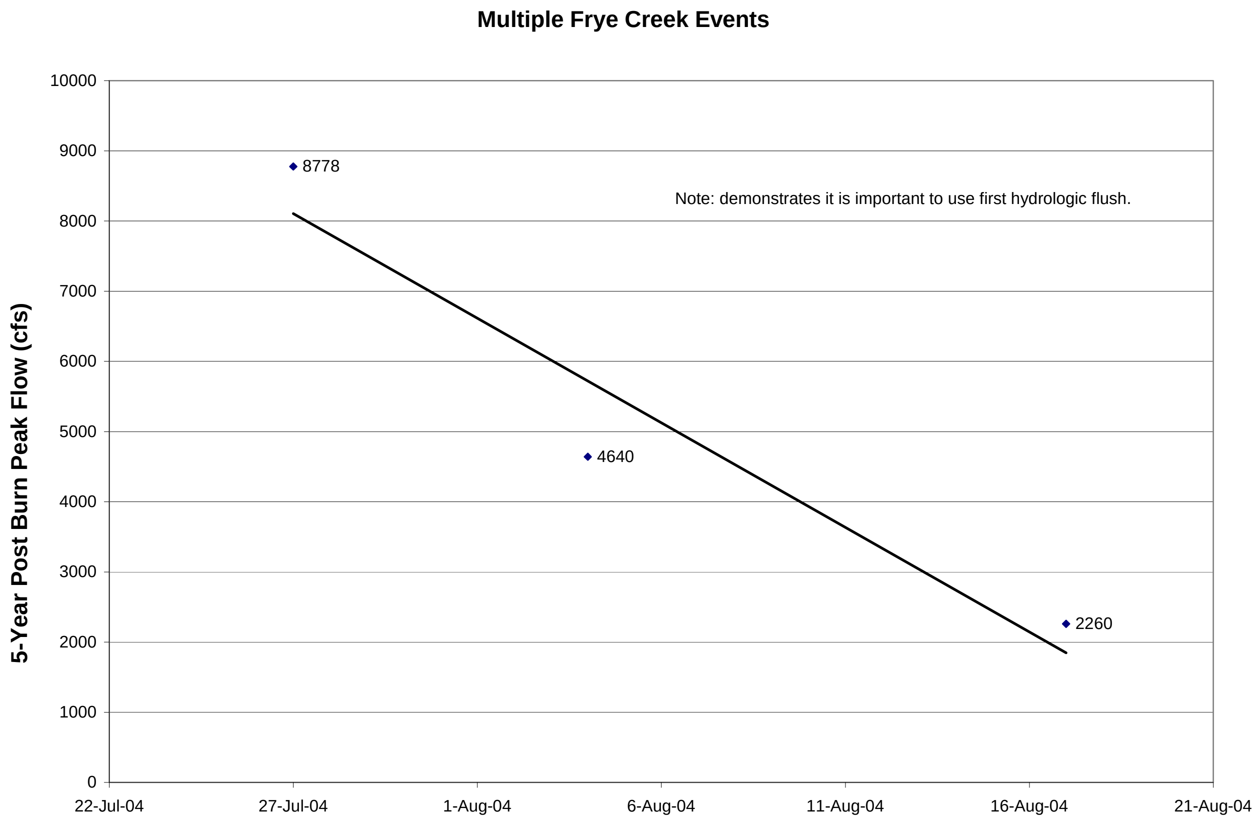


Figure 8: Calculated 5-Year Peak Flows For Sequential Events on Frye Creek.

An Empirical 5-Year Post-Burn Runoff Equation for Southeast Arizona Watersheds

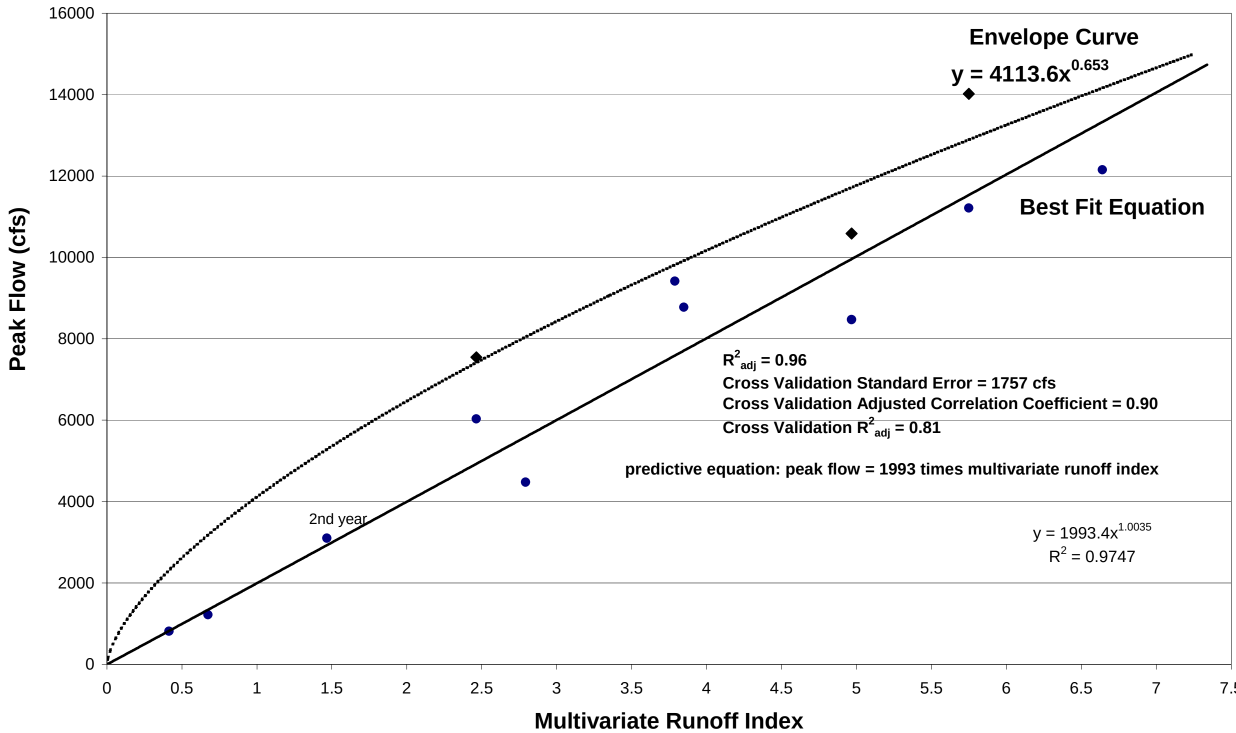
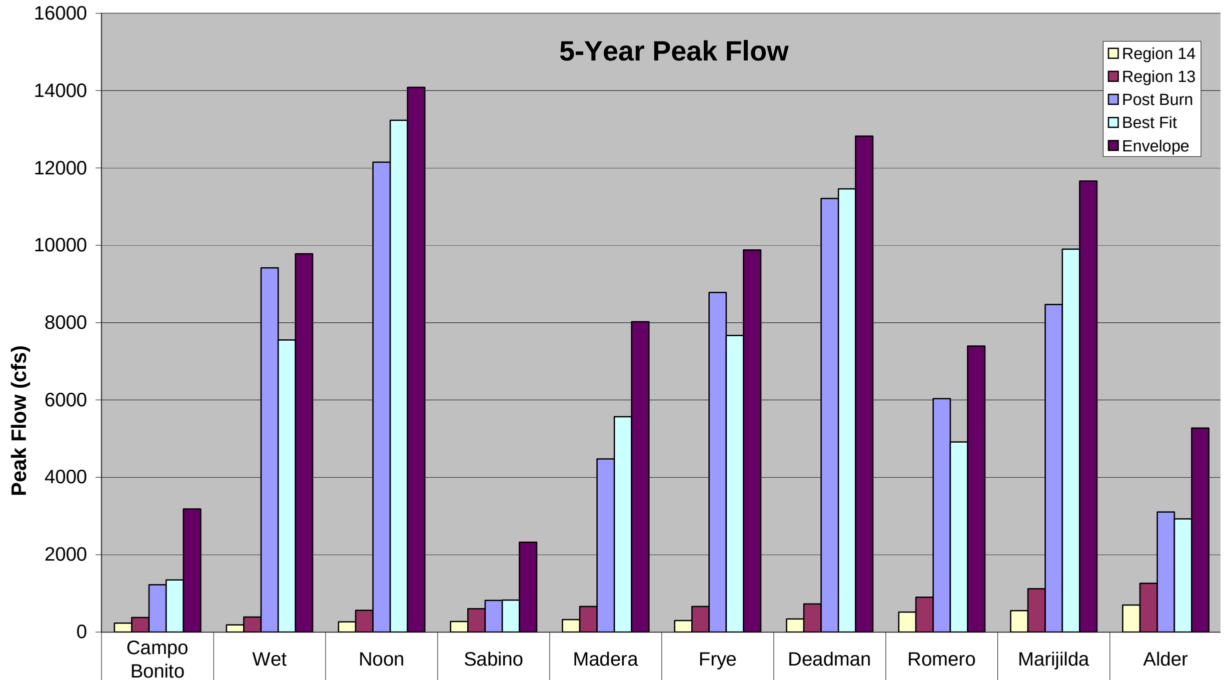


Figure 9: An empirical equation to estimate post-burn runoff during recovery (Southeast Arizona Watersheds). 2nd year = those events that occurred during the second year after the burn; the other 9 events occurred during the first year after the burn. These equations are for small watersheds less than 15 square miles (38.8 square kilometers); and include sites with average basin elevations from 5500 to 8100 feet (1676.4 to 2469 meters) above msl. Multivariate runoff index $=1000(\alpha\psi)^{0.54}\beta^{2}\phi^{-1.28}$; where α = high severity burn + moderate severity burn as a fraction of total watershed (square miles/square miles); ψ = total drainage area (square miles); β = modified channel relief ratio (feet/feet); and ϕ = average basin elevation above mean sea level (thousands of feet). Note: α times ψ in above equation = hyper-effective drainage area.



	Campo Bonito	Wet	Noon	Sabino	Madera	Frye	Deadman	Romero	Marijilda	Alder
Region 14	231	182	262	270	319	296	335	515	549	695
Region 13	376	388	559	601	657	659	723	902	1116	1259
Post Burn	1219	9416	12149	818	4476	8778	11213	6035	8470	3103
Best Fit	1344	7550	13233	825	5567	7669	11459	4912	9900	2923
Envelope	3185	9778	14082	2320	8021	9878	12824	7394	11662	5277

Figure 10: As basin size increases from left to right, the peak flow generally increases using pre-burn equations (yellow/first bar & red/second bar). The Post-Burn equations results are very different (light blue/fourth bar & burgundy/fifth bar). The target post-burn value is shown in blue/third bar. Peak flows are shown in cubic feet per second (cfs).

NOAA TECHNICAL MEMORANDA
National Weather Service, Western Region Subseries

The National Weather Service (NWS) Western Region (WR) Subseries provides an informal medium for the documentation and quick dissemination of results not appropriate, or not yet ready, for formal publication. The series is used to report on work in progress, to describe technical procedures and practices, or to relate progress to a limited audience. These Technical Memoranda will report on investigations devoted primarily to regional and local problems of interest mainly to personnel, and hence will not be widely distributed.

Papers 1 to 25 are in the former series, ESSA Technical Memoranda, Western Region Technical Memoranda (WRTM); papers 24 to 59 are in the former series, ESSA Technical Memoranda, Weather Bureau Technical Memoranda (WBTM). Beginning with 60, the papers are part of the series, NOAA Technical Memoranda NWS. Out-of-print memoranda are not listed.

Papers 2 to 22, except for 5 (revised edition), are available from the National Weather Service Western Region, Scientific Services Division, 125 South State Street - Rm 1311, Salt Lake City, Utah 84138-1102. Paper 5 (revised edition), and all others beginning with 25 are available from the National Technical Information Service, U.S. Department of Commerce, Sills Building, 5285 Port Royal Road, Springfield, Virginia 22161. Prices vary for all paper copies; microfiche are $3.50. Order by accession number shown in parentheses at end of each entry.

ESSA Technical Memoranda (WRTM)

2 Climatological Precipitation Probabilities. Compiled by Lucianne Miller, December 1965.
3 Western Region Pre- and Post-FP-3 Program, December 1, 1965, to February 20, 1966. Edward D. Diemer, March 1966.
5 Station Descriptions of Local Effects on Synoptic Weather Patterns. Philip Williams, Jr., April 1966 (Revised November 1967, October 1969). (PB-17800)
8 Interpreting the RAREP. Herbert P. Benner, May 1966 (Revised January 1967).
11 Some Electrical Processes in the Atmosphere. J. Latham, June 1966.
17 A Digitalized Summary of Radar Echoes within 100 Miles of Sacramento, California. J. A. Youngberg and L. B. Overaas, December 1966.
21 An Objective Aid for Forecasting the End of East Winds in the Columbia Gorge, July through October. D. John Coparanis, April 1967.
22 Derivation of Radar Horizons in Mountainous Terrain. Roger G. Pappas, April 1967.

ESSA Technical Memoranda, Weather Bureau Technical Memoranda (WBTM)

25 Verification of Operation Probability of Precipitation Forecasts, April 1966-March 1967. W. W. Dickey, October 1967. (PB-176240)
26 A Study of Winds in the Lake Mead Recreation Area. R. P. Augulis, January 1968. (PB-177830)
28 Weather Extremes. R. J. Schmidli, April 1968 (Revised March 1986). (PB86 177672/AS). (Revised October 1991 - PB92-115062/AS)
29 Small-Scale Analysis and Prediction. Philip Williams, Jr., May 1968. (PB178425)
30 Numerical Weather Prediction and Synoptic Meteorology. CPT Thomas D. Murphy, USAF, May 1968. (AD 673365)
31 Precipitation Detection Probabilities by Salt Lake ARTC Radars. Robert K. Belesky, July 1968. (PB 179084)
32 Probability Forecasting--A Problem Analysis with Reference to the Portland Fire Weather District. Harold S. Ayer, July 1968. (PB 179289)
36 Temperature Trends in Sacramento--Another Heat Island. Anthony D. Lentini, February 1969. (PB 183055)
37 Disposal of Logging Residues Without Damage to Air Quality. Owen P. Cramer, March 1969. (PB 183057)
39 Upper-Air Lows Over Northwestern United States. A.L. Jacobson, April 1969. PB 184296)
40 The Man-Machine Mix in Applied Weather Forecasting in the 1970s. L.W. Snellman, August 1969. (PB 185068)
43 Forecasting Maximum Temperatures at Helena, Montana. David E. Olsen, October 1969. (PB 185762)
44 Estimated Return Periods for Short-Duration Precipitation in Arizona. Paul C. Kangieser, October 1969. (PB 187763)
46 Applications of the Net Radiometer to Short-Range Fog and Stratus Forecasting at Eugene, Oregon. L. Yee and E. Bates, December 1969. (PB 190476)
47 Statistical Analysis as a Flood Routing Tool. Robert J.C. Burnash, December 1969. (PB 188744)
48 Tsunami. Richard P. Augulis, February 1970. (PB 190157)
49 Predicting Precipitation Type. Robert J.C. Burnash and Floyd E. Hug, March 1970. (PB 190962)
50 Statistical Report on Aeroallergens (Pollens and Molds) Fort Huachuca, Arizona, 1969. Wayne S. Johnson, April 1970. (PB 191743)
51 Western Region Sea State and Surf Forecaster's Manual. Gordon C. Shields and Gerald B. Burdwell, July 1970. (PB 193102)
52 Sacramento Weather Radar Climatology. R.G. Pappas and C. M. Veliquette, July 1970. (PB 193347)
54 A Refinement of the Vorticity Field to Delineate Areas of Significant Precipitation. Barry B. Aronovitch, August 1970.
55 Application of the SSARR Model to a Basin without Discharge Record. Vail Schermerhorn and Donal W. Kuehl, August 1970. (PB 194394)
56 Areal Coverage of Precipitation in Northwestern Utah. Philip Williams, Jr., and Werner J. Heck, September 1970. (PB 194389)
57 Preliminary Report on Agricultural Field Burning vs. Atmospheric Visibility in the Willamette Valley of Oregon. Earl M. Bates and David O. Chilcote, September 1970. (PB 194710)
58 Air Pollution by Jet Aircraft at Seattle-Tacoma Airport. Wallace R. Donaldson, October 1970. (COM 71 00017)
59 Application of PE Model Forecast Parameters to Local-Area Forecasting. Leonard W. Snellman, October 1970. (COM 71 00016)
60 An Aid for Forecasting the Minimum Temperature at Medford, Oregon, Arthur W. Fritz, October 1970. (COM 71 00120)
63 700-mb Warm Air Advection as a Forecasting Tool for Montana and Northern Idaho. Norris E. Woerner, February 1971. (COM 71 00349)
64 Wind and Weather Regimes at Great Falls, Montana. Warren B. Price, March 1971.
65 Climate of Sacramento, California. Laura Masters-Bevan. NWSO Sacramento, November 1998 (6th Revision. (PB99-118424)
66 A Preliminary Report on Correlation of ARTCC Radar Echoes and Precipitation. Wilbur K. Hall, June 1971. (COM 71 00829)
69 National Weather Service Support to Soaring Activities. Ellis Burton, August 1971. (COM 71 00956)
71 Western Region Synoptic Analysis-Problems and Methods. Philip Williams, Jr., February 1972. (COM 72 10433)
74 Thunderstorms and Hail Days Probabilities in Nevada. Clarence M. Sakamoto, April 1972. (COM 72 10554)
75 A Study of the Low Level Jet Stream of the San Joaquin Valley. Ronald A. Willis and Philip Williams, Jr., May 1972. (COM 72 10707)
76 Monthly Climatological Charts of the Behavior of Fog and Low Stratus at Los Angeles International Airport. Donald M. Gales, July 1972. (COM 72 11140)
77 A Study of Radar Echo Distribution in Arizona During July and August. John E. Hales, Jr., July 1972. (COM 72 11136)
78 Forecasting Precipitation at Bakersfield, California, Using Pressure Gradient Vectors. Earl T. Riddiough, July 1972. (COM 72 11146)
79 Climate of Stockton, California. Robert C. Nelson, July 1972. (COM 72 10920)
80 Estimation of Number of Days Above or Below Selected Temperatures. Clarence M. Sakamoto, October 1972. (COM 72 10021)
81 An Aid for Forecasting Summer Maximum Temperatures at Seattle, Washington. Edgar G. Johnson, November 1972. (COM 73 10150)
82 Flash Flood Forecasting and Warning Program in the Western Region. Philip Williams, Jr., Chester L. Glenn, and Roland L. Raetz, December 1972, (Revised March 1978). (COM 73 10251)
83 A comparison of Manual and Semiautomatic Methods of Digitizing Analog Wind Records. Glenn E. Rasch, March 1973. (COM 73 10669)
86 Conditional Probabilities for Sequences of Wet Days at Phoenix, Arizona. Paul C. Kangieser, June 1973. (COM 73 11264)
87 A Refinement of the Use of K-Values in Forecasting Thunderstorms in Washington and Oregon. Robert Y.G. Lee, June 1973. (COM 73 11276)
89 Objective Forecast Precipitation Over the Western Region of the United States. Julia N. Paegle and Larry P. Kierulff, September 1973. (COM 73 11946/3AS)
91 Arizona "Eddy" Tornadoes. Robert S. Ingram, October 1973. (COM 73 10465)
92 Smoke Management in the Willamette Valley. Earl M. Bates, May 1974. (COM 74 11277/AS)
93 An Operational Evaluation of 500-mb Type Regression Equations. Alexander E. MacDonald, June 1974. (COM 74 11407/AS)
94 Conditional Probability of Visibility Less than One-Half Mile in Radiation Fog at Fresno, California. John D. Thomas, August 1974. (COM 74 11555/AS)
95 Climate of Flagstaff, Arizona. Paul W. Sorenson, and updated by Reginald W. Preston, January 1987. (PB87 143160/AS) (Revised August 2002 3rd Revision)
96 Map type Precipitation Probabilities for the Western Region. Glenn E. Rasch and Alexander E. MacDonald, February 1975. (COM 75 10428/AS)
97 Eastern Pacific Cut-Off Low of April 21-28, 1974. William J. Alder and George R. Miller, January 1976. (PB 250 711/AS)
98 Study on a Significant Precipitation Episode in Western United States. Ira S. Brenner, April 1976. (COM 75 10719/AS)
99 A Study of Flash Flood Susceptibility-A Basin in Southern Arizona. Gerald Williams, August 1975. (COM 75 11360/AS)
102 A Set of Rules for Forecasting Temperatures in Napa and Sonoma Counties. Wesley L. Tuft, October 1975. (PB 246 902/AS)
103 Application of the National Weather Service Flash-Flood Program in the Western Region. Gerald Williams, January 1976. (PB 253 053/AS)
104 Objective Aids for Forecasting Minimum Temperatures at Reno, Nevada, During the Summer Months. Christopher D. Hill, January 1976. (PB 252 866/AS)
105 Forecasting the Mono Wind. Charles P. Ruscha, Jr., February 1976. (PB 254 650)
106 Use of MOS Forecast Parameters in Temperature Forecasting. John C. Plankinton, Jr., March 1976. (PB 254 649)
107 Map Types as Aids in Using MOS PoPs in Western United States. Ira S. Brenner, August 1976. (PB 259 594)
108 Other Kinds of Wind Shear. Christopher D. Hill, August 1976. (PB 260 437/AS)
109 Forecasting North Winds in the Upper Sacramento Valley and Adjoining Forests. Christopher E. Fontana, September 1976. (PB 273 677/AS)
110 Cool Inflow as a Weakening Influence on Eastern Pacific Tropical Cyclones. William J. Denney, November 1976. (PB 264 655/AS)
112 The MAN/MOS Program. Alexander E. MacDonald, February 1977. (PB 265 941/AS)
113 Winter Season Minimum Temperature Formula for Bakersfield, California, Using Multiple Regression. Michael J. Oard, February 1977. (PB 273 694/AS)
114 Tropical Cyclone Kathleen. James R. Fors, February 1977. (PB 273 676/AS)
116 A Study of Wind Gusts on Lake Mead. Bradley Colman, April 1977. (PB 268 847)
117 The Relative Frequency of Cumulonimbus Clouds at the Nevada Test Site as a Function of K-Value. R.F. Quiring, April 1977. (PB 272 831)
118 Moisture Distribution Modification by Upward Vertical Motion. Ira S. Brenner, April 1977. (PB 268 740)
119 Relative Frequency of Occurrence of Warm Season Echo Activity as a Function of Stability Indices Computed from the Yucca Flat, Nevada, Rawinsonde. Darryl Randerson, June 1977. (PB 271 290/AS)
121 Climatological Prediction of Cumulonimbus Clouds in the Vicinity of the Yucca Flat Weather Station. R.F. Quiring, June 1977. (PB 271 704/AS)
122 A Method for Transforming Temperature Distribution to Normality. Morris S. Webb, Jr., June 1977. (PB 271 742/AS)
124 Statistical Guidance for Prediction of Eastern North Pacific Tropical Cyclone Motion - Part I. Charles J. Neumann and Preston W. Leftwich, August 1977. (PB 272 661)
125 Statistical Guidance on the Prediction of Eastern North Pacific Tropical Cyclone Motion - Part II. Preston W. Leftwich and Charles J. Neumann, August 1977. (PB 273 155/AS)
126 Climate of San Francisco. E. Jan Null, February 1978. (Revised by George T. Pericht, April 1988 and January 1995). (PB88 208624/AS)
127 Development of a Probability Equation for Winter-Type Precipitation Patterns in Great Falls, Montana. Kenneth B. Mielke, February 1978. (PB 281 387/AS)
128 Hand Calculator Program to Compute Parcel Thermal Dynamics. Dan Gudgel, April 1978. (PB 283 080/AS)
129 Fire whirls. David W. Goens, May 1978. (PB 283 866/AS)
130 Flash-Flood Procedure. Ralph C. Hatch and Gerald Williams, May 1978. (PB 286 014/AS)
131 Automated Fire-Weather Forecasts. Mark A. Mollner and David E. Olsen, September 1978. (PB 289 916/AS)
132 Estimates of the Effects of Terrain Blocking on the Los Angeles WSR-74C Weather Radar. R.G. Pappas, R.Y. Lee, B.W. Finke, October 1978. (PB 289767/AS)
133 Spectral Techniques in Ocean Wave Forecasting. John A. Jannuzzi, October 1978. (PB291317/AS)
134 Solar Radiation. John A. Jannuzzi, November 1978. (PB291195/AS)
135 Application of a Spectrum Analyzer in Forecasting Ocean Swell in Southern California Coastal Waters. Lawrence P. Kierulff, January 1979. (PB292716/AS)
136 Basic Hydrologic Principles. Thomas L. Dietrich, January 1979. (PB292247/AS)
137 LFM 24-Hour Prediction of Eastern Pacific Cyclones Refined by Satellite Images. John R. Zimmerman and Charles P. Ruscha, Jr., January 1979. (PB294324/AS)
138 A Simple Analysis/Diagnosis System for Real Time Evaluation of Vertical Motion. Scott Heflick and James R. Fors, February 1979. (PB294216/AS)
139 Aids for Forecasting Minimum Temperature in the Wenatchee Frost District. Robert S. Robinson, April 1979. (PB298339/AS)

140 Influence of Cloudiness on Summertime Temperatures in the Eastern Washington Fire Weather district. James Holcomb, April 1979. (PB298674/AS)
141 Comparison of LFM and MFM Precipitation Guidance for Nevada During Doreen. Christopher Hill, April 1979. (PB298613/AS)
142 The Usefulness of Data from Mountaintop Fire Lookout Stations in Determining Atmospheric Stability. Jonathan W. Corey, April 1979. (PB298899/AS)
149 Misinterpretations of Precipitation Probability Forecasts. Allan H. Murphy, Sarah Lichtenstein, Baruch Fischhoff, and Robert L. Winkler, February 1980. (PB80 174576)
150 Annual Data and Verification Tabulation - Eastern and Central North Pacific Tropical Storms and Hurricanes 1979. Emil B. Gunther and Staff, EPHC, April 1980. (PB80 220486)
151 NMC Model Performance in the Northeast Pacific. James E. Overland, PMEL-ERL, April 1980. (PB80 196033)
152 Climate of Salt Lake City, Utah. William J. Alder, Sean T. Buchanan, William Cope (Retired), James A. Cisco, Craig C. Schmidt, Alexander R. Smith (Retired), Wilbur E. Figgins (Retired), February 1998 - Seventh Revision (PB98-130727)
153 An Automatic Lightning Detection System in Northern California. James E. Rea and Chris E. Fontana, June 1980. (PB80 225592)
154 Regression Equation for the Peak Wind Gust 6 to 12 Hours in Advance at Great Falls During Strong Downslope Wind Storms. Michael J. Oard, July 1980. (PB91 108367)
155 A Raininess Index for the Arizona Monsoon. John H. Ten Harkel, July 1980. (PB81 106494)
156 The Effects of Terrain Distribution on Summer Thunderstorm Activity at Reno, Nevada. Christopher Dean Hill, July 1980. (PB81 102501)
157 An Operational Evaluation of the Scofield/Oliver Technique for Estimating Precipitation Rates from Satellite Imagery. Richard Ochoa, August 1980. (PB81 108227)
158 Hydrology Practicum. Thomas Dietrich, September 1980. (PB81 134033)
159 Tropical Cyclone Effects on California. Arnold Court, October 1980. (PB81 133779)
160 Eastern North Pacific Tropical Cyclone Occurrences During Intraseasonal Periods. Preston W. Leftwich and Gail M. Brown, February 1981. (PB81 205494)
161 Solar Radiation as a Sole Source of Energy for Photovoltaics in Las Vegas, Nevada, for July and December. Darryl Randerson, April 1981. (PB81 224503)
162 A Systems Approach to Real-Time Runoff Analysis with a Deterministic Rainfall-Runoff Model. Robert J.C. Burnash and R. Larry Ferral, April 1981. (PB81 224495)
163 A Comparison of Two Methods for Forecasting Thunderstorms at Luke Air Force Base, Arizona. LTC Keith R. Cooley, April 1981. (PB81 225393)
164 An Objective Aid for Forecasting Afternoon Relative Humidity Along the Washington Cascade East Slopes. Robert S. Robinson, April 1981. (PB81 23078)
165 Annual Data and Verification Tabulation, Eastern North Pacific Tropical Storms and Hurricanes 1980. Emil B. Gunther and Staff, May 1981. (PB82 230336)
166 Preliminary Estimates of Wind Power Potential at the Nevada Test Site. Howard G. Booth, June 1981. (PB82 127036)
167 ARAP User's Guide. Mark Mathewson, July 1981, Revised September 1981. (PB82 196783)
168 Forecasting the Onset of Coastal Gales Off Washington-Oregon. John R. Zimmerman and William D. Burton, August 1981. (PB82 127051)
169 A Statistical-Dynamical Model for Prediction of Tropical Cyclone Motion in the Eastern North Pacific Ocean. Preston W. Leftwich, Jr., October 1981. (PB82195298)
170 An Enhanced Plotter for Surface Airways Observations. Andrew J. Spry and Jeffrey L. Anderson, October 1981. (PB82 153883)
171 Verification of 72-Hour 500-MB Map-Type Predictions. R.F. Quiring, November 1981. (PB82-158098)
172 Forecasting Heavy Snow at Wenatchee, Washington. James W. Holcomb, December 1981. (PB82-177783)
173 Central San Joaquin Valley Type Maps. Thomas R. Crossan, December 1981. (PB82 196064)
174 ARAP Test Results. Mark A. Mathewson, December 1981. (PB82 198103)
176 Approximations to the Peak Surface Wind Gusts from Desert Thunderstorms. Darryl Randerson, June 1982. (PB82 253089)
177 Climate of Phoenix, Arizona. Robert J. Schmidli and Austin Jamison, April 1969 (Revised July 1996). (PB96-191614)
178 Annual Data and Verification Tabulation, Eastern North Pacific Tropical Storms and Hurricanes 1982. E.B. Gunther, June 1983. (PB85 106078)
179 Stratified Maximum Temperature Relationships Between Sixteen Zone Stations in Arizona and Respective Key Stations. Ira S. Brenner, June 1983. (PB83 249904)
180 Standard Hydrologic Exchange Format (SHEF) Version I. Phillip A. Pasteris, Vernon C. Bissel, David G. Bennett, August 1983. (PB85 106052)
181 Quantitative and Spacial Distribution of Winter Precipitation along Utah's Wasatch Front. Lawrence B. Dunn, August 1983. (PB85 106912)
182 500 Millibar Sign Frequency Teleconnection Charts - Winter. Lawrence B. Dunn, December 1983. (PB85 106276)
183 500 Millibar Sign Frequency Teleconnection Charts - Spring. Lawrence B. Dunn, January 1984. (PB85 111367)
184 Collection and Use of Lightning Strike Data in the Western U.S. During Summer 1983. Glenn Rasch and Mark Mathewson, February 1984. (PB85 110534)
185 500 Millibar Sign Frequency Teleconnection Charts - Summer. Lawrence B. Dunn, March 1984. (PB85 111359)
186 Annual Data and Verification Tabulation eastern North Pacific Tropical Storms and Hurricanes 1983. E.B. Gunther, March 1984. (PB85 109635)
187 500 Millibar Sign Frequency Teleconnection Charts - Fall. Lawrence B. Dunn, May 1984. (PB85-110930)
188 The Use and Interpretation of Isentropic Analyses. Jeffrey L. Anderson, October 1984. (PB85-132694)
189 Annual Data & Verification Tabulation Eastern North Pacific Tropical Storms and Hurricanes 1984. E.B. Gunther and R.L. Cross, April 1985. (PB85 1878887AS)
190 Great Salt Lake Effect Snowfall: Some Notes and An Example. David M. Carpenter, October 1985. (PB86 119153/AS)
191 Large Scale Patterns Associated with Major Freeze Episodes in the Agricultural Southwest. Ronald S. Hamilton and Glenn R. Lussky, December 1985. (PB86 144474AS)
192 NWR Voice Synthesis Project: Phase I. Glen W. Sampson, January 1986. (PB86 145604/AS)
193 The MCC - An Overview and Case Study on Its Impact in the Western United States. Glenn R. Lussky, March 1986. (PB86 170651/AS)
194 Annual Data and Verification Tabulation Eastern North Pacific Tropical Storms and Hurricanes 1985. E.B. Gunther and R.L. Cross, March 1986. (PB86 170941/AS)
195 Radid Interpretation Guidelines. Roger G. Pappas, March 1986. (PB86 177680/AS)
196 A Mesoscale Convective Complex Type Storm over the Desert Southwest. Darryl Randerson, April 1986. (PB86 190998/AS)
197 The Effects of Eastern North Pacific Tropical Cyclones on the Southwestern United States. Walter Smith, August 1986. (PB87 106258AS)
198 Preliminary Lightning Climatology Studies for Idaho. Christopher D. Hill, Carl J. Gorski, and Michael C. Conger, April 1987. (PB87 180196/AS)
199 Heavy Rains and Flooding in Montana: A Case for Slantwise Convection. Glenn R. Lussky, April 1987. (PB87 185229/AS)
143 The Depth of the Marine Layer at San Diego as Related to Subsequent Cool Season Precipitation Episodes in Arizona. Ira S. Brenner, May 1979. (PB298817/AS)
144 Arizona Cool Season Climatological Surface Wind and Pressure Gradient Study. Ira S. Brenner, May 1979. (PB298900/AS)
146 The BART Experiment. Morris S. Webb, October 1979. (PB80 155112)
147 Occurrence and Distribution of Flash Floods in the Western Region. Thomas L. Dietrich, December 1979. (PB80 160344)
200 Annual Data and Verification Tabulation Eastern North Pacific Tropical Storms and Hurricanes 1986. Roger L. Cross and Kenneth B. Mielke, September 1987. (PB88 110895/AS)
201 An Inexpensive Solution for the Mass Distribution of Satellite Images. Glen W. Sampson and George Clark, September 1987. (PB88 114038/AS)
202 Annual Data and Verification Tabulation Eastern North Pacific Tropical Storms and Hurricanes 1987. Roger L. Cross and Kenneth B. Mielke, September 1988. (PB88-101935/AS)
203 An Investigation of the 24 September 1986 "Cold Sector" Tornado Outbreak in Northern California. John P. Monteverdi and Scott A. Braun, October 1988. (PB89 121297/AS)
204 Preliminary Analysis of Cloud-To-Ground Lightning in the Vicinity of the Nevada Test Site. Carven Scott, November 1988. (PB89 128649/AS)
205 Forecast Guidelines For Fire Weather and Forecasters -- How Nighttime Humidity Affects Wildland Fuels. David W. Goens, February 1989. (PB89 162549/AS)
206 A Collection of Papers Related to Heavy Precipitation Forecasting. Western Region Headquarters, Scientific Services Division, August 1989. (PB89 230833/AS)
207 The Las Vegas McCarran International Airport Microburst of August 8, 1989. Carven A. Scott, June 1990. (PB90-240268)
208 Meteorological Factors Contributing to the Canyon Creek Fire Blowup, September 6 and 7, 1988. David W. Goens, June 1990. (PB90-245085)
209 Stratus Surge Prediction Along the Central California Coast. Peter Felsch and Woodrow Whitlatch, December 1990. (PB91-129239)
210 Hydrotools. Tom Egger. January 1991. (PB91-151787/AS)
211 A Northern Utah Soaker. Mark E. Struthwolf, February 1991. (PB91-168716)
212 Preliminary Analysis of the San Francisco Rainfall Record: 1849-1990. Jan Null, May 1991. (PB91-208439)
213 Idaho Zone Preformat, Temperature Guidance, and Verification. Mark A. Mollner, July 1991. (PB91-227405/AS)
214 Emergency Operational Meteorological Considerations During an Accidental Release of Hazardous Chemicals. Peter Mueller and Jerry Galt, August 1991. (PB91-235424)
215 WeatherTools. Tom Egger, October 1991. (PB93-184950)
216 Creating MOS Equations for RAWS Stations Using Digital Model Data. Dennis D. Gettman, December 1991. (PB92-131473/AS)
217 Forecasting Heavy Snow Events in Missoula, Montana. Mike Richmond, May 1992. (PB92-196104)
218 NWS Winter Weather Workshop in Portland, Oregon. Various Authors, December 1992. (PB93-146785)
219 A Case Study of the Operational Usefulness of the Sharp Workstation in Forecasting a Mesocyclone-Induced Cold Sector Tornado Event in California. John P. Monteverdi, March 1993. (PB93-178697)
220 Climate of Pendleton, Oregon. Claudia Bell, August 1993. (PB93-227536)
221 Utilization of the Bulk Richardson Number, Helicity and Sounding Modification in the Assessment of the Severe Convective Storms of 3 August 1992. Eric C. Evenson, September 1993. (PB94-131943)
222 Convective and Rotational Parameters Associated with Three Tornado Episodes in Northern and Central California. John P. Monteverdi and John Quadros, September 1993. (PB94-131943)
223 Climate of San Luis Obispo, California. Gary Ryan, February 1994. (PB94-162062)
224 Climate of Wenatchee, Washington. Michael W. McFarland, Roger G. Buckman, and Gregory E. Matzen, March 1994. (PB94-164308)
225 Climate of Santa Barbara, California. Gary Ryan, December 1994. (PB95-173720)
226 Climate of Yakima, Washington. Greg DeVoir, David Hogan, and Jay Neher, December 1994. (PB95-173688)
227 Climate of Kalispell, Montana. Chris Maier, December 1994. (PB95-169488)
228 Forecasting Minimum Temperatures in the Santa Maria Agricultural District. Wilfred Pi and Peter Felsch, December 1994. (PB95-171088)
229 The 10 February 1994 Oroville Tornado--A Case Study. Mike Staudenmaier, Jr., April 1995. (PB95-241873)
230 Santa Ana Winds and the Fire Outbreak of Fall 1993. Ivory Small, June 1995. (PB95-241865)
231 Washington State Tornadoes. Tresté Huse, July 1995. (PB96-107024)
232 Fog Climatology at Spokane, Washington. Paul Frisbie, July 1995. (PB96-106604)
233 Storm Relative Isentropic Motion Associated with Cold Fronts in Northern Utah. Kevin B. Baker, Kathleen A. Hadley, and Lawrence B. Dunn, July 1995. (PB96-106596)
234 Some Climatological and Synoptic Aspects of Severe Weather Development in the Northwestern United States. Eric C. Evenson and Robert H. Johns, October 1995. (PB96-112958)
235 Climate of Las Vegas, Nevada. Paul H. Skrbac and Scott Cordero, December 1995. (PB96-135553)
236 Climate of Astoria, Oregon. Mark A. McInerney, January 1996.
237 The 6 July 1995 Severe Weather Events in the Northwestern United States: Recent Examples of SSWEs. Eric C. Evenson, April 1996.
238 Significant Weather Patterns Affecting West Central Montana. Joe Lester, May 1996. (PB96-178751)
239 Climate of Portland, Oregon. Clinton C. D. Rockey, May 1996. (PB96-17603) - First Revision, October 1999
240 Downslop Winds of Santa Barbara, CA. Gary Ryan, July 1996. (PB96-191697)
241 Operational Applications of the Real-time National Lightning Detection Network Data at the NWSO Tucson, AZ. Darren McCollum, David Bright, Jim Meyer, and John Glueck, September 1996. (PB97-108450)
242 Climate of Pocatello, Idaho. Joe Heim, October 1996. (PB97-114540)
243 Climate of Great Falls. Montana. Matt Jackson and D. C. Williamson, December 1996. (PB97-126684)
244 WSR-88D VAD Wind Profile Data Influenced by Bird Migration over the Southwest United States. Jesus A. Haro, January 1997. (PB97-135263)
245 Climatology of Cape for Eastern Montana and Northern Wyoming. Heath Hockenberry and Keith Meier, January 1997. (PB97-133425)
246 A Western Region Guide to the Eta-29 Model. Mike Staudenmaier, Jr., March 1997. (PB97-144075)
247 The Northeast Nevada Climate Book. Edwin C. Clark, March 1997. (First Revision - January 1998 - Andrew S. Gorelow and Edwin C. Clark - PB98-123250)
248 Climate of Eugene, Oregon. Clinton C. D. Rockey, April 1997. (PB97-155303)
249 Climate of Tucson, Arizona. John R. Glueck, October 1997
250 Northwest Oregon Daily Extremes and Normans. Clinton C. D. Rockey, October 1997
251 A Composite Study Examining Five Heavy Snowfall Patterns for South-Central Montana. Jonathan D. Van Ausdall and Thomas W. Humphrey. February 1998. (PB98-125255)
252 Climate of Eureka, California. Alan H. Puffer. February 1998. (PB98-130735)
253 Inferenced Oceanic Kelvin/Rossby Wave Influence on North American West Coast Precipitation. Martin E. Lee and Dudley Chelton. April 1998. (PB98-139744)

254 Conditional Symmetric Instability—Methods of Operational Diagnosis and Case Study of 23-24 February 1994 Eastern Washington/Oregon Snowstorm. Gregory A. DeVoir. May 1998. (PB98-144660)
255 Creation and Maintenance of a Comprehensive Climate Data Base. Eugene Petrescu. August 1998. (PB98-173529)
256 Climate of San Diego, California. Thomas E. Evans, III and Donald A. Halvorson. October 1998. (PB99-109381)
257 Climate of Seattle, Washington. Dana Felton. November 1998. (PB99-113482)
258 1985-1998 North Pacific Tropical Cyclones Impacting the Southwestern United States and Northern Mexico: An Updated Climatology. Armando L. Garza. January 1999. (PB99-130502)
259 Climate of San Jose, California. Miguel Miller. April 1999. (PB99-145633)
260 Climate of Las Vegas, Nevada. Paul H. Skrbac. December 1999
261 Climate of Los Angeles, California. David Bruno, Gary Ryan, with assistance from Curt Kaplan and Jonathan Slemmer. January 2000
262 Climate of Miles City, Montana. David A. Spector and Mark H. Strobin. April 2000
263 Analysis of Radiosonde Data for Spokane, Washington. Rocco D. Pelatti. November 2000
264 Climate of Billings, Montana. Jeffrey J. Zeltwanger and Mark H. Strobin. November 2000
265 Climate of Sheridan, Wyoming. Jeffrey J. Zeltwanger, Sally Springer, Mark H. Strobin. March 2001
266 Climate of Sacramento, California. Laura Masters-Bevan. December 2000 (7th Revision)
267 Sulphur Mountain Doppler Radar: A Performance Study. Los Angeles/Oxnard WFO. August 2001
268 Prediction of Heavy Snow Events in the Snake River Plain Using Pattern Recognition and Regression Techniques. Thomas Andretta and William Wojcik. October 2003
269 The Lewis and Clark Expedition 18-03-1806, Weather, Water and Climate, Vernon Preston, Pocatello Idaho, December 2004.
270 Climate of San Diego, California, Emmanuel M. Isla, September 2004 (2nd Edition)
271 Climate of Las Vegas, Nevada, Andrew S. Gorelow, January 2005, (2nd Edition)
272 Climate of Sacramento, California, Revised by: Laura A. Bevan and George Cline, June 2005
273 Climate of Flagstaff, AZ 4th Revision. Mike Staudenmaier, Jr, Reginald Preston(R) Paul Sorenson (R) , August 2005
274 Climate of Prescott, AZ, Bob Fogarty, Mike Staudenmaier Jr., Flagstaff WFO, AZ, August 2005.
275 Climate of San Diego, CA, 3rd Revision. Noel M. Isla, Jennifer Lee, March 2006
276 Climate of Reno, NV, Brian Ohara, Reno, NV October 2006
277 Forecaster's Handbook for Extreme Southwestern California Based On Short Term Climatalogical Approximations: Part I - The Marine Layer and Its Effect On Precipitation and Heating Ivory J. Small, October 2006
278 Forecaster's Handbook for Extreme Southwestern California Based On Short Term Climatalogical Approximations: Part II – Wind Effects on Terrestrial and Marine Environments Ivory J. Small, December 2006
279 Effects of Wildfire in the Mountainous Terrain of Southeast Arizona: An Empirical Formula to Estimate 5-Year Peak Discharge from Small Post-Burn Watersheds, William B. Reed and Mike Schaffner , June 2007

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Department of Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic impact of natural and technological changes in the environment and to monitor and predict the state of the solid Earth, the oceans and their living resources, the atmosphere, and the space environment of the Earth.

The major components of NOAA regularly produce various types of scientific and technical information in the following kinds of publications.

PROFESSIONAL PAPERS -- Important definitive research results, major techniques, and special investigations.

CONTRACT AND GRANT REPORTS -- Reports prepared by contractors or grantees under NOAA sponsorship.

ATLAS -- Presentation of analyzed data generally in the form of maps showing distribution of rainfall, chemical and physical conditions of oceans and atmosphere, distribution of fishes and marine mammals, ionospheric conditions, etc.

TECHNICAL SERVICE PUBLICATIONS -- Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

TECHNICAL REPORTS -- Journal quality with extensive details, mathematical developments, or data listings.

TECHNICAL MEMORANDUMS -- Reports of preliminary, partial, or negative research or technology results, interim instructions, and the like.

Information on availability of NOAA publications can be obtained from:

NATIONAL TECHNICAL INFORMATION SERVICE

U. S. DEPARTMENT OF COMMERCE

5285 PORT ROYAL ROAD

SPRINGFIELD, VA 22161