Los Alamos Post-Fire Watershed Recovery: A Curve-Number-Based Evaluation

Russell K. Livingston[1], T. Andrew Earles, Ph.D., P.E.[2], and Kenneth R. Wright, P.E.[3]

[1] Adjunct Scientist, Wright Water Engineers, Inc., 2490 West 26th Avenue, Suite 100A, Denver, CO 80211, telephone: 303-480-1700, and fax: 303-480-1020.
[2] Water and Civil Engineer, Wright Water Engineers, Inc., 2490 West 26th Avenue, Suite 100A, Denver, CO 80211, aearles@wrightwater.com, telephone: 303-480-1700, and fax: 303-480-1020.
[3] Chief Engineer, Wright Water Engineers, Inc., 2490 West 26th Avenue, Suite 100A, Denver, CO 80211, krw@wrightwater.com, telephone: 303-480-1700, and fax: 303-480-1020.

Abstract

The Cerro Grande fire of April 2000 burned 19,300 hectares (ha) (47,650 acres [ac]) in and around the Los Alamos National Laboratory (LANL). Wright Water Engineers, Inc. (WWE) analyzed immediate post-fire flood hydrology because greatly increased flood and debris flows in the many burned subbasins posed concerns to downstream areas and infrastructure of LANL. After three years of forest recovery and working with scientists and land managers of LANL, WWE conducted evaluations on the effect of the then-ongoing revegetation/restoration of the burned areas on flood flows, specifically for the 100-year flood (Q_{100}).

Applying the SCS Technical Release 55 (TR-55) method, WWE computed pre-fire and post-fire runoff curve numbers (CNs) for 31 subbasins. These data, supplemented by similar data for 24 small subbasins affected by the 2002 Long Mesa fire at Mesa Verde National Park, were used in an analysis that included four major components:

1. Estimation of CNs that represent pre-fire conditions for watersheds.
2. Use of CN ratios to demonstrate subbasin recovery, including burn severity effects represented by a Wildfire Hydrologic Impact (WHI) factor.
3. For various WHIs, development of a theoretical relation showing the change in the CN ratio due to post-fire hydrologic changes during an "ideal" recovery period.
4. From these concepts estimate the Q_{100} at various stages of subbasin recovery.

For most subbasins with moderate to severe burn intensities, recovery was estimated to take from 6 to 10 years. For the most severely burned subbasins, however, analysis shows that recovery to pre-fire hydrologic conditions may take up to 10 to 20 years.

Introduction

The Cerro Grande fire of April 2000 burned 19,300 ha (47,650 ac) in and around LANL. Following the fire, it was quickly realized that the potential for greatly increased flood and debris flows in the many burned subbasins posed a variety of concerns to downstream areas and some of the infrastructure of LANL. WWE was asked by officials of LANL to conduct investigations into the effect of ongoing revegetation/restoration of the burned areas on subbasin hydrology, specifically the 100-year flood (Q_{100}).

Curve Numbers

In the early stages of the post-fire analysis of potential flood flows, the TR-55 method was one of the approaches used by LANL, the Burned Area Emergency Response (BAER) team, and others to predict the post-fire change in the Q_{100}. This method was developed by the Natural Resource Conservation Service (NRCS), formerly the Soil Conservation Service (SCS). The method incorporates vegetation, stream channel, and soils information to determine runoff coefficients, which are then used in conjunction with design storms to estimate resultant flood magnitude.

Central to the application of the TR-55 method is the determination of a subbasin SCS runoff CN, the value of which characterizes the subbasin infiltration capacity, and is dependent on factors such as the Hydrologic Soil Group, cover type, treatment, hydrologic condition, and antecedent runoff condition. Because the method is empirical, Dr. John Moody (U.S. Geological Survey [USGS], personal communication 2003) cautions against the use of CNs for evaluating watershed response to fires, especially in areas such as Los Alamos that are dominated by convective storms that have not been sufficiently tested by the method. Nonetheless, many others, including Dr. Robert Jarrett of USGS and interagency BAER teams, recognize this method can be useful for evaluation of post-fire hydrology, especially when time is critical.

As part of previous investigations for LANL, WWE computed pre- and post-fire CNs for 31 subbasins in the Los Alamos area and used these CNs as input to a model (HEC-HMS) for estimation of the potential increase—post-fire compared to pre-fire—in flood discharges for all areas affected by the Cerro Grande fire. In consideration of these CN determinations, the subbasins were initially delineated to reflect as uniform a burn severity as practical. The pre-fire CNs were based on rainfall-runoff analysis by LANL for those subbasins where rainfall-runoff data existed, while the post-fire CNs were initially determined by area weighting the burn severity in each subbasin using the following criteria given in Table 1. The initial post-fire CN values were "fine-tuned" based on data from rainfall/runoff events in the summer following the fire.

TABLE 1
POST-FIRE CURVE NUMBERS FOR VARIOUS BURN SEVERITIES

Burn Severity	Estimated CN
Unburned	55-75
Low	80-83
Moderate, without hydrophobic soils	87
Moderate, with hydrophobic soils	89
High, without hydrophobic soils	92
High, with hydrophobic soils	95

Pre-Fire Versus "Natural" Condition

As emphasized by Dr. Craig Allen (USGS, spoken communication 2003), the objective of post-fire recovery should be to return to a "natural" condition rather than to a "pre-fire" condition. The "pre-fire" condition—as represented by the pre-fire CN—does not equate to the "natural" condition. Fire suppression since about 1880 has resulted in extensive overgrowth of most forest systems. Thus the hydrologic characteristics of those systems have changed by varying degrees since that time, resulting in an "unnatural" hydrologic condition. In the specific case of the Cerro Grande fire, the overgrown condition of the burned forest is not expected to be the future condition because of recent changes in forest-management practices and philosophy, and as a result, return to the condition of the forests prior to the Cerro Grande fire is not a reasonable goal nor expectation. Therefore, in the following discussion the post-fire recovery period is defined as from the immediate aftermath of the fire ("initial condition") to the "natural" condition.

The "natural" condition was quantified using information given in TR-55. For the Los Alamos area, which is characterized by soils that are in Hydrologic Soil Groups C and D, Table 2-2e of TR-55 shows CNs for various types of land cover and the hydrologic conditions: poor, fair, or good. Table 2 summarizes information shown for the "woods" cover type.

Again for a land cover type of "woods," footnotes for Table 2-2e of TR-55 describe the poor hydrologic condition partly in terms of whether or not the area has been subjected to "regular burning," whereas the description of the good condition speaks of "protected" areas. From these data one can subjectively conclude that future conditions for wooded subbasins in the Los Alamos area would consist of:

1. Cycles of prescribed fire or minor (low intensity) wild land fire, which are intended to mimic low intensity wildfire (Robichaud 2000) and thus can be initially characterized by a CN typical of "poor" hydrologic conditions, and
2. Recovery" periods, which would eventually be characterized by a CN typical of the "good" hydrologic condition. In consideration of this rationale, the "natural" condition was defined for subsequent discussions as the hydrologic response associated with a CN about 10 percent greater than the CN associated with the "pre-fire" condition.

TABLE 2
SUMMARY OF CURVE NUMBER INFORMATION FOR HYDROLOGIC SOIL GROUPS C AND D

Hydrologic Condition	Soil Group C		Soil Group D	
	CN	Ratio to CN for a Hydrologic Condition of "Good"	CN	Ratio to CN for a Hydrologic Condition of "Good"
Poor	77	1.10	83	1.08
Good	70	-----	77	-----
Source: NRCS				

Curve Number Ratios

The approach to subbasin recovery used by WWE was based on a CN ratio, the ratio of post-fire CN to pre-fire CN. With recovery of the watershed, and in the absence of subsequent disturbances such as another wildfire or a significant change in land use, this ratio decreases at some rate over time, as revegetation and other variables change the subbasin hydrology, subbasin hydrologic response should move towards its "natural" condition (CN=1.1 represents the pre-fire CN ratio of 1.0 plus 10 percent) and then, if pre-fire watershed management practices continue, to its pre-fire (CN=1.0) condition.

The scope of the analysis of the relation between the CN ratio and the flood hydrology of burned subbasins during the recovery period included:

- Examination of how the CN ratio varies depending on burn severity.
- Estimation of the approximate number of years before the post-fire CN ratio approaches 1.1, which represents the time of hydrologic recovery to the "natural" condition.
- Examination of how the relation varies over time from the initial post-fire condition to the time when the subbasin has hydrologically recovered (CN~1.1) from a hydrologic standpoint.
- Using the estimated changes in the CN ratio during the subbasin recovery period, showing how a subbasin Q_{100} might change over time.

The overall objective of this analysis is to provide LANL officials and others with information on how the flood hydrology of the small (less than 2.5 square miles) affected subbasins may change over time, and thus additional information on which to base ongoing management decisions in the wake of the Cerro Grande fire.

Curve Number Ratios and Burn Severity

In order to analyze CN data previously compiled by WWE for 31 designated subbasins in the study area, as well as other similar data that will be discussed later, it was necessary to classify the information using Figure 1, which defines a WHI as a function of the percentages of the subbasin that have been determined to have burn severities of "high" or "moderate." Since areas with "low" burn severity naturally recover within only a couple of years and do not have sufficient hydrophobicity to significantly change their water infiltration characteristics ("Fire Burn Intensity," Gallatin National Forest, unpublished) they were not considered in determining a subbasin WHI. The relationship was developed based on engineering judgment and iteratively refined by study of relationships between available data on pre-fire and post-fire CNs. Figure 1 indicates that for a burned subbasin for which 20 percent of its area had a *moderate burn severity*, the WHI would vary depending on the extent of *high burn severity*, as shown in Table 3.

TABLE 3
VARIATIONS IN WILDFIRE HYDROLOGIC IMPACT CLASSIFICATION DUE TO HIGH BURN SEVERITY

Percentage of Subbasin With a High Burn Severity	Wildfire Hydrologic Impact Classification
0-6	Low
7-48	Moderate
49-80	Severe

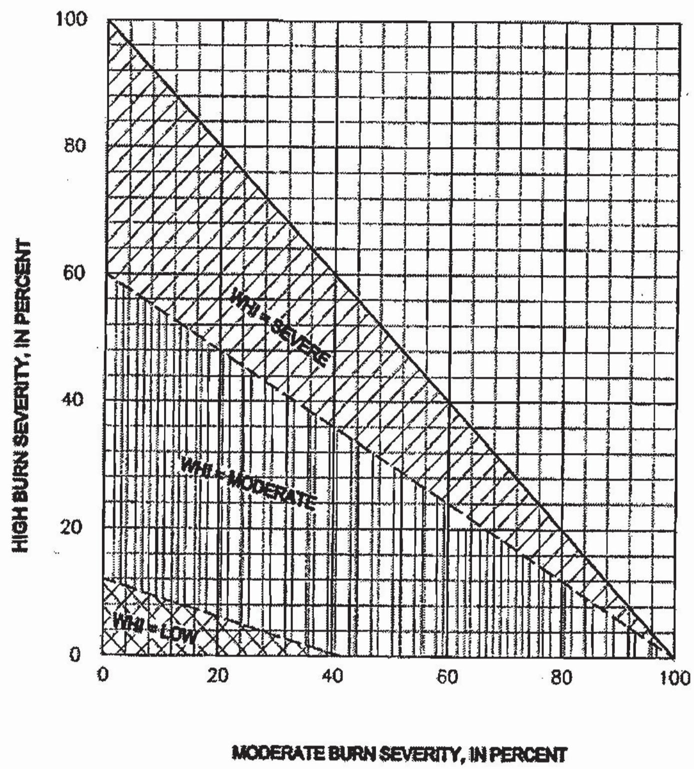

Figure 1. WHI for Small Burned Subbasins as a Function of Burn Severity

Two aspects of this classification system are noteworthy. First, although the depicted "sudden" changes from one classification to the next are not realistic, there is insufficient information on which to quantify a "transition" category. In such circumstances where the subbasin burn severity data place it in close proximity to the dashed lines separating the classifications, it seems prudent to evaluate the subbasin based on both WHI classifications and the subsequent results either averaged or one result chosen as preferable based on engineering or management considerations. Second, the system does not differentiate or attempt to quantify the hydrologic consequences of hydrophobic soils. However, in general terms the data for most of the subbasins in the severe WHI category does indicate a very high percentage (over 40 percent) of hydrophobic soils, and many of the subbasins in the moderate category have a high percentage (30 to 50 percent) of hydrophobic soils; subbasins in the low category typically only have a small portion (0 to 20 percent) of the subbasin with hydrophobic soils.

Figure 2 was developed by analysis of: (1) CN data for the 31 small, 31 to 650 hectare (0.12 to 2.5 square miles) subbasins in the Los Alamos study, and (2) similar data for 24 small, 28 to 59 hectare (0.11 to 2.3 square miles) subbasins affected by the 2002 Long Mesa fire at Mesa Verde National Park (MVNP) in southwestern Colorado (U.S. Department of the Interior 2002). These data show that the post-fire CN ratio for these subbasins varies depending on their pre-fire CNs and WHI (severe, moderate, or low, as defined by Figure 1). The overall shape of the relations is based on the shape of the limiting relation (CN ratio=100/CN) and the fairly well defined relations for the WHIs of "low" and "severe." Since the data are less definitive for a WHI of "moderate" (note the five low ratio values—1.10 to 1.13—that are from the Long Mesa data set), the overall shape of the general relation for a WHI of "moderate" was based on the more definitive relations for a WHI of "low" or "severe."

The generalized relation given in Figure 2 can be used to predict the post-fire CN for any subbasin in the Los Alamos area that has been impacted by severe wild land fire if the pre-fire CN is known and burn severity data are available in order to determine the WHI from Figure 1. Figure 2 is applicable to the Los Alamos area and other areas in the southwest with similar pre-fire CN values and hydrology. Since ratios of CNs are used to evaluate the post-fire condition relative to the pre-fire CNs, Figure 2 is not applicable to areas with different pre-fire rainfall/runoff characteristics.

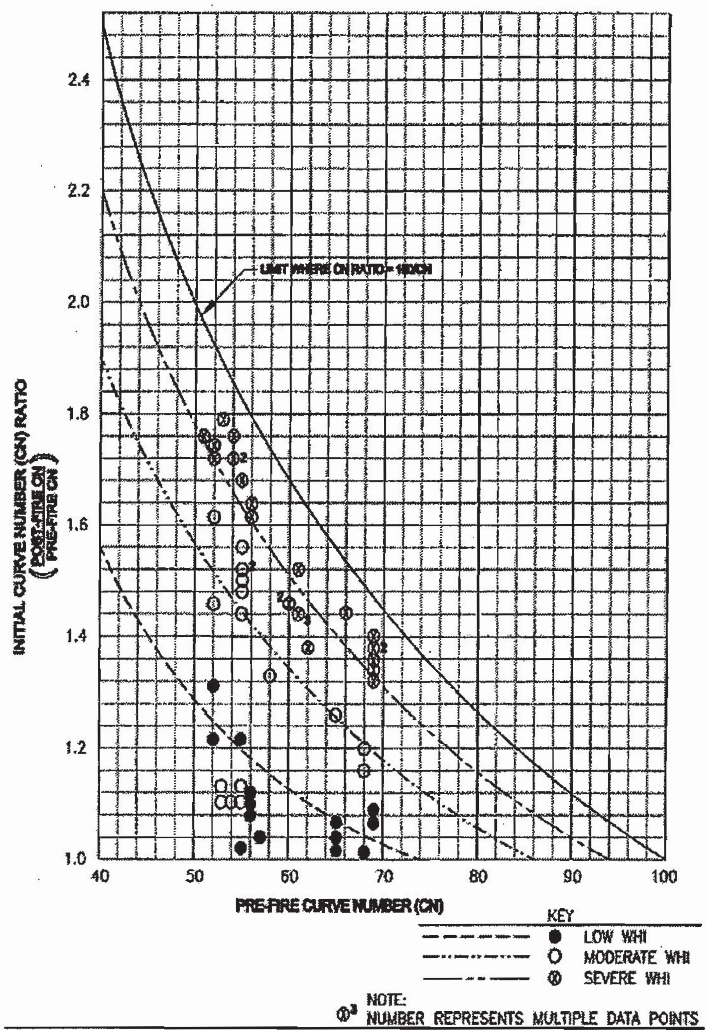

Figure 2. General Relation Between Pre- and Initial Post-Fire CN Ratio for Indicated WHI

Time Required for Hydrologic Recovery of Burned Subbasins

The literature provides little information on subbasin recovery, particularly as it relates to changes in flood hydrology in the aftermath of major forest fires. For some Australian watersheds affected by brushfire, Brown (1972) indicated that recorded streamflow data suggested that the watersheds might have recovered in four or five years. Helvey (1980) reported that for ponderosa pine/douglas fir forests impacted by wildfire large increases in runoff occurred during years two through seven. According to Ms. Deborah Martin (USGS, spoken communication 2003), who has done extensive post-fire hydrologic research, the literature generally speaks of median recovery periods of 3 to 8 years, with some periods of up to 15 years. Clearly, there are many factors that cause such a wide range in recovery periods, and some severely burned areas have not recovered from forest fires that occurred well beyond 15 years ago. Higher altitude forests subjected to severe fires can take a century or more to fully recover.

There is some information more specific to higher-elevation forests in New Mexico. Veenhuis (2002) analyzed annual peak discharges on two similar watersheds, Rito de los Frijoles (burned) and Bland Canyon (unburned), both before and after the La Mesa fire in 1977. Mr. Veenhuis concluded that, as of 1999, the Rito de los Frijoles watershed had not fully recovered in the 22 years since the fire. Dr. Craig Allen (spoken communication 2003), who has extensive experience with the ecology of the area burned by this fire, agrees with Veenhuis' conclusion.

One can also examine some regional vegetation-recovery data, which has a dominant impact on hydrologic response. Areas of MVNP that were affected by the Pony-Bircher fires (2000) had an average of 65 percent bare soil in reseeded areas after two years of post-fire recovery (Floyd-Hanna, et al. 2002), but "there was no significant difference in shrub cover between burned and unburned areas" (Floyd, et al. 2000). Similar data for the Cerro Grande fire indicated that by the fall of 2001 estimated vegetative ground cover for 30 study units averaged about 50 percent, an increase of about eight percent since the preceding spring (Buckley, et al. 2002). It would seem reasonable that both areas would be recovering at a much more rapid rate had the burn severity been less and the weather conditions more normal.

Variation in CN Ratio During Recovery Period

Because the literature is generally lacking post-fire CN data during the recovery period, the most difficult part of the analysis was determining how the CN ratio changes during the post-fire recovery period. The previous discussions have provided ratios immediately after the fire, and some general information suggests a total recovery period—to "pre-fire" conditions—of up to 15 to 20 years or more for severely burned subbasins, compared to less than 5 years for subbasins without significant portions burned in the severe or moderate range.

Some additional information is available from WWE's investigation of the hydrologic consequences of the previously mentioned Pony-Bircher fires. For two of the burned subbasins, Morefield and Prater Canyons, field investigations by WWE found the initial post-fire CN to be about 87 compared to a pre-fire CN of 60, or a CN ratio of 1.45. Based on burn severity information presented in the BAER report on this fire, the WHI for both of these subbasins would be "severe". After 27 months of recovery, WWE determined that the CN had changed to about 80. This results in a CN ratio of 1.33 after about 2 years of recovery during a period of general drought conditions throughout the region. The nine years of pre- and post-fire observations by WWE of Morefield Canyon indicates that post-fire recovery has been remarkably slow in the semi-arid environment of the region.

Based on the previous discussions concerning the overall time for a fire-affected subbasin to recover and the CN ratios for various WHIs as given in Figure 2, Figure 3 conceptually shows the time required before the CN ratio would return to 1.1, an indication the subbasin had hydrologically recovered to the "natural" condition. This relationship indicates that a subbasin with a pre-fire CN of 52 and a WHI of severe, which results in an estimated post-fire CN ratio of 1.7 (see Figure 2), would not completely return to the "natural" hydrologic conditions within a period of about 20 years. This compares to a recovery period of about 12 years if the same subbasin had a WHI of moderate (estimated post-fire CN ratio of 1.45) and only about 4 years if the WHI was low (estimated post-fire CN ratio of 1.15).

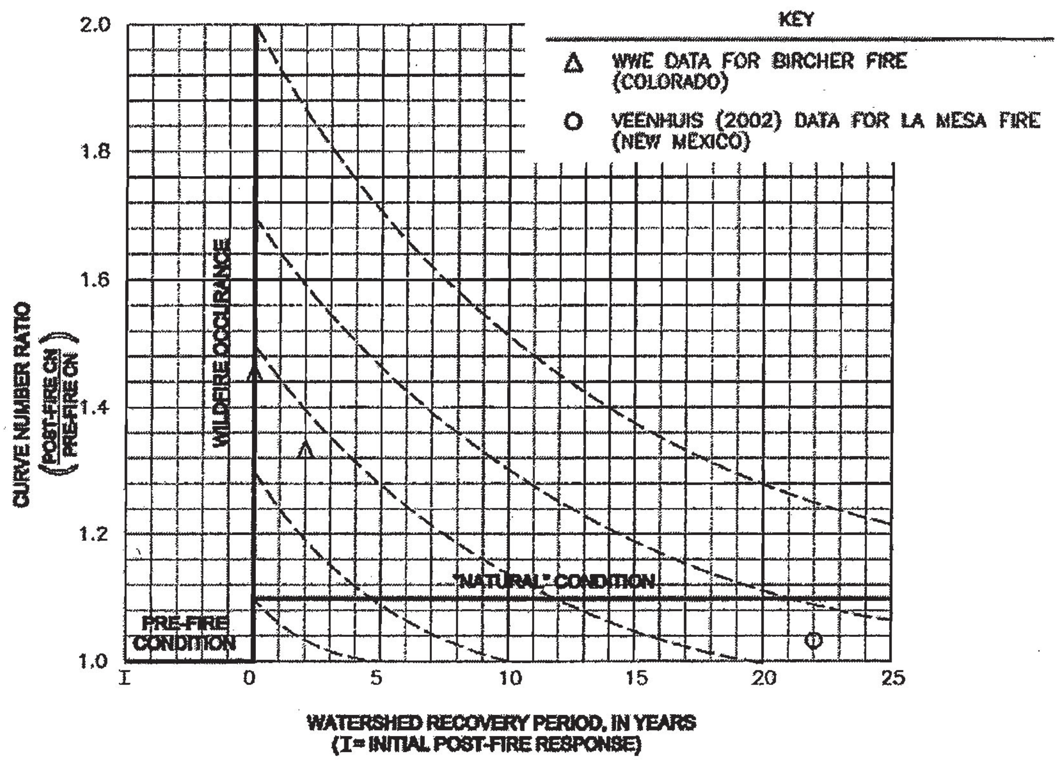

Figure 3. Conceptual Change in Curve Number Ratio During Period of Post Wildfire Watershed Recovery

Figure 3 is intended to illustrate a conceptual reduction in the CN ratio during an "ideal" recovery period. Obviously the rate of hydrologic recovery of any particular subbasin depends on many factors, including:

- Extent of post-fire rehabilitation, such as seeding, contour furrowing, installation of straw wattles, etc.
- Weather conditions during the growing season, such as the amount, timing, duration, and intensity of precipitation, temperature, wind, etc.
- Freeze and thaw cycles and snowmelt during the winter period.
- Land use during the recovery period, such as occurrence of logging (thinning) or road building.

Lastly, the relationship shown in Figure 3 indicates immediate and rapidly improving watershed recovery, a response that is questioned by some researchers. Most certainly there has to be some "threshold" of vegetative recovery before its impact on flood hydrology would be felt within a particular subbasin, but data are not available to quantify the amount of time required to reach this point in the recovery process.

Curve Number Ratio as it Relates to Q_{100}

To illustrate how this approach might be used to estimate changes in the Q_{100} and other flood discharges during the post-fire recovery period, Pueblo Canyon Tributary 01 (PUET01) was selected because of its severe burn conditions and the general importance of Pueblo Canyon to LANL officials. The BAER team data indicated that 76 percent of this basin had a burn severity of high and 20 percent had a burn severity of moderate. Table 4 shows for this subbasin the WHI classification, the computation of estimated post-fire CN ratios, estimated post-fire CNs as a function of time, and the associated estimated Q_{100} for selected post-fire years of recovery:

TABLE 4
ESTIMATED POST-FIRE CN RATIOS, POST-FIRE CN AS A FUNCTION OF TIME, AND ASSOCIATED Q_{100} DURING POST-FIRE RECOVERY PERIOD FOR SUBBASIN PUET1

Sub-basin	Pre-Fire CN	WHI (Fig 1)	Estimated Post-Fire CN Ratio (Fig 2)	Estimated Post-Fire Q_{100}				
				Year	Estimated Post-Fire CN Ratio (Fig 3)	Estimated Post-Fire CN	Discharge cms (cfs)	Discharge cms/km^2 (cfs/mi^2)
PUET1	56	Severe	1.62[1]	Initial	1.6	91	35 (1,250)	15.74 (1,440)
				2	1.5	85	28 (990)	12.57 (1,150)
				5	1.4	78	20 (720)	9.07 (830)
				10	1.2	70	13 (460)	5.74 (525)
				20	1.1	60	6 (210)	2.68 (245)

[1] Note that application of the method provided an estimated post-fire CN ratio of 1.62 for this subbasin, which was very close to the "observed" ratio of 1.63.

The method described herein was similarly used to estimate the Q_{100} for selected post-fire years for all basins in Los Alamos, Pueblo, Rendija, and Guaje Canyons that were impacted by the Cerro Grande fire. Though the post-fire Q_{100} for all subbasins did increase from the pre-fire condition, the results of this analysis indicate that six subbasins were not burned severely enough to cause an estimated Q_{100} greater than that expected to represent the "natural" condition. On the other hand, this analysis shows that seven basins are not expected to recover to "natural" conditions within a 10-year period, and that one severely-burned subbasin would not be expected to recover to pre-fire conditions within a 20-year period (if the subbasin was protected from wildfire and not subjected to occasional thinning and prescribed burning as part of forest management practices.)

Discussion

As stated at the outset, the overall objective of the analysis was to provide LANL with information on how the flood hydrology of the affected subbasins may change over time, and to thus provide additional information on which to base ongoing management decisions in the wake of the Cerro Grande fire. The examination of CN ratios for burned subbasins, which has utilized existing curve-number data for the Los Alamos area as well as similar other areas, has yielded several relationships (Figures 1, 2, and 3) that are regional in nature and reflect "ideal" conditions for restoration and, therefore, do not attempt to quantify the unique conditions of any particular subbasin. Further research will ideally provide the data necessary to validate these relationships and this general approach to quantifying the post-fire flood hydrology of small watersheds.

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