Site and Cover Effects on Event Runoff, Jornada Experimental Range, New Mexico

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ABSTRACT: Event rainfall depth, runoff depth, and periodic cover density measurements were taken for a total of 21 plots (2mx2m) at 5 different locations on the National Science Foundation Jornada Long-Term Ecological Research Site in southern New Mexico. Runoff properties are characterized by plot, plot group, and site using Curve Number (CN) analysis. Results show differences within groups, between groups and with cover. Distinct trends of CN with cover are seen with the effects being most profound at the better sites (lower CN). However, a near-common value (CN~90) is projected for all brush sites under conditions of no cover. These findings affirm customary but seldom-demonstrated expectations, and indicate that the most hydrologic improvement per unit of cover would be on the better sites (lower CN), and the futility of vegetation management for hydrologic benefits on the harsher sites (high CN).
KEY TERMS: Rainfall-runoff, hydrology, Curve Number, rangelands.

INTRODUCTION

Enlightened management of rangelands requires knowledge of the land's responses to rainfall, and of the effects of natural and management-caused variations in that response. One often-used approach to this is the Curve Number (CN) method, first pioneered by the USDA Soil Conservation Service (now Natural Resources Conservation Service) in the mid 1950's (USDA, 1972). In it, the event direct runoff depth Q from a rainstorm of depth P is given by

$$Q = (P-0.2S)^2/(P+0.8S) \qquad P>0.2S,\ Q=0 \text{ otherwise} \qquad [1]$$

where S is an index of water storage potential at the onset of the event, and P, Q, and S are in inches. The storage index "S" is further coded to Curve Number (CN) by

$$CN = 1000/(10+S) \qquad [2]$$

CN is dimensionless, and may be seen as a measure of the site's hydrologic condition, affected by soils, cover, and land use. Curve Numbers may vary from a low of 0 (S= , Q=0 for any P) to 100 (S=0, Q=P). Tables of CN as a function of soils and cover for a variety of land conditions are given in agency documents, and the method is widely used for hydrologic design, environmental impact planning, and post-event appraisals.

Despite the technique's wide use and authoritative origins, CNs themselves are largely a

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table look-up matter. The origin of the table values is almost never documented, and calibration of the method for CN on field data is rare. This paper will define CNs from data for series of rangeland sites in southern New

Mexico, and explore cover relationships with an eye towards management concerns.

Background

Location and setting: The analyses were done for rainfall-runoff data collected from plots at the Jornada Research Site, in Dona Ana County, southern New Mexico, about 25 miles NW of Las Cruces, at an elevation of about 4600 ft. The climate is hot and dry in the summer (June maximums are in the mid-90^{o}F range), and cold and dry in the winter (January minimums are in the high 30^{o}F range). Average annual precipitation is about 9 inches, with more than half of that from July through September as local thundershowers. Pan evaporation is about 90 inches. (Bolin and Ward, 1986).

The Jornada LTER (Long-Term Ecological Research) site is operated under the auspices of New Mexico State University and Duke University. LTER experiments are located on the NMSU College ranch and the USDA Jornada Experimental Range. Its cover is typified by shrubs such as creosote bush (*Larrea tridentata*) and mesquite (*Prospois glanulosa*), and has been under a woody plant invasions for about the past 100 years, replacing black grama (*Bouteloua eripoda*) (Schlesinger et al, 1990).

Runoff Plots and Instrumentation: Permanent rainfall runoff plots at five different sites were established beginning in 1982, and were monitored through late 1992. Figure 1 gives the coverage durations of the various sites. The 2x2 meter plots were in groups of four at each site, with 2 associated pairs of contrasting high or low cover, as identified in Figure 1. Slopes ranged from 3.9 to 9.7 percent, and are given in Table 1. Plot instrumentation consisted of calibrated collecting barrels, and standard rain gages, so that with frequent readings matched to an accompanying recording rain gage overall rainfall and runoff depths were recorded. The cover densities were recorded on each plot several times over the duration of study, using line intercepts and grids,and the average values are given in Table 1. The plots were not grazed during the period of record, but have a history of grazing use over the previous 100+ years.

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          |.82.|.83.|.84.|.85.|.86.|.87.|.88.|.89.|.90.|.91.|.92.|.93.|.94.|
   ----------------------------------------------------------------------------

Creosote Control
 1,2      |--------------------high -----------------------------------|
 3,4           |----------------low -----------------------------------|
Creosote Termite Sprayed
  1        |---------------high------------|
  2        |---------------high------------------------------|
  5              |---------high------------------------------|
 3,4             |------------------low----------------------|
Creosote Caliche
 1,3                                                |---------low-------------|
 2,4                                                |---------high------------|
Grass Summerford
 1,2                                                |---------low-------------|
 3,4                                                |---------high------------|
Grass IBP
 1,2                                                |---------low-------------|
 3,4                                                |---------high------------|

   ----------------------------------------------------------------------------
          |.82.|.83.|.84.|.85.|.86.|.87.|.88.|.89.|.90.|.91.|.92.|.93.|.94.|
```

Figure 1. Coverage duration in calendar years for the Jornada runoff plots. The "high" and "low" designations refer to the relative cover densities of the plot clusters.

The five plot locations were selected considering the variety of conditions in the area: The names are almost self-explanatory: Creosote bush is common in the area, and thus Creosote Control (CC), Creosote

Caliche (CL), and Creosote Termite (CT). The latter results from a chlordane treatment to exterminate termites and an attempt to detect its hydrologic effects. These three are "brush" sites. Also, there were two "grassland" sites: Summerford Mountain (GS), and IBP (GI). The IBP site is so named from its association with other IBP ecological studies on the Jornada Range. The brush label implies a creosote bush site, while the grass label simply mean no creosote, but the presence of other vegetation, including some grass. The first four sites are within a half mile of each other at the LTER/Jornada Watershed area, and GI site is about 6 miles to the northwest.

The soils on the CC,CL,CT and GS sites are of Onite series, with a surface loamy sand texture and Hydrologic Soil Group B. The GI site is of the Pintura series, a fine sand of Hydrologic Soil Group A. Further background on the soils is given is given by Wierenga *et al* (1989) and USDA (1977), and on the ecology of the area by Elkins *et al* (1986), and Bolton *et al* (1990).

Data: In keeping with the limits of the instrumentation, no events were defined within a single day. That is, a day's rainfall and runoff was assumed to be a single event. There was a small fraction -less than **2** percent - which had the runoff depth exceeding rainfall depths, and these were excluded from the data analysis. Only runoff-causing events were considered. From the period of record 4074 measurements were taken, 2452 of which were accompanied by valid rainfall and runoff.

ANALYSIS

Curve Number Determinations from Data

By analysis of the rainfall and runoff event data, the CNs were determined for each plot. The asymptotic method using ordered data was applied (Hawkins, 1992). The ordering tactic matches rainfall and runoffs of equal return period (in keeping with its application), and the asymptotic approach recognizes the observed tendency of event CN to vary with rainfall depth, dropping to a stable near-constant level as rainfall depth increases. The fitting equation

$$CN(P) = CN_4 + (100-CN_4)*\mathbf{exp}(-kP) \qquad [3]$$

is used, in which CN_4 and k are coefficients fixed by iterative least squares to observed the observed P and CN (determined by inverse solution of [1] to

$$S = 5[P+2Q-\sqrt{(4Q^2+5PQ)}] \qquad [4]$$

and then substitution of S into equation 2.) CN_4 is the CN approached as P grows larger, and taken as the descriptive Curve Number. An example of the fitting is given in Figure 2, and the results of the analysis are given in Table 1.

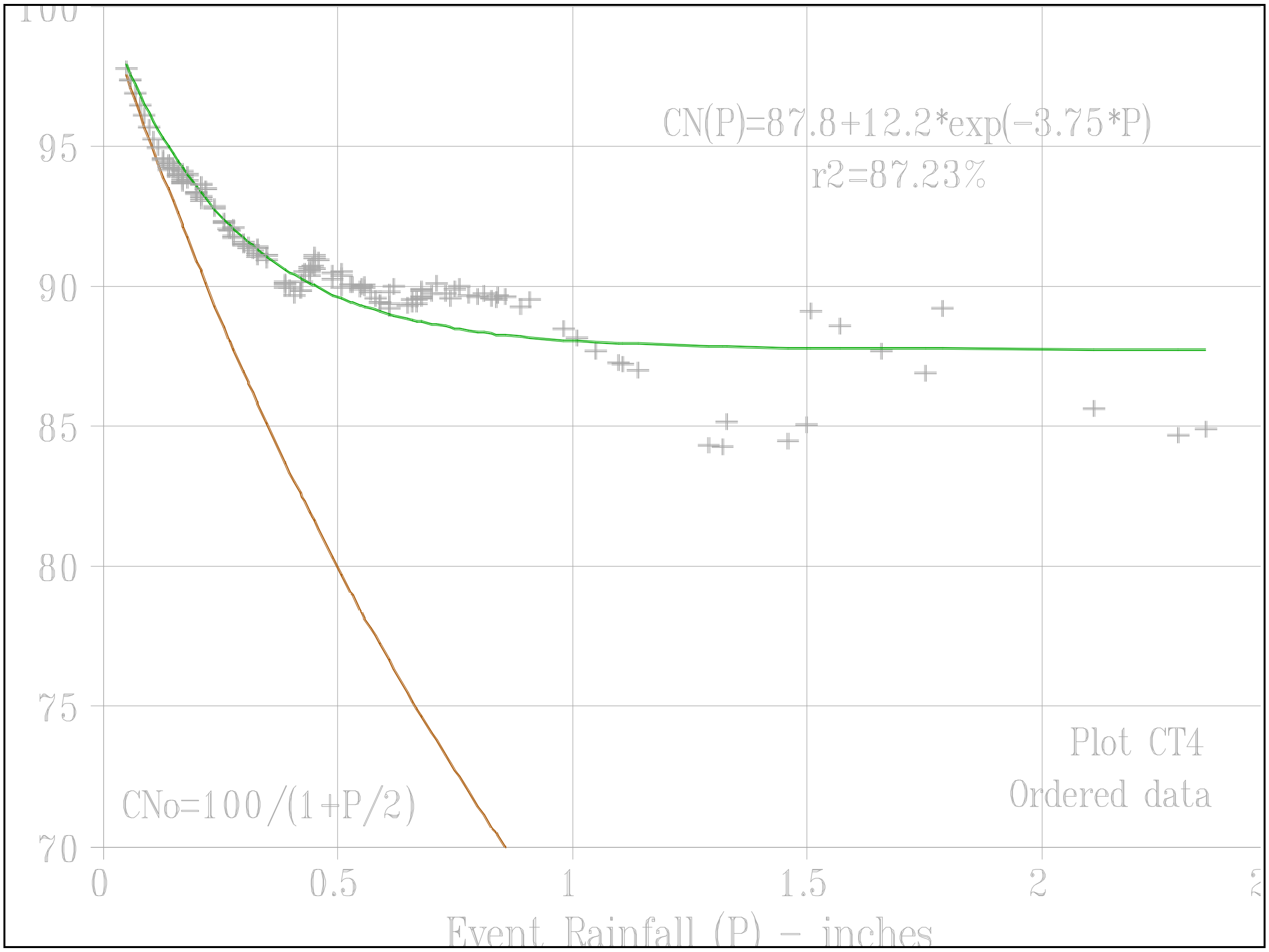

Figure 2. Curve Number fitting for Creosote Termite Plot 4. CNo is that CN at which Q=0, P=Ia.

Plot Groups and Cover Associations

Plot Groups: Within each site the CNs for the designated high and low cover plots were averaged, and the results are shown in Table 2. For the Creosote Termite site plots 2 and 5 were used for the "high" condition. Note that this shows a distinct hydrologic association with cover. Each site cover group consists of a sample of 2, so statistical inference is limited. Nevertheless, the creosote bush sites have distinctly higher CNs that the grassland sites. As will be seen, this is also related to plant cover.

Cover Associations: The rough relationships seen between cover and CN in Table 2 can be quantified by utilizing the cover densities for the plots. Figure 3 shows this relationship between the realized CNs and the representative cover densities for the plots at each site. The lines shown are the least squares fits to the CN and cover data given by groups in Table 1. The goodness-of-fit statistics are given in Table 3.

Several items are of interest in Table 2 and 3 and Figure 3.

First there are distinct relationships between cover and CN: the higher cover leads to lower CNs within a site. These are often assumed, but are seldom demonstrated as such with rainfall-runoff data.

Table 1. Data, Plot, and Curve Number Fittings Summary

Plot	Fr yr	To yr	N #	Slope %	Cover %	CN CN	k in^{-1}	r^2 %	SE CN
Creosote Control									
CC1	82	94	215	6.5	70.6	84.01	2.764	85.54	1.39
CC2	82	94	192	5.0	46.3	83.47	2.232	92.37	1.06
CC3	83	94	170	3.4	16.5	88.20	4.872	90.64	0.68
CC4	83	94	156	3.9	9.3	87.92	4.724	76.82	1.17
Creosote Termite Sprayed									
CT1	82	88	81	5.8	71.7	81.16	1.531	87.14	1.73
CT2	82	92	126	4.1	70.6	81.51	2.210	86.19	1.44
CT5	83	92	130	5.2	50.4	79.44	2.277	96.98	0.87
CT3	83	92	142	4.0	27.1	85.08	2.841	92.34	0.93
CT4	83	92	145	5.3	21.3	87.75	3.747	87.23	0.97
Creosote Caliche									
CL1	89	94	128	5.1	0.2	93.44	7.782	36.70	1.40
CL3	89	94	135	5.8	1.0	92.03	11.343	63.68	1.06
CL2	89	94	121	7.4	40.1	89.41	5.966	82.33	0.88
CL4	89	94	133	4.6	46.9	90.41	5.410	72.63	1.01
Grass Summerford									
GS1	89	94	108	9.1	19.1	73.51	1.675	97.30	0.90
GS2	89	94	114	9.9	35.1	83.63	2.690	88.45	1.15
GS3	89	94	105	8.6	51.5	59.09	1.072	99.44	0.58
GS4	89	94	111	9.7	55.1	77.32	2.066	94.76	1.07
Grass IBP									
GI1	89	94	96	5.5	24.7	83.06	2.585	86.51	2.23
GI2	89	94	92	4.7	14.6	80.67	2.745	88.57	1.61
GI3	89	94	86	4.2	21.7	71.42	1.784	95.09	1.52
GI4	89	94	97	5.9	27.4	70.56	1.627	98.55	0.78

Notes: N is the number of events with 0<Q<P. Cover is the average cover density as measured. CN4 is asymptotic CN, or fitted CN as P->4 with ordered data. r^2 is the coefficient of determination in percent for the above, using CN as the fitting objective.

Table 2. Average CNs for Cover groups by sites.

Plot Group Site	Curve Number Low Cover	Curve Number High Cover
Creosote Control	88.06	83.74
Creosote Termite	86.42	80.48
Creosote Caliche	92.74	89.91
Grass Summerford	78.57	68.21
Grass IBP	81.67	70.99

Second, the trend lines for the brush sites extrapolate to a common hypothetical condition of no cover and CN of about 90. This might be seen as the "bare-soil" CN common to this general area. The "grass" sites extrapolate to a CN value is the mid-80s at no cover.

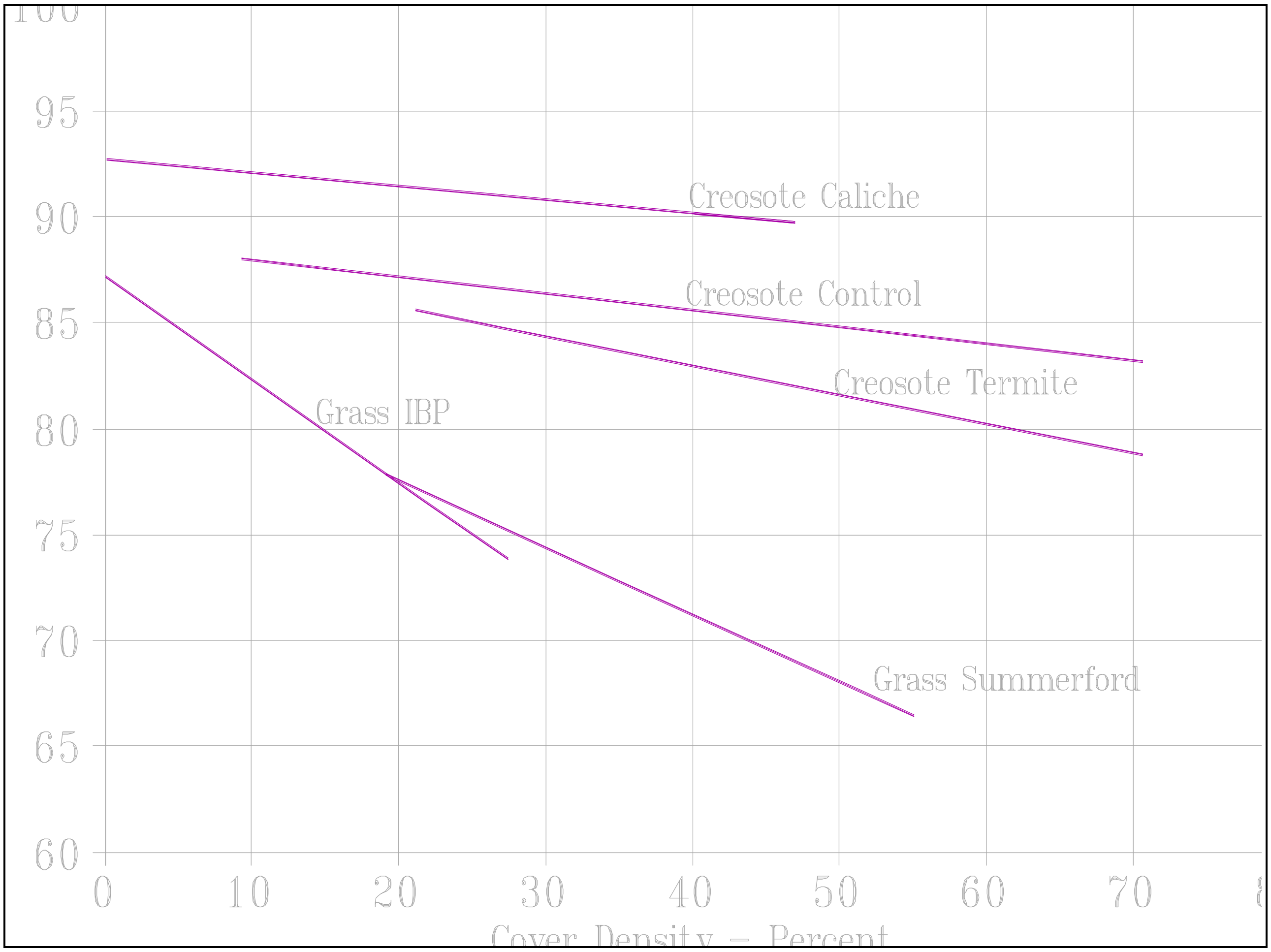

Figure 3. Curve Number - Cover relationships for different sites. Data taken from

Table 3. Fits to CN=a+b*Cover(%) for Jornada sites

Site	a CN	b CN/%	r^2 %	SE CN
Creosote Control	88.72	-0.0790	79.26	1.39
Creosote Termite	88.44	-0.1367	67.48	2.58
Creosote Caliche	92.73	-0.0636	79.41	0.99
Grass Summerford	83.83	-0.3159	12.74	16.75
Grass IPB	87.16	-0.4851	17.62	7.07

Third, the slopes ("b" in Table 3) are smaller for the higher CN sites. These are the harsher and less productive sites. Conversely, the lower CN grassed sites have steeper slopes, and thus a small change in cover has a larger effect on CN. This suggests that the poorer sites would be difficult to manage for hydrologic goals, but that the good sites would give better return for a unit of managed cover.

Comparisons with Handbook Curve Numbers

In professional application, CN selection is guided by table and charts in agency documents based on soils

(Hydrologic Soils Groups A - D), land use and type, and cover. The studies here allow comparison with such estimated CN values with actual data-derived values.

First, rangeland CN are estimated from Tables and Charts in the SCS Hydrology Guide National Engineering Handbook (USDA, 1972). Its Figures 9.5 and 9.6 are similar to Figure 3 here, and give CNs for forest-range complexes as a function of cover by soils and land types. The closest cognate to the Jornada site descriptions is given by "Herbaceous", represented by the following:

A Soils CN = 83.0 - 0.23*cover(%) [5a]
B Soils CN = 75.0 - 0.29*cover(%) [5b]

In addition, NEH4's Table 9.1 suggests values for various soils of cover condition (Poor, Fair, Good) for rangelands, with the division points between these cover classes is 50% and 75% respectively. (Enderlin and Markowitz, 1962.) The tabular values for CN using the category "Pasture or Range" are as follows for Poor, Fair, and Good cover conditions respectively: For A soils; 45, 36, 25, for B soils 66, 60, and 25.

Table 4. Comparisons of handbook-based and data-determined Curve Numbers.

Plot	Soil Type	Cover %	NEH4 Fig 9.6	NEH4 Tab 9.1	Local Charts	Data Analysis
<u>Creosote Control</u>						
CC1	B	70.6	66.8	59	78.3	84.01
CC2	B	46.3	72.4	67	80.3	83.47
CC3	B	16.5	79.2	67	82.7	88.20
CC4	B	9.4	80.8	67	83.3	87.92
<u>Creosote Termite</u>						
CT1	B	71.7	66.5	59	78.3	81.16
CT2	B	70.6	66.8	59	78.3	81.51
CT3	B	27.1	76.8	67	81.8	85.08
CT4	B	21.3	78.1	67	82.3	87.75
CT5	B	50.4	71.4	59	80.0	79.44
<u>Creosote Caliche</u>						
CL1	B	0.2	83.0	67	84.0	93.44
CL2	B	40.1	73.8	67	80.8	89.41
CL3	B	1.0	82.8	67	83.9	92.03
CL4	B	46.9	72.2	67	80.2	90.41
<u>Grass Summerford</u>						
GS1	B	19.1	76.8	67	82.5	73.51
GS2	B	35.1	74.9	67	81.2	83.63
GS3	B	51.5	71.2	59	79.9	59.09
GS4	B	55.1	70.3	59	79.6	77.32
<u>Grass IBP</u>						
GI1	A	24.7	79.6	47	76.8	83.06
GI2	A	14.6	70.8	47	77.7	80.67
GI3	A	21.7	68.7	47	77.0	71.42
GI4	A	27.43	67.0	47	76.5	70.56

Second, a local CN guide specifically for southwestern conditions is available in chart form. While its NRCS origin is anecdotal and difficult to document, it does find wide use by federal and local land and water management agencies (see e.g. Zeller, 1982). The "Desert Brush" class is used here as to represent the Jornada conditions. The graphically CN-cover relations are abbreviated by the following expressions:

A Soils CN = 79.0 - 0.09*cover(%) [6a]
B Soils CN = 84.0 - 0.08*cover(%) [6b]

The charts include no "A" soils information, thus the above entries for the A soils in equations 5a and 6a above are extrapolated from the performance of the D, C, and B soils. CN values for the Jornada plots have been calculated from the above according to the soils information (all "B" soils except for the GI site, which is "A") and the cover data given in Table 4. The plot CN estimates from these information sources, appropriately rounded, are given in Table 4. The comparisons are displayed in Figure 4.

```
                    ------------- RUNOFF CURVE NUMBER ---------------
                  50        60        70        80        90      100
                ...|....+....|....+....|....+....|....+....|....+....|
Creosote Control
    CC1                     e       e          e     o
    CC2                             e    e       e  o
    CC3                             e           e   e   o
    CC4                             e            e  e    o
Creosote Termite
    CT1                     e       e          e  o
    CT2                     e       e          e   o
    CT5                     e           e       oe
    CT3                             e         e    e  o
    CT4                             e          e   e     o
Creosote Caliche
    CL1                             e               ee        o
    CL3                             e      e      e       o
    CL2                             e               ee       o
    CL4                             e    e       e         o
Grass Summerford
    GS1                             e      o  e     e
    GS2                             e       e    e   o
    GS3                     o           e        e
    GS4                     e          e      o  e
Grass IBP
    GI1         e                    e        e     o
    GI2         e                   e          e  o
    GI3         e              e        o      e
    GI4         e                   e   o      e
                ...|....+....|....+....|....+....|....+....|....+....|
                  50        60        70        80        90      100
                    ------------- RUNOFF CURVE NUMBER ---------------
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Figure 4. Plot of observed Curve Numbers (o) and handbook table and chart estimates (e).Boldface indicates an overplot.

SUMMARY AND DISCUSSION

The rainfall-runoff hydrology for rangeland plots in southern New Mexico was studied, and the Curve Numbers determined. These data-defined values were compared to the handbook estimates based on soils and vegetation. The correspondence between the two is not encouraging. Differences exist between nearby sites and even between adjacent plots, but rough trends are found with plant cover. The plotted results hint at the overriding importance of the basic soil resource in limiting hydrologic response, and a smaller role for vegetation.

The differences in CN-cover relations between the brush and grass sites create some interesting management rhetoric. In short, the brush sites are hydrologically active but robust: the hydrology is not strongly influenced by cover. Thus rehabilitation efforts or grazing restraints (or excesses) that affect cover may have little impact on the relative hydrologic response. The grass sites give more pronounced responses to cover, suggesting cover management could have a more profound effect on hydrologic response, and priority attention to them in management.

As an illustration of the above, the maximum one-day rainfall in the 12-year record was 84.84 mm (3.34 in) on June 8, 1987. Flexing the cover from 50% to 20% with this rainfall on the Creosote Control and the Summerford results from Table 4 with the Curve Number equation (eq 1) shows a 10% change in runoff depth for the Creosote site, but a 64% change for the grass site. Clearly cover is a more important consideration on the better sites.

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