DETERMINING WATERSHED CONDITIONS AND TREATMENT PRIORITIES

by
Rhey M. Solomon
James R. Maxwell
Larry J. Schmidt
USDA Forest Service
Albuquerque, New Mexico

Abstract

A method is presented for evaluating watershed conditions and alternative watershed treatments. A computer model simulates runoff responses from design storms. The model also simulates runoff changes due to management prescriptions that affect ground cover and structural treatments. Techniques are identified for setting watershed tolerance values for acceptable ground cover and establishing treatment priorities based on the inherent potentials of the watershed.

Introduction

Watershed conditions have historically been an important issue in the Southwest and Intermountain West. Early in this century, forest reserves were set aside primarily to sustain favorable conditions of flow for downstream users. During the period 1910-1960, considerable research was devoted to investigating relationships between vegetation, soil, ground cover, and runoff. Classic studies revealed a strong relationship between ground cover of plants and litter and surface runoff (Croft and Bailey, 1964; Meeuwig, 1960). As ground cover decreases, surface runoff increases especially from intense summer storms (Coleman, 1953). Primed with this knowledge, Federal land management agencies began adjusting livestock numbers to conform with land capability, aggressively suppressing wildfires, and installing runoff controls such as contour trenches. Many of these controls were installed by the CCC in the 1930's to improve or protect vegetation cover.

By the 1960's, many communities that had experienced flood damages associated with poor watershed condition now enjoyed the benefits of managed watersheds with revitalized cover. Many who experienced the consequences of poor watershed condition have passed on. The new generation, and the influx of people unaware of local history, generally take the absence of severe floods in managed areas for granted. In some cases, people have developed lands that were once active floodplains.

In the Southwest, the emphasis of the 1960's was on increasing water yield through vegetation changes. The 1970's spawned a degree of environmental awareness with an emphasis on water quality. Most universities shifted attention to these areas. These two items had scientific and media appeal, and overshadowed the traditional watershed condition concerns. The 1980's have given us stronger emphasis on commodity production, and population shifts to the Southwest. These pressures are reawakening a concern for watershed conditions among land managers.

Periodic summer floods have renewed interest in the role of watershed condition in regulating flood peaks. This has encouraged a reevaluation of past research to find means of assessing watershed condition. Some of the most relevant research was completed before the age of computer libraries and was difficult to discover. However, a strong body of knowledge exists which relates vegetation cover and soil conditions to runoff.

A technique for linking plant and litter cover to peak flow is fabricated from this knowledge base and builds upon the approach outlined by Lull (1949). We have developed a process model that ties ground cover to peak runoff for a specified design storm typical of the summer season in the Southwest. The model can determine the potential for reducing peak flows by increasing ground cover and installing structural treatments. The procedure also proposes a rationale for determining a minimum tolerance cover necessary to protect the site and downstream values.

This paper outlines and documents an approach for quantifying watershed condition. We first discuss the computer model used to simulate runoff. Using this computer tool, we show examples of how changes in watershed conditions alter peak flows, and discuss the ability to improve runoff responses through changes in vegetative cover and structural treatments. To adequately translate this modeling tool to an easily understood concept, we introduce the concept of "tolerance" and a "watershed condition index".

Modeling Approach

A principal indicator of watershed condition is the fluvial system's ability to transport water through a watershed without damaging channel stability, floodplain improvements, or riparian values. Because flow energies, area of inundation, and unstable conditions are greatest during peak flows, we need to assess the effects of land management on the magnitude and frequency of damaging peak flows. Our approach is to model the hydrologic processes affecting runoff and then look at effects management could have on these processes.

The two principal hydrologic processes which management can influence are infiltration and surface detention storage. We can, therefore, propose land treatments that affect these two components. Optimum infiltration and storage are best accomplished by assuring an adequate ground cover of plants and litter (Rosa, 1954; Croft and Bailey, 1964). We can also increase them by such activities as soil ripping, plowing, or other techniques that break up compacted or sealed surfaces (Croft and Bailey, 1964). These techniques are short lived unless vegetative cover is increased in conjunction with initial treatment.

Horton (1933) concluded that streamflow consists of two components: (1) direct overland runoff and (2) ground water flow. He proposed that storm flows occur when rainfall exceeds infiltration rates and that base flows are fed by ground water aquifers. This exceedance of infiltration is apparant to anyone who has been caught in an intense Southwestern rainstorm. However, this is not the sole source of runoff in forests or where rainfall intensities are moderate (Hibbert, 1975). We focused on overland flow because of our ability to affect this component and its importance in generating peak flows in the Southwest. We also incorporated the variable source area concept (Hewlett and Nutter, 1970) into the modeling approach, because it is important, and perhaps the dominant process, in forests that are in good watershed condition.

Our goal was to model runoff processes and express them in simple terms that have meaning to the manager as well as the scientist. To meet this goal, we searched for a model that best met the following objectives:

1. Sensitive to hydrologic processes that management can affect.

2. Theoretically defensible.

3. Requires minimal data input (i.e., data that is readily available or easily estimated).

4. Applies to the full range of conditions in the Southwest.

5. Applies to small (1-10 sq. mi.) watersheds where management practices can affect hydrologic responses.

6. Applies to individual rainfall events.

All major hydrologic processes which occur during rainstorms can be simulated in detail with the current state-of-the-art. The problem is to mirror these complex processes using only readily available data. Therefore, our efforts focused on models that consider only the most significant factors in simulating the processes controlling runoff.

Numerous models were reviewed. The "event" oriented models we investigated were: the SCS model (USDA, 1972) and various modifications (Ward et al., 1981; Knisel, 1980); the "Rational" Formula; HYMO (USDA, 1973); the Stanford Model (Crawford and Linsley, 1956); and USDAHL-70 (Holton and Lopez, 1971). Each of these models has merit but none meets all the listed objectives. The principal failing was an inability to model short, intense rainstorms and be sensitive to changes in infiltration and storage. Accordingly, we were required to piece together parts from various models to best meet the objectives. The result was a simple computer model that is sensitive to land management treatments, requires a moderate amount of data, and appears theoretically sound. The model was developed in the belief that watershed conditions are best reflected by flood flows resulting from intense rainstorms. If satisfactory watershed conditions are a principal objective of management, then we need to demonstrate our ability to affect peak flow and timing of runoff.

The Model

The model SHOWER was developed by incorporating theoretical as well as empirical relationships that describe the processes outlined previously. Where data or theory were vague or absent, assumptions were made to fill these voids. A complete discussion of the model is given by Solomon (1982).

Precipitation is the driving input. This input is infiltrated for a designated time increment. Precipitation that does not infiltrate is cumulated in detention storage until the next time increment. Quantities in excess of infiltration and detention storage become surface overland flow. The model places this excess water into the channel system and routes it to the downstream point of interest.

Water that infiltrates the soil is added to the soil water and cumulates until the soil is filled to gravitational free water. At this point water is fed to the channel at a rate dependent on the amount of water in excess of free water holding capacity and the drainage density. This soil excess is added to the surface excess and routed to the downstream point of interest.

Watershed Condition Examples

Two examples portray the concept of watershed condition and our ability to affect storm hydrographs. Agricultural Research Service Watershed 47.003, near Albuquerque, New Mexico (Hickok et al., 1959), and Halfway Creek, near Farmington, Utah (Doty, 1971), were chosen because of available data describing treatment responses. These watersheds contrast sharply as shown in Table 1.

Table 1. Watershed Characteristics for Example Watersheds.

Characteristic	Albuquerque 47.003	Halfway Creek
Area:	176 Acres	464 Acres
Average Slope:	10%	50%
Channel Slope:	3%	38%
Soils:	Clay loam and silt loam; 2-3 feet deep	shallow loam, sandy loam
Vegetation:	sagebrush, grasses, snakeweed, saltbrush	oakbrush, sagebrush, aspen
Ground Cover:	25%	60-80%
Mean Annual Precipitation:	8"	30"

These two watersheds illustrate runoff sensitivity to vegetative cover and structural treatments for actual storm events. We found that it is not the total volume of rainfall that dictates the hydrograph, but rather the distribution and intensity of rainfall. Many models fail to mimic hydrograph peaks because they fail to model rainfall input on a short enough time base.

Ground Cover Changes

Ground cover can have marked effects on surface runoff (Croft and Bailey, 1964; Woodward, 1943; Meeuwig, 1960). Watershed 47.003 shows how the computer model responds to cover changes and how dominant cover can be in determing peak flow responses. Three rainstorms are used: (1) August 3, 1964, (2) September 2, 1965, and (3) June 10, 1966. These storms were of moderate volume and intensity as shown in Table 2. They were simulated for different cover conditions.

Figure 1 shows the considerable influence management can exercise on peak flow. Increasing ground cover from 25 to 35 percent would cause about a 50 percent reduction in peak flow for all the storms modeled. Conversely, allowing ground cover to deteriorate from 25 to 15 percent would increase peak flows about 50 percent. Comparing different storms, the storm of September 2, 1965 would have produced the same peak flow as the June 10, 1966 storm if ground cover were 5 percent rather than 25 percent. This would translate to a 2 year storm producing a peak flow more characteristic of a 10 year storm.

Total storm runoff volumes are plotted in Figure 2 as a function of cover. These changes show the same pattern as Figure 1. Reduced runoff volumes have implications to reservoir management and translate to greater soil water for increased plant growth and base flows.

August 3, 1964			September 2, 1965			June 10, 1966		
Time (Minutes)	Accumulated Volume (Inches)	Intensity (In/hr)	Time (Minutes)	Accumulated Volume (Inches)	Intensity (In/hr)	Time (Minutes)	Accumulated Volume (Inches)	Intensity (In/hr)
0			0			0		
		.48			.36			6
5	.04		5	.03		2	.2	
		.48			.12			5.1
10	.08		10	.04		4	.37	
		.48			.12			3.6
15	.12		15	.05		6	.49	
		.24			.12			5.1
20	.18		20	.06		8	.66	
		2.28			.12			4.5
25	.37		25	.07		10	.81	
		2.28			.12			2.7
30	.56		30	.08		12	.90	
		1.32			.36			2.4
35	.67		35	.11		14	.98	
		.48			.72			1.5
40	.71		40	.17		16	1.03	
		.24			1.08			.3
45	.73		45	.26		18	1.04	
		.12			2.28			
	.74		50	.45				
					1.32			
			55	.56				
					.06			
			60	.61				
					.24			
			65	.63				

Table 2. Precipitation Data for Three Storms on the Albuquerque Watershed 47.003.

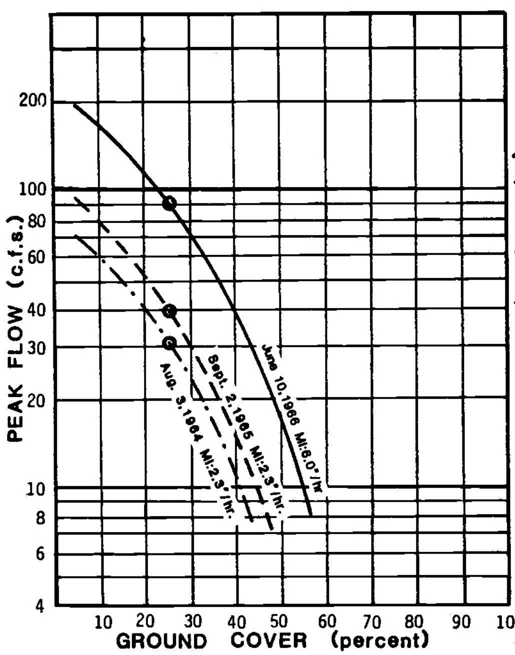

Figure 1. Peak Flow Responses to Ground Cover Changes for Three Summer Storms.

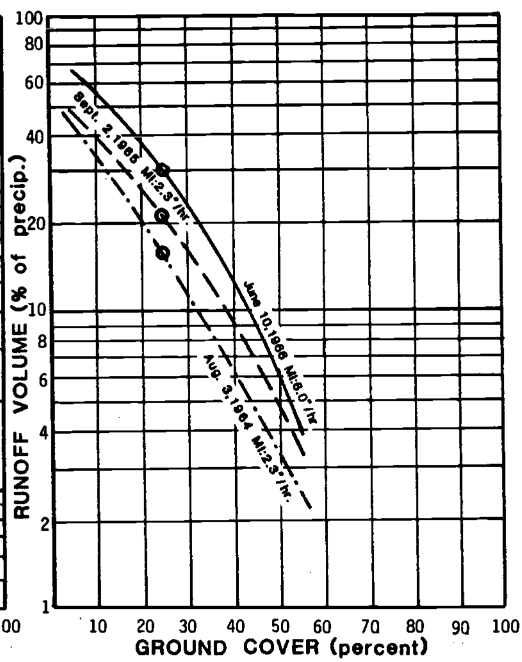

Figure 2. Runoff Responses to Ground Cover Changes for Three Summer Storms.

The next step in model verification and refinement will be to simulate hydrographs on watersheds where significant cover changes have actually taken place and hydrologic data are available. The classic Watersheds A and B of the Great Basin Station in Utah (Meeuwig, 1960) offer this opportunity and hopefully will confirm the preliminary results.

Structural Treatments

When cover decreases on a watershed due to overuse, rehabilitation can be difficult. Reestablishment of vegetative cover and favorable soil structure may require decades. In today's economy, managers must be concerned about the resource entropy associated with harvesting resources in excess of the land capability (Rifkin and Howard, 1980). The state of entropy comes from dissipating the soil productivity through erosion. This makes any stabilizing treatment far more costly than proper management would have been. Green (1971) captures this concept in his statement:

> The most difficult job is to guard against negating the benefits of spending by accomodating public pressures for certain types of land use that can either act counter to the goals of watershed management or increase the management cost of rehabilitation activity. The public land manager is no less responsible for fiscal integrity than he is for biological, ecological and physical concern for the resource.

In many cases, recovery may have to be aided with structural treatments. These treatments serve two purposes: (1) they reduce erosion and runoff immediately; and (2) they help reestablish cover by reducing water losses and increasing available water. Such structural treatments were applied to Halfway Creek (Doty, 1971). Before-and-after situations were modeled with SHOWER. Peak flows agree well with actual hydrographs for those storms. Additionally, SHOWER was used to simulate what the hydrograph from the storm in 1945 would have looked like with trenching and what the hydrograph from the storm in 1965 would have looked like without trenching (Figure 3).

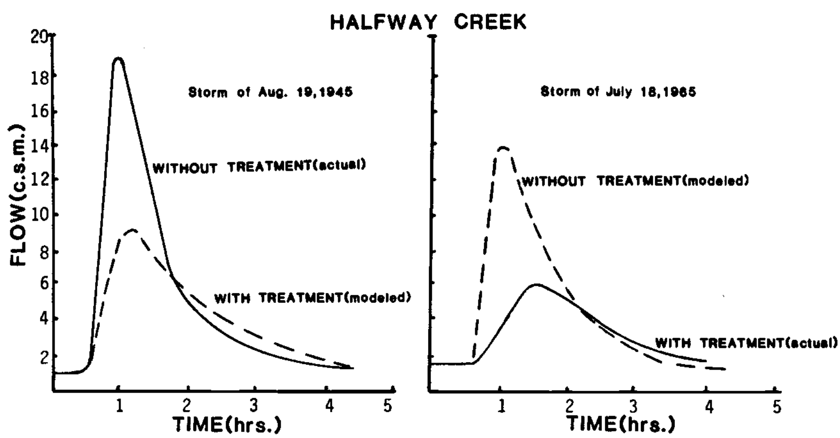

Figure 3. Pre-and Post-Treatment Hydrographs for Halfway Creek.

This type of comparison visually demonstrates the direct effects of structural treatments for an event rather than by traditional means such as paired watersheds. This method does not lend itself to statistical interpretation as other methods might, but the decision maker can readily identify the tradeoffs being made.

Cover Versus Structures

Through modeling, it is possible to compare hydrograph changes from increasing cover versus installing structural treatments. Numerous simulation runs were made on Watershed 47.003 for the storm of August 3, 1965. Figure 4 shows the increase in cover and corresponding amount of contour trenching or furrowing necessary to reduce peak flow by equal amounts. This diagram clearly demonstrates that both structural measures and cover can effectively control surface runoff. However, prudent planning should consider only the improvement in cover for evaluating long term benefits. Structural treatments, while effective, are relatively short lived and provide only temporary site control pending establishment of vegetation. The structural measures may temporarily be more effective than the long term cover. This is because the design of the structures must consider the risk of failure over the period required to attain satisfactory cover. This is a function of downstream consequences of structural failure, a level of risk, and the costs of retreatment if the measures are damaged. It certainly is not prudent or justified to expect more than temporary control of runoff from structural measures.

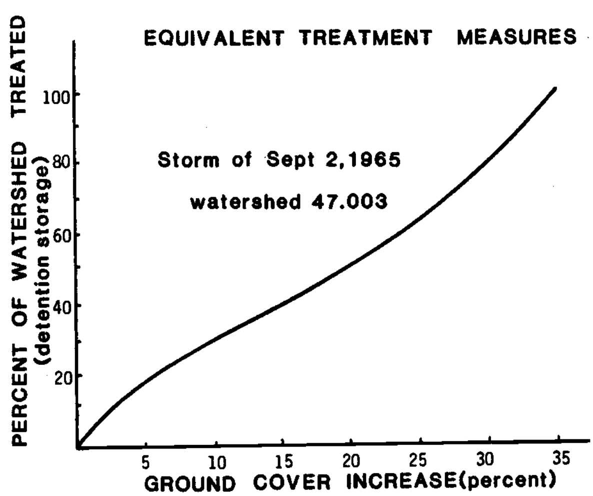

Figure 4. Comparison of Treatment Effectiveness.

SHOWER offers a technique for evaluating peak flow alterations due to changes in cover and structural treatments. Additionally, roads can be incorporated into the model by considering the road network as one or more hydrologic units and applying the appropriate infiltration characteristics and runoff routing factors. Roads are also considered an extension of the channel network for soil water flow (Megahan, 1972).

The Concept of Tolerance

The previous section showed how reducing ground cover increases runoff. When do such increases become unacceptable? We must answer this question to distinguish between satisfactory and unsatisfactory watershed conditions.

Watersheds and land units have a maximum potential ground cover that can be achieved naturally. This condition prevailed over most of the Southwest before 1880. Persistent land disturbance progressively reduces ground cover from the potential. Eventually, runoff may increase to a point where it causes economic or environmental impacts which the land manager deems unacceptable. Ultimately, runoff may increase to a point where water flows and land productivity are permanently impaired.

The following discussion presents techniques to derive tolerance levels of ground cover for runoff. Two levels of tolerance are discussed: (1) a variable "management" tolerance responsive to social concerns for selected areas; and (2) an absolute "resource" tolerance responsive to permanent physical damage for all areas.

Management Tolerance

SHOWER calculates flood peaks for varying levels of ground cover. For each watershed, the land manager must decide how big an increase in flood peaks (how big a risk of increased flood damages) he is willing to accept (Schmidt, 1978). Watershed priority (Shaw et al., 1981) should be used to determine this marginal level of risk. Many low priority watersheds may not warrant a management tolerance because risks of flood damages are very low. If the flood peak calculated for existing ground cover exceeds the management tolerance set for a watershed, the watershed condition is unsatisfactory.

Resource Tolerance

Channel networks form as a function of the erosive force of runoff and the erodibility of the watershed. A channel forms where runoff becomes sufficient to incise the surface. In any area, there is some minimum drainage area or slope distance required for a channel to form (Schumm, 1977).

As ground cover is progressively reduced from the potential, the erosive force of runoff increases and the resistance of the surface to erosion decreases. Thus, the drainage area or slope distance required for a channel to form is reduced. Eventually, the channel network will expand headward in response to these changes. If unchecked, this process ultimately will severely degrade the watershed and permanently impair the discharge-sediment function of the fluvial system.

One approach for deriving a resource tolerance for runoff computes a critical slope distance, represented by complete expansion of the channel network up all slope depressions to the ridge. The resource tolerance is exceeded when ground cover is reduced enough to permit such a drastic response, which would occur over several decades.

Horton (1945) introduced the concept of the "belt of no erosion." For channel erosion, he defined it as the mean horizontal distance from a channel to the nearest ridge. It can be computed using two equations:

$$\mathbf{B} = \frac{5280}{2d} \qquad \text{(Equation 1)}$$

$$\mathbf{B} = \frac{65}{f(\sin^{1.17}a)(\cos^{.501}a)} \cdot \frac{s^{1.67}}{r} \qquad \text{(Equation 2)}$$

where: **B** = belt of no erosion (feet),
d = drainage density (miles per square mile),
f = surface friction factor,
a = slope angle (degrees),
s = soil shear resistance factor (pounds per square foot), and
r = maximum runoff intensity (inches per hour).

A "tolerance" **B** is computed by extending the channel network to the ridge and using equation 1. Equation 2 can be solved for any level of cover. Eventually, reducing ground cover will increase r and lower s to the point where the existing **B** (equation 2) declines to the tolerance **B** (equation 1). At that level of cover, watershed condition is unsatisfactory. If ground cover is not increased, radical channel expansion will ultimately occur.

Measure of Watershed Condition

A measure of cover can provide an index of watershed condition that is straightforward, responsive, and meaningful to management. Watershed conditions can be evaluated using ratings that represent the general hydrologic conditions of the land. These condition ratings are determined by comparing measured existing cover against estimated potential and tolerance cover. Lands with different natural capabilities are thus equalized; desert watersheds are not compared with forested watersheds for condition ratings. The watershed condition index is defined by:

$$\mathbf{W} = \frac{E - T}{P - T}$$

Where:

W = watershed condition index,
E = existing area-weighted cover,
P = the natural maximum weighted cover, and
T = the cover conditions necessary to prevent excessive risk of flood damage or channel expansion.

If existing cover is below tolerance levels the watershed condition is unsatisfactory ($W < 0.0$). Satisfactory conditions are defined as having W between 0.0 and 0.5. Optimum conditions are W values greater than 0.5. The distinction between satisfactory and optimum watershed conditions is arbitrary and serves only to alert management to the conditions relative to potential and tolerance. A watershed in satisfactory condition meets minimum land stewardship requirements but is closer to tolerance than to potential cover. An optimum condition watershed is closer to potential.

A further expansion of the classification system is needed if the system is to have more meaning to management. In addition to knowing how well a watershed performs hydrologically, the manager needs to know where he can invest the fewest dollars for the greatest returns. This is done by putting watersheds into "opportunity classes." These opportunity classes are a measure of the difference between potential and tolerance cover (P-T). The larger this difference is, the greater are the opportunities for affecting favorable conditions of flow. The smaller this difference is, the more limited are the opportunities. We can therefore display watershed conditions as shown in Figure 5. The numerical ratings in Figure 5 give the treatment priority. An UNSATISFACTORY/FULL opportunity watershed would receive first priority for planning treatment measures. Note that all unsatisfactory watersheds regardless of opportunity class, should be planned for restoration before satisfactory watersheds.

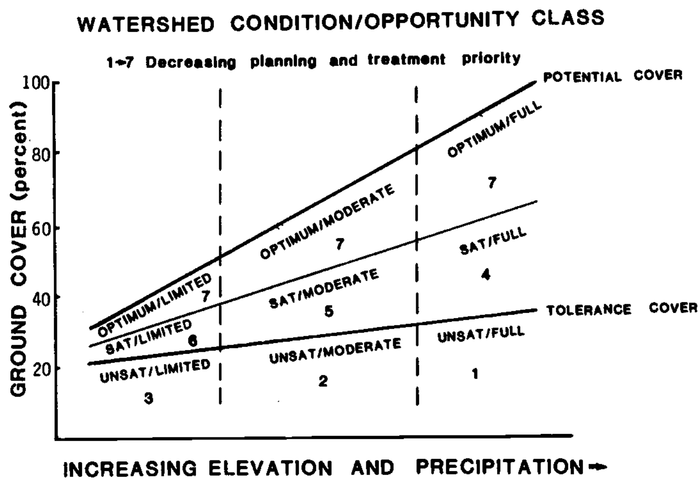

Figure 5. Watershed Conditions and Opportunity Classes.

This classification system is purposely made simple by relating watershed performance to a single index, ground cover. It serves to convey the concept of favorable watershed conditions to management. Our feeling is that the concepts for improving hydrologic response have often been needlessly complicated by technical specialists. Over the years, appreciation of our ability to affect runoff and erosion has been given to specialists, and therefore, a commitment to maintaining favorable conditions of flow has been partially lost by management. It is again time that all levels of managers, technical specialists, and decision makers realize their responsibilities for maintaining satisfactory watershed conditions. This can only come about by instilling an understanding of the processes of watershed management in a straightforward way.

Future Research, Equipment, and Data Needs

The process of developing the model and technique identified several needs as follows:

1. Rainfall and runoff data for short time increments (1 to 5 minutes) on small basins (5 to 10 sq. mi.).

2. Gaging equipment which is event oriented, solid state (to enhance accuracy), and directly computer-processible to facilitate data handling.

3. An assessment of current ground cover conditions for public lands.

4. Techniques for estimating potential ground cover for various ecosystems in the West.

5. Effects on baseflows and interflow resulting from alterations of infiltration and reduced overland flow.

6. Relationship between cover and activities on infiltration and runoff.

Conclusion

Good watershed conditions benefit everyone. Rain and snow are absorbed into the soil reservoir on slopes and released over a longer period of the year. This increases the effective regulating capacity of downstream reservoirs. Reservoirs and irrigation works require less maintenance because of reduced sediment. Productive soil is maintained on-site providing for sustained production of lumber, fuelwood, livestock, wildlife, recreation and water. There is ample evidence in the literature of the efficacy of improving watershed condition and the relationships between ground cover and runoff. There are examples of successful treatments in New Mexico in pinyon-juniper and juniper-grasslands (USDA, 1960; Columbus, 1980).

To achieve and maintain satisfactory watershed conditions, land uses must be designed to match the inherent capability of the land and be compatible with the needs of downstream communities. Floods, muddy water, and streams that dry up quickly are symptoms of unsatisfactory watershed conditions. Many of these consequences have been inherited by the present generation and are accepted as the natural situation. However, we can in many cases make positive changes in watershed condition and hydrologic responses.

References Cited

Colman, E.A. 1953. Vegetation and watershed management. The Ronald Press Co., New York. 412 p.

Columbus, J.T. 1980. Watershed abuse-the effect on a town. Rangeland 2(4):148-150.

Crawford, N.H. and R.K. Linsley. 1962. The synthesis of continuous streamflow hydrographs on a digital computer. Dept. of Civil Engineering, Stanford Univ. Technial Report No. 12. 121 p.

Croft, A.R. and R.W. Bailey. 1964. Mountain water. USDA Forest Service, Intermountain Region, Ogden, Utah. 64 p.

Doty, R.D. 1971. Contour trenching effects on streamflow from a Utah watershed. USDA Forest Service Research Paper INT-95. 19 p.

Green, A.W. 1971. Some economic considerations of watershed stabilization on National Forests. USDA Forest Service Research Paper INT-92. 10 p.

Hewlett, J.D. and W.L. Nutter. 1970. The varying source area of streamflow from upland basins. In: Proc. of the Symp. on Interdisciplinary Aspects of Watershed Management. p. 65-83. Amer. Soc. of Civil Engr. New York.

Hibbert, A.R. 1975. Percolation and streamflow in range and forest lands. In: Proceedings of Fifth Workshop of the United States/Australia Rangelands Panel, Boise, Idaho. pp. 61-72.

Hickok, R.B., R.V. Keppel and B.R. Rafferty. 1959. Hydrograph synthesis for small aridland watersheds. Jour. of Agric. Engineering. 40(10):608-611, 615.

Holtan, H.N. and N.C. Lopez. 1971. USDAHL-70 model of watershed hydrology. USDA Agricultural Research Service. Technical Bulletin No. 1435. 84p.

Horton, R.E. 1933. The role of infiltration in the hydrologic cycle. Amer. Geophy. Union. Trans. 14:446-460.

Horton, R.E. 1945. Erosional development of streams and their drainage basins; hydrophysical approa to quantitative morphology. Bull. of the Geological Soc. of Amer. 56:275-370.

Knisel, W.G. (ed). 1980. CREAMS-a field scale model for chemical, runoff, and erosion from agricultural management systems. USDA Conservation Research Report No. 26. 643 p.

Meeuwig, R.O. 1960. Watersheds A and B-a study of surface runoff and erosion in the subalpine zone of central Utah. Jour. of Forestry. 58(7):556-560.

Megahan, W.F. 1972. Subsurface flow interception by a logging road in mountains of central Idaho. In: Proc. Natl. Symp. of Watersheds in Transition. Fort Collins, Co. Am. Water Resour. Assoc. p. 350-356.

Rifkin, J. and T. Howard. 1980. Entropy. The Viking Press, New York. 305 p.

Rosa, J.M. 1954. Guides for program development flood prevention on small watersheds of the Rocky Mountain area. USDA Forest Service, Intermountain Region, Ogden, Utah. 152 p.

Schmidt, L.J. 1978. The use of risk in specifying job quality. USDA Forest Service, Southwestern Region. Hydrology Note No. 8. 8 p.

Schumm, S.A. 1977. The fluvial system. John Wiley and Sons, New York. 338 p.

Shaw, D., R. Solomon, J. Maxwell, and L. Schmidt. 1981. A system for focusing the watershed management program in the Southwestern Region for the 1980's. USDA Forest Service, Southwestern Region. Hydrology Note No. 11. 17 p.

Solomon, R.M. 1982. SHOWER-storm hydrograph output for watershed evaluation and restoration. USDA Forest Service, Southwestern Region. 30 p.

Ward, A., T. Bridges and 8. Wilson. 1981. A simple procedure for developing a design storm hydrograph. Water Res. 8ull. 17(2):209-214.

Woodward, L. 1943. Infiltration-capacity of some plant-soil complexes on Utah range watershed-lands. Trans. Am. Geophy. Union. 24:468:475.

USDA. 1960. Tour guide to 8ernalillo watershed protection project. USDA Forest Service, Southwestern Region, Cibola National Forest. 7 p.

USDA. 1972. Hydrology. Section 4, National Engineering Handbook. USDA Soil Cons. Service, Washington, DC.

USDA. 1973. HYMO: problem-oriented computer language for hydrology modeling. USDA Agricultural Research Service. ARS-5-9. 75 p.