Infiltration and Soil Stability of a Summer Range[1]

TEJA SINGH[2]

Former Research Assistant, Utah State University, Logan.

Highlight

Infiltration and sediment production rates, under simulated rainfall, were determined for plots covered with mule-ear wyethia and on plots from which wyethia had been replaced by grasses as a result of spraying. The sediment produced during the 50-minute period averaged 0.447 ton/acre. As the infiltration rates for the wyethia and grass plots (2.74 and 2.38 inches/hour, respectively) were not significantly different, single equations expressing average infiltration rates and mass infiltration were derived for extrapolating experimental results to other areas with similar vegetation.

Infiltration is an important process in replenishing the soil moisture that eventually supports all vegetative growth and herbage production. It also determines the amount of water available for surface runoff and peak flows from excess precipitation that is not transmitted directly into the soil mantle. A knowledge of infiltration capacities by soil types or specific conditions is of paramount importance, especially in cases where infiltration can be modified through the ameliorating influence of growing vegetation and the impact of various land use practices.

The infiltration characteristics of the Ao horizon determine immediately the amount of water that will enter into a virgin soil. The physical properties of the mineral surface which influence the amount, size, and distribution of soil pores, also exercise important influence on infiltration capacities. Many of these properties are amenable to modification through management practices and by the amount of living and dead vegetative material present in the area. A comparative study of the infiltration rates, therefore, provides a convenient method for evaluating the influence of existing vegetation and other land use practices on flood protection and erosion hazards. The soil particles dislodged and carried away as sediment in storms of known intensity and duration are an important measure of the soil stability of an area.

On large areas, infiltration rates can be obtained by analyzing rainfall and runoff data collected for storms of different intensities and durations, a procedure that provides integrated rates for entire watersheds. Such large land units, however, are often heterogeneous in vegetation, soils, geology, climate, and topography. The relative importance of a given vegetation and a contemplated land use can be more easily determined through artificial application of simulated rainfall on small experimental plots.

Rain-simulators have certain advantages over infiltrometers of the flooding type. Infiltration rates measured by the latter are different from those under natural conditions in several ways. Raindrop impact, important in soil detachment and, therefore, essential in any rainfall–erosion study for evaluating the protective role of vegetation, is not provided by infiltration rings that merely pond water at the soil surface. The rain simulators, on the other hand, create conditions whereby puddling of soil surface and movement of detached soil particles reduce surface porosity, as in natural rain storms.

The rain-simulator infiltrometers used extensively for studying hydrologic response of rangelands include the Northfork infiltrometer (Rowe, 1940), the Rocky Mountain infiltrometer (Dortignac, 1951), the Intermountain infiltrometer (Packer, 1957), and the mobile raindrop applicators (Osborn, 1952; Barnes and Costel, 1957). Because of limited plot size the infiltration and sediment data obtained from such devices are useful primarily in relative comparisons of different treatments or soil and site characteristics (Dyrness, 1967).

The previous studies on rainfall erosion are reviewed by Smith and Wischmeier (1962), who aptly stated that the greatest deterrent to soil erosion was plant and litter cover. A review of the relationship between infiltration and soil erosion, and the erosion potential of forest watersheds, has more recently been made by Dyrness (1967). An excellent review of infiltration and erosion studies on rangelands has similarly been done by the American Society of Range Management (1962). Dortignac and Love (1961) found that the weight of dead organic material and non-capillary porosity of surface soil had the most influence on infiltration. Of the nine site characteristics studied by Packer (1951), the ground cover density and the size of bare openings were found to be most closely related to quantities of runoff and erosion. Infiltrometer tests on the sub-alpine range in central Utah have shown that a ground cover of 70 to 75% was required for effective control of storm runoff and sediment (U.S. Forest Service, 1951).

Experimental Procedure

The Rocky Mountain infiltrometer used in the study has a plot measuring 11.7 × 30.4 inches. The plot frame is 6 inches in depth, of which 3 inches are driven into the soil. A rain trough, 1.1 × 30.4 inches, is mounted on each long side of the frame to provide a measure of the rainfall ap-

[1] Research based on unpublished data presented in an M.S. thesis at Utah State University, Logan, Utah. Received June 7, 1968; accepted for publication November 12, 1968.

[2] Present address: Research Scientist, Forestry Branch, Canada Department of Fisheries and Forestry, Calgary, Alberta.

Table 1. Average vegetation (percent) cover on wyethia and grass plots.

Species	Mud Flat		Buyer's Place	
	Wyethia plots	Grass plots	Wyethia plots	Grass plots
Grasses				
Slender wheatgrass (*Agropyron trachycaulum* (Link) Malte)	9.3	15.2	2.0	6.5
Mountain brome (*Bromus carinatus* Hook. and Arn.)	2.5	5.8		
Bulbous bluegrass (*Poa bulbosa* L.)	4.2	3.3		
Junegrass (*Koleria cristata* (L.) Pers.)	1.5	5.5		1.5
Bearded wheatgrass (*Agropyron subsecundum* (Link) Hitchc.)		3.7		
Sheep fescue (*Festuca ovina* L.)			3.2	5.0
Letterman needlegrass (*Stipa lettermani* Vasey)			0.3	4.2
Bluegrass (*Poa douglasii* Nees)		0.2	0.3	0.3
Oniongrass (*Melica bulbosa* Geyer. ex Port. and Coult.)			0.3	
Forbs				
Mule-ear wyethia (*Wyethia amplexicaulis* (Nutt.) Nutt.)	36.0		43.7	
Western yarrow (*Achillea lanulosa* Nutt.)		0.5	1.2	2.5
Geranium (*Geranium fremontii* T. & G.)				0.5
Cluster tarweed (*Madia glomerata* Hook.)	0.3			
Aster (*Aster* sp.)				0.3
Shrub				
Big sagebrush (*Artemisia tridentata* Nutt.)			1.5	
Total	53.8	34.2	52.5	20.8

plied. The details on design and fabrication of various parts, including the type F nozzles used in the rain simulator, are provided by Dortignac (1951). A uniform distribution pattern of rain of desired intensity is obtained through a trial-and-error procedure by minor variations in water pressure on the rain applicator and by interchanging nozzles and nozzle parts.

The study was conducted at two locations, Mud Flat and Buyer's Place, situated on open hillsides in the mountain summer ranges of Cache National Forest in northeastern Utah. The area had been grazed heavily in the past, causing dense infestations of mule-ear wyethia. A study designed to investigate the beneficial effects of herbicides for increasing production of forage from rangelands was previously carried out by Tingey and Cook (1955); as a result unsprayed plots with predominantly wyethia vegetation occurred side by side with sprayed plots in which grasses were more abundant. The areas offered an opportunity to determine the effect of change in vegetation on infiltration and erosion at each location. The initial variability in the species composition and percentage of plant cover, as determined by the point method (American Society of Range Management, 1962) at the time of infiltration runs, is shown in Table 1.

The main associated species on the wyethia plots were

Table 2. Average percent ground cover and bare surface on experimental plots prior to infiltration runs.

Location	Vegetation	Litter	Rock	Bare
Mud Flat				
Wyethia plots	54	26	2	18
Grass plots	34	28	5	33
Average	44	27	4	25
Buyer's Place				
Wyethia plots	53	17	10	20
Grass plots	21	25	14	40
Average	37	21	12	30

slender wheatgrass and bulbous bluegrass at the Mud Flat site, and sheep fescue and slender wheatgrass at Buyer's Place. The important species on the grass plots were slender wheatgrass, mountain brome, and junegrass at the former, and slender wheatgrass, sheep fescue, and letterman needlegrass at the latter site.

Annual rainfall is about 30 inches at Mud Flat and slightly less at Buyer's Place. Because of high elevation and proximity to the Wasatch Front, both areas experience intense, short-duration storms during summer (Shands and Ammerman, 1947; U.S. Weather Bureau, 1960) which often generate peak flows large enough to damage diversion works, carry sediment loads to fill reservoirs, and cause considerable damage to lands situated below (Bailey, 1941; Bailey et al., 1947; Marston, 1952; Meeuwig, 1965). It was, therefore, decided to study the extreme effects of such storms by applying rainfall at an intensity of 4 inches/hr. Preliminary runs suggested that a period of 50 minutes was sufficient to obtain steady or nearly steady infiltration rates. A height of 7 ft, estimated for the falling raindrops to attain terminal velocities equivalent to those under natural storms (Dortignac, 1951), was maintained during the field measurements.

Twenty plots were used in paired comparisons in which wyethia plots were treated side by side with grass plots. The exact placing of the Rocky Mountain infiltrometer plot frame was determined by dividing each experimental unit into two plots, of which one was taken as decided by a random selection. The percentage vegetation, litter cover and bare surface on the plot area were determined just prior to each infiltration run (Table 2).

To minimize variations in surface soil moisture, the sample plots were brought to moisture content near field capacity (Dortignac, 1951; Adams et al., 1957; Meeuwig, 1965) by placing burlap bags over the soil surface and applying a total rainfall of 2 inches in 30 minutes. Particular care was taken to avoid excessive runoff. The wetted plots were covered by tarpaulin sheets and allowed to drain overnight.

Runoff was collected at the end of each 10-minute period and measured with graduate cylinders. Proportional samples, or aliquots, of runoff were also taken for determining the sediment produced during each 10-minute interval.

Results and Discussion

The average total infiltration for the 50-minute period was 2.28 inches for wyethia plots and 1.98 inches for grass plots. Although the infiltration rates of the former remained higher than those of the latter throughout the infiltration run (Fig. 1),

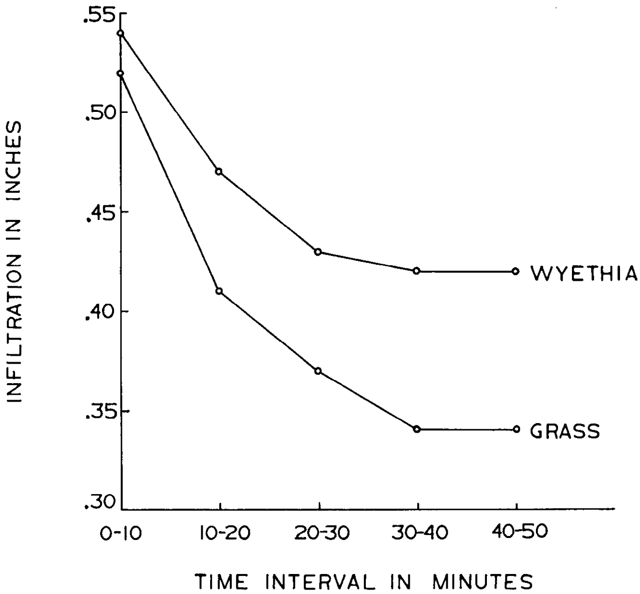


FIG. 1. Infiltration in inches at 10-minute intervals for wyethia and grass plots.

the difference was found to be nonsignificant at each location.

The slightly higher infiltration response from wyethia plots was partly due to the resistance offered by its broad leaves to raindrop impact (Duley and Domingo, 1949; Ellison, 1945; Lassen et al., 1952; Osborn, 1954; Rauzi and Fly, 1968). As evident from Table 1, wyethia plots had an admixture and understory of grasses; the combination, and greater vegetation cover of wyethia plots than of grass plots, acted more effectively as a cushion at different layers. The infiltration capacities of the two vegetation types, however, did not show significant difference and the data from both types were combined for further analysis. The average rates thus obtained at each location are shown in Table 3.

Table 3. Average infiltration and sediment for each 10-minute interval at Mud Flat and Buyer's Place.

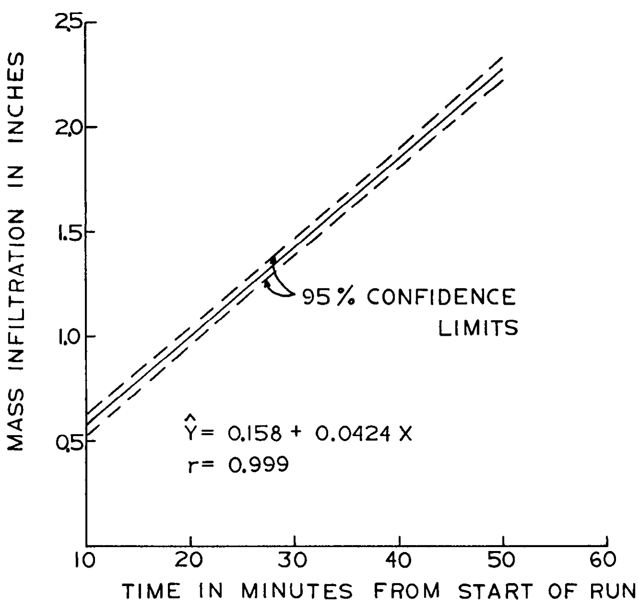
Time interval (minutes)	Mud Flat		Buyer's Place	
	Infiltration (inches)	Sediment (ton/acre)	Infiltration (inches)	Sediment (ton/acre)
0–10	0.56	0.042	0.50	0.124
10–20	0.46	0.057	0.42	0.235
20–30	0.43	0.066	0.37	0.154
30–40	0.41	0.054	0.36	0.124
40–50	0.40	0.051	0.35	0.075

The infiltration rates are characterized by an initial high rate that decreased rapidly at first but more slowly afterwards till nearly constant rates were attained after about 40 minutes of simulated rainfall. A number of factors contribute to this change, e.g. puddling of soil surface and closing of soil pores from raindrop impact, swelling of colloids, and decrease in available storage space above a restrictive horizon. The effect of such changes becomes less pronounced as rain continues. Average infiltration rates (Y inches/10-minute interval) were, therefore, expressed as a negative exponential function of time (X minutes) at each location:

Mud Flat: $\text{Log } 10Y = 0.9482 - 0.2093 \text{ Log } X$; $r = 0.989$

Buyer's Place: $\text{Log } 10Y = 0.9224 - 0.2290 \text{ Log } X$; $r = 0.994$

Linear regression equations for average mass infiltration Y inches at time X minutes are presented in Fig. 2.



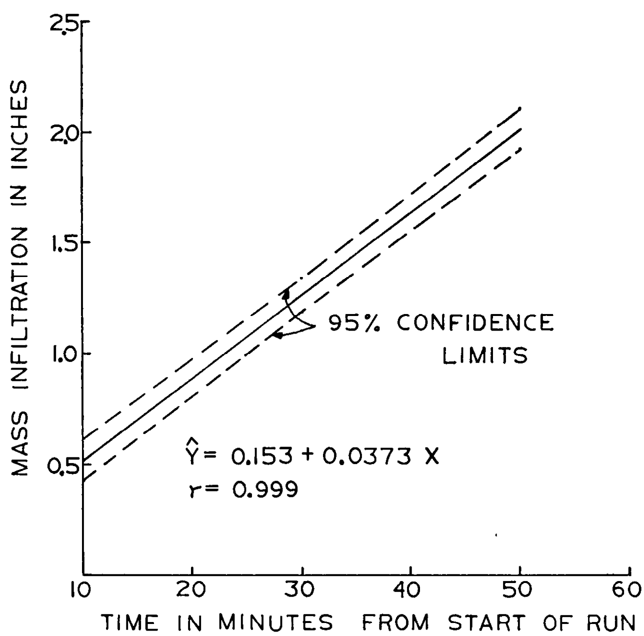


FIG. 2. Average mass infiltration at Mud Flat (left) and Buyer's Place (right).

The total infiltration rate for the entire run averaged 2.74 inches/hour for wyethia plots and 2.38 inches/hour for grass plots. The rates are higher than those determined by Dortignac and Love (1960) with the Rocky Mountain infiltrometer in an extensive study on the pondersosa pine–bunch grass type of the Colorado Front Range. The average infiltration rates obtained by them for the last 20 minutes of a 50-minute sprinkling application on pre-wetted soils at a rainfall intensity of 4.5 inches/hour were 1.94 inches/hour for pine grass and 1.50 inches/hour for grassland. The corresponding rates for wyethia and grass plots in the present study were 2.52 and 2.04 inches/hour, respectively.

The higher rates at Mud Flat were due to greater vegetation and litter cover than at Buyer's Place. The total vegetation canopy cover and litter averaged 71% at the former compared with 58% for the latter. These are considerably less than the 70% minimum ground cover density (plant basal area and surface litter) requirements recommended by Packer (1951) to control runoff and erosion on the steep grass ranges of Boise River watershed in Idaho when simulated rainfall at an intensity of 3.6 inches/hour was applied for 30 minutes.

At Mud Flat, eroded material was initially greater from wyethia plots than from the grass plots; the largest quantity of sediment was produced during the 20 to 30 minute interval from the former plots and during the 30 to 40 minute interval for the latter plots. The sediment rates decreased more rapidly from wyethia sites so that the total sediment collected from the grass sites averaged slightly greater than the wyethia plots for the entire 50-minute period. The trend appeared to be the result of greater accumulation of duff under wyethia plots than under grass plots. Considerable movement of this light material was noticed from wyethia plots early in the infiltration run and the quantity dropped rapidly thereafter. Sediment movement for the grass plots, on the other hand, involved mineral material that moved more slowly and more consistently throughout the test run. At Buyer's Place the peak sediment occurred in the first 10-minute interval for the wyethia plots and in the 10 to 20 minute interval on the grass plots.

The total sediment rates for the 50-minute period did not differ significantly by vegetation types. The combined data from wyethia and grass plots showed earlier sediment peaks at Buyer's Place than at Mud Flat. The factors responsible for high infiltration capacities generally account for low sediment production. Increased erosion rates, however, have been observed to accompany increased infiltration rates following intense fires (Pillsbury, 1953).

The total sediment produced at the two locations

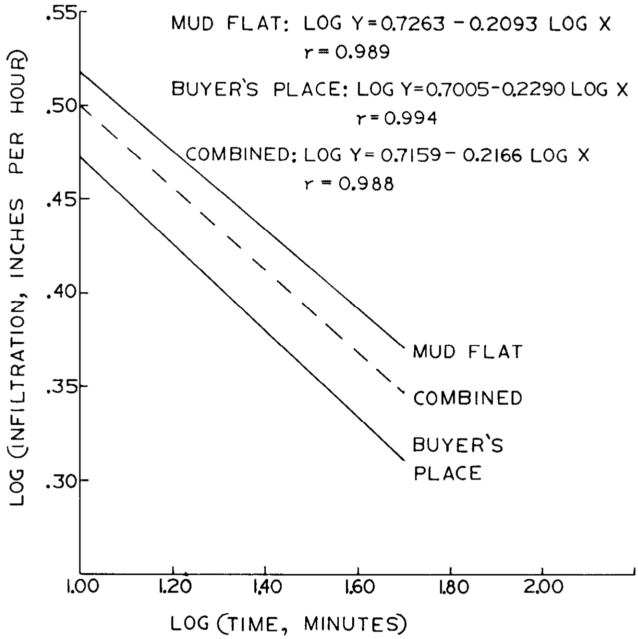


FIG. 3. Regressions of average infiltration in inches per hour from start of run.

averaged 0.447 ton/acre for the entire 50-minute period. The erosion resulting from storms of 4-inches/hour intensity, maintained continuously for 50-minute period (a rare occurrence), is considerably lower than from many other land uses (Ursic and Dendy, 1963), and well below the acceptable maximum soil loss rates postulated by Shrader et al. (1963). As these rates differ widely according to soil types, further work needs to be done to define quantitatively the acceptable levels of erosion and run-off for determining adequacy of soil-protecting cover.

Further tests on the regression equations showed that the regressions were not significantly different by locations. The data were, therefore, combined in an attempt to obtain single regression relationships for each category:

Average infiltration rate (inches/hour):

$$\text{Log Y} = 0.7159 - 0.2166 \text{ Log X}; \ r = 0.988$$

Average mass infiltration (inches):

$$Y = 0.156 + 0.0404X; \ r = 0.999$$

where X is time from start of run up to a total of 50 minutes. These provide relative estimates of average infiltration within precision of 1% (Fig. 3, 4).

A discussion of vegetation factors cannot possibly be separated from edaphic factors; both are interdependent and influence each other mutually. Considerable variations can sometimes exist in soil conditions even on a small area. The effects of such conditions on infiltration and sediment rates

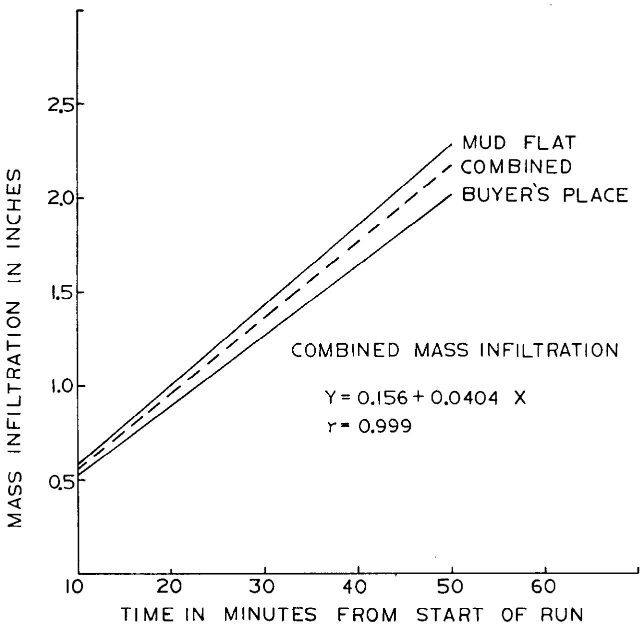


FIG. 4. Relation between time from start of run and average mass infiltration.

of wyethia and grass plots were kept to the minimum by the paired test procedure adopted in the study.

The above-mentioned regression relationships, based on research data from two widely separated locations, strongly suggest the possibility of extending the experimental results over other areas of similar plant–soil conditions.

In view of the direct relationship between infiltration and overland flow, the study supports the hypotheses put forth elsewhere (Satterlund, 1967) that vegetation can provide a precise indication of potential runoff, especially when the broad formations are considered in more detail, particularly in the arid and semi-arid regions where total water supplies are scanty and limiting.

The integrating and ubiquitous role of vegetation as site indicator has wide acceptance in ecology. The concept of plant community as an expression of total environment, and therefore its single most important indicator, should be explored further and usefully applied in the context of infiltration–runoff–sediment interrelationships, thereby providing broad and acceptable estimates of the impact of specific site and vegetation conditions for which no information of wide extent is available otherwise.

LITERATURE CITED

ADAMS, J. E., DON KIRKHAM, AND D. R. NIELSEN. 1957. A portable rainfall-simulator infiltrometer and physical measurements of soil in place. Soil Sci. Soc. Amer. Proc. 21: 473–477.

AMERICAN SOCIETY OF RANGE MANAGEMENT AND THE AGRICULTURAL BOARD. SUBCOMMITTEE ON RANGE RESEARCH METHODS. 1962. Basic problems and techniques in range research. National Academy of Sciences—National Research Council. Pub. 890.

BAILEY, R. W. 1941. Land erosion—normal and accelerated—in the semiarid West. Amer. Geophys. Union Trans. (Part II):240–250.

BAILEY, R. W., G. W. CRADDOCK, AND A. R. CROFT. 1947. Watershed management for summer flood control in Utah. U.S. Dep. Agr. Misc. Pub. 639.

BARNES, O. K., AND GERALD COSTEL. 1957. A mobile infiltrometer. Agron. J. 49:105–107.

DORTIGNAC, E. J. 1951. Design and operation of Rocky Mountain infiltrometer. U.S. Forest Service, Rocky Mountain Forest and Range Exp. Sta. Paper 5.

DORTIGNAC, E. J., AND L. D. LOVE. 1960. Relation of plant cover to infiltration and erosion in ponderosa pine forests of Colorado. Amer. Soc. Agr. Eng. Trans. 3:58–61.

DORTIGNAC, E. J., AND L. D. LOVE. 1961. Infiltration studies on ponderosa pine ranges of Colorado. U.S. Forest Service, Rocky Mountain Forest and Range Exp. Sta. Paper 59.

DULEY, F. L., AND C. E. DOMINGO. 1949. Effect of grass on intake of water. Nebr. Agr. Exp. Sta. Res. Bull. 159.

DYRNESS, C. T. 1967. Erodibility and erosion potential of forest watersheds. *In*: Forest Hydrology, Pergamon Press, New York, p. 599–610.

ELLISON, W. D. 1945. Some effects of raindrops and surface-flow on soil erosion and infiltration. Amer. Geophys. Union Trans. 26:415–429.

LASSEN, LEON, H. W. LULL, AND BERNARD FRANK. 1952. Some plant-soil-water relations in watershed management. U.S. Dep. Agr. Circular 910.

MARSTON, R. B. 1952. Ground cover requirements of summer storm runoff control on aspen sites in northern Utah. J. Forest. 50:303–307.

MEEUWIG, R. O. 1965. Effects of seeding and grazing on infiltration capacity and soil stability of a subalpine range in central Utah. J. Range Manage. 18:173–180.

OSBORN, BEN. 1952. Storing rainfall at the grass roots. J. Range Manage. 5:408–414.

OSBORN, BEN. 1954. Effectiveness of cover in reducing soil splash by raindrop impact. J. Soil and Water Conserv. 9: 70–76.

PACKER, P. E. 1951. An approach to watershed protection criteria. J. Forest. 49:639–644.

PACKER, P. E. 1957. Intermountain infiltrometer. U.S. Forest Service Intermountain Forest and Range Exp. Sta. Misc. Pub. 14.

PILLSBURY, A. F. 1953. Discussion of "some effects of fire and ash on the infiltration capacity of soil." Amer. Geophys. Union Trans. 34:293–295.

RAUZI, FRANK, AND C. L. FLY. 1968. Water intake on midcontinental rangelands as influenced by soil and plant cover. U.S. Dep. Agr. Tech. Bull. 1390.

ROWE, P. B. 1940. The construction, operation and use of the North Fork infiltrometer. U.S. Dep. Agr. Flood Control Coordinating Committee. Misc. Pub. 1.

SATTERLUND, D. R. 1967. Forest types and potential runoff. *In*: Forestry Hydrology, Pergamon Press, New York, p. 497–505.

SHANDS, A. L., AND D. AMMERMAN. 1947. Maximum recorded United States point rainfall. U.S. Weather Bur. Tech. Paper 2.

SHRADER, W. D., H. P. JOHNSON, AND J. F. TIMMONS. 1963. Applying erosion control principles. J. Soil and Water Conserv. 18:195–199.

SMITH, D. D., AND W. H. WISCHMEIER. 1962. Rainfall erosion. Advances in Agron. 14:109–148.

TINGEY, D. C., AND C. WAYNE COOK. 1955. Eradication of mule ear with herbicides and its relation to production of forage on range lands. Utah Agr. Exp. Sta. Bull. 375.

URSIC, S. J., AND FARRIS E. DENDY. 1963. Sediment yields from small watersheds under various land uses and forest covers. Proc. Fed. Inter-Agency Sedimentation Conf., 1963. U.S. Dep. Agr. Misc. Pub. 970, p. 47–52.

U.S. FOREST SERVICE. 1951. Infiltrometer records obtained at the Great Basin Branch Station, Ephraim, Utah. Unpub. records, Intermountain Forest and Range Exp. Sta.

U.S. WEATHER BUREAU. 1960. Generalized estimates of probable maximum precipitation for the United States west of the 105th meridian for areas to 400 square miles and duration to 24 hours. U.S.W.B. Tech. Paper 38.