Journal of Arid Environments (1987) 12, 111–118

Important factors influencing water infiltration and sediment production on arid lands in New Mexico

James C. Wood*, M. Karl Wood* & John M. Tromble†

Accepted 28 May 1985

Factors influencing infiltration rates and sediment production were evaluated on representative study areas of four watersheds in New Mexico under various land management practices. Multiple regression analysis was used to determine the most important factors influencing infiltration and sediment production. Factors found important were soil texture, soil organic matter, soil bulk density, plant cover, biomass production, time to runoff and time to ponding. Of all variables studied, total ground cover was considered to be the most important single variable influencing infiltration and sediment production.

Introduction

Since the United Nations meeting on desertification in Nairobi, Kenya in 1977, much effort has been directed towards reduction of high levels of pollutants in the world's waters. Although point sources of pollution account for a large portion of this problem, non-point sources equal and exceed these levels. Non-point sources of water pollution are not clearly defined, but are intermittent and diffuse when entering stream channels or waterways. The major source of water pollution in New Mexico is non-point and originates over extensive areas of arid rangelands under various uses. To reduce pollutants from these rangelands, it is essential to determine major hydrologic factors influencing soil surface erosion and pollutant transport. These factors can then be used in hydrologic models that are sensitive to changes in land management.

Raindrop impact has from 8 to 25 times more erosive energy than overland flow (Troeh, Hobbs *et al.*, 1980). Most surface water that does not infiltrate the soil is available for runoff. Gravitational forces acting on this water force it to move from higher elevations to lower elevations. This water movement across the land surface provides the main mechanism of sediment transport and, consequently, pollution. Although soil erosion is a naturally occurring process, some land uses have accelerated this process. The most extensive land use in New Mexico is livestock grazing and includes numerous critical watersheds necessary for surface as well as ground water replenishment. Proper range management is essential to reduce non-point pollution. This study determined factors influencing infiltration and sediment production on selected rangeland watersheds in New Mexico.

---

* Department of Animal and Range Sciences, New Mexico State University, Las Cruces, New Mexico 88003, U.S.A.

† Agricultural Research Service, U.S. Department of Agriculture, Las Cruces, New Mexico 88003, U.S.A.

Agricultural Experiment Station Journal Article No. 1109. This study was supported by funds from the U.S. Environmental Protection Agency, Contract No. 71-541-40.

0140–1963/87/020111+08 $03.00/0

Methods

Representative study areas were selected on four watersheds under various land management practices (Table 1) in each of the four major drainage basins of New Mexico. Climate, vegetation and soils varied somewhat according to the geographic location of each watershed. Study sites were chosen to best represent the current and alternative land management practices, plant communities and soils of each watershed.

In the Rio Bonito watershed, land management practices included year-long cattle grazing at light (35% removal of present year's plant growth), moderate (50% removal) and heavy (65% removal) stocking levels, exclusion of livestock grazing, short-duration grazing at a heavy stocking level, and grazing of fertilized rangeland at a heavy stocking level. In the Arroyo de las Palmas watershed, land management practices included year-long cattle grazing at moderate and heavy stocking levels. In the Canada Largo watershed, land management practices included pinyon–juniper sites that had no control; that had been chained in 1962 with debris left in place; that had been chained, windrowed, burned and reseeded in 1962; and that had been dozed, burned and reseeded in 1974. Some sites with sagebrush in the Canada Largo watershed were plowed in 1976 and reseeded, while other sites had no control. A third area with sagebrush was burned in 1979. In the Rock Tank Canyon watershed, land management practices included cattle grazing year long at a heavy stocking level and seasonal grazing at a moderate level. Four study plots (1 m × 1 m) were randomly located in each site. Randomness was restricted by accessibility within the area and the limited distance between spray nozzles.

At each study site, a metal runoff frame was driven into the soil to isolate a plot. Simulated rainfall was applied at antecedent soil moisture and again 24 h later when the soil was at or near field capacity. After the first rainfall application, the plots were covered with clear polyethelene plastic and sealed to prevent uneven evaporation and to allow drainage of excess water. Rainfall was simulated with a modified version of the Purdue sprinkling-type infiltrometer (Bertrand & Parr, 1961). Water was uniformly ejected across each plot from a 0·635-mm G10 Fulljet nozzle under a pressure of $62{\cdot}1 \times 10^3$ Pa and at a height of approximately 2·7 m. An average rainfall intensity of 11·35 cm/h (standard deviation 0·54 cm/h) was chosen to ensure that runoff would occur on all plots. Rainfall was terminated when infiltration approached a constant rate. This was considered to be the terminal infiltration rate used in all regression equations.

Sediment production was determined from a 1-litre suspended sample of collected runoff which was thoroughly agitated to ensure homogeneity. Sediment production was considered to be the amount of sediment suspended in solution. This was found by filtering the subsample through a suction apparatus, air-drying the filtrate at 30°C for 24 h and weighing the dry filtrate. The concentration was then converted to kilograms of sediment per hectare per centimeter of runoff.

Grass, forb, litter and rock cover ($> 0{\cdot}635$ mm diameter) were estimated using a line intercept technique (Canfield, 1942) comprised of five transects located at given intervals across the plot. After all measurements had been taken, vegetation was clipped and separated into grasses and forbs. Litter was also collected within each plot and was considered to be any dead material such as twigs and fallen leaves on the soil surface. All samples were air-dried at 60°C for 1 week, weighed, and converted to kg/ha.

Soil moisture content was measured gravimetrically directly adjacent to the plot before each rainfall application. Two core samples were taken, one from 0–5 cm and one from 5–10 cm. The core samples were also used to determine soil bulk density. Conglomerate soil samples were taken from a depth of 0–5 cm within each study plot to determine soil texture by the Bouyoucos hydrometer method (Bouyoucos, 1962) and organic matter content by acid dichromate digestion (Broadbent, 1965).

Table 1. *Description of watersheds*

Location and drainage	Elevation	Climate	Geology and soils	Dominant vegetation
Rio Bonito watershed, part of the Pecos River drainage mainly in Lincoln County, New Mexico. Area 200 km^2. Nine study sites	1524–2134 m	Annual precipitation 330–406 mm, 65% as high-intensity summer thunderstorms. Temperatures range from −34 to 39°C with an average annual temperature of 10°C	Limestone, dolomite, sandstone, siltstone and shales. Soils are Aridic, Lithic, or Cumulic Haplustolls	Bluegramma (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), fourwing saltbush (*Atriplex canescens*), oak (*Quercus* spp.), pinyon (*Pinus edulis*) and juniper (*Juniperus* spp.)
Arroyo de las Palmas watershed, part of the Canadian River drainage in Quay County, New Mexico. Area 23 km^2. Four study sites	1158–1463 m	Annual precipitation 330–406 mm, 78% as high-intensity summer thunderstorms. Average annual temperatures range from 14 to 16°C	Alluvium derived from redbed material. Soils are Ustic Torriorthents, Mollic Torrerts, or Ustochreptic Calciorthids	Bluegrama, galleta (*Hilaria jamesii*), tobosa (*Hilaria mutica*), black grama (*Bouteloua eriopoda*), sideoats grama (*Bouteloua curtipendula*), prickly pear (*Opuntia* spp.) and mesquite (*Prosopis glandulosa*)
Canada Largo watershed, part of the San Juan River drainage mainly in Rio Arriba County, New Mexico. Area 230 km^2. Eight study sites	1951–2134 m	Annual precipitation 330–430 mm, 40% as high-intensity summer thunderstorms. Average annual temperatures range from −3 to 16°C	Residuum or alluvium derived from sandstone or shale. Soils are Typic Ustorthents, Typic Haplustalfs, or Lithic Ustorthents	Western wheatgrass, crested wheatgrass (*Agropyron cristatum*), intermediate wheatgrass (*Agropyron intermedium*), pubescent wheatgrass (*Agropyron trichophorum*), bluegrama, pinyon, juniper, sagebrush (*Artemesia* spp.) and rabbitbrush (*Chrysothamnus* spp.)
Rock Tank Canyon watershed, part of the Rio Grande drainage mainly in Socorro County. Area 100 km^2. Three study sites	1829–2220 m	Annual precipitation 250–400 mm, 50% as high-intensity summer thunderstorms. Temperatures range from zero or below to 38°C with an average annual temperature of 10°C	Alluvium derived from volcanic rock. Soils are mainly Aridic Argiustolls	Bluegrama, western wheatgrass, spike muhly (*Muhlenbergia wrightii*), bottlebrush squirreltail (*Sitanion hystrix*), fourwing saltbush, rabbitbrush spp., pinyon and juniper

A completely random experimental design was used at each study site. All variables were entered in a forward stepwise regression analysis technique (Draper & Smith, 1966) and were significant at the $\alpha = 0{\cdot}10$ level of confidence. The Y-intercept (B_0), slope (B_X) and coefficient of determination (R^2) are given for all regression equations presented. All variables used in the regression analysis procedures are presented in Table 2.

Results and discussion

The following discussion is based on regression analysis of the factors most important for explaining variations in infiltration and runoff water quality. Figure 1 shows the relationships between environmental components as they influence infiltration rates. This study determined the magnitude of influence for these variables. Regression equations are presented in Tables 3 and 4. Factors in all regression equations are presented so that the first variable accounts for the greatest portion of the error of regression. The second variable operates on the remaining error, and so on.

Rio Bonito watershed

Variations in terminal infiltration rates were best explained by total ground cover (TC), forb cover (FC) and soil surface silt fractions (ST) Table 3). Infiltration rates were positively correlated with forb cover and total ground cover, and negatively correlated with soil surface silt fractions. All plant cover estimates were of the plants' crown or total area covered by leaves, twigs and branches. This variable was found to be more meaningful for rangelands than basal cover, which is used in many models developed for croplands such as the Universal Soil Loss Equation. Sediment production rates were

Table 2. *Dependent and independent variables used in regression and correlation analysis*

Variable	Description	Units
IRD	Terminal infiltration rate, soil surface initially dry	cm/h
IRW	Terminal infiltration rate, soil surface initially at field capacity	cm/h
SPD	Sediment production, soil surface initially dry	kg/ha/cm
SPW	Sediment production, soil surface initially at field capacity	kg/ha/cm
TPOND	Ponding time	s
TRUN	Runoff time	s
SM_2	Initial soil moisture, 0–5 cm depth	%
SM_4	Initial soil moisture, 5–10 cm depth	%
BD_2	Bulk density, 0–5 cm depth	g/cm^3
BD_4	Bulk density, 5–10 cm depth	g/cm^3
SD	Sand fraction, 0–5 cm depth	%
ST	Silt fraction, 0–5 cm depth	%
CL	Clay fraction, 0–5 cm depth	%
PC	Plant cover	%
GC	Grass cover	%
FC	Forb cover	%
LC	Litter cover	%
RC	Rock cover	%
TC	Total ground cover	%
GPRD	Grass production	kg/ha
FPRD	Forb production	kg/ha
LPRD	Litter production	kg/ha
ROUGH	Surface roughness (microrelief)	cm
SLOPE	Slope	%

Table 3. *Regression equations for all treatments and plant communities combined in the Rio Bonito, Arroyo de las Palmas, Canada Largo, and Rock Tank Canyon watersheds, New Mexico*

Dependent variable	Soil moisture	Regression equations	Coefficient of determination (R^2)
Rio Bonito watershed			
Terminal infiltration rate	Antecedent	$\hat{Y} = 3\cdot694 + 0\cdot025\,X_{\mathrm{TC}} + 0\cdot032\,X_{\mathrm{FC}} - 0\cdot062\,X_{\mathrm{ST}}$	0·49
	Field capacity	$\hat{Y} = 0\cdot877 + 0\cdot035\,X_{\mathrm{TC}}$	0·56
Sediment production	Antecedent	$\hat{Y} = 13\cdot027 - 0\cdot615\,X_{\mathrm{TC}} + 49\cdot555\,X_{\mathrm{BD}_4}$	0·43
	Field capacity	$\hat{Y} = -10\cdot197 + 41\cdot162\,X_{\mathrm{BD}_4} - 6\cdot140\,X_{\mathrm{IRW}}$	0·63
Arroyo de las Palmas watershed			
Terminal infiltration rate	Antecedent	$\hat{Y} = 1\cdot537 + 0\cdot034\,X_{\mathrm{TC}} + 0\cdot075\,X_{\mathrm{SD}} - 3\cdot247\,X_{\mathrm{BD}_1}$	0·87
	Field capacity	$\hat{Y} = 0\cdot830 + 0\cdot009\,X_{\mathrm{TC}} + 0\cdot001\,X_{\mathrm{GPRD}} + 0\cdot120\,X_{\mathrm{TRUN}}$	0·79
Sediment production	Antecedent	$\hat{Y} = 37\cdot763 - 0\cdot650\,X_{\mathrm{ST}}$	0·21
Canada Largo watershed			
Terminal infiltration rate	Antecedent	$\hat{Y} = 1\cdot794 + 0\cdot0004\,X_{\mathrm{GPRD}} + 0\cdot090\,X_{\mathrm{TPOND}} + 0\cdot248\,X_{\mathrm{TRUN}}$	0·45
	Field capacity	$\hat{Y} = 2\cdot100 + 0\cdot439\,X_{\mathrm{TRUN}} - 0\cdot036\,X_{\mathrm{SM}_2}$	0·38
Sediment production	Antecedent	$\hat{Y} = 18\cdot344 - 1\cdot962\,X_{\mathrm{TC}} + 1\cdot685\,X_{\mathrm{PSD}} + 23\cdot185\,X_{\mathrm{OM}}$	0·55
	Field capacity	$\hat{Y} = 135\cdot100 - 2\cdot392\,X_{\mathrm{TC}} + 11\cdot442\,X_{\mathrm{SLOPE}}$	0·54
Rock Tank Canyon watershed			
Terminal infiltration rate	Antecedent	$\hat{Y} = 4\cdot335 + 0\cdot564\,X_{\mathrm{TRUN}} - 2\cdot839\,X_{\mathrm{BD}_4}$	0·75
	Field capacity	$\hat{Y} = 3\cdot917 + 0\cdot00003\,X_{\mathrm{LPRD}} - 0\cdot102_{\mathrm{SM}_4}$	0·83
Sediment Production	Antecedent	$\hat{Y} = -59\cdot498 + 151\cdot851\,X_{\mathrm{BD}_2} - 27\cdot265\,X_{\mathrm{TRUN}}$	0·61
	Field capacity	$\hat{Y} = -55\cdot607 + 71\cdot282\,X_{\mathrm{BD}_4}$	0·26

Table 4. *Regression equations for all watersheds combined*

Dependent variable	Soil moisture	Regression equations	Coefficient of determination (R^2)
Terminal infiltration rate	Antecedent	$\hat{Y} = 0\cdot897 + 0\cdot019\,X_{\mathrm{TC}} + 0\cdot040\,X_{\mathrm{CL}} + 0\cdot055\,X_{\mathrm{TRUN}}$	0·48
	Field capacity	$\hat{Y} = 1\cdot087 + 0\cdot021\,X_{\mathrm{TC}} + 0\cdot062\,X_{\mathrm{OM}} + 0\cdot042\,X_{\mathrm{TRUN}}$	0·50
Sediment production	Antecedent	$\hat{Y} = 193\cdot286 - 1\cdot263\,X_{\mathrm{TC}} - 1\cdot970\,X_{\mathrm{ST}} - 0\cdot586\,X_{\mathrm{GC}}$	0·46
	Field capacity	$\hat{Y} = 178\cdot578 - 1\cdot230\,X_{\mathrm{TC}} - 1\cdot412\,X_{\mathrm{ST}} - 0\cdot845\,X_{\mathrm{PC}}$	0·41

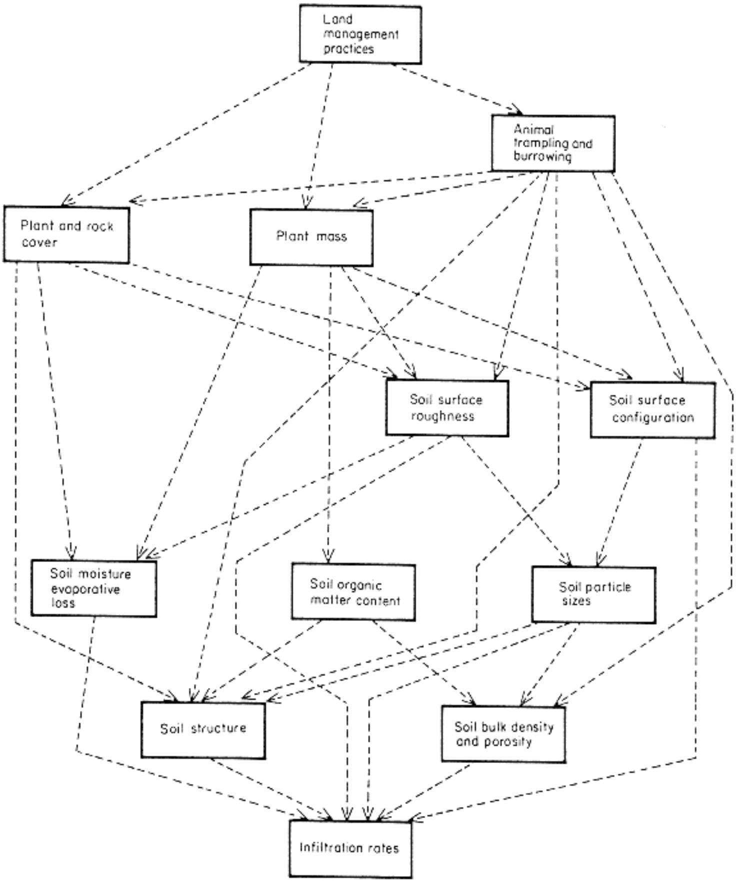

Figure 1. Relationship of factors influencing infiltration rates on arid rangelands (Wood, 1987).

correlated best with total ground cover (TC), bulk density 5–10 cm (BD_4) and terminal infiltration (IRW). Bulk density in the zone of 0–5 cm depth varies seasonally. These soils experience high diurnal temperature changes and contain enough clay to experience shrink–swell activities in fall and spring. Livestock trampling and summer rains increase the bulk density after it has been lowered by temperature changes. As total ground cover and terminal infiltration decreased, sediment production increased. Bulk density was positively correlated with sediment production. Soils with low bulk densities are usually well aggregated and quite resistant to erosion (Packer, 1963; Meeuwig, 1970; Blackburn, 1975).

Arroyo de las Palmas watershed

Total ground cover (TC) accounted for the greatest portion of error in the regression equations for infiltration rates under antecedent and field capacity soil moisture (Table 3). Under antecedent conditions, soil surface sand fraction (SD) and bulk density at 0–5 cm (BD_2) were also found to be important factors influencing infiltration rates. Infiltration rate equations with soils at field capacity were improved by the addition of grass production (GPRD) and time to runoff (TRUN) variables. Sites with the same cover had different infiltration rates resulting from variation in standing biomass or production. This variable influenced the above- and below-ground organic matter contents. All variables had a positive relationship with infiltration except bulk density at 0–5 cm, which showed a negative correlation. Sediment production rates were extremely variable between the two soil types studied; consequently, the regression equations did not show a significant correlation.

Canada Largo watershed

Coefficients of determination (R^2) were somewhat low because of the large amount of variation between and within sites (Table 3). Terminal infiltration rates at antecedent and field capacity were influenced most by grass production (GPRD), time to ponding (TPOND), time to runoff (TRUN) and soil moisture at 0–5 cm (SM_2). The first three variables mentioned were positively correlated with infiltration. An increase in any or all of them usually resulted in a corresponding increase in infiltration. Soil surface moisture was negatively correlated with infiltration such that increases in soil moisture at these depths reduced infiltration. Total ground cover (TC) was found to explain approximately 40% of the variation in antecedent and field capacity sediment production. Coefficients were improved somewhat by the inclusion of soil surface sand fractions (SD) and organic matter content (OM) for antecedent conditions, and of slope (SLOPE) for field capacity conditions. All variables except total ground cover were positively correlated with sediment production. Organic matter content and soil surface sand fraction were found to be positively correlated, mainly because the highest amounts were present in some of the most erosive soils and hydrophobic conditions were encountered. Although soil surface sand fraction and organic matter content are usually associated with good infiltration and runoff water quality, coarse, sandy soils high in organic substances can actually repel water and induce runoff when hydrophobic conditions are encountered. Meeuwig (1970) found this type of soil condition in the Carson Range of the Sierra Nevada.

Rock Tank Canyon

Terminal infiltration rates were well correlated with time to runoff (TRUN) and bulk density at 5–10 cm (BD_4) under antecedent moisture conditions, and with litter production (LPRD) and soil moisture at 5–10 cm (SM_4) under field capacity conditions (Table 3). Bulk density and soil moisture were negatively correlated with infiltration, while time to runoff and litter production were positively correlated. Sediment production rates were greatly affected by bulk density at depths of 0–5 cm and 5–10 cm (BD). As bulk density increased at either depth, a corresponding increase occurred in sediment loss. Under antecedent conditions, time to runoff characteristics were negatively correlated with sediment production and resulted in higher R^2 values. Field capacity sediment production rates were variable and contributed to low R^2 values.

New Mexico watersheds

The equations for all watersheds combined were useful for determining which site characteristics had the most important overall impact on infiltration and sediment production (Table 4). Total ground cover (TC) was the most important variable studied, influencing infiltration and sediment production under both soil moisture conditions. About half of the variation in terminal infiltration rates was explained by total ground cover, soil surface clay fraction (CL) and time to runoff (TRUN) under antecedent conditions, and by total ground cover, organic matter content (OM) and time to runoff (TRUN) under field capacity conditions. An increase in any of these variables represented a corresponding increase in infiltration. Sediment production was most influenced by total ground cover (TC), soil surface silt fractions (ST), plant cover (PC) and grass cover (GC) variables, all of which were negatively correlated with sediment production. Total ground cover (TC) and soil surface silt fraction variables (ST) were found in regression equations for both soil moisture conditions; however, grass cover (GC) variables were found to be most important under antecedent conditions. Plant cover (PC) variables (grass and forb cover) were found to be most important under field capacity moisture conditions.

Although all the variables presented in Table 2 had some influence on infiltration and sediment production, certain independent variables were found to have a greater influence than others on these dependent variables. Of all the variables studied, total ground cover (TC) was considered to be the most important, and was present in more regression equations than any other variable. This is especially important to land managers because it is a site characteristic that can be directly manipulated with land management practices. Total ground cover (TC) can be optimized by assuring sufficient ground cover remains to protect the soil surface from raindrop impact. Indirect effects of optimum ground cover are increased biomass production, soil organic matter, soil structure, soil bulk density, soil moisture, and infiltration and runoff water quality. However, cover should not be used as the only plant variable for predicting infiltration and sediment production. This is a common practice in many hydrologic models for forest, crop and range lands (Soil Conservation Service, 1972; Branson, Gifford *et al.*, 1981). Under various grazing levels in New Mexico, two sites may have the same plant cover but significantly different amounts of biomass which result in different infiltration rates and sediment production. Many infiltration models include hydraulic conductivity (Philip, 1983; Knight, 1983; Youngs, 1983), but this soil variable is most commonly measured in a laboratory with soils that have had their structure impaired or destroyed. Therefore, the inclusion of soil porosity and structure is imperative for accurate and precise modeling of infiltration rates and sediment production on these arid and semi-arid rangelands. The flow sheet in Fig. 1 is supported by this study with new emphasis on the magnitude of differences.

References

Bertrand, A. R. & Parr, J. F. (1961). Design and operation of the Purdue sprinkling infiltrometer. *Purdue University Research Bulletin*, No. 723. 16 pp.

Blackburn, W. H. (1975). Factors influencing infiltration and sediment production of semiarid rangelands in Nevada. *Water Resources Research*, **11**: 929–937.

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analysis of soil. *Agronomy Journal*, **54**: 464–465.

Branson, F. A., Gifford, G. F., Renard, F. G. & Hadley, R. F. (1981). *Rangeland Hydrology*. Dubuque, IO: Kendall/Hunt. 340 pp.

Broadbent, F. E. (1965). Organic matter. In: Black, C. A. (Ed.), *Methods of Soil Analysis*, pp. 1397–1400. *American Society of Agronomy, Agronomy Series*, No. 9.

Canfield, R. H. (1942). Measurement of grazing use by the line interception method. *Journal of Forestry*, **42**: 192–194.

Draper, N. R. & Smith, H. (1966). *Applied Regression Analysis*. New York: John Wiley. 407 pp.

Knight, J. H. (1983). Infiltration functions from exact and approximate solutions of Richard's equation. In: *Proceedings of the National Conference on Advances in Infiltration*, pp. 24–33. St. Joseph, MN: American Society of Agricultural Engineers.

Meeuwig, R. O. (1970). Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. *Journal of Range Management*, **23**: 185–188.

Packer, P. E. (1963). Soil stability requirements for the Callatin elk winter range. *Journal of Wildlife Management*, **27**: 401–410.

Phillip, J. R. (1983). Infiltration in one, two, and three dimensions. In: *Proceedings of the National Conference on Advances in Infiltration*, pp. 1–13. St. Joseph, MN: American Society of Agricultural Engineers.

Soil Conservation Service (1972). *Hydrology. Section 4, National Engineering Handbook*. Washington, DC: U.S. Department of Agriculture/Government Printing Office. 458 pp.

Troeh, F. R., Hobbs, J. A. & Donahue, R. L. (1980). *Soil and Water Conservation for Productivity and Environmental Protection*. Englewood Cliffs, NJ: Prentice-Hall. 718 pp.

Wood, M. K. (1987). Describing and quantifying water resources with small plots on rangeland. In: *Proceedings of the 2nd International Rangeland Congress*. Adelaide, Australia (in press).

Youngs, E. G. (1983). The use of similar media theory in the consideration of soil water redistribution in infiltrated soils. In: *Proceedings of the National Conference on Advances in Infiltration*, pp. 48–54. St. Joseph, MN: American Society of Agricultural Engineers.