Factors Influencing Infiltration and Erosion on Chained Pinyon-Juniper Sites in Utah¹

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Highlight

Relationships between vegetal and edaphic factors and infiltration rates and erosion as measured on 550 infiltrometer plots at chained pinyon-juniper sites in Utah were analyzed by multiple regression analysis. Those factors most important for predicting infiltration rates (regardless of time interval) included total porosity in the 0-3 inch layer of soil, percent bare soil surface, soil texture in the 0-3 inch layer of soil, and crown cover (percent or tons per acre). The ability to predict infiltration rates (as determined by R²) varied with time and geographic location. Not only did predictive ability vary, but independent variables explaining such variance also changed with time and location. Factors that influence sediment discharge were so variable from one geographic location to another that no consistent relation was found.

Factores que Influyen en la Infiltración y Erosión en Monte de Pino y Enebro Controlado por la Cadena

Resumen³

El estudio se llevó a cabo en el Estado de Utah de E.U.A. con los objetivos de determinar que factores influyen más la erosión e infiltración de agua. Se usaron 550 infiltrometers a través de los años 1967 y 1968 y en varias

localizaciones en ambos sitios de pino y enebro controlado por la cadena y sin control. Los resultados fueron analizados por regresión múltiple.

Se encontraron que los factores que ocurrieron con más frecuencia en la ecuación de predicción fueron la porosidad total en la copa de 0-3 pulgadas del suelo, porcentaje de suelo desnudo, textura del suelo en la copa de 0-3 pulgadas y la cobertura vegetal. La habilidad para predecir la intensidad de la infiltración fué variable durante el año y entre las localizaciones los factores independientes que explican dicha variación fueron también variables durante el año y entre las localizaciones.

Los factores que influyen erosión fueron muy variables entre las localizaciones y por éso no fué posible encontrar una interrelación consistente entre la intensidad de erosión y los factores de medio-ambiente.

Defining those factors which influence infiltration rates is requisite

to understanding hydrologic behavior of the 61.4 million acres (Dortignac, 1960) of pinyon-juniper woodland (*Pinus monophylla-Juniperus osteosperma*) in the western United States. Many factors that influence infiltration have been recognized, but studies of semi-arid wildland situations have been limited.

Williams et al. (1969) and Gifford et al. (1970) have reported infiltration rate differences at random points between 28 chained and 28 nearby unchained pinyon-juniper sites in central and southern Utah. Sediment yields also were measured. Study results indicate that conversion of pinyon-juniper cover to grassland has not necessarily increased infiltration rates nor always reduced sediment yields at a given point on such lands. Similar findings have been reported from small watershed studies in Arizona (Brown, 1970).

This study reports the influence of several vegetal and edaphic factors on infiltration and sediment production rates of pinyon-juniper sites in Utah.

Methods

A Rocky Mountain infiltrometer (Dortignac, 1951) was utilized to simulate high intensity (3 inches/hr or greater) rainfall on plots approximately 2.5 ft² in size. Twenty-eight treated and 28 nearby untreated pinyon-juniper sites were sampled during the summers of 1967 and 1968. A total of 550 infiltrometer plots were studied. Descriptions of the sites have been

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given previously (Williams et al., 1969; Gifford et al., 1970).

All plots were pre-wet a minimum of 2–3 hours before infiltrometer runs began. Runoff was measured at selected time intervals during each infiltrometer run. Simulated rainfall was applied to each plot until a constant runoff rate was reached.

Sediment was measured by collecting the total runoff plus the sediment from each plot, then thoroughly mixing, and finally taking a 1-quart sample. The water was then evaporated off, the sediment oven-dried, and the sample weights converted to tons per acre.

Soil surface characteristics of each plot included percent bare surface soil, percent litter, percent rock (soil particles greater than 2 mm in diameter), and percent basal area of plants. These soil surface characteristics were measured with a point quadrat frame which covered an entire infiltrometer plot. The quadrat frame contained 100 points; therefore, each strike equalled 1% coverage.

Vegetal crown cover determinations were made in two ways. The first method utilized the point quadrat frame, and crown cover measurements were taken concurrently with soil surface characteristic measurements. The second method consisted of clipping each plot. The total vegetal cover was bagged, then taken to the lab and oven-dried for 24 hours. This oven-dry weight (tons/acre) was used as an index of vegetal crown cover.

Percent rock greater than 2 mm diameter and soil texture were determined from disturbed soil samples collected from the top 3 inches of soil immediately adjacent to each plot or from the plot itself. Soil texture was determined by the hydrometer method (Bouyoucos, 1962).

Bulk density was determined from undisturbed samples taken from each plot with a upland soil sampler. Samples were returned to the laboratory and oven-dried at 105 C for 24 hours.

The percentage of water-stable sand-sized (0.02–2 millimeter diameter) soil aggregates in sieved soil samples was determined by using a modified Bouyoucos hydrometer method in which the Calgon was omitted.

Organic matter was determined by the loss on ignition method.

Soil porosity was measured on undisturbed soil samples prior to bulk density determinations. Porosity was determined at two moisture levels, one at oven-dry conditions and the other at 30-cm tension. Measurements were made by using a technique similar to that employed by Hoover et al. (1954).

Percent moisture of the surface soil of each plot was determined 5 min after an infiltrometer run was completed. The soil moisture by weight was determined by weighing the sample in wet condition, oven-drying at 105 C for 24 hr, then weighing again.

Analysis of Variables

An area-wise multiple regression analysis was utilized in analyzing infiltration-erosion relationships within and among the four major geographic locations. Other independent variables, besides those described under "Methods" included site, treatment (untreated vs. treated), and total silt plus clay in the surface 3 inches of soil. Some independent variables were included as squared and/or cubed values where preliminary graphing procedures indicated non-linear relationships.

The five dependent variables were chosen to represent certain important aspects of natural high intensity convectional thunderstorms. Dependent variables included: (1) infiltration rate during the 3–4 min time interval (this variable gives an indication of infiltration rates at the onset of a high intensity convectional storm); (2) infiltration rate during the 8–13 min time interval (this variable gives the infiltration rate perhaps midway through a typical convectional storm); (3) infiltration rate

FIG. 1. Map of Utah showing the four geographic locations which were studied (Price, Eureka, Blanding, and Milford, Utah). The two large black squares indicate sites which are instrumented for longterm studies.

during the 33–38 min time interval (this time interval represents the final or constant infiltration rate); (4) erosion in tons/acre/inch of runoff; and (5) total water retained on a plot for 40 min (this variable gives the integrated retention capability of the soil).

Stepwise multiple regression equations were developed for each of four chosen geographical areas in Utah: (1) east central part (Price area), (2) west central part (Eureka area), (3) southwest portion (Milford area), and (4) southeast portion (Blanding area). Figure 1 is a map showing the location of the infiltrometer studies. In addition, composite multiple regression equations were derived from all infiltrometer plots taken throughout the state.

Results and Discussion

Infiltration Rate During the 3 to 4-Minute Time Interval

The multiple regression models accounted for 62% of the variability associated with infiltration rates during the 3 to 4-min time interval within the Eureka area; 51% within the Price area; 41% within the Milford area; 32% within the Blanding area; and 43 percent as a composite of all areas.

Of the 18 dependent variables (increased to 40 by including squared and/or cubed values), only treatment (untreated vs. chained) and sand-sized water stable aggregates in the top 3 inches of soil failed to explain 1% or more of the variance in any of the multiple regression equations.

It is possible that effects of sand-sized aggregates are not apparent during the initial stages of an infiltration run. These effects become important when they are considered simultaneously with soil particles rearranging to block larger pores. This phenomenon could become more important after longer periods of simulated rainfall.

The following four variables were important in at least three out of five of the prediction equations: (1) total porosity (0–3 inches soil depth), (2) percent bare soil, (3) silt plus clay percent (0–3 inches depth), and (4) percent soil less than 2 mm diameter, cubed (0–3 inches depth).

Infiltration Rate During the 8 to 13-Minute Time Interval

The amount of variance associated with infiltration rates during the 8 to 13-min time interval which was explained by the regression models was rather uniform among geographic locations. Sixty-six percent of the variance was explained within the Milford area; 65% within the Eureka area; 62% within the Price area; and 59% within the Blanding area. Only 46% of the variance was explained when all data was pooled.

Percent bare soil surface (squared) was important in four of the five equations for this particular time interval. Crown cover (%), percent rock (0–3 inches), total porosity, and soil moisture percent (5 minutes following infiltrometer run) each were important in three out of five multiple regression model equations.

The importance of these variables to infiltration rates is understandable. Crown cover and/or bare soil apparently have increased impor-

tance as the time from the beginning of an infiltrometer run is increased. Percent rock in the surface 3 inches of soil and total porosity manifest an influence on soil moisture primarily through their effects on permeability and hydraulic conductivity in the subsoil. Conceivably these factors would show an importance once the soil surface is wetted and moisture begins percolating through subsurface soils.

Soil moisture percent of the soil 5 min after the end of an infiltration run reflects an interrelation of soil physical conditions. Soil aggregation, organic matter content, micro pores, etc. influence the magnitude of this factor. These factors all have an influence on infiltration rates of the soil throughout an infiltration run as well as during the 8 to 13-min time interval.

Infiltration Rate During the 33 to 38-Minute Time Interval

Seventy percent and 68% of the variability in infiltration rates during the 33 to 38-min time interval was accounted for within the Milford and Price areas, respectively. In contrast, the regression models accounted for only 47% and 45% of infiltration rate variability within the Eureka and Blanding sites, respectively. The variance accounted for with all data combined was 46%.

Of the 18 independent variables used to develop the models, only two variables were important in three or more model equations. Crown cover (tons/acre) was important in three out of five model equations and crown cover (tons/acre, squared) was important in four of the five equations. Again, this relationship can be attributed to the protection against raindrop impact afforded by crown cover. As in infiltration run progresses, the duration of applied rainfall increases, thus providing a greater opportunity for destruction of those soil surface features that normally promote infiltration. Surface runoff and infiltration together transport smaller particles into larger

pores, thereby impeding infiltration rates.

The only variable (either singularly or squared) which failed to explain at least 1% or more of the variability in any of the five regression equations was percent basal area.

Total Water (Inches) Retained on Each Infiltration Plot

The multiple regression equations explained from 47% (Blanding area) to 69% (Milford area) of the variability associated with total water retained on an infiltrometer plot after 40 minutes. The Price and Eureka areas were intermediate with 65% and 60% of the variability accounted for, respectively. The variance explained with all data combined was 50%.

Only two variables did not explain (either singularly, squared, or cubed) 1% or more of the variability in at least one of the model equations. These two were bulk density and percent basal area coverage.

Crown coverage (tons/acre) was important in all five equations. Micro-porosity (porosity at 30 cm tension) was important in three out of five equations. Percent soil moisture 5 min after an infiltrometer run also was important in four out of five prediction equations.

The relative importance of these variables is understandable. The importance of crown cover has previously been discussed. The fact that crown cover in tons/acre appears in all five of the multiple regression equations for total water retained on each plot is evidence of its increasing importance as the infiltration run advances.

Erosion—Tons per Acre per Inch of Runoff

Sixty-three percent of the variability associated with erosion in tons/acre/inch of runoff was explained within the Eureka area. The model for the Blanding area accounted for only 49% of the variability and 34% or less of the variance was explained for the remaining two sites and for all data pooled.

These results indicate the extreme complexities in predicting erosion. Interactions among factors or lack of measurement of contributing factors could be a cause for such low explained percentages.

Bulk density and site were the only two variables that were important in three or more multiple regression equations. The fact that the site exerts an influence indicates that certain unmeasured site conditions are contributing to unexplained variability.

It is unusual that no variables pertaining to crown cover (either percent coverage or tons/acre) or aggregate stability explained at least 1% or more of the variability in any of the equations. It is possible that aggregates greater than 2 mm diameter are of more importance than aggregates less than 2 mm diameter for predicting erosion losses. There is also the possibility that stability of soil aggregates is a function of season of sampling, as shown by Bisal and Ferguson (1968).

Conclusions

Studies of factors influencing infiltration and erosion on 28 chained pinyon-juniper sites throughout central and southern Utah have shown that geographic location, time of the event, and the parameter of interest (infiltration rates during select time periods, erosion, or total water retained on plot) are important considerations in such determinations.

Table 1 shows percent variance in infiltration rates, total water retained, and sediment production explained by multiple regression equations during different time periods within an infiltrometer run. Within a given time period, the explained variance in infiltration rates varied considerably with geographic location (3 to 4-min and 33 to 38-min time intervals). At other times (8 to 13-min time interval), the response among locations was rather uniform.

Explained variance associated with infiltration rates at a given

Table 1. Percent variance ($R^2 \times 100$) in infiltration rates (inches/hr), total water (inches) retained on infiltrometer plots, and sediment production (tons/acre/inch of runoff) explained by multiple regression equations.

Geographic location	Infiltration rate time interval			Total water retained on plots	Sediment production
	3-4 min.	8-13 min.	33-38 min.		
Price Area	51	62	68	65	33
Eureka Area	62	65	47	69	63
Blanding Area	32	59	45	47	49
Milford Area	41	66	70	69	31
Composite	43	46	46	50	29

location was not uniform among varying time intervals.

Lumping all geographic locations together generally tends to minimize effectiveness of the predictive equations, regardless of the dependent variable.

Not only does the ability to explain variance associated with infiltration change with time and geographic location, but the parameters explaining such variance also change with time and location. Such variation was also shown in predicting total sediment discharge and to a lesser extent in predicting total water retained on the plots. Those variables that were important in most of the equations for predicting infiltration rates during a given time period were similar for the 3 to 4 and 8 to 13-min time intervals, but changed somewhat for the 33 to 38-min infiltration rate. Important variables that influenced total water retained on the plots were similar to the factors that influenced infiltration rates during the 33 to 38-min time interval. Those factors important in predicting infiltration rates (regardless of time interval) include total porosity in the 0 to 3-inch layer of soil, percent bare soil surface, soil texture in the 0 to 3-inch layer of soil, and crown cover (percent or tons/acre). Percent bare soil may be particularly important on many of our semi-arid rangeland watersheds, especially as related to annual runoff values (Lusby, 1970; Branson and Owen, 1970).

The factors that influenced sediment discharge in this study were so variable from one geographic

location to another that no consistent relationship was found. This finding was similar to studies in the big sagebrush (*Artemisia tridentata*) type in both Nevada (Gifford and Skau, 1967) and Utah (Gifford, 1972). Much additional work is needed in this field of study.

Based on the above, it is important that range and forest hydrologists working in the pinyon-juniper and other vegetation types recognize the complexity that exists with regard to hydrologic phenomenon. Though limitations exist for small plot estimates of infiltration (Hickok and Osborn, 1969), this study indicates that guidelines prepared for hydrologic analysis on pinyon-juniper sites similar to those sampled in this study should take into consideration the geographic area, the parameter of interest and, where applicable, the timing of an event.

Literature Cited

- BISAL, F., AND W. F. FERGUSON. 1968. Monthly and yearly changes in aggregate size of surface soils. *Canad. J. Soil Sci.* 48:159-164.
- BOUYOUCOS, G. J. 1962. Hydrometer method for making particle size analysis of soils. *Agron. J.* 54:464-465.
- BRANSON, F. A., AND J. R. OWEN. 1970. Plant cover, runoff and sediment yield relationships on Mancos Shale in western Colorado. *Water Resour. Res.* 6:783-790.
- BROWN, H. E. 1970. Status of pilot watershed studies in Arizona. *Proc. A.S.C.E., J. Irrig. and Drainage Div.* 96:11-23.
- DORTIGNAC, E. J. 1951. Design and operation of Rocky Mountain infiltrometer. U. S. Forest Serv., Rocky

- Mt. Forest & Range Expt. Sta. Paper 5: 68 p.
- DORTIGNAC, E. J. 1960. Water yield from pinyon-juniper woodland. *In* Water Yield in Relation to Environment in the southwestern United States, A.A.A.S. Symp., Sul Ross St. Coll., Alpine, Texas: 74 p.
- GIFFORD, G. F. 1972. Infiltration rate and sediment production trends on a plowed big sagebrush site. *J. Range Manage.* 25:53-55.
- GIFFORD, G. F., AND C. M. SKAU. 1967. Influence of various rangeland cultural treatments on runoff and sediment production from the big sage type, Eastgate Basin, Nevada. *In* Proc. Third Annual Amer. Water Resour. Conf., Nov. 8-10, San Francisco: 137-148.
- GIFFORD, G. F., G. WILLIAMS, AND G. B. COLTHARP. 1970. Infiltration and erosion studies on pinyon-juniper conversion sites in southern Utah. *J. Range Manage.* 23:402-406.
- HICKOK, R. B., AND H. B. OSBORN. 1969. Some limitations on estimates of infiltration as a basis for predicting watershed runoff. *Trans. A.S. A.E.* 12:798-800, 803.
- HOOVER, M. D., D. F. OLSON, AND L. J. METZ. Soil sampling for pore space and percolation. U. S. Forest Service, Southeastern Forest Expt. Sta. Un-numbered Publ.: 29 p.
- LUSBY, G. C. 1970. Hydrologic and biotic effects of grazing *vs* nongrazing near Grand Junction, Colorado. *J. Range Manage.* 23:256-260.
- WILLIAMS, G., G. F. GIFFORD, AND G. B. COLTHARP. 1969. Infiltrometer studies on treated *vs* untreated pinyon-juniper sites in central Utah. *J. Range Manage.* 22:110-114.