Technical Report No. 54

GRASSLAND INFILTRATION PHENOMENA

Delbert Noel Wolff

Colorado State University

GRASSLAND BIOME

U. S. International Biological Program

June 1970

ABSTRACT

GRASSLAND INFILTRATION PHENOMENA

The infiltration of precipitation into grassland sites, especially rangelands, is a critical factor in maintaining vigor of the plant cover. Infiltration rates on grassland sites are effected by numerous interacting phenomena of the soil, atmospheric, and vegetational systems. A review of infiltration literature including the processes involved, factors affecting it, and methods of measurement is presented. Infiltration data collected on a wide variety of grassland sites is summarized by geographic region, range condition, and soil index and is represented in tabular form.

On the typical grassland areas range condition exhibits a greater control over infiltration values than does soil influences. However, the reverse situation occurs in semi-arid regions where vegetation is characteristically sparse. The average (P = 0.5) one hour duration storm is capable of being infiltrated on practically all range sites studied. Good and excellent condition ranges can generally accommodate the average (P = 0.5) ten minute duration storm without producing too much runoff.

Delbert Noel Wolff
Department of Recreation and
Watershed Resources
Colorado State University
Fort Collins, Colorado 80521
June, 1970

TABLE OF CONTENTS

	PAGE
INTRODUCTION	1
Ecology	1
The Problem	4
REVIEW OF INFILTRATION LITERATURE	6
Factors Affecting Infiltration	7
Precipitation	8
Antecedent Moisture	13
Ground Cover	14
Season	17
Frost	18
Temperature	19
Fertilizer	20
Entrapped Air	20
Slope	22
Soil Properties	24
Soil Wettability	27
Infiltration Processes	28
Infiltration Measurement Methods	41
Sprinkling Devices	42
Cylinder Infiltrometers	46
Plot Method	50
Hydrograph Method	51
Laboratory Studies	53

TABLE OF CONTENTS (continued)

	PAGE
Grassland Infiltration Studies.	55
GRASSLAND INFILTRATION DATA	65
Explanation of Data Arrangement	65
Interpretation of Results	77
Mixed Prairie.	78
True Prairie	79
Highland Region.	81
Semi-arid Area	81
Summary and Conclusions	82
BIBLIOGRAPHY.	85
APPENDIX.	99

LIST OF TABLES

TABLE		PAGE
1	Soil characteristics significantly correlated with infiltration during third hour of wet run. (After Free *et al*., 1940)	27
2	Factors affecting infiltration rate. (After Gray *et al*., 1969)	39

LIST OF FIGURES

FIGURE		PAGE
1	Typical maximum infiltration rate curves.	12
2	Moisture-depth curves for Yolo silt loam. (After Bodman and Colman, 1943).	30
3A	Relationship of range condition and soil indices to median infiltration rates.	66
3B	Relationship of range condition and soil indices to median infiltration rates.	66
3C	Relationship of range condition and soil indices to median infiltration rates.	67
3D	Relationship of range condition and soil indices to median infiltration rates.	67
4A	Median infiltration rates for various range conditions and soil indices	68
4B	Median infiltration rates for various range conditions and soil indices	68
4C	Median infiltration rates for various range conditions and soil indices.	69
4D	Median infiltration rates for various range conditions and soil indices.	69
4E	Median infiltration rates for various range conditions and soil indices.	70
5A	Rainfall-infiltration rate curves for various range use conditions and storm durations on Mixed Prairie sites	72
5B	Rainfall-infiltration rate curves for various range use conditions and storm durations on True Prairie sites	73
5C	Rainfall-infiltration rate curves for various range use conditions and storm durations on Highland sites	74
5D	Rainfall-infiltration rate curves for various range use conditions and storm durations on Semi-arid sites..	75

INTRODUCTION

The process of infiltration is one of the most important phases of the hydrologic cycle. On grassland areas infiltration holds even greater significance because through it soil water, the major physical resource limiting vegetation growth, is replenished. The grasslands of the western United States are regions of extreme temperature variations and relatively low annual precipitation. The vegetation growth necessary to provide forage and to protect the land from the erosive forces of wind and intense rainstorms is in delicate balance with the forces of nature. This is the case over vast portions of the grassland ecosystem.

Ecology

For the purpose of describing the grasslands of the western United States, the regional breakdown recognized by Borchert (1950) will be used. This classification includes the True Prairie (tall grass), Mixed Prairie (short grass), and the western highlands. The prairies as we now recognize them owe their origin to the regional climatic changes affected by the tectonic activity of the mid-Tertiary period about 25 million years ago (Weaver, 1954).

The delineation between the True Prairie and the forested region to the east is generally considered to be approximately along the Mississippi River. The western edge of the True Prairie blends into the Mixed Prairie approximately along the 100th meridian. Along the eastern boundary the average annual precipitation varies from approximately 40 inches in the south to about 23 inches in the north.

A similar south to north precipitation gradient is noted along the True Prairie-Mixed Prairie ecotone where annual precipitation ranges from about 30 inches in Oklahoma to 20 inches in North Dakota (Weaver, 1954).

The Mixed Prairie, as was the case with the True Prairie, is fairly well confined within certain annual precipitation isohyets which limit it to that region lying between the True Prairie and the base of the Rocky Mountains. Mixed Prairie constitutes the largest grassland association in North America spreading over nearly 640 million acres in the United States and Canada. It is characterized by climatic extremes and a nearly continuous blanket of short grass sod beneath the taller vegetation (Weaver and Albertson, 1956). Average annual precipitation varies from 8 to 20 inches with the same general south to north precipitation-ecotone phenomena present here as was the case on the True Prairie.

The entire Great Plains region receives about 70 to 80 percent of its annual precipitation during the growing season. Over the True Prairie precipitation is distributed very well with about 3 to 4 inches per month occurring during the spring and summer. On the Mixed Prairie, however, it varies considerably. Weaver (1954) has pointed out that the chief difference between the Mixed and True Prairie is the greater amount of precipitation received by the latter, which favors the development of deeper, more moist soils and a decreased evaporation rate.

That grassland region designated as western highland by Borchert (1950) cannot be categorized climatically, floristically, or areally as accurately as the short and tall grass prairies. The western highlands encompass the great expanse of the Rocky Mountain and intermountain regions where grasslands can occur as relatively small acreages or vast tracts either in forest openings at the higher elevations or along the shrub-forest tension zones.

Annual precipitation on mountain grasslands is essentially that of the surrounding forest with about one-fourth of the approximately 30 inch annual average occurring during the growing season (Paulsen, 1969). In the semi-arid areas grass cover is not continuous and shrubs or trees are often the dominant vegetation. Average precipitation varies locally between 12 and 35 inches annually with roughly one-half falling during the summer (Pace, 1966).

The semi-arid region, as referred to in this report, was not separately described by Borchert (1950). Herein the semi-arid region will include those areas of the southwestern United States which receive only about ten inches annual precipitation but yet provide some grazing use. Rainfall in this region varies widely in frequency of occurrence, volume, and precipitation rate. Storms usually result, in the summer, from purely convective build up or from a cluster of convective cells along weak, fast moving cold fronts (Osborn and Reynolds, 1963). The individual convective cells usually cause precipitation over an area of only about two or three miles radial extent (Osborn and Keppel, 1965).

The Problem

Since the intake of water into the soil is of paramount significance in the management of grasslands, a better understanding of the factors affecting infiltration is needed. Despite its relative infancy, the concept of infiltration as a branch of hydrologic phenomena has already experienced the enigma which has beset so many other scientific disciplines--that of conflicting terminology. Broadly speaking infiltration is defined as the downward entry of water into the soil. This basic definition is generally accepted in professional circles but here the agreement ends. Horton (1940) defined infiltration capacity as the maximum rate at which a given soil, when in a given condition, can absorb rain as it falls. He then distinguished infiltration rate by declaring it to be the actual rate of water intake by the soil. More recently Richards (1952) has suggested that the term infiltration capacity be abandoned and that infiltration rate be used to describe what Horton referred to as infiltration capacity. Because Richards' definition is probably the most straight-forward and descriptive way of defining the phenomena, the term infiltration rate will be used in this paper. The term maximum infiltration rate will be used to designate what Horton referred to as infiltration capacity and what Richards preferred to call infiltration rate, i.e., the greatest rate at which water can be infiltrated into the soil at a given time and under a given set of site conditions. The term grasslands will refer to vegetation types which through an interaction of edaphic and climatic factors support grasses as the major component of the vegetation.

This paper will review the literature pertinent to an empirical and theoretical understanding of the phenomena which affect infiltration and its measurements. The objective will be to deal with the processes of infiltration as they occur on the Mixed and True Prairies of the mid-continental grasslands, the "parks" of the Rocky Mountains, and the grazing areas of the intermountain and southwest regions. From infiltration data collected by various researchers, generalizations will be made relating soils, site condition, and grazing impact to measured infiltration values.

REVIEW OF INFILTRATION LITERATURE

The necessity of at least a portion of the natural precipitation being taken into the soil would be denied by no one--indeed the basic processes of the hydrologic cycle were recognized by Leonardo da Vinci nearly 500 years ago. Bouyoucos (1922) paid tribute to the soil-water relationship when he suggested it to be

> ... one of the best indices of the physical characteristics of soil. Texture, structure, colliodal and organic content, surface activation, etc., tend to be revealed by the behavior of the soil toward water.

Later Bouyoucos (1929) reaffirmed that position and continued:

> The behavior of a soil toward water probably gives truer and more comprehensive composite information concerning the soil than the behavior of the same soil toward any other agent. This is probably due to two main factors: first, water, besides being the most natural and universal reagent, is also the chief natural agent by which the soil has been formed; second, most of the physical properties of the soil run parallel with its behavior toward water... .

This general subject was brought into focus more clearly by Horton (1933) who was first to point out the inseparable relationship between the process which we now call infiltration and the complex interactions of the hydrologic cycle.

Horton's initial description of the role of infiltration in the hydrologic cycle triggered a tremendous amount of attention and research from workers in several professional fields. The agronomists, agriculturalists, and general land use managers were greatly concerned because infiltration is the primary source of soil water and determines the type of farming and management practices that can be employed on a given site. Hydrologists and agricultural engineers, designers of water control structures based on runoff, have contributed empirical knowledge toward the understanding of factors influencing infiltration. Soil physicists, more interested from a physical point of view, have attempted to describe the process of infiltration strictly from mathematical models.

Factors Affecting Infiltration

After over 35 years of intensive research, it remains virtually impossible to apply laws governing the behavior of water movement into the soil to field situations. Experimental results show that factors which dominate infiltration under one set of conditions may act in the same manner elsewhere, but yet be overshadowed by some other variable more important on that particular site. Infiltration results are often found to vary both between and within sites and the exceptions to nearly every statement of generality are many.

Haupt (1967) stated that infiltration rates for a given plot can vary dynamically over time, whether from season to season, week to week, day to day, or hour to hour with a rainstorm. As will be pointed out later in this section, the numerous researchers who have studied the factors affecting infiltration have failed to agree on any one or a combination of factors which may exert the controlling influence on infiltration into a soil at a given point in time. From this it follows that any attempt to devise a hierarchy of factors influencing infiltration, based on relative importance, would be futile. In an attempt to distinguish between maximum infiltration rate at a point in time versus infiltration rate expanded over time and area, Lewis and Powers (1938) suggested a very detailed list of variables. However, practically all of the factors influencing infiltration in a very short run situation are also active, even though often at different degrees of intensity, over larger areas and greater time. For this reason it is impractical to attempt to separate them. Also, the interdependency between edaphic, vegetational, climatic, and animal (including man) influences are extremely complex.

Precipitation. Precipitation is the source of water available for infiltration at the soil surface. Precipitation may arrive at the earth's surface in one of several forms, the most common of which are rain and snow. To enter the soil, water must be in the liquid state and be at a point on the earth's surface which is capable of absorbing it. Precipitation which falls as snow or some other solid form may melt and become immediately available for infiltration or it may be temporarily stored.

Raindrops, the liquid phase of precipitation, arrive at the earth's surface in a given storm in varying sizes, shapes, and velocities. The median diameter of raindrops measured by Laws and Parsons (1942) was a function of precipitation rate. Drop diameter for precipitation rates of 0.01 inches per hour ranged from 0 to 2.75 millimeters, with the average being approximately one millimeter. Size ranges and median raindrop diameter were found to increase with precipitation rate. At a rainfall rate of six inches per hour, drop diameters ranged from 0.25 to 7.00 millimeters with the average diameter near 3.25 millimeters.

According to Laws (1941) the shape of falling water droplets are altered during their fall and at terminal velocity are typically mushroom shaped and flattened on the bottom. As the raindrop becomes more flattened during fall, and hence subject to greater air resistance, it tends to break up into smaller drops. Kohnke and Bertrand (1959) feel that this explains why drop sizes greater than seven millimeters are not generally reported. Laws (1941) determined the velocity of various diameter drops in still air. His data showed that when dropped from a height of 20 meters terminal velocity increases with drop diamter at a decreasing rate to a maximum velocity of nine meters per second for a drop size of six millimeters in diameter.

The size, shape, and velocity of a raindrop as it strikes the soil surface can play an important role in determining infiltration, especially where bare soil is exposed. Horton (1940) recognized that the amount of material detached by raindrop splash will influence the degree of structural deterioration, clogging of macropores, puddling, and surface packing and sealing of the soil. Hendrickson (1934) and Musgrave and Free (1937) noted a very evident decrease in infiltration rate when slightly turbid water was used as opposed to using clear water. Kohnke and Bertrand (1959) placed emphasis on the kinetic energy of the raindrop as being the dominant rain characteristic in soil erosion processes. Theoretically this force could be determined for a single drop by the formula,

$$E = 1/2mv^2 \quad (1)$$

where, E = the kinetic energy

m = mass of raindrop

v = velocity of the raindrop.

Shape of the drop is also an important factor in that it determines the volume of the drop which will strike the surface at the initial instant of impact.

Wischmeier and Smith (1958) vividly described the magnitude of kinetic energy imposed upon the soil surface by raindrop impact when they stated that

> ... the dead weight of the water falling in thirty minutes of a common thunderstorm ... may well exceed 100 tons on each acre. ... The rainfall energy to be expended during the thirty minutes may well exceed two million foot-pounds per acre. If the rain is driven by violent winds, the energy of impact may be even greater.

Rogers et al. (1967) attempted to measure drop size distribution in a storm both over time and area and from this data to calculate the storm's kinetic energy. Raindrop characteristics were measured during a five year period by photographing falling drops. They found total volume of rain and kinetic energy parameters to be very difficult to determine correctly at low rainfall rates. Data from the first minute of storms was eliminated because thunderstorms typically have a greater proportion of large drops during that time. Bearing in mind the work by Adams <u>et al</u>. (1957), who found splash erosion and its resultant ramifications to be most severe on dry soils, question could be raised as to the validity of ignoring this initial period of the storm in calculating kinetic energy data and their consequent application in erosion equations.

On a more general scale other characteristics of precipitation also influence infiltration. Precipitation rate has been shown to have a marked effect on infiltration. Craddock and Pearse (1938) working on four rangeland cover types varying from 30 to 40 percent slope found runoff on an average to increase by only one-third even though precipitation rate was doubled. Since the experimental areas were covered with vegetation, the supposed effect of steeper slope causing more rapid runoff may have been nullified. Also, considering that the plots were only 0.005 acre size, the increased slope may have allowed a relatively greater amount of water to drain from detention storage. Using the hydrograph analysis method of determining infiltration on sprinkled plots of 0.005 acre size, Sherman (1938) found his data to indicate infiltration to be 60 percent greater at a rate of 2.5 inches per hour than at 1.2 inches per hour. Although this data is representative of the limited area involved, such conclusions would be of little value in predicting infiltration rates during a natural storm over a natural watershed where rainfall rate and maximum infiltration rate vary.

Expressions of rate, however, say nothing about another important rainfall characteristic--duration. A particular soil is commonly considered capable of infiltrating water at some given rate which generally decreases with time (see Figure 1). Any increase in precipitation rate up to the soil's maximum infiltration rate would lead to the conclusion that more intense storms do increase infiltration rates; however, once the soil's maximum infiltration rate has been exceeded by the rainfall rate, any greater rates would not result in increased infiltration rates.

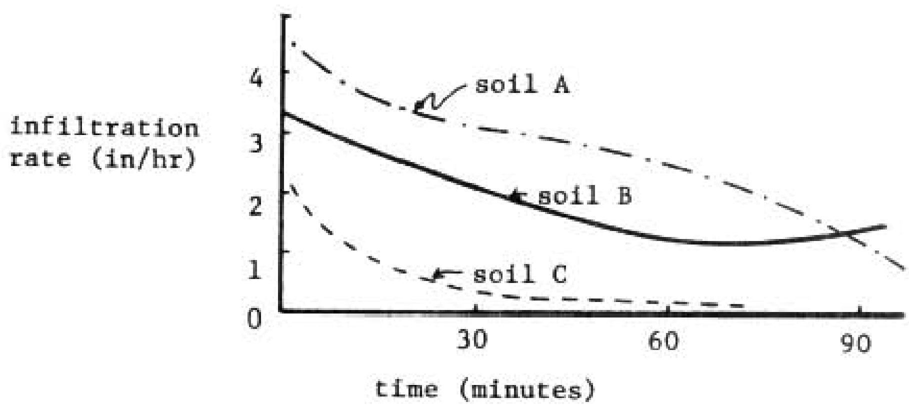


Figure 1. Typical maximum infiltration rate curves.

<u>Antecedent Moisture</u>. The effects of antecedent moisture on infiltration have been discussed by several authors. Experimenting in the laboratory with surface samples of Putnam silt loam soil, Neal (1938) found that during the first 20 minutes of the tests antecedent moisture had a greater influence on infiltration values than any other single factor.

The recovery of infiltration rate, especially where storms are separated by only a few hours or a day or so, is very important. Reinhart and Taylor (1954) recognized this and noted that antecedent moisture plays the dominant role in determining available storage. Smith (1949), who approached the subject from a more theoretical aspect, evaluated several factors influencing infiltration but concluded antecedent moisture to be the most significant. In Australia, on loam, clay loam, and clay soils supporting perennial grass cover, Tisdall (1951) also found antecedent moisture to play an important role in infiltration, especially during the initial stages of water application.

Contrary to these findings, however, are the results reported by other workers. Lowdermilk (1930), Duley and Kelly (1941), and Duley (1939) found that rapid reduction in infiltration rates were accompanied by formation of a nearly impervious surface layer of soil which was of much greater significance than antecedent moisture.

Philip (1957e) applied his mathematical analysis approach to infiltration to the influence of antecedent soil moisture on infiltration rates and summarized his findings thusly.

> The results are in general agreement with experiment and indicate that, at small times after infiltration begins, increasing the initial moisture content reduces the infiltration rate but increases the velocity of advance of the wet front [proposed by Bodman and Colman, 1943]. As time increases the influence of the initial soil moisture on the infiltration rate becomes less and is ultimately negligible; on the other hand the influence on wet front advance persists and, in fact, becomes more marked.

As pointed out by Neuberger _et al_. (1964), the effect of antecedent moisture is heavily dependent on the soil in question. Based on studies of South Dakota rangeland, their conclusions were that watersheds of medium textured soils showed no significant correlation between the rainfall-runoff relationship and antecedent moisture, but watersheds with fine textured soils did.

Adams _et al_. (1957) have shown that a higher initial soil water content, i.e., near or at field capacity, reduces the effects of splash erosion on bare soils by nearly one-half as compared to what occurred on air-dry soils. The implications of this observation as it would affect the clogging of surface pores could be important.

Ground Cover. The importance of adequate floristic ground cover has long been stressed as an essential prerequisite in efforts to control flooding and erosional problems. Vegetation itself does not control runoff, the source of erosion and flooding difficulties, but its presence does increase the hydraulic roughness. This in turn slows overland flow allowing more time for infiltration to occur.

The effects of a simple surface mulch cover on infiltration rates has been demonstrated by Duley and Kelly (1941) and Alderfer and Merkle (1944). In comparing infiltration rates on mulched and bare soils, both studies indicated infiltration values to be initially higher on the mulched plots. The significantly higher values were maintained throughout the test runs. On four percent Austin clay slopes treated with mulches of straw and of gravel, Adams (1966) noted results essentially similar to those of the earlier works. Adams, however, was also studying the effects on runoff, erosion, and evaporation of dioctadecyl dimethyl ammonium chloride (DDAC). The DDAC was effective in reducing evaporation but was found to materially increase runoff and erosion. He suggested that such chemical treatment of alternate soil surface strips might prove feasible if soil movement could be prevented. The enhancement of infiltration and the decrease of runoff and erosion attributable to surface stones and gravel were studied in Maine by Epstein et al. (1966). They concluded these effects to be due to the interception and dissipation of raindrop energy which in turn reduces surface sealing. Also, soils containing large amounts of coarse fragments tended to exhibit less compaction and correspondingly greater noncapillary pore space.

Studies of infiltration as related to volume of standing vegetation and natural mulch by Rauzi (1960) indicated that 45 to 84 percent of the variation in infiltration was due to differences in organic matter above the surface. As vegetation debris builds up at the surface, it serves as a sponge by absorbing the impact of the raindrop and storing the water. This additional moisture creates a humid micro-climate within the debris layer and hastens its decay. As decomposition occurs it is incorporated into the A horizon, thus adding organic material to the soil profile. Vegetation also creates micro-depressions on the soil surface which act as small reservoirs during a storm.

In comparing infiltration rates on slopes of Marshall silt loam with close vegetation versus bare ground, Musgrave and Free (1936) concluded that the major effect of close vegetation is in reducing the overland flow velocity, thus, allowing more time for infiltration to occur.

Other effects of vegetation which are beneficial to increased infiltration include the creation of soil channels by decomposing roots and the favorable environment for soil fauna activity. It was noted by Pearse and Woolley (1936) that any type of herbaceous cover will increase infiltration rates, but the nature of the plant root system will determine to what degree. They found that fibrous rooted species took up 1.5 times more water than did tap rooted species. Upon examination of the treated profile, they observed that water had penetrated to a large extent along the roots; hence, the denser root systems had presented a greater opportunity for water intake. Craddock and Pearse (1938) arrived at similar conclusions.

Kincaid _et al_. (1964) working in semi-arid areas of varying cover density found that the percent of gravel content, both on the surface and within the surface one-fourth inch of soil, to be directly related to infiltration rates when vegetation cover was absent or sparse. As the vegetation cover increased, the influence of gravel appeared to decrease until it was entirely overshadowed by that of vegetation cover. They also observed that grassland areas showed prompter and more abrupt responses to rainfall at depths of up to 18 inches than did bare areas. The greater soil water depletion noticed under grass was blamed on evapotranspiration losses, while the positive water responses were due to greater infiltration. The effects of vegetation as related to range soils and uses will be discussed in a future section.

Season. The fact that generally our worst floods occur during the winter months leads one naturally to assess the effect of season and related phenomena on infiltration. Horton (1933) recognized a marked seasonal variation in maximum infiltration rates and attributed it to the effects of temperature, soil fauna activity, and perforations which permitted freer entry of water and escape routes for soil gases. After further study Horton (1937) suggested that when analyzing infiltration from a basin approach, one should make determinations at various times of the year. This procedure would allow for the considerable range of values he often noted between maximum and minimum infiltration rates. Beutner _et al_. (1940) and Horner and Lloyd (1940) also found infiltration rates to be greater during the warm months, but added that actual maximum infiltration rates vary on a given site from one year to the next.

At Badger Wash Schumm and Lusby (1963) found season of year, as a result of winter frost action, to be the main source of variability in infiltration rates. During the winter the surface soil was frost heaved and made porous, thus resulting in high infiltration rates during the spring. As the heaved soil settled and became more compact from the action of rains, infiltration rates dropped to a minimum in late summer and fall.

Frost. In addition to the example just cited, frost can have a more direct effect on infiltration. Infiltration rates can be altered drastically by the presence of soil frost during precipitation. The degree of this impact is controlled by the type of frost. In describing soil frost the problem of sematics is again encountered because there is no generally accepted set of criteria being used. Stoeckeler and Weitzman (1960) described three frost structures: (1) concrete frost, extremely dense soil freezing with many ice lenses and small crystals which block all air and water movement, (2) porous concrete frost, resembles concrete frost but air can be blown through it readily, and (3) partly frozen frost, permeable to air and shows individual ice crystals even though many parts appear unfrozen. This classification resembles, and could probably be considered a condensation of the four types--concrete, granular, honeycomb, and stalactite--recognized earlier by Storey (1955) and Trimble et al. (1958). Stoeckeler and Weitzman and Storey have all noted that the more solid the frost, the less permeable it is, and therefore, the greater its inhibitive influence on infiltration. Generally, heavier textured soils are affected to a much greater degree than lighter ones. Too, they found less dense frost types apparently have little or no influence on infiltration.

Haupt (1967) has reported that, in general, an increase in infiltration rate is observed as impervious frosts melt, but that infiltration rates decrease as less dense frosts melt. Also a factor in the permeability of various frost types is the initial soil water content. Linsley et al. (1949) stated that freezing of a soil with low moisture content tends to increase its maximum infiltration rate while the opposite is true of a soil frozen while moist. Mace (1968) studied the influence of soil frost on soil water recharge by snowmelt. He observed that recharge on grassland areas containing concrete frost occurred during the latter part of the snowmelt when the soil was thawing. Thawing was primarily from the surface downward and the thawed soil was saturated with free water on the surface.

Temperature. The effect of temperature and the resulting change in viscosity of water on infiltration rates of a silt loam soil were studied by Lewis and Powers (1938). Using tap water at temperatures of 0.56°, 18.9°, and 37.2° Centigrade, they observed that the hot water infiltrated faster but only until four inches of the soil had been penetrated. Duley and Domingo (1942) showed that water temperatures varying from 4.4° to 43.3° Centigrade had only a minor effect on infiltration rates. From this they concluded that temperature variations encountered in natural precipitation would not significantly affect infiltration rates. Moore (1940) attempted to determine the effect of soil temperature on infiltration, but even though his data indicated a rise in infiltration rate with increased soil temperature up to 35° Centigrade, he felt other factors could have affected the results.

Fertilizer. Data collected by Free *et al.* (1940), Rauzi and Smika (1963), and Tanner and Mamaril (1959) indicate that infiltration is not significantly altered by commercial fertilizers or changes in soil pH. Huberty and Pillsbury (1941), working on Ramona loam soils found ammonium sulfate to slightly lower infiltration and that it required double commercial rates of calcium nitrate to significantly increase infiltration. Mazurak and Conard (1959) could detect no significant change in infiltration rates after six years of applying commercial rates of ammonium nitrate to grasslands in the central plains.

Entrapped Air. The effect of soil gases trapped below a downward moving water front is a commonly recognized barrier to infiltration; however, only a few workers have mentioned this in their works. Free and Palmer (1940) showed entrapped air to have a very marked effect on infiltration into columns of graded sand. Water first entered the sand by gravity and capillarity, but once the air became compressed the moisture front advanced more slowly until sufficient pressure built up to cause an upward release of air. Earlier, Powers (1934) had found that entrapped air was definitely a factor in slow infiltration rates into a closed tube of sandy loam soil. The rate of water intake into an open bottomed tube was about double that into a closed tube.

In discussing infiltration over a large area under natural conditions, Horton (1940) makes the following statement,

> ... it appears that: 1. the escape of air from soil during infiltration takes place chiefly through the large soil pores and through macro-openings, such as insect, root, and earthworm perforations and sun-checks. 2. the escape of air takes place chiefly through the summits of the soil surface irregularities where the detention depth is slight, ...

Horton then devised a laboratory experiment whereby he could study the effects of entrapped air by actually controlling and measuring air pressure within the soil. In a soil which was vented at various depths, no build up of pressure occurred and maximum infiltration rates, especially in the latter stages of the experiment, were greater than in a similar but unvented soil.

Christiansen (1944) noted that as water enters the soil, it slowly dissolves trapped air, thus freeing the soil of air from the surface downward. Smith et al. (1966) expanded on Christiansen's idea and listed three main distributions of air within a partially saturated soil. These included: bulk air pockets or confined air; air bubbles within the water mass called entrapped air; and, air in solution or dissolved air. Working with columns of sand subjected to successive flows of water and air, they found that most of the air which moved downward through the sand column did so as entrapped air. According to Adam and Corey (1968) the diffusion of entrapped gas occurs more rapidly in fine textured materials, thus resulting in a higher concentration of dissolved gas in the liquid present. Atmospheric pressure at the time of initial water entry into the soil and changes in barometric pressure during the test were also found to affect the volume of gas entrapped. Here then we have another factor influencing infiltration--the ability of infiltrating water to absorb air.

Slope. The work by various researchers on the effect of slope on infiltration does not coincide even where essentially similar study techniques were used. Working with disturbed soils, both in place on slopes of two to ten percent, (Duley and Kelly, 1939) and under laboratory conditions of zero to 16 percent slope (Neal, 1938), it was found that the degree of slope apparently had only minor effect on infiltration. There was, however, a tendency for infiltration to increase as the slope became more gentle. This was probably due to gentle slopes permitting more surface water retention in micro-depressions. Krimgold and Beenhouwer (1954) have pointed out that relief influences water movement within the soil and therefore infiltration--both because of its profound effect on soil forming processes and the lateral gradient it affords the soil mantle.

The results of studies of the influence of slope, especially gentle slopes of up to approximately 20 percent, on infiltration rates have been characteristically dominated, if not overshadowed, by the effects of other factors such as seasonal variation, soil type, soil surface, and cover conditions (Beutner et al., 1940). Results by Duley and Hays (1932) working on bare cultivated areas indicated that as they varied the slope of natural soils from zero to three percent, a rapid increase in runoff occurred. Thereafter the increase in runoff for each percent greater slope was only slight.

Reviewing literature from cropped lands throughout the United States, Wischmeier (1966) found runoff to be influenced largely by the effect of slope on surface detention. Increased slope length, in most instances, resulted in decreased runoff during the growing season and increased runoff during the dormant season. These were generalities and individual storm exceptions were common. Efforts to consistently relate the exceptions to factors such as storm size, maximum 15 or 30 minute rainfall rate, crop growth stage, or antecedent moisture were not successful. Swanson and Dedrick (1966) were able to simulate fairly long slopes by using 12 foot by 35 foot plots with the long axis perpendicular to the contour and introducing the volume of runoff from one plot uniformily across the top of the next lower one. This system which allowed measurement of overland flow velocity in addition to water application and runoff rates, could prove to be quite a valuable technique in evaluating slope length effects on infiltration.

Soil Properties. The effect of the physical properties of the soil itself in conjunction with the surface covering are probably the two most important factors affecting infiltration. Such physical soil characteristics as organic matter (Free et al., 1940, Wischmeier and Mannering, 1965, and Johnson, 1957), porosity (Musgrave and Free, 1936 and 1937, Dortignac and Love, 1960, and Tanner and Mamaril, 1959), depth of fractured soil (Osborn, 1952), and, soil structure and texture (Rauzi et al., 1968) have all been cited as being the primary limiting factor controlling infiltration into a given soil. For this reason no generalizations can be made concerning specific soil characteristics which will dominate infiltration at a specific point. Organic matter within the soil acts as a binding agent in the formation of soil aggregates. Total soil porosity, permeability, and hence infiltration are heavily dependent upon organic content, degree of compaction, degree of aggregation, texture, and structure of the soil. Soil structure, which can be altered by land use, and depth of soil fracture are determined to a large extent by morphology and geologic history of the site.

Some of the physical factors affecting infiltration into variously structured soils have been discussed by Smith (1949). In structured soils the shape of the aggregates is of utmost importance because this determines how tightly they can be packed and consequently how impervious a layer will be formed when the soil is thoroughly wetted and swollen. When dealing with infiltration into zonally structured soils, the uncertainties are compounded. Each zone has unique pecularities as does the areas of transition between soil layers.

Soil rain-crust permeability characteristics were studied by Tackett and Pearson (1965) who placed soil from the A and B horizons of the same profile in separate three by three inch cylinders and applied two inches of simulated precipitation. General results were that harder, more impenetrable crusts were formed by the B horizon due to the finer textured material. Microscopic examination of the B horizon crust revealed a very thin coating of closely packed clay particles within the surface five millimeters.

Free et al. (1940) studied infiltration data from experiments on 68 sites throughout the United States. The soils varied over six of the great soil groups, 39 soil series, nine groups of parent material, and textures ranging from gravelly silt loam to clay. Summarizing the data from all sites and correlating it with infiltration during the third hour of the wet run, the relationships in Table 1 were developed. It was found that the infiltration data for all profiles could be expressed by the formula

$$I = bt^{a} \qquad (2)$$

where, I = cumulative infiltration (inches)

t = time of infiltration (minutes)

b = a coefficient varying for the initial runs from 1 to 0.0087

a = an exponent varying for the initial runs from 0.04 to 0.82.

As referred to in Table 1, dispersion ratio and suspension percentage are measures of the ease with which soil particles are brought into suspension. The suspension percentage is the amount of particulate matter in suspension after agitation of ten grams of soil in enough water to make one liter of solution. Dispersion ratio is then obtained by dividing the suspension percentage by the percent of silt and clay in the soil sample as determined by mechanical analysis. Both of these factors are inversely related to aggregation which is a measure of the stability of soil particles after wetting. Clay, silt, and organic matter are referred to as percentages. Moisture equivalent is the maximum percentage of water that a soil can retain in opposition to a centrifugal force of 1000 times the force of gravity. Non-capillary porosity, as recognized by Free et al. (1940), is the difference between total porosity and the moisture equivalent. Volume weight is the weight of a given volume of soil compared to the weight of an equal volume of water. For all practical purposes it is synonymous with bulk density.

Table 1. Soil characteristics significantly correlated with infiltration during third hour of wet run. (After Free *et al.*, 1940)

Correlation with Infiltration	Surface Soil	Subsurface Soil
	Total porosity	*Total porosity
	Aggregation	*Organic matter
Positive	*Organic matter	*Non-capillary porosity
	*Non-capillary porosity	
	Volume weight	Moisture equivalent
Negative	Suspension	Silt and clay
	Dispersion	*Clay

* indicates highly significant (at the one percent level); otherwise significant at the five percent level.

Soil Wettability. Extremely dry soils have frequently been observed to show an initial resistance to wetting. Krammes and DeBano (1965) suggest that this phenomena is probably caused by the formation of inpenetrable air film at the soil-water interface. They concede, however, that hydrophobic (water repellent) characteristics also exist in soils of fairly high moisture content or wherever the soil particles are coated with organic substances.

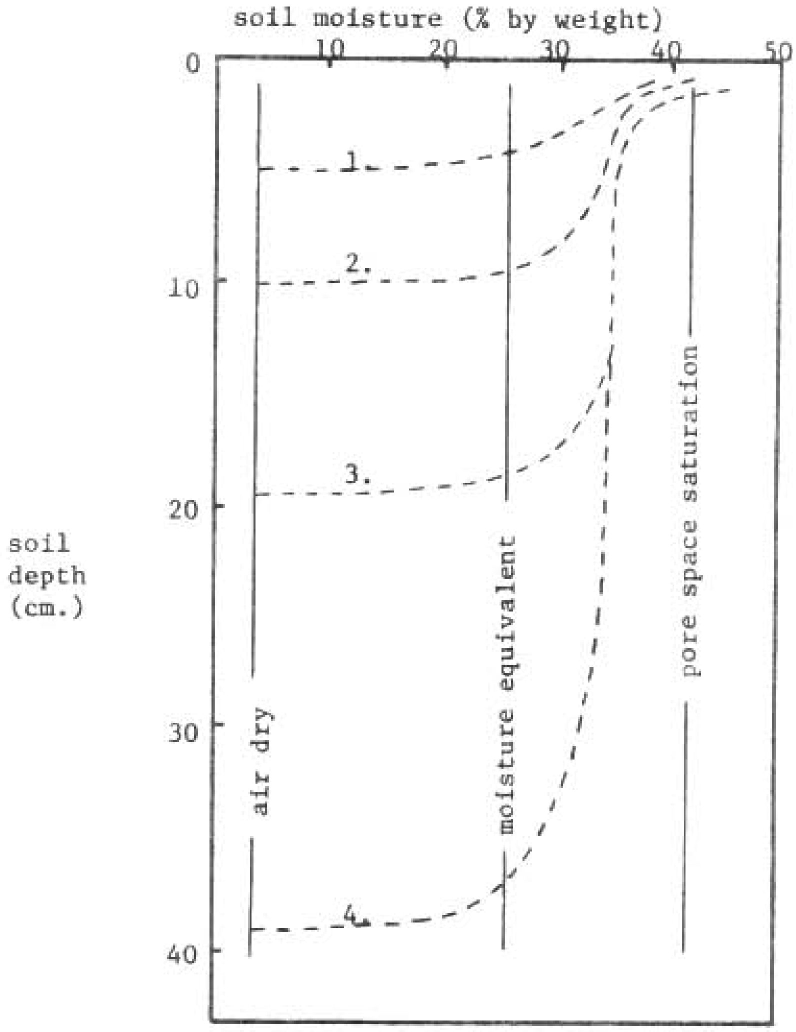
The implications of water repellent soils on land management activities first received significant attention in the chaparral brushland areas of California. The exact geographic extent of water repellent soils is still not known but they have been reported, at least locally, over most of the western United States (DeBano, 1968). Although hydrophobic soils have been reported on both burned and unburned areas, the condition appears to be intensified by burning. Depending upon local conditions, soil hydrophobicity can be of either a temporary or permanent nature.

Infiltration Processes

Infiltration can, by strict interpretation of definitions, be separated from quantitative permeability, which according to Richards (1952) is the quality or state of a porous medium relating to the readiness with which such a medium conducts or transmits fluids. More simply infiltration refers to the movement of water through the soil mass. The two phenomena are by their very nature, however, mutually limiting (Kohnke, 1968). No more water can be transmitted downward through the soil than initially enters it, nor can water at the surface be infiltrated more rapidly than pore space becomes available beneath the surface. Therefore, in discussing infiltration we are of necessity also, at least indirectly, considering the characteristics of soil permeability.

Evans et al. (1951) stated that permeability and infiltration can be identical but only if the following conditions are satisfied: (1) the soil is homogenous throughout, (2) a zero head of water is maintained at the soil surface, (3) no lateral movement of the water occurs, (4) the surface soil is not a restriction to water movement, and (5) there is always atmospheric pressure at the base of the downward advancing water front. Considering the heterogenous composition of soils and the complicated physical processes by which water enters and moves through the soil profile, it seems very improbable that these requirements would ever be fulfilled in naturally developed soils.

Bodman and Colman (1943), while working with uniform samples of Yolo silt and sandy loam soils, were able to divide the wetted portion into four distinct parts: the saturation zone, transition zone, transmission zone, and the wet front. The saturation zone penetrated to only less than two centimeters below the surface--even after maximum wetting depth had been attained. Below this, in the transition zone, soil water content (by weight) decreased with increased depth to about six centimeters. The location of this zone did not appear to change with duration of water application. The average for these two soils was 70 to 80 percent pore space saturation. As more water entered through the upper two zones, the downward extent of the transmission zone lengthened. Soil water content in this zone decreased slowly with depth and duration of application until the wet front was reached. This wet front was the demarcation line between moist and dry soil. It was characterized by a very steep soil water gradient and represented the visible extent of moisture penetration (see Figure 2). These observations by Bodman and Colman were affirmed mathematically and discussed by Philip (1957). Philip attributed the transition zone to a thin surface soil region in which the capillary potential arises from a combination of both moisture content and depth from the soil surface.



Infiltration times are indicated by numbers on curves.

1. 12.3 minutes
2. 76 minutes
3. 280 minutes
4. 1,020 minutes

Figure 2. Moisture-depth curves for Yolo silt loam. (After Bodman and Colman, 1943).

Bodman and Colman (1943) also noted

> ... that unless the larger holes [non-capillary pores] left by decayed roots and by animals come to the soil surface, water will not move into them from the soil mass during infiltration. They will, in fact, act as nonconducting passages and, so long as they fail to extend into a zone of positive moisture potentials, may actually retard soil water movement. ... This observation demonstrates the lack of positive or even zero pressure potentials in the infiltration zone.

From this they concluded that

> ... the decrease in infiltration rate with time is caused primarily by a decrease in moisture potential gradient within the transmission zone of the soil. The average gradient in moisture potential within this zone is evidently approaching, as a limit, that of the gravitational potential.

Working with undisturbed soils of varying initial moisture content, Taylor and Heuser (1953) subjected samples 120 centimeters long and ten centimeters in diameter to water under a constant head of 1.2 centimeters. Their results indicated that infiltration rates are largely dependent on moisture potential gradient within the soil. This gradient appeared to be significantly greater in the wetting zone and across the wetting front than within the zone of transmission. Capillary conductivity was of secondary importance in determining infiltration rates.

Free and Palmer (1940) used graded sand to demonstrate that in soil columns uninfluenced by entrapped air, infiltration rates reach essentially constant values which are a function of the diameter of the soil particles. Arend and Horton (1943) proposed that under normal circumstances the length of time required for maximum infiltration rate to become reasonably constant varied inversely with precipitation rate. Horton (1933) states that maximum infiltration rate for most natural soils generally changes from maximum to minimum values relatively quickly after water is applied--one to three hours.

Many workers, although not specifically studying it, have reported that infiltration rates appear to stabilize or become essentially constant after some period of water application. The ranges of time reportedly required vary from two to three minutes (Pearse and Woolley, 1936), to as much as eight hours or more (Duley and Kelly, 1941), with an average figure being about 30 minutes.

Observations by Russel (1946) do not agree with the constant infiltration rate concept. Working with six-foot columns of undisturbed Marshall silt loam soil, he found that infiltration rates cannot be properly termed constant; that actually they are curvilinear. Considering the variability of natural soils and the multitude of potentially influencial factors which can affect infiltration rates, it would seem difficult to refute Russel's conclusions. However, in a practical sense and for field determinations in which it is conceded that data are more qualitative than quantitative, it is commonly assumed that infiltration rates do approach a more or less stable value.

Nearly all reported experimental data have been collected during that portion of the infiltration run which included the constant rate. Also many workers, especially those using sprinkling devises, conducted what is referred to as dry runs prior to making the actual or wet run infiltration test. The reasoning behind this is to assure that in comparative studies the initial water content of all test soils is as nearly equal as possible, and to lessen or eliminate experimental error resulting from interception losses (where vegetation is present) and detention of water at the soil surface. Rauzi and Hanson (1966) reported that infiltration rates during wet runs were only about one-half of that during dry runs.

Osborn (1952) discussed the possible fallacy involved in relying too heavily on such constant rate or wet run data. He pointed out that the maximum infiltration rate of a site during the initial period of rainfall should not be overlooked when attempting to determine what actually occurs during natural rainstorms. This is because most of the annual rangeland precipitation occurs during the summer months as a result of short duration, high rainfall rate, convective type storms which typically fall on dry soil and usually amount to less than two inches.

The idea of defining the movement of water into and through soils by the use of mathematical models and formulae is older than the concept of infiltration itself. In the past 60 years numerous theoretical and empirical approaches have been used in attempts to define and explain the factors affecting infiltration and percolation. More recent works have utilized information gained earlier, updated it, and presented more refined prediction and explanation equations for experimentally determined phenomena.

Lewis and Powers (1938) attributed the determination of rate of water movement through the soil to three conditions--soil pores, hydraulic gradient, and viscosity of the water. These physical processes of infiltration are noted by Smith (1949) to be basically a function of water flowing into either a saturated soil or an unsaturated soil. In a saturated soil all the pores are completely filled with water. The mechanics of flow in a saturated soil can be expressed by Darcy's Law,

$$V = Ki \qquad (3)$$

where, V = rate of flow

K = hydraulic conductivity of the soil which is dependent primarily upon size, number, and continuity of pores

i = hydraulic-head gradient of driving force.

Flow through an unsaturated soil, one in which all or part of the pores contain a gas or vapor, is more complex. Here water movement is determined more by a combination of factors including capillarity, air-water interfaces, and gravity. In summarizing his mathematical analysis of the interaction between capillarity and gravity during steady state infiltration, Philip (1968) proposes that, where the pore radius is small, capillarity dominates soil water movement. As the radii become larger, gravitational forces play an increasing role until they become the dominant factor.

An early investigation by Gardner (1920) noted the existence of a water front within an insoluble uniform textured soil. He stated that such a soil possesses a characteristic capillarity constant, which in addition to the water content and soil water gradient, determines capillary flow. Gardner hastened to add that this is not valid for stratified soils.

Miller and Gardner (1962) stated that no really satisfactory empirical equation has been derived which explains infiltration into non-uniform or stratified soils. They showed infiltration rates to be dependent upon soil water content, potential gradient, and the nature of transmitting pores, not only during the initial stages of infiltration but also during extended test runs.

A recent paper by Skaggs et al. (1968) reviewed four of the more widely accepted theoretical and empirical infiltration equations and compared their predictions with measured values obtained on several soils. The equations studied were

Green and Ampt (1911)

$$f = A\left\{1 + \frac{B'(P + H)}{F}\right\} \qquad (4)$$

where, f = infiltration capacity

F = accumulative infiltration

H = head of water on the surface

P = capillary potential at the wetting front

A, B' = constants dependent on soil type and conditions,

Philip (1957)

$$f = St^{-1/2} + C \tag{5}$$

where, f = infiltration capacity

t = time

S, C = constants dependent on soil and initial moisture content

Horton (1940)

$$f = f_c + (f_o + f_c)e^{-K_f t} \tag{6}$$

where, f = infiltration capacity

t = time

f_c = infiltration capacity at steady state

f_o = infiltration capacity at time, $t = o$

K_f = a constant depending on the soil and its surface conditions

Holtan *et al*. (1967)

$$f = a(S_t - F)^n + f_c \tag{7}$$

where, f = infiltration capacity

S_t = storage potential of the soil above the impeding strata (total porosity minus the antecedent soil moisture in units of length) a, n = constants dependent on the soil type, surface, and cropping conditions

f_c = constant rate of infiltration after prolonged wetting

F = accumulated infiltration.

In comparing the results of these equations with dry run experimental data obtained from runoff hydrographs for simulated storms, Skaggs et al. (1968) noted that Equation (4) gave a very good fit during the initial 15 minutes. Between about 15 and 45 minutes, it gives slightly high infiltration rate readings but thereafter drops below the measured rates and becomes increasingly lower with time. Equation (5) indicated a too low rate until about 12 minutes have elapsed and then a slightly high reading to about 42 minutes. Beyond this time the rate predicted is once again low and continues to become even lower with time. Equations (6) and (7) fit the measured results very well throughout the range of time studied except beyond 50 minutes where it predicts very slightly high rates.

It was observed from the prediction and experimental curves presented by Skaggs et al. (1968) that the deviations noted for the dry run situation were magnified during wet runs.

Another common empirical infiltration equation is that developed by Kostiakov and discussed by Gray et al. (1969)

$$i = Kt^a \qquad (8)$$

where, i = total infiltration

a, K = constants characterizing ability of soil to absorb water

t = time.

They state that Equation (8) is successful for defining the time rate of infiltration for water applications of short duration. Equations (2) and (8) are essentially similar.

The infiltration equations all seem to revolve about hydraulic or capillary conductivity and the total water potential gradient within the soil. Gray et al. (1969) listed in Table 2 a number of important factors affecting these two quantities.

Gardner (1967) presented a brief but informative review of the development of mathematical theory in the understanding of the physical processes of infiltration. He pointed out that the most noteworthy progress in this field has occurred since 1950. Prior to that time emphasis was placed on the mechanics of experimentally determining infiltration values. However, once the mathematical barrier to the explanation of unsaturated flow was broken, numerous more theoretically inclined researchers became interested in infiltration phenomena.

Only recently have partial differential equations been used in formulating theoretical infiltration equations. In this regard Philip's (1957a, 1957b, 1957c, and 1957d) series of papers was a major breakthrough. Philip (1957a) started with an equation for the flow of water in an unsaturated porous system developed by Klute (1952)

Table 2. Factors affecting infiltration rate. (After Gray et al., 1969).

- Infiltration Rate
  - Capillary or Hydraulic Conductivity
    - Fluid Properties
      - Density
      - Viscosity
    - Porous Medium Properties
      - Moisture Content
      - Pore Size, Shape, Distribution and Continuity
        - Particle Size Distribution
        - Porosity
        - Layering (Homogeneity)
        - Colloid Content
        - Colloid Swelling
        - Salt Content
        - Organic Matter
        - Shrinkage Cracks
        - Root & Animal Activity
      - Surface Conditions
        - Tillage
        - Packing
        - Inwash of Particles
  - Gradient of Total Potential
    - Pressure Gradient
      - Pressure at Soil Surface
        - Hydrostatic Head
        - Barometric Pressure
      - Pressure at Wet Front
        - Moisture Content
        - Surface Tension
        - Contact Angle
        - Pressure of Confined Air
      - Depth to Wet Front
        - Moisture Content
        - Volume Infiltrated
    - Gravitational Gradient

$$\frac{\partial}{\partial t}(\rho_\sigma \theta) = \nabla (\rho k \nabla \Phi) \qquad (9)$$

where, ρ_σ = bulk density of the medium

θ = moisture content on a dry weight basis

ρ = fluid density

K = coefficient of aqueous conductivity

$\nabla \Phi$ = gradient of the total moisture potential

and derived, through the use of differential equations, a complicated equation describing the infiltration rate of water into a semi-infinite column of homogenous soil. This infiltration equation, Philip showed, was closely comparable to measured rates but only for a finite period of slightly less than 12 days. Realizing this inadequacy, Philip (1957b) then approached solution of Equation (9) from a different angle and developed theorems leading to the formulation of an accurate equation for determining cumulative infiltration at times beyond twelve days.

In the fourth paper of the series Philip (1957d) proposed a new term, sorptivity, which is a measure of the ability of a substance to take up or lose a liquid by capillary action. This term is expressed in cm $sec^{-1/2}$. By integrating Equation (5), which was found to give very good approximations when tested against numerical infiltration data, Philip presented

$$i = St^{1/2} + At \qquad (10)$$

where, i = cumulative infiltration

S = sorptivity

A = a measure of permeability

t = time.

Equation (10) was easier to work with than Equation (5) and appeared to meet the practical needs of applied hydrology.

Infiltration Measurement Methods

The methods, techniques, and equipment used in measuring infiltration rates are nearly as numerous as the factors affecting it. Most early experimental work was designed primarily for measuring erosion and surface runoff. These first experimenters had little or no results for guidance and their equipment was designed almost entirely from speculation and trial and error. Results were, at best, often crude. These experiments did, however, serve to point out many of the pitfalls encountered in both the equipment and procedures used in measuring infiltration.

The general methods of determining infiltration rates listed by Parr and Bertrand (1960) include sprinkling devices, cylinder infiltrometers, plot method, watershed hydrograph analysis, and undisturbed soil cores or columns of disturbed soil. More recent workers have improved upon some of these methods and altered them to fit particular situations. Slater (1957) observed that future improvements in infiltrometers are likely to be confined to modification of existing apparatus.

There are numerous variations of each method but all work on one of three basic principles. After water has been applied, either naturally or artificially, to an area of known size, infiltration is measured by determining: (1) the time required for a given volume of water to be infiltrated; (2) the volume of water infiltrated during a specific period of time; or (3) the difference between volume of water applied and surface runoff. Possible methods of water application include sprinkling, flooding, and natural precipitation. The size of experimental areas vary from a few square inches in the case of some cylinder infiltrometers to entire natural watersheds.

Sprinkling Devices. The sprinkling approach was recognized early as being the most satisfactory means of artificially wetting a plot. First attempts were understandably crude; Duley and Hays (1932) used an ordinary sprinkler can while others experimented with garden hoses. The basic research of Laws (1941) and Laws and Parsons (1943), as discussed earlier, was responsible for revealing much information concerning the characteristics of raindrops, thus enabling more recent workers to better simulate natural rainfall conditions.

Although numerous methods and modifications have been used to artifically sprinkle plots in the past, the four types of infiltrometers most commonly used were discussed and compared by Wilm (1943). (1) The modified type-F infiltrometer used a 6.6 foot by 12 foot plot sprinkled by 13 type-F nozzles. Rainfall was measured during the test runs by two trough gages each one inch wide and twelve feet long. (2) Rocky Mountain infiltrometer (discussed later). (3) Modified North Fork Equipment--water was applied to the 2.5 square foot plot by two type-F nozzles. (4) Pearse Square Foot Apparatus--water was applied at ground level uniformly along the upper edge of a one square foot area surrounded by a metal frame. Wilm concluded from this study that only relative estimates of true infiltration can be expected when using these infiltrometers, but that any of the four should provide a satisfactory estimate.

Ellison and Pomerene (1944) designed a water applicator measuring six feet by seven feet with which drop size, drop velocity, and application rate could be varied individually. The device consisted primarily of a water tank, screen for developing drops of the desired size, motor to agitate the screen so that the drops would be distributed over the plot surface, and a curtain which could be drawn beneath the screen to commence or terminate the simulated rainfall. The water tank was a metal six foot by seven foot pan with 0.042 inch diameter holes spaced on four inch centers in the bottom. Below the pan was a screen made of chicken wire covered with cheese cloth. When wetted the cloth sagged into the wire openings and the droplets formed on short pieces of yarn hanging from the sagging cloth. Raindrop size was controlled by the screen openings and yarn size. Raindrop velocity was determined by the height of the screen above the plot surface. Control of the rate of application was attained merely by altering the depth of water in the tank. This apparatus was a bulky laboratory method and required a large frame from which to suspend it.

There are two methods of simulating natural rainfall currently in common use. Basically, one is a series of spray nozzles calibrated to supply water at a known rate to the test plot, and the other involves water dripping from an elevated raindrop forming screen. Both can be operated on moderately steep terrain and are designed to simulate natural rainfall conditions as nearly as possible by regulating precipitation rate, drop size, and drop velocity.

The Rocky Mountain infiltrometer used by Dortignac (1951) consisted essentially of a metal frame holding three standard U.S.D.A. type-F spray nozzles 30 inches above the plot. The type-F nozzle consists of a series of alternating disks and sleeves enclosed in a cylindrical shell. The exact design and arrangement of the various parts strongly affect the resulting spray. The nozzles were pointed upward and toward the plot at an angle of 4° from the vertical. Water was applied to an area of about 40 square feet with the actual measurement plot of 2.5 square feet lying in the center of this area. Runoff from the plot was collected in a trough and measured. The infiltrometer apparatus, 500 gallon water tank, and necessary accessories required a 1.5 ton truck for transportation.

The mobile raindrop applicator used by Osborn (1952 and 1953) and by Rauzi and his co-workers in their rangeland infiltration studies was a modification of the simulated rainfall principle developed by Ellison and Pomerene (1944). Sufficient mobility was incorporated into this unit so that it could be transported on a 1.5 ton truck.

The drip screen could be elevated to a height at which drops falling at 80 percent of terminal velocity of natural precipitation could be attained. Infiltration was measured on a four square foot area (two feet square) located at the center of the circular 13 square foot sprinkled area. Rates of application could be varied from two to six inches per hour.

The Intermountain type-F infiltrometer described by Packer (1957) allowed simultaneous infiltration measurements on three two foot by six foot plots within a watertight nine foot by nine foot sprinkled area. Two banks of seven each F-type nozzles were placed on parallel sides of the plot and canted slightly inward. The nozzles were located 18 inches outside the plot wall and 30 inches above the plot surface. This apparatus required more time to assemble and was bulkier than the Rocky Mountain infiltrometer. Transportation requirements included two 1.5 ton trucks; one for the mechanical apparatus and one for the 1000 gallon water tank.

Sprinkling apparatus are designed to function properly only in still air; therefore, all field units are equipped with wind screens. In most cases they are complicated and time consuming to operate and require a large water supply.

Adams _et al_. (1957) developed an ingenious but complicated field device for evaluating infiltration, splash erosion, and runoff. It is a combination rainfall simulator and cylinder infiltrometer. The raindrop applicators were glass capillary tubes with chrome wires suspended in the openings to regulate flow into a six inch long and 5.75 inch diameter cylinder. Even though it is basically a field operation, determination of the effect on infiltration of the previously mentioned factors involves time consuming laboratory analysis.

Cylinder Infiltrometers. Compared to the sprinkling apparatus, the cylinder infiltrometer is a relatively uncomplicated device which consists of a concentric metal ring driven into the soil to the desired depth. Water is then applied to the ring and the rate and volume of intake measured. The size of cylinder infiltrometers vary from a few inches to several feet in diameter. After water is applied, infiltration is measured in one of two ways. One method is known as the constant head--here water within the infiltrometer is maintained at a constant level throughout the experiment. Intake rates are measured by recording the amount of water applied during a given time period. The second, perhaps less common technique, is to apply a measured quantity of water to the infiltrometer and record the time required for it to be totally infiltrated.

Some workers make use of a second ring which is approximately twice the diameter of the first. The outer ring acts to provide a buffer soil zone which receives the same treatment as the inner area. Only infiltration values from the inner ring are considered in the final analysis. Buffering is simply a method of subjecting both the test plot and an area surrounding it to the same infiltration processes. This eliminates, or at least reduces the infiltration increasing effects of lateral flow of soil water and air from the test area.

Cox (1952) described a recording double ring infiltrometer which used the constant head approach and was capable of continuously recording water intake. The two concentric rings were eight and twenty inches in diameter and each was equipped with a float device to maintain the water head at a constant level both within and between the cylinders. Water was fed to the inner ring from a recording rain gage which had a top area equal to the infiltrometer ring; this enabled water intake to be read directly from the rain gage chart.

Schiff (1953) presented a strong case for a "balanced buffer". He pointed out that a partial buffer, one in which the water level in the outer ring is less than the inner ring, will permit lateral flow from the inner ring. Likewise, an excessive buffer with the water level in the outer ring higher than that of the inner ring, will reduce normal downward flow from the inner ring.

Marshall and Stirk (1950) used ring type infiltrometers with an inner ring of one foot and outside rings varying in size up to three feet in diameter to study the effects of buffering on infiltration rates. They found buffering to generally reduce infiltration rates but they also noted that the results were too variable for the exact extent of the buffering effect to be evaluated. Swartzendruber and Olson (1961) observed that buffering in sand models reduced measured infiltration rates and that buffering effectiveness is strongly dependent on ring diameter. Arnovici (1955) noted similar buffering effects and also pointed out that the diameter of single ring apparatus affects infiltration rates. He found infiltration values to decrease at a fairly constant rate as ring size increases from one to four inches. Using rings larger than four inches in diameter, the infiltration values continued to decrease but at a slower rate.

Arnovici (1955) also demonstrated that, generally speaking, the deeper the cylinder is forced into the soil the less the infiltration rate will be. He continued by noting ring-determined infiltration rates to be strongly affected by the presence or absence of slowly permeable soil layers at or below the bottom of the cylinder. Both Schiff (1953) and Arnovici recognized that infiltration rates increased as the surface water head increased.

After noting that considerable discrepancy between infiltration values measured with cylinder devices often occurred within apparently similar soils, Shull (1954) experimented with single ring infiltrometers to determine the effect of depth of cylinder on infiltration values. He used one foot diameter cylinders placed at depths of 0.2, 0.4, 0.6, and 0.8 of a foot in a cultivated silty loam soil and proved that shallower cylinder depths did result in significantly greater infiltration. This effect became apparent soon after water was applied and remained for at least 16 hours.

In comparing sprinkled plot infiltration values with cylinder measurements on cultivated soils, Slater (1957) found a good correlation especially when median cylinder infiltration rates were used rather than averages, even though the cylinder rates were higher. Studying infiltration on grazed ranges in the southern Great Plains, Rhoades *et al*. (1964) obtained results similar to those of Slater. Comparing cylinder infiltrometers with a mobile infiltrometer such as that used in experiments by Rauzi *et al*. (1968), Rhoades *et al*. showed the cylinder device to take in two to three times more water. This difference they attributed to: (1) the two inch head maintained in the cylinders; (2) greater lateral flow from the cylinders; and (3) surface sealing caused by raindrop impact.

The problem of entrapped air (as discussed in a previous section) and of the relatively small experimental area employed are the most serious drawbacks of cylinder infiltrometers. These disadvantages are, however, a direct result of their attractive features, which include complete portability, ease of operation, small water supply needed, inexpensiveness, and rapid, reasonably accurate results.

Haise *et al*. (1956) and Johnson (1963) have recognized the desirability of all investigators using a standard test for infiltration measurements. They felt that by incorporating some of the advantages of other methods, and at the same time eliminating or reducing their disadvantages, a ring infiltrometer of sufficient size could provide entirely satisfactory results.

Johnson set forth specifications for a standard ring infiltrometer apparatus which was both economic and versatile in operation. Cylinders 20 inches high and of different diameters--12, 18, and 24 inches--would be used. Whether to use a single- or double-ring system would be decided by the experimenter, but if the single-ring setup was chosen the largest ring feasible would be selected. The 12 inch and 24 inch rings would be used for the double-ring experiment. Johnson suggested that the rings be driven six to eight inches into the soil and a constant head of one to six inches be maintained with the aid of some type of depth gage. Water intake measurements should be made at intervals not exceeding 15 minutes during the first hour, 30 minutes during the second hour, and 60 minutes during the remainder of a period of at least six hours. Haise's recommendations were very similar but were designed primarily for determining infiltration characteristics of irrigated soils.

Plot Method. The underlying principle of the plot approach to evaluating infiltration is similar to that of the cylinder infiltrometer. Infiltration rates are calculated in both methods by measuring the time required for water to be infiltrated into a flooded plot. The major difference is that the plot method uses a much larger area. Plot sizes used have ranged from eight square feet (Duley and Domingo, 1943a) to 3600 square feet (Burgy and Luthin, 1956). Parker and Jenny (1945) reported using 0.22 acre plots in studying infiltration into orchard soils but only shallow furrows were flooded, not the entire plot.

The superiority of the use of buffering areas in the plot study approach to infiltration rate determination has been conclusively demonstrated. Kohnke (1938) found infiltration rates to increase as unbuffered linear boundary of the plot increased, and Duley and Domingo (1943a) recorded a 75 percent increase in infiltration rates of unbuffered plots when compared to buffered ones. In comparing results between infiltration values obtained by the plot versus cylinder methods, Burgy and Luthin (1956) found six inch diameter single ring infiltrometers randomly spaced to give values within 30 percent of the mean infiltration rate as determined on a 3600 square foot plot area with uniform soils.

The plot approach has not gained wide acceptance in infiltration measurements, especially field studies. It is susceptible to many of the same errors involved in cylinder devices and requires large amounts of water plus considerable time to prepare the area for testing. Since size of the plot can be controlled, the effects of either increased or retarded lateral flow should be minimal. The method is considered to give good results but requires an essentially level test area. The plot method is probably best suited for a permanent laboratory setup.

<u>Hydrograph Method</u>. The determination of infiltration rates from the analysis of runoff hydrographs has been studied primarily by hydrologists and arises from the need to predict runoff from storms of a given rainfall rate and duration on a watershed. Horton (1937) divided surface runoff producing storms into two categories: those in which the maximum infiltration rate of all soils within the watershed were exceeded at the same time for at least one hour by precipitation rate (rainfall excess period); and, those storms in which

these conditions were not fulfilled. Horton then described a method by which average maximum infiltration rate for the drainage basin could be determined using either type of storm. His basic assumption was that surface runoff approximated the difference between precipitation and infiltration during the period of rainfall-excess. To find the infiltration rate consisted of arriving at a value for infiltration that satisfied the following condition:

$$\text{Surface Runoff} = \text{Total Precipitation} - (\text{Infiltration Rate} \times \text{Duration of Excess}). \qquad (11)$$

Sherman (1938) pointed out that due to the detention of water on the surface, infiltration rate for even a small watershed cannot be assumed as being the difference between rainfall and surface runoff. However, Cook (1946) concluded that infiltration data can be used to determine runoff but only if it is from a relatively small, physically homogenous area. To compute runoff from a large watershed, he suggested, one would have to sum the runoff volumes from all individual homogenous sub-units within the watershed.

Holtan and Kirkpatrick (1950) devised a means of considering separately the three interacting phenomena of rainfall, infiltration, and hydraulics in an attempt to predict runoff where only short term data are available. They presented a family of curves representing runoff expectancy for a ten year return period from small watersheds of five to ten percent slope under various farming practices and vegetation cover. It was noted, however, that a particular set of runoff curves would be valid only for very physically similar watersheds.

Because soils, topography, vegetation, and other infiltration related physical factors vary over a natural watershed, the infiltration rate arrived at by the hydrograph method would, at best, only be an average. This figure would also vary with season and antecedent moisture conditions thus being of limited value in specific land use management activities or in a comparative approach to studying infiltration responses.

Laboratory Studies with Soil Cores. Much effort and time has been devoted to finding suitable ways of determining infiltration and percolation rates of soils by using small samples evaluated in the laboratory. Both undisturbed field samples and samples screened and packed in the laboratory have been studied. The most formidable problem arising with the undisturbed sample is cutting and extracting it from the soil in its natural state. One of the earlier and more intensive studies of this was done by Slater and Byers (1931). They developed an auger-like device for cutting field samples four inches in diameter and nine inches long. The sample was removed by lifting it out by hand where the column was stable enough or by digging out the entire sampler and coating the core with paraffin. In studying undisturbed cores and laboratory samples screened and packed from the same soils, they could make no generalizing statement relating measured percolation values to sampling method. These tests were run on several soil types.

Coile (1936) and Lutz (1947) each described a method for taking small undisturbed soil samples. Both of these methods involved jacking a cylinder into the soil and then digging it out. Goode and Christiansen (1945) developed a lucite cylinder encased by a steel jacket which when driven into the soil was capable of successfully extracting a sample 4.5 inches in diameter and 36 inches long. With this transparent coating the condition of the soil sample was apparent immediately and could be retaken if necessary.

Swanson (1950) developed a portable wheel mounted rig to act as a stabilizer for driving a small core sampler. With this apparatus he was able to obtain an undistrubed soil sample from which relative measures of infiltration could be made. This basic principle is now rather widely used and involves heavier and more mechanized equipment. Andrews and Broadfoot (1958) designed the first hand-operated sampler which used a soil cutter rotating about a fixed sample collecting tube. This device was compact, portable, and capable of removing undisturbed soil cores from depths of up to 17 feet. The cores, however, were only approximately 2.75 inches in diameter and five inches long.

GRASSLAND INFILTRATION STUDIES

It would be difficult to overestimate the importance of infiltration to the ecology of the grasslands. Since a healthy vegetation cover is essential to prevent soil losses by both wind and water erosion and to make the area suitable for grazing, a high infiltration rate is desirable. Obviously a healthy plant cover and high infiltration values are complementary. The desirable effect of native prairie vegetation on infiltration as compared to both cultivated and reseeded areas has been reaffirmed emphatically in the work of Rice and Dragoun (1965) on small watersheds in Nebraska. In managing grasslands the problem arises of manipulating grazing intensity to obtain maximum animal use consistent with ground cover conditions which will permit satisfactory infiltration and prohibit excessive erosion. Achieving such a balance is a most difficult task in a region of low average annual precipitation.

Prior to the severe drought of the 1930's little effort had been directed toward treatment of grazing lands to enhance infiltration and soil moisture conditions. Since then increasing importance has been placed upon finding ways of holding water where it falls and making it available for forage production.

According to Humphrey (1959) the amount of water which can be stored is dependent upon the amount and distribution of precipitation as well as the water holding capacity of the soil layer. The role of specific vegetation factors as related to range infiltration will be discussed, but first it might be well to cite the principal ways in which Humphrey feels vegetation cover influences water. These include interception (water may eventually reach the ground or it may not), helps in retention of water and reducing runoff and erosion, and uses water in the growth process.

Working with soil and vegetation conditions typical of the Intermountain region, Woodward (1943) showed that a high cover density had a three fold effect on infiltration. It resulted in: (1) higher initial maximum infiltration rate, (2) higher final maximum infiltration rate, and (3) increased duration of rain during which maximum infiltration rate exceeded the minimum value. These general results were substantiated on several rangeland sites in Nebraska by Duley and Domingo (1949). They concluded that total ground cover, including live grasses and associated litter, was of greater significance than either grass species or soil characteristics. Contrary to this are the results of Dortignac and Love (1960) who, while studying infiltration in mountain meadows and pine-grass types, found infiltration values to be closely related with vegetation type. This association they attributed to the differences in organic matter and physical properties between types; however, they also noted that infiltration rates vary even within cover types having similar species composition.

Turner and Dortignac (1954) studied infiltration and erosion rates on six common mountain grassland cover types in western Colorado and found both infiltration and erosion to be more closely related to cover type than to percent of ground covered. For instance, the Bluegrass type, with 86 percent of the ground covered, showed an infiltration rate of 1.5 inches per hour while the weed type, consisting of forbs and sparse grass, infiltrated water at 2.9 inches per hour with only 48 percent of the surface covered. Although total weight of sediment eroded from the Bluegrass type was low, the heavy runoff posed a serious threat to less densely vegetated downslope sites. It was pointed out that even though some species show relatively high infiltration rates, they do not necessarily provide satisfactory protection against soil erosion. Earlier Johnson and Niederhof (1941) had arrived at essentially the same results while working in the pine-grassland types along the eastern slope of the central Colorado Rocky Mountains.

In southwestern Idaho Craddock and Pearse (1938) studied the detrimental effects of trampling stands of cheatgrass and wheatgrass. Using sites varying in degree of slope and percent of ground cover, they found that at least 70 percent ground cover was needed for satisfactory runoff and erosion protection.

Results obtained by Rauzi (1960) in Montana and North Dakota indicated a strong relationship between water intake and the amount of natural mulch and forage yield. Where the amount of standing vegetation was dense, it appeared to overshadow the effect of mulch. Johnston (1952) working in Alberta, Canada, compared infiltration rates on undisturbed range plots with values on plots from which fresh mulch, current vegetation, or all surface organic matter had been removed. His results were similar to those reported by Rauzi.

As has just been pointed out, there is a combination of surface cover factors which exert considerable control over the processes of infiltration on grasslands. Any influence which alters this combination will in some way effect infiltration. Grazing is perhaps the most common such impact and is of utmost concern to rangeland managers.

Duley and Domingo (1949) found that overgrazing of Nebraska grasslands caused surficial compaction and removed the bulk of growing plant material, thereby reducing the accumulation of natural mulch cover. Dyksterhuis and Schmutz (1947) noted that when green forage was scarce the coarse, undecayed, natural mulch was grazed. Working with upland short grasses and Western wheatgrass in Kansas, Hopkins (1954) found infiltration to occur considerably faster on ungrazed land and the difference increased with time. After approximately 1.5 hours infiltration rates for the ungrazed and grazed areas leveled off at about eight and 1.5 inches per hour, respectively.

Rauzi et al. (1968) consolidated and summarized extensive infiltration data which had been collected on rangelands in the northern and central plains by his co-workers and himself over a period of twelve years. In all, 670 infiltration tests were made on the 37 test locations specifically chosen to represent as wide a variety of soil and cover conditions as possible. Analysis of the results proved the amount of total weight of vegetal cover to be more important than measures of texture, structure, or percent of bare ground exposed. Generally the amount of vegetal material per acre necessary to increase infiltration rates by one inch per hour varies widely both between and within general soil types. The results did, however, show that it requires less additional total cover to increase infiltration rates on the lighter textured soils and also that soils of good structure infiltrated water more rapidly than poorly structured ones.

Rauzi (1963) compared heavily grazed, moderately grazed, and ungrazed ranges in North Dakota and found the ungrazed areas to have three times the standard crop and to infiltrate water nearly four times faster than heavily grazed areas. Osborn (1952), Texas and Oklahoma; Dortignac and Love (1960) and Dunford (1954), central Colorado mountain grasslands; Branson et al. (1962), northeastern Montana; and, Rhoades et al. (1964), northwestern Oklahoma have all reported infiltration rates to be higher on less intensely grazed ranges.

Runoff from three small differentially grazed South Dakota watersheds was studied during a series of three rainstorms by Sharp et al. (1964). Runoff from the first storm was entirely as expected, i.e., it increased with grazing intensity. The second storm, which was the lightest of the three, caused only a small percentage of the rainfall to become runoff from any area. During the third storm, however, runoff from the lightly grazed watershed was actually more than ten percent greater than from the heavily grazed one. Soil water data collected from the surface one foot of soil during the observation period offers the best explanation. Prior to the initial storm soil water content was least under the lightly grazed cover; but following the second storm this situation had been reversed, thus allowing less infiltration into the lightly grazed watershed during the third storm.

Rangelands which have been subjected to periodic burning naturally have reduced amounts of mulch and therefore, more exposed area between grass clumps. Osborn (1953) demonstrated under actual grazing conditions on the southern plains that 4,000 to 6,000 pounds per acre total ground cover was necessary to provide satisfactory protection against splash erosion. While studying soil water conditions as affected by burning of native eastern Kansas pastures, Hanks and Anderson (1957) took advantage of the opportunity provided by a heavy natural rainstorm to evaluate the effects on infiltration. Their data indicated that about 56 percent of the precipitation became runoff from the burned plots while approximately 16 percent of the precipitation became runoff on the unburned check area. Because at the time of the storm all plots supported nearly a year's vegetation growth, annual burning, regardless of the time of year performed, greatly reduced infiltration values.

Scott (1956) compared relative infiltration values on burned and unburned sites of varying ground cover in northern California. His results indicated significantly higher infiltration rates on the burned plots up to one year after treatment. These results, however, ignore the possible detrimental effects of reduced vegetation cover on the overall hydrology of the site.

On sparsely vegetated rangeland soils in Arizona, Lyford (1968) studied the effect of single plants on infiltration rates. Rates were found to be considerably higher under the plant canopy than in the inter-plant area. Higher under-canopy infiltration rates were attributed primarily to biotic activity, protection from raindrop impact, and protection from animal compaction. Physical differences in the soils were observed to be due mainly to biotic activity and wind deposited soil material. Even though quantitative infiltration rates were affected somewhat by different plant species, general trends remained similar.

Dunford (1954) removed all mulch from 0.01 acre plots in the ponderosa pine type, which is frequently associated with mountain grasslands, and found that heavy surface runoff and erosion occurred. The untreated check plots showed no surface runoff or erosion. Effects of the treatment decreased steadily and were lost completely in five years. On areas where all mulch plus trees were removed, the surface runoff and erosion effects were more pronounced.

The treatment and use of rangelands in a manner which leaves them capable of infiltrating maximum amount of precipitation has long been recognized by range managers as a prime prerequisite to the production of forage and the control of runoff and erosion (Rauzi, 1960). The manipulation of vegetation cover has been generally regarded as the major means of altering infiltration values. Such practices as contour furrowing, range pitting, and water spreading have proven useful in enhancing on site infiltration for at least several years when used in conjunction with seeding and/or controlled grazing. Proper post treatment range utilization is a major factor in extending the effective life of these practices.

Brehm and Malmsten (1954) reviewed earlier studies which evaluated the comparative effects of pitting versus contour furrowing on ranges throughout the northern plains. They noted that in general contour furrowing showed greater benefits than pitting, especially where the furrows were kept small (six inches or less in width and depth) and spaced at distances of about five feet. By using more and smaller furrows, the disadvantage of relatively large areas of disturbed soil was avoided. Best results with both types of treatments were noted on fairly uniform slopes of less than 20 percent.

Barnes (1952) made an evaluation of the effects of range pitting on Wyoming plains ten years after the operation and found carrying capacity of the range had been increased by approximately one-third. The actual storage capacity of the pits was equal to 0.3 inches of precipitation. Data from a limited number of tests showed the pitting had increased infiltration rate by as much as fifty percent. Rauzi and Lang (1956) studied three additional years' data from the same area and expressed the beneficial effects in terms of increased grazing capacity and animal weight gains. Thirteen years after treatment both increases were still evident even though at a declining rate. Working with approximately 20 years of data collected from extensive range experiments in Nebraska, Dragoun and Kuhlman (1968) concluded that surface runoff was reduced and soil water increased by both contour furrowing and pitting, but that furrowing was definitely better.

Where sufficient runoff occurs at least once per year, the results of flood water spreading as a means of increasing infiltration and consequently forage production have generally been favorable. Monson and Quesenberry (1958) reported forage yields on treated ranges in Montana to average 300 to 350 percent greater than on untreated areas. Branson (1956) and Houston (1960), working on separate areas in southeastern Montana, also reported significant forage production gains from water spreading.

One of the major problems which can arise in an operation of this type is that of sedimentation. Hubbell and Gardner (1950) studied this condition extensively in New Mexico and noted that excessive sediment deposits damaged to some degree all grasses studied except western wheatgrass. They did not study the direct effect of this sediment on infiltration; however, soil water data showed that water had penetrated deeper into the flooded soils. This increased soil water effect was more noticeable during the fall of the year than in the spring.

In semi-arid areas of Arizona the effects of range improvement treatments such as brush clearing, pitting, and seeding to grasses were tested on surface characteristics and soil movement due to rainfall. Kincaid and Williams (1966) found the soil exposed by pitting to be quickly washed away but that surface characteristics stabilized after one summer's rain. In most instances the lower portion of 12 foot long rectangular plots on gently sloping terrain showed the most erosion. This they attributed to increased quantity and velocity of overland flow on the lower one-half of the plot.

The adverse effect of rain induced surface crusts on erosion and infiltration is obvious. Fletcher and Martin (1948) designed a study to evaluate the effect of algae and mold crusts of desert soils on these factors. Their conclusions were that organic carbon content and nitrogen content in such crusts were as much as 300 and 400 percent higher than in the underlying soil, respectively. Based on observational evidence they also believed microfloral invasion of the crust to improve infiltration and to aid larger plant species in becoming established.

GRASSLAND INFILTRATION DATA

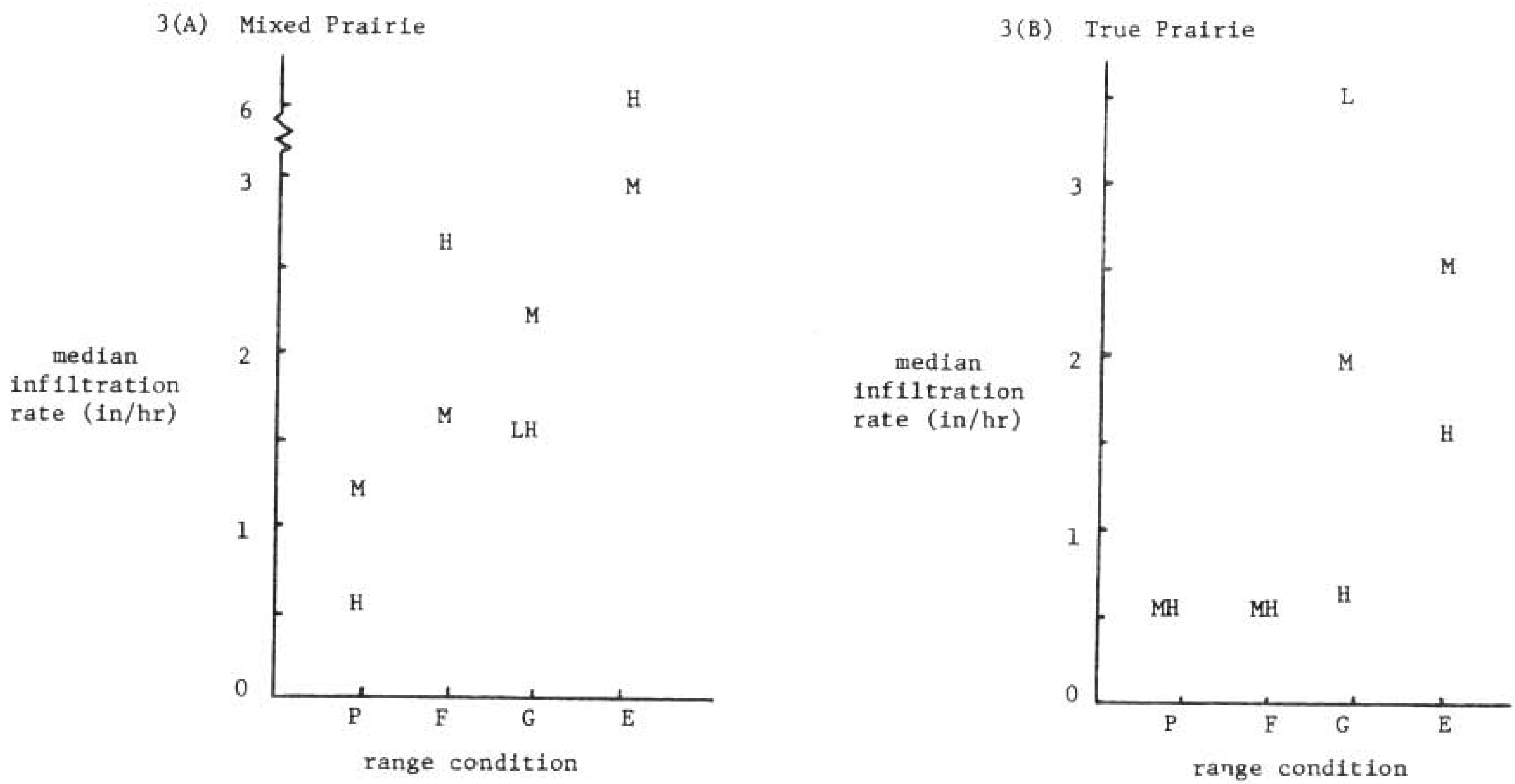
Infiltration rates and supplemental data were drawn from 41 grassland infiltration references. These references describe infiltration studies on numerous contrasting grassland areas. The studies vary in geographical location, season of measurement and infiltration measurement methodology used.

To facilitate comparison and interpretation of data from such a large number of varied infiltration experiments, a composite summary sheet was considered the most practical approach. To supplement the summary sheet, several figures are used to emphasize certain aspects of the data. Appendix A shows the location of experiments.

The composite summary sheet, Appendix B, lists measured infiltration rate data and the pertinent circumstances surrounding its collection. Specific information in Appendix B includes: the reference from which data was taken; location of the experiment; precipitation regime of the area; time of the experiment; soil conditions; plant cover data; cultural use of the immediate site; slope percent; description of the infiltration rate measuring apparatus; measured infiltration rates; and, other comments clarifying experimental circumstances.

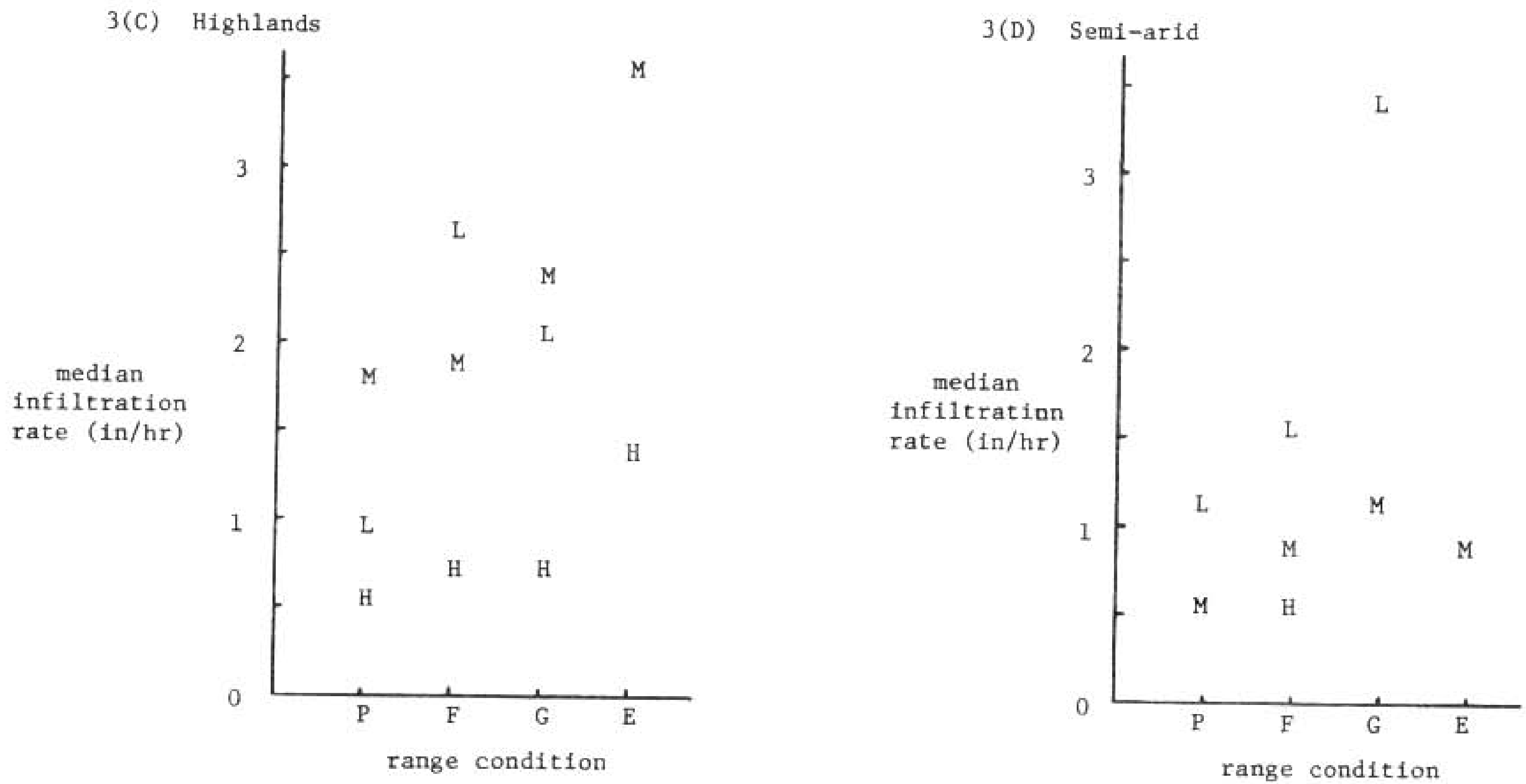
Explanation of Data Arrangement

To simplify the assembling of data for Figures 3 and 4, symbols were used in certain categories of Appendix B. Under "Location"



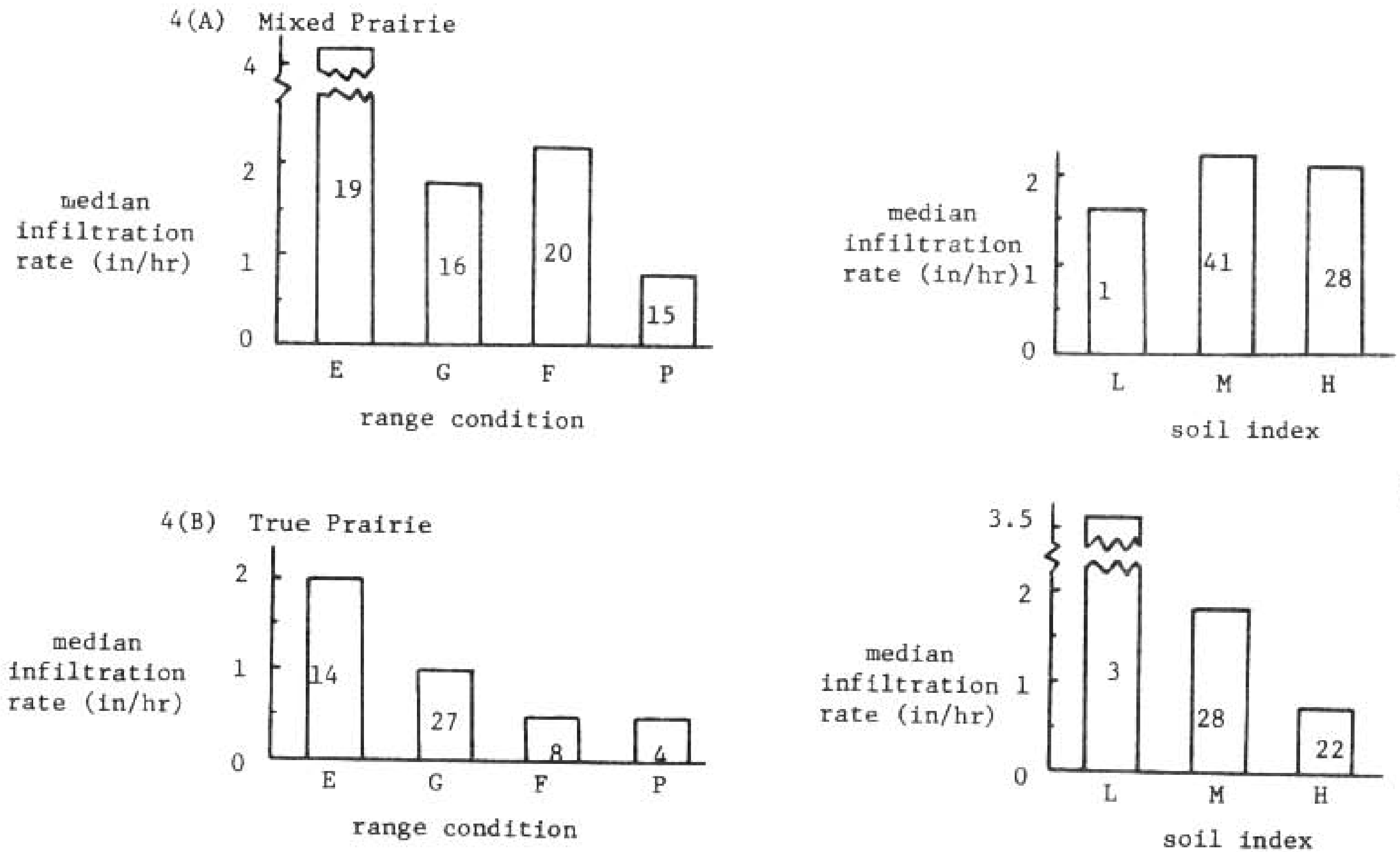
H, M, and L refer to heavy, medium, and light soil indices.

Figures 3A and 3B. Relationship of range condition and soil indices to median infiltration rates.



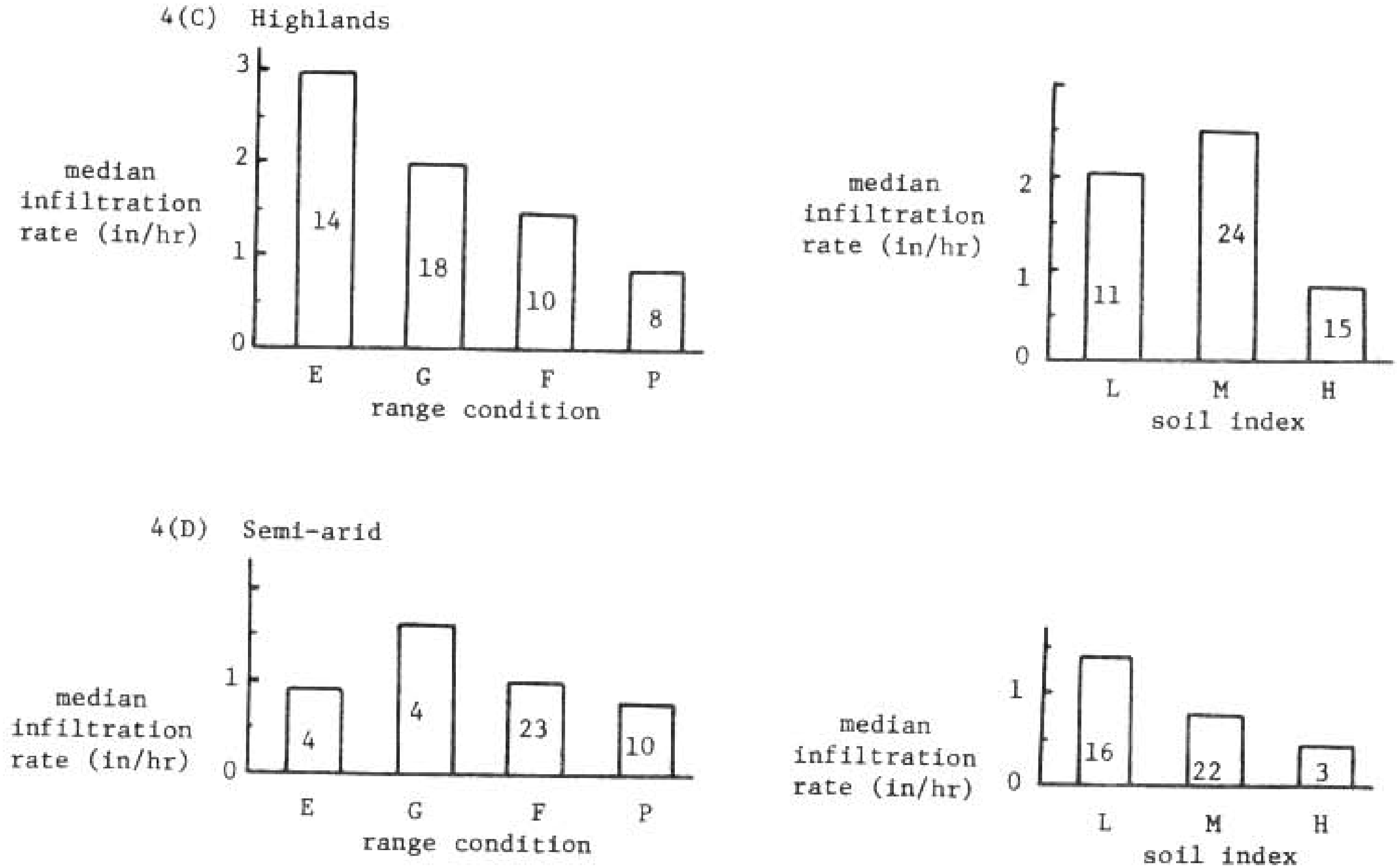
H, M, and L refer to heavy, medium, and light soil indices.

Figures 3C and 3D. Relationship of range condition and soil indices to median infiltration rates.



E, G, F, and P refer to excellent, good, fair, and poor range condition
H, M, and L refer to heavy, medium, and light soil indices

Figures 4A and 4B. Median infiltration rates for various range conditions and soil indices.

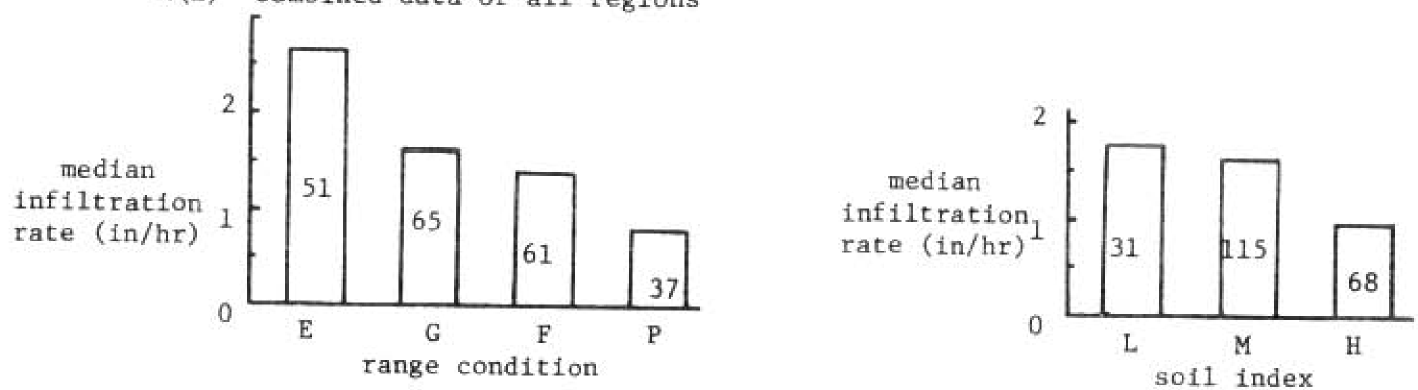


E, G, F, and P refer to excellent, good, fair, and poor range conditions
H, M, and L refer to heavy, medium, and light soil indices

Figures 4C and 4D. Median infiltration rates for various range conditions and soil indices.

54

4(E) Combined data of all regions



E, G, F, and P refer to excellent, good, fair, and poor range condition
H, M, and L refer to heavy, medium, and light soil indices

Figure 4E. Median infiltration rates for various range conditions and soil indices.

the following symbols (T), (M), (H), and (S) are used to indicate True Prairie, Mixed Prairie, Highlands region, and Semi-arid areas, respectively. Soil conditions are keyed by (L), (M), and (H) which refer to light, medium, and heavy soil indices. Range conditions recognized include: excellent, good, fair, or poor condition and are indicated by (E), (G), (F), or (P), respectively.

Where a range condition classification was not specifically reported by the researcher, a subjective decision was made based on available information concerning plant species, percent ground cover, past use of the site, and precipitation regime. Infiltration rate data for each of the range condition classes were further divided into three general soil index classifications: light, medium, and heavy. Where the information was available, consideration was given to both surface and subsurface soil characteristics such as texture, drainage properties, degree of erosion, parent material, and structure in arriving at a relative index rating. In several instances this information was not available and the decision as to which range condition class or soil grouping a site should be placed in involved subjective considerations. In some instances the infiltration data in Appendix B represent an average value for a number of individual infiltration tests on a given site.

Figures 5A, 5B, 5C, and 5D provide a means of schematically indicating the relative frequency with which runoff and infiltration can be expected to occur within the different grassland regions and

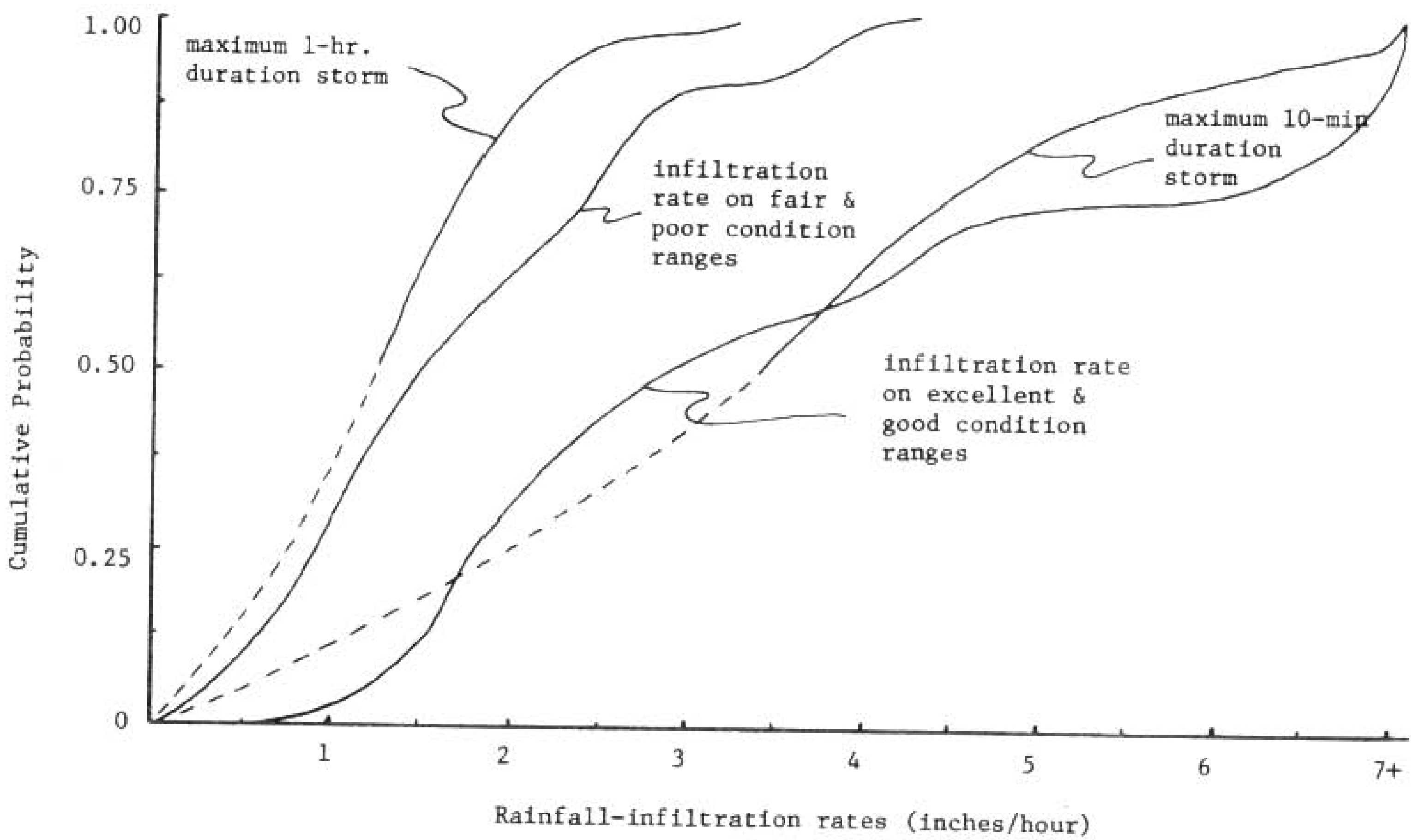


Figure 5A. Rainfall-infiltration rate curves for various range use conditions and storm durations on Mixed Prairie sites.

54

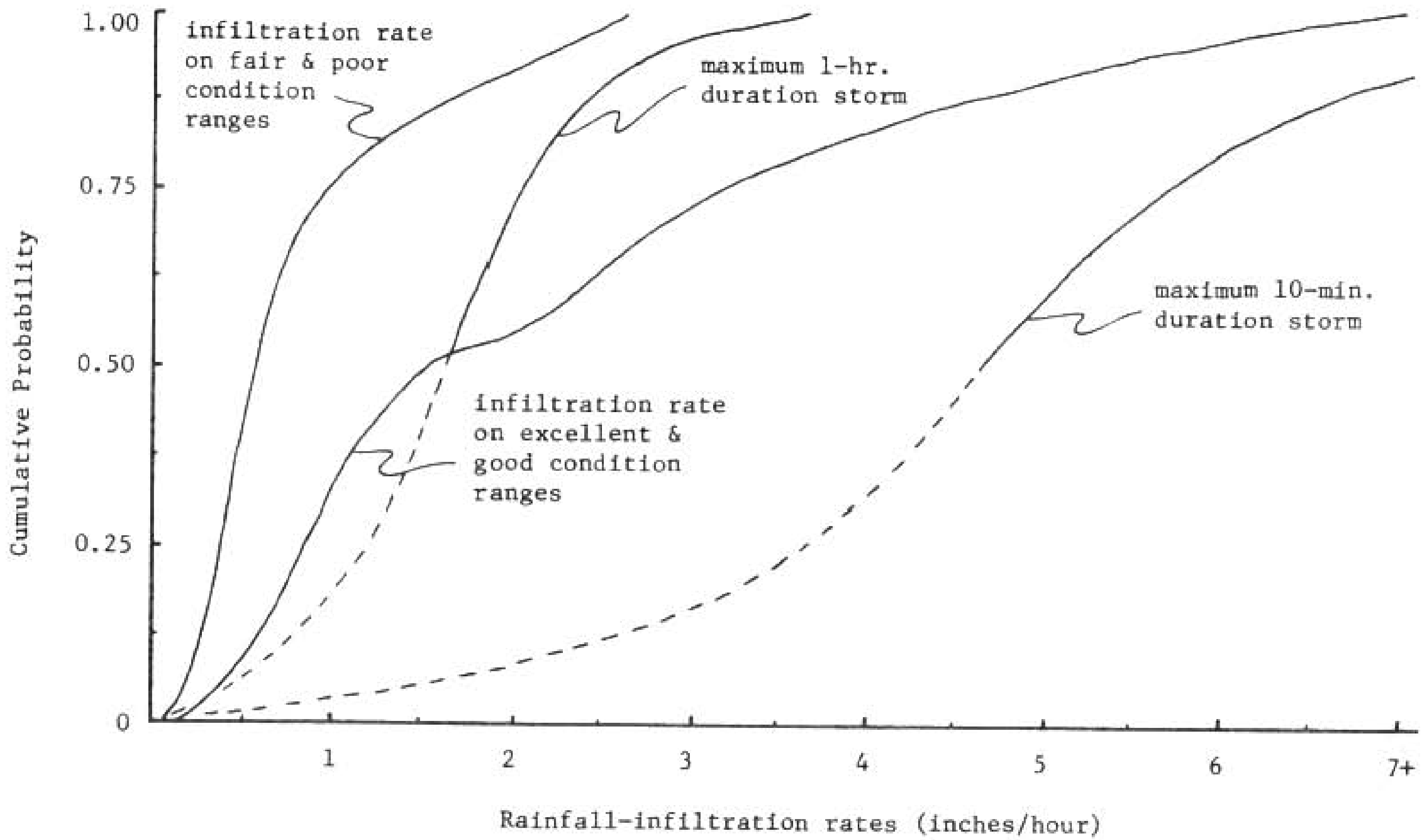


Figure 5B. Rainfall-infiltration rate curves for various range use conditions and storm durations on True Prairie sites.

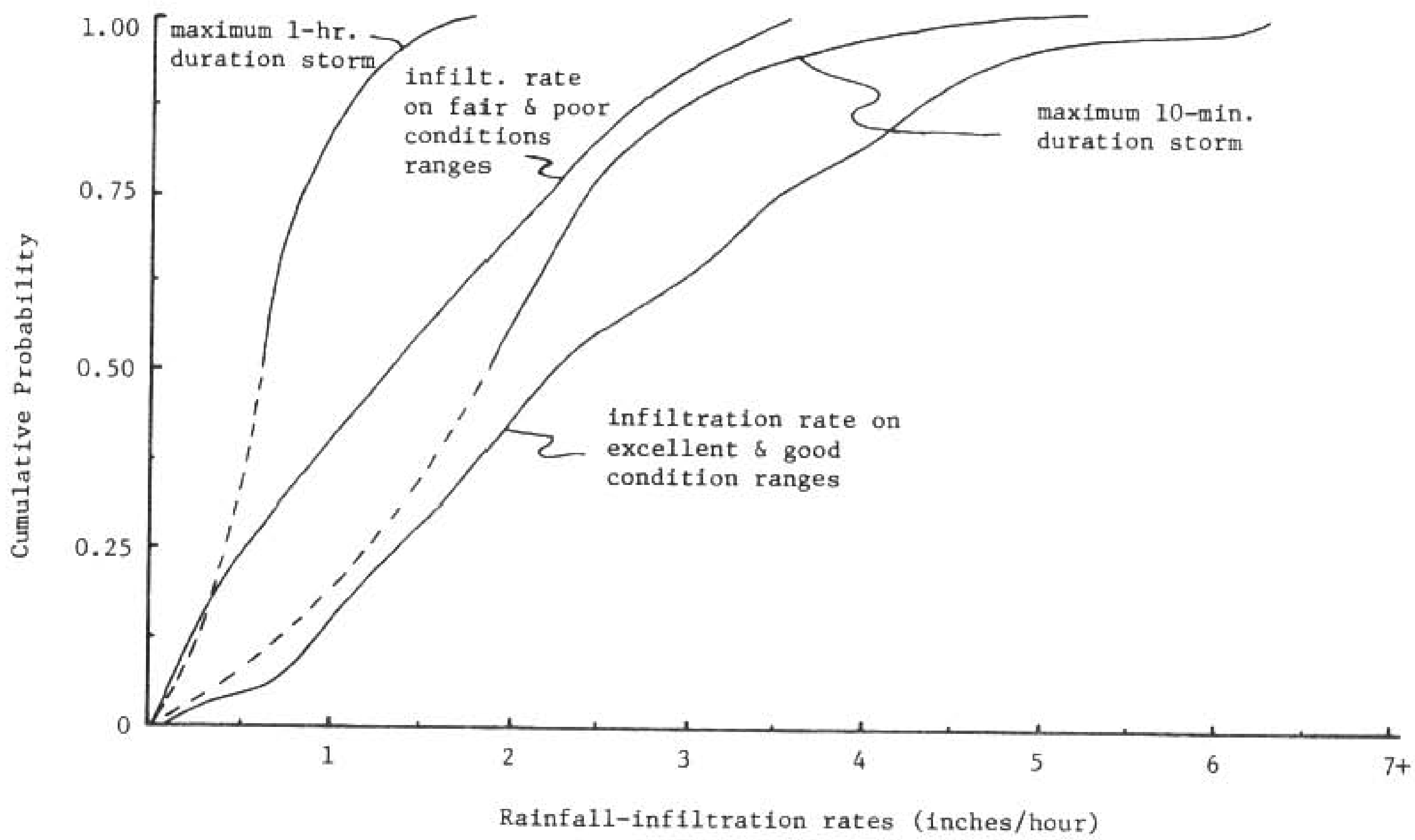


Figure 5C. Rainfall-infiltration rate curves for various range use conditions and storm durations on Highland sites.

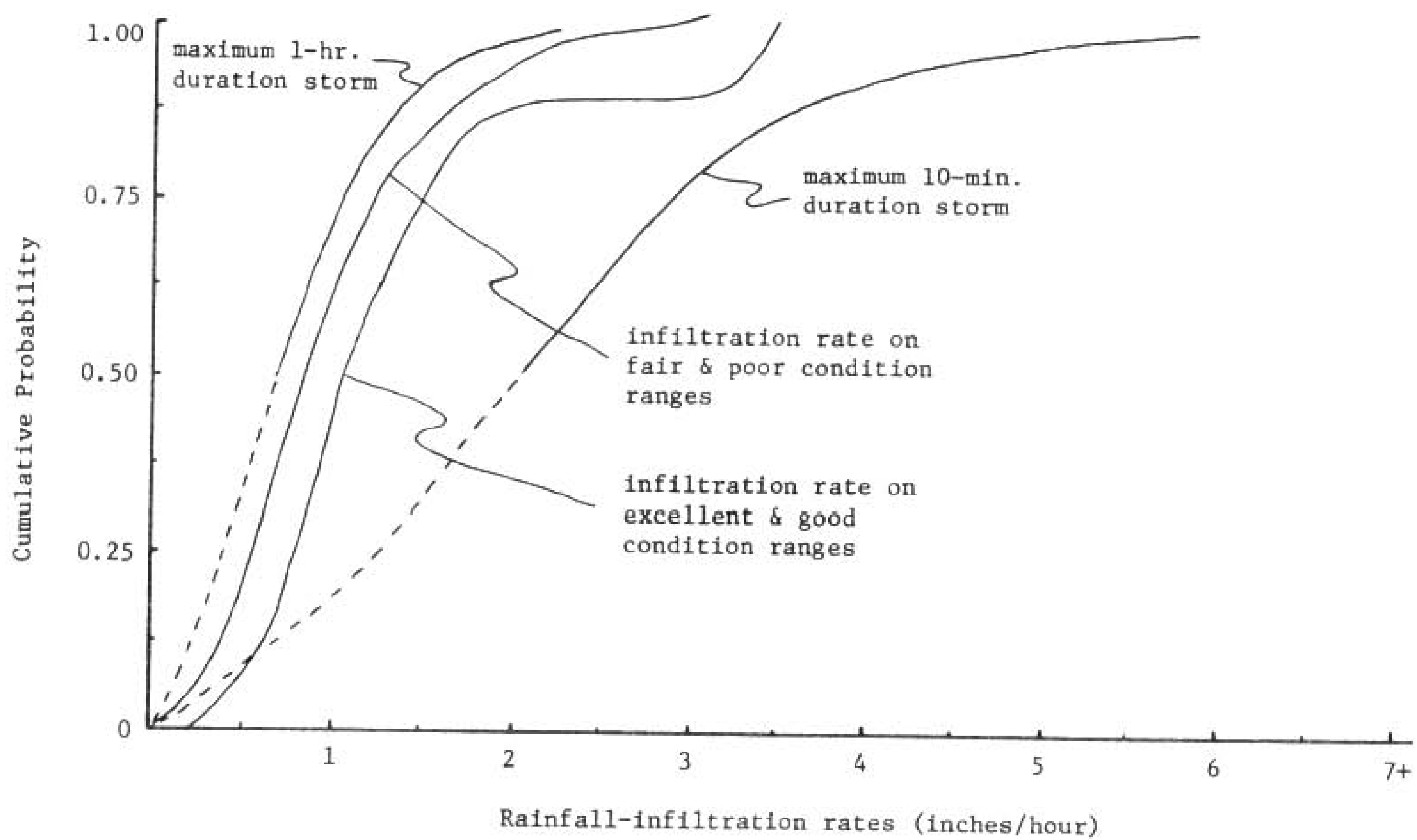


Figure 5D. Rainfall-infiltration rate curves for various range use conditions and storm durations on Semi-arid sites.

range condition groupings. The following procedures were used to categorize the data assembled in Appendix B. First, the individual studies were separated by geographic regions as discussed in the Ecology section, i.e., True Prairie, Mixed Prairie, Highlands, and Semi-arid areas. Then, within each geographical region the quantitative infiltration data were arranged into 0.2 inch per hour infiltration rate classes according to the soil index and range condition described for each test location.

Infiltration values for a one hour period were used because this was the time interval rate most frequently reported in the literature. Where other time intervals were reported, the rate most nearly coinciding with the initial one hour period was used. Also, because a preponderance of the data was thus reported, dry run infiltration rates were used where given.

All of the Mixed Prairie data used in the analysis are from dry run tests. For the True Prairie, 70 percent of the data are from dry run experiments. Only 63 percent of the Semi-arid region data are for dry runs and unfortunately, this is the region in which the initial infiltration rate is the most important. Thirty percent of the Highland region data are for the dry run; however, in this region dry run data are probably less important because of the most frequent showers and generally higher soil moisture content.

Rainfall data in Figure 5 were derived from USWB Technical Paper No. 40 (1961). Cumulative frequency curves were developed for extreme storms of ten minute and one hour durations using return periods of 2, 5, 10, 25, 50, and 100 years. The ten minute duration storm was chosen because over vast areas of the regions studied, storms of short duration and high rainfall rate occur relatively frequently and account for a high percentage of the total annual precipitation. The one hour duration storm was used because much of the infiltration data presented in Figures 3 and 4, and consequently the conclusions derived therefrom, were for infiltration rates calculated from one hour tests. In Figure 5 infiltration data from Appendix B were grouped into two classes. Excellent and good range conditions were grouped together and fair and poor range conditions were likewise grouped.

In referring to the cumulative distribution of infiltration and precipitation rates in Figure 5, it should be recognized that the two rates are not strictly comparable. The precipitation curves represent the probability of storm events not exceeding the indicated precipitation rate. The cumulative distribution of infiltration rates are based only on the reported data and do not include the extremely high or low values which no doubt occur locally over a region.

Interpretation of Results

Infiltration data groupings by geographical area, range condition, and soil indices are illustrated in Figures 3 and 4. These figures represent consolidation of the data in Appendix B, and are presented to facilitate visual analysis of soil, range condition, and infiltration rate relationships. Slight discrepancies in the expected relationship between soil index or range condition and median infiltration rates in Figure 4 are, in many instances, due to lack of data in a particular classification. Where data from all regions are combined (see Figure 4E), the relationships are as anticipated.

Shortage of data is probably the cause for most inconsistencies in Figures 3 and 4. Other reasons could include experimental methods used, very localized test site conditions such as soil cracking, or perhaps other experimental details which were not reported.

Considering range condition data collectively from all sites (see Figure 4E), a definite trend of higher average infiltration rates with improved range condition is noted. Likewise, analyzing all 214 data and disregarding range condition, a trend toward higher infiltration rates with lighter index soils is found. Range condition presents the stronger relationship, however. From Figure 3 it appears that, all regions considered, median infiltration values for medium index soils show the best relationship with range condition.

It should also be recognized that the quantitative aspects of infiltration data are only relative and are not totally correct when applied under circumstances alien to those under which the experiment was conducted.

Mixed Prairie. A relatively wide variation in median infiltration values for different Mixed Prairie range conditions is indicated by the data in Figure 4A. Neither range condition nor soil characteristics can be definitely correlated to Mixed Prairie infiltration rates.

However, when the interaction of the two is analyzed (see Figure 3A) a good relationship between range condition and soils, especially the medium indices, is found.

Infiltration rates were relatively high under excellent range conditions but drop markedly for the other condition classes. Median infiltration rates for good and fair condition ranges were very similar and slightly in excess of two inches per hour with fair condition areas actually having the higher rate. Ranges in poor condition gave the expected low infiltration value.

Data for the Mixed Prairie (see Figure 5A) indicate that an intense ten minute duration storm on fair and poor range conditions will result in runoff at all times. For the one hour duration storm, total infiltration would occur at all times under all range conditions.

Because the Mixed Prairie is of such great importance to grazing interests, it has received considerable range infiltration research attention. However, results from much of the soil-plant-water relationship research have been expressed in terms of differences in range carrying capacity, herbage yield, or animal weight gains, rather than infiltration characteristics. Too often when infiltration rates were reported, it was done only as a matter of secondary importance and therefore complete information was often not presented.

True Prairie. Included in the infiltration data for the True Prairie region are data collected under various degrees of pasture usage in the eastern United States. The eastern data were included because data from the True Prairie were somewhat lacking.

One possible explanation for the apparent lack of rangeland related infiltration data from the True Prairie is that grazing is of relatively minor importance there. Crop oriented agriculture is predominant in that region and as a result, most infiltration studies have been conducted on cultivated sites.

Considering median infiltration values for the entire True Prairie region for range and soil conditions separately (see Figure 4B), it can be seen that soil index shows a very marked effect on measured infiltration rates. Excellent and good range conditions show a positive trend, but between fair and poor range conditions there appears to be no difference.

Examining the interactions of soil and range conditions (see Figure 3B), it is found that on fair and poor condition ranges, soil index is of minimal importance in determining infiltration rates. On excellent and good condition ranges, however, soil index shows a very definite and positive influence on infiltration.

The True Prairie is the only region to show runoff for a one hour duration storm (see Figure 5B). Runoff for the ten minute duration storm at the 0.5 probability level is greater for this region than any other. Although this is contrary to what might be expected, overland flow does not necessarily have to occur when the infiltration rate of a soil is exceeded. Water could be standing on the surface and its runoff inhibited by the very gentle slopes and heavy grass cover characteristic of the region.

Highlands region. In the Highlands various range conditions (see Figure 4C) exhibit excellent infiltration rate relationships. Soil index, however, does not show a definite relationship. In analyzing the interactions of soil index and range condition (see Figure 3C), it is found that medium and heavy index soils do give the expected infiltration relationships, but not light index soils. Generally, the implication is that range condition affects infiltration rates more than soil conditions in the Highlands region.

Infiltration rates for the excellent and good range conditions always exceed the rainfall rate for the one hour duration (see Figure 5C). Also, fair and poor condition ranges appear to be capable of infiltrating the entire one hour duration storm practically all of the time. An intense ten minute duration storm will cause runoff at all times from fair and poor condition ranges. The same storm on excellent and good condition ranges will result in runoff about half of the time.

Semi-arid. Data from the Semi-arid region (see Figure 4D) indicate that range condition has practically no effect on median infiltration rates. From Figures 3D and 4D infiltration rates do, however, appear to be closely related to soil index, especially in the fair and poor range condition areas. This observation cannot be extended to the excellent and good condition ranges because of the lack of data.

In addition to the lack of data for some range conditions, the Semi-arid data also include infiltration values for the Badger Wash study (Thompson, 1968), and possibly others like it. At Badger Wash it was found that the season of year was more closely related to variations in infiltration rates than was range or soil conditions.

For the one hour duration storm (see Figure 5D), total infiltration will occur under all range conditions with the possible exception of extremely high rainfall rates. The ten minute duration storm will produce runoff at all times from all range conditions. These seemingly high infiltration probabilities in Semi-arid regions could be due to the low percentage (less than eight percent) of heavy index soils studied.

Summary and Conclusions

As evidenced by the section on Infiltration Measurement Methods, there is no widely accepted method of determining infiltration rates. To a large degree, this non-standardization is due to modifications of equipment and procedures necessitated by specific field problems. An additional source of confusion encountered when attempting to analyze, compare, and interpret different experimental results is the manner in which the research effort is described.

Infiltration data analyzed herein include values determined with a variety of infiltrometer apparatus types. Also, it was not possible to be completely consistent in reporting data from either wet or dry run tests, or for similar time segments of the infiltration test run. The quantitative aspects of infiltration data are only relative and apply only to the specific conditions under which it was collected.

Bearing in mind the obvious limitations of this interpretation of the amassed infiltration data, it is felt that the 214 infiltration values gathered from 41 references represent a broad spectrum of rangeland sites and experimental circumstances. These data should be sufficient to permit reliable generalizations concerning range and soil conditions as they relate to infiltration rates.

Since field working conditions, economic factors, available time, and accuracy desired will always affect the choice of instruments, the use of different types of infiltrometers will be perpetuated. However, some reasonable standard procedures should be followed when reporting experimental infiltration results. As has been brought out earlier in this report, a tremendous number of factors can materially affect infiltration values. For this reason every effort should be made by the experimenter to include in his report pertinent information concerning at least the generally recognized influencial factors.

In future studies more emphasis should be placed on infiltration rates during the initial phase of the test. This time interval, about the first 20 minutes, is especially critical where an effort is being made to relate land use characteristics to actual infiltration rates. The importance of infiltration data for the longer periods (often reported as final infiltration rates) is not questioned; however, it should not be the only value receiving attention.

The recent trend in infiltration research has been to emphasize the explanation and prediction of infiltration through the application of mathematical and physical theoretical concepts. Future research effort will probably be directed at applying these theoretically derived infiltration approximations, which are currently valid under rather limited conditions, to areas the size of natural watersheds.

BIBLIOGRAPHY

Adam, K. M., and A. T. Corey. 1968. Diffusion of entrapped gas from porous media. Hydrology Paper No. 27, Colorado State University, Fort Collins, 42 pp.

Adams, J. E. 1966. Influence of mulches on runoff, erosion, and soil moisture depletion. Proc. Soil Sci. Soc. Am., 30(1):110-114.

Adams, J. E., D. Kirkham, and D. R. Nielsen. 1957. A portable rainfall-simulator infiltrometer and physical measurements of soil in place. Proc. Soil Sci. Soc. Am., 21(5):473-477.

Alderfer, R. B., and F. G. Merkle. 1944. The comparative effects of surface application versus incorporation of various mulching materials of structure, permeability, runoff, and other soil properties. Proc. Soil Sci. Soc. Am., 8:79-86.

Alderfer, R. B., and R. R. Robinson. 1947. Runoff from pastures in relation to grazing intensity and soil compaction. Jour. Am. Soc. Agron., 39(11):948-958.

Andrews, L. A., and W. M. Broadfoot. 1958. The San Dimas soil core sampler. Soil Science, 85:297-301.

Arend, J. L., and R. E. Horton. 1943. Some effects of rain intensity, erosion, and sedimentation on infiltration-capacity. Proc. Soil Sci. Soc. Am., 7:82-89.

Arnovici, V. S. 1955. Model study of ring infiltrometer performance under low initial soil moisture. Proc. Soil Sci. Soc. Am., 19(1):1-6.

Barnes, O. K. 1952. Pitting and other treatments on native range. Wyo. Agr. Expt. Stat. Bull. No. 318, 23 pp.

Beutner, E. L., R. R. Gaebe, and R. E. Horton. 1940. Sprinkled-plot runoff-and infiltration-experiments on Arizona desert soils. Trans. Am. Geophys. Union, 21(2):550-558.

Bodman, G. B., and E. A. Colman. 1943. Moisture and energy conditions during downward entry of water into soils. Proc. Soil Sci. Soc. Am., 8:116-122.

Borchert, J. R. 1950. The climate of the central North American grassland. Assoc. Am. Geog. Ann., 40(1):1-39.

Bouyoucos, G. J. 1922. Relation between heat of wetting, moisture equivalent, and unfree water. Soil Science, 14:431-434.

Bouyoucos, G. J. 1929. A new simple, and rapid method for determining the moisture equivalent of soils, and the role of soil colloids on this moisture equivalent. Soil Science, 27:233-241.

Branson, F. A. 1956. Range forage production changes on a water spreader in southeastern Montana. Jour. Range Mangt., 9:187-191.

Branson, F. A., R. F. Miller, and I. S. McQueen. 1962. Effects of contour furrowing, grazing intensities and soils on infiltration rates, soil moisture and vegetation near Fort Peck, Montana. Jour. Range Mangt., 15(3):151-158.

Brehm, C. D., and H. E. Malmsten. 1954. Contour furrows on pasture and range land. Jour. Soil and Water Conserv., 9(3):111-114.

Brown, J. W., and J. L. Schuster. 1969. Effects of grazing on a hardland site in southern High Plains. Jour. Range Mangt., 22(6):418-423.

Burgy, R. H., and J. N. Luthin. 1956. A test of the single- and bouble-ring types of infiltrometers. Trans. Am. Geophys. Union, 37(2):189-191.

Christiansen, J. E. 1944. Effect of entrapped air upon the permeability of soils. Soil Science, 58:355-365.

Coile, T. S. 1936. Soil samplers. Soil Science, 42(2):139-142.

Cook, H. L. 1946. The infiltration approach to the calculation of surface runoff. Trans. Am. Geophys. Union, 27(5):726-743.

Cox, M. B. 1952. Recording the intake of water into the soil. Jour. Soil and Water Conserv., 7(2):79-80.

Craddock, G. W., and C. K. Pearse. 1938. Surface runoff and erosion on granitic mountain soils of Idaho as influenced by range cover, soil disturbance, slope, and precipitation intensity. U. S. Dept. Agr. Cir. No. 482, 24 pp.

DeBano, L. F. 1968. Observations on water repellent soils in western United States. Symp. on Water-Repellent Soils Proc. 1968:17-29, illus. Univ. Calif., Riverside, Calif.

Dee, R. F., T. W. Box, and E. Robertson, Jr. 1966. Intensity of grass vegetation on water intake of Pullman silty clay loam. Jour. Range Mangt., 19(2):77-79.

Diebold, C. H. 1951. Soil layers causing runoff from hardland wheat fields in Colorado and New Mexico. Jour. Soil and Water Conserv., 6(4):202-209.

Dortignac, E. J. 1951. Design and operation of the Rocky Mountain Infiltrometer. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, Paper No. 5, 68 pp.

Dortignac, E. J., and L. D. Love. 1960. Relation of plant cover to infiltration and erosion in Ponderosa Pine forests of Colorado. Trans. Am. Soc. Agr. Engin., 3(1):58-61.

Dortignac, E. J., and L. D. Love. 1961. Infiltration studies on Ponderosa Pine ranges of Colorado. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, Paper No. 59, 34 pp.

Dragoun, F. J., and A. R. Kuhlman. 1968. Effect of pasture management practices on runoff. Jour. Soil and Water Conserv., 23(2): 55-57.

Duley, F. L. 1939. Surface factors affecting the rate of intake of water by soils. Proc. Soil Sci. Soc. Am., 4:60-64.

Duley, F. L., and C. E. Domingo. 1943. Effect of water temperature on rate of infiltration. Proc. Soil Sci. Soc. Am., 8:129-131.

Duley, F. L., and C. E. Domingo. 1943a. Reducing the error in infiltration determinations by means of buffer areas. Jour. Am. Soc. Agron., 35(7):595-605.

Duley, F. L., and C. E. Domingo. 1949. Effect of grass on intake of water. Nebr. Agr. Expt. Sta. Bull. No. 159, 15 pp.

Duley, F. L., and O. E. Hays. 1932. The effect of the degree of slope on runoff and soil erosion. Jour. Agr. Research, 45:349-360.

Duley, F. L., and L. L. Kelly. 1939. Effect of soil type, slope, and surface conditions on intake of water. Nebr. Agr. Expt. Sta. Bull. No. 112, 16 pp.

Duley, F. L., and L. L. Kelly. 1941. Surface condition of soil and time of application as related to intake of water. U. S. Dept. Agr. Cir. No. 608, 30 pp.

Dunford, E. G. 1954. Surface runoff and erosion from pine grasslands of the Colorado front range. Jour. Forestry, 52(12): 923-927.

Dyksterhuis, E. J., and E. M. Schmutz. 1947. Natural mulches or "litter" of grasslands: with kinds and amounts on a southern prairie. Ecology, 28(2):163-179.

Ellison, W. D., and W. H. Pomerene. 1944. A rainfall applicator. Agr. Engin., 25(6):220.

Epstein, E., W. J. Grant, and R. A. Struchtemeyer. 1966. Effect of stones on runoff, erosion, and soil moisture. Proc. Soil Sci. Soc. Am., 30(5):638-640.

Evanko, A. B., and R. A. Peterson. 1955. Comparisons of protected and grazed mountain rangelands in southwestern Montana. Ecology, 36:71-82.

Evans, D. D., D. Kirkham, and R. K. Frevert. 1951. Infiltration and permeability in soil overlying an impermeable layer. Proc. Soil Sci. Soc. Am., 15:50-54.

Fletcher, J. E., and W. P. Martin. 1948. Some effects of algae and molds in the rain-crust of desert soils. Ecology, 29(1):95-100.

Free, G. R., G. M. Browning, and G. W. Musgrave. 1940. Relative infiltration and related physical characteristics of certain soils. U. S. Dept. Agr. Tech. Bull. No. 729, 51 pp.

Free, G. R., and V. J. Palmer. 1940. Interrelationship of infiltration, air movement, and pore size in graded silica sand. Proc. Soil Sci. Soc. Am., 5:390-398.

Gardner, W. 1920. A capillary transmission constant and methods of determining it experimentally. Soil Science, 10:103-126.

Gardner, W. R. 1967. Development of modern infiltration theory and application in hydrology. Trans. Am. Soc. Agr. Engin., 10(3):379-381, 390.

Goode, W. E., and J. E. Christiansen. 1945. Obtaining soil cores for permeability tests. Agr. Engin., 26:153-155.

Gray, D. M., D. I. Norum, and J. M. Murray. 1969. Infiltration characteristics of prairie soils. Presented at Annual Meeting Society Range Mangt., Calgary, Canada.

Green, W. H., and G. A. Ampt. 1911. Studies in soil physics, Part I, Flow of air and water through soils. Jour. Agr. Science, 4:1-24.

Haise, H. R., W. W. Donnan, J. T. Phelan, L. F. Lawhon, and D. G. Shockley. 1956. The use of cylinder infiltrometers to determine the intake characteristics of irrigated soils. U. S. Dept. Agr., Agr. Research Service, 41-7, 10 pp.

Hanks, R. J., and K. L. Anderson. 1957. Pasture burning and moisture conservation. Jour. Soil and Water Conserv., 12(5): 228-229.

Haupt, H. F. 1967. Infiltration, overland flow, and soil movement on frozen and snow-covered plots. Water Resources Research, 3(1):145-161.

Hendrickson, B. H. 1934. The choking of pore-space in the soil and its relation to runoff and erosion. Trans. Am. Geophys. Union, 14(2):500-505.

Holtan, H. N. 1961. A concept for infiltration estimates in watershed engineering. U. S. Dept. Agr., Agr. Research Service, 41-51, 25 pp.

Holtan, H. N., C. B. England, and V. O. Shanholtz. 1967. Concepts in hydrologic soil grouping. Trans. Am. Soc. Agr. Engin., 10(3):407-410.

Holtan, H. N., and M. H. Kirkpatrick, Jr. 1950. Rainfall, infiltration, and hydraulics of flow in runoff computation. Trans. Am. Geophys. Union, 31(5):771-779.

Hopkins, H. H. 1954. Effects of mulch upon certain factors of the grassland environment. Jour. Range Mangt., 7(6):255-258.

Horner, W. W., and C. L. Lloyd. 1940. Infiltration-capacity values as determined from a study of an eighteen-month record at Edwardsville, Illinois. Trans. Am. Geophys. Union, 21(2):522-541.

Horton, R. E. 1933. The role of infiltration in the hydrologic cycle. Trans. Am. Geophys. Union, 14(2):446-460.

Horton, R. E. 1937. Determination of infiltration-capacity for large drainage-basins. Trans. Am. Geophys. Union, 18(2):371-383.

Horton, R. E. 1940. An approach toward a physical interpretation of infiltration-capacity. Proc. Soil Sci. Soc. Am., 5:399-417.

Houston, W. R. 1960. Effects of water spreading on range vegetation in eastern Montana. Jour. Range Mangt., 13:289-293.

Hubbell, D. S., and J. L. Gardner. 1950. Effects of diverting sediment-laden runoff from arroyos to range and crop lands. U. S. Dept. Agr. Tech. Bull. No. 1012, 83 pp.

Huberty, M. R., and A. F. Pillsbury. 1941. Factors influencing infiltration-rates into some California soils. Trans. Am. Geophys. Union, 22(2):686-697.

Humphrey, R. R. 1959. Forage and water. Jour. Range Mangt., 12(4):164-170.

Johnson, A. I. 1963. A field method for measurement of infiltration. U. S. Geological Survey Water Supply Paper No. 1544-F, 27 pp.

Johnson, C. E. 1957. Utilizing the decomposition of organic residues to increase infiltration rates in water spreading. Trans. Am. Geophys. Union, 38(3):326-332.

Johnson, W. M., and C. H. Niederhof. 1941. Some relationships of plant cover to runoff, erosion, and infiltration on granite soils. Jour. Forestry, 39:854-858.

Johnston, A. 1962. Effects of grazing intensity and cover on the water-intake rate of fescue grassland. Jour. Range Mangt., 15(1):79-82.

Kincaid, D. R., J. L. Gardner, and H. A. Schreiber. 1964. Soil and vegetation parameters affecting infiltration under semiarid conditions. Int. Assoc. Sci. Hydrology Publ. No. 65, pp. 440-453.

Kincaid, D. R., and G. Williams. 1966. Rainfall effects on soil surface characteristics following range improvement treatments. Jour. Range Mangt., 19(6):346-351.

Klute, A. 1952. A numerical method for solving the flow equation for water in unsaturated materials. Soil Science, 73:105-116.

Kohnke, H. 1938. A method for studying infiltration. Proc. Soil Sci. Soc. Am., 3:296-303.

Kohnke, H. 1968. Soil Physics. McGraw-Hill Book Co., New York, pp. 28-30.

Kohnke, H., and A. R. Bertrand. 1959. Soil Conservation. McGraw-Hill Co., New York, 298 pp.

Krammes, J. S., and L. F. DeBano. 1965. Soil wettability: a neglected factor in watershed management. Water Resources Research, 1(2):283-286.

Krimgold, D. B., and O. Beenhouwer. 1954. Estimating infiltration. Agr. Engin., 35:719-725.

Lauritzen, C. W., and N. L. Stoltenberg. 1940. Some factors which influence infiltration and its measurement in Houston Black Clay. Jour. Am. Soc. Agron., 32(11):853-866.

Laws, J. O. 1941. Measurements of the fall-velocity of water-drops and raindrops. Trans. Am. Geophys. Union, 22(3):709-721.

Laws, J. O., and D. A. Parsons. 1943. The relation of raindrop-size to intensity. Trans. Am. Geophys. Union, 24(2):452-460.

Lewis, M. R., and W. L. Powers. 1938. A study of factors affecting infiltration. Proc. Soil Sci. Soc. Am., 3:334-339.

Leithead, H. L. 1950. Field methods used to demonstrate range conservation. Jour. Range Mangt., 3(2):95-99.

Linsley, R. K., Jr., M. A. Kohler, and J. L. Paulhus. 1949. Applied Hydrology. McGraw-Hill Book Co., New York, 689 pp.

Lowdermilk, W. C. 1930. Influence of forest litter on runoff, percolation, and erosion. Jour. Forestry, 28:474-491.

Lutz, J. F. 1947. Apparatus for collecting undisturbed soil samples. Soil Science, 64(5):399-401.

Lyford, F. P. 1968. Soil infiltration rates as affected by desert vegetation. Master's Thesis, University of Arizona, Tuscon, Arizona.

Mace, A. C., Jr. 1968. Effects of soil freezing on water yields. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, Research Note No. 121.

Marshall, T. J., and G. B. Stirk. 1950. The effect of lateral movement of water in soil on infiltration measurements. Australian Jour. Agr. Res., 1(3):253-265.

Mazurak, A. P., and E. C. Conard. 1959. Rates of water entry in the three great soil groups after seven years in grasses and small grains. Agron. Jour., 51(5):264-267.

Miller, D. E., and W. H. Gardner. 1962. Water infiltration into stratified soil. Proc. Soil Sci. Soc. Am., 26(2):115-119.

Monson, O. W., and J. R. Quesenberry. 1958. Putting flood waters to work on rangelands. Mont. Agr. Expt. Sta. Bull. No. 543, 39 pp.

Moore, R. E. 1940. The relation of soil temperature to soil moisture: pressure potential, retention, and infiltration rates. Proc. Soil Sci. Soc. Am., 5:61-64.

Musgrave, G. W., and G. R. Free. 1936. Some factors which modify the rate and total amount of infiltration of field soils. Jour. Am. Soc. Agron., 28(9):727-739.

Musgrave, G. W., and G. R. Free. 1937. Preliminary report on a determination of comparative infiltration-rates of some major soil-types. Trans. Am. Geophys. Union, 18(2):345-349.

Neal, J. H. 1938. The effect of the degree of slope and rainfall characteristics on runoff and soil erosion. University of Missouri Agr. Expt. Sta. Res. Bull. No. 280, 47 pp.

Neuberger, J. W., A. L. Sharp, and A. R. Kuhlman. 1964. Precipitation-runoff relationship on western South Dakota watersheds. South Dakota Farm and Home Research, 15(1):6-9.

Osborn, H. B. 1952. Storing rainfall at the grass roots. Jour. Range Mangt., 5(6):408-414.

Osborn, H. B. 1953. Field measurements of soil splash to evaluate ground cover. Jour. Soil and Water Conserv., 8(6):255-260, 266.

Osborn, H. B., and R. V. Keppel. 1965. Dense rain gage networks as a supplement to regional networks in semiarid regions. Int. Assoc. Sci. Hydrol., Publ. No. 68, pp. 675-687.

Osborn, H. B., and W. N. Reynolds. 1963. Convective storm patterns in the southwestern United States. Int. Assoc. Sci. Hydrol. Bull., 8(3):71-83.

Pace, C. P. 1966. Grazing and watershed value of native Arizona plants _in_ Native Plants and Animals as Resources in Arid Lands of the Southwestern United States. Am. Assoc. Advance. Sci., Rocky Mountain and Southwest Division Contribution, 8:31-40.

Packer, P. E. 1957. Intermountain infiltrometer. U. S. Forest Service Intermountain Forest and Range Experiment Station, Misc. Publ. No. 14, 41 pp.

Parker, E. R., and H. Jenny. 1945. Water infiltration into soil. Soil Science, 60:353-376.

Parr, J. F., and A. R. Bertrand. 1960. Water infiltration into soils. Advances in Agronomy, 12:311-363.

Paulsen, H. A., Jr. 1969. Forage values on a mountain grassland-Aspen range in western Colorado. Jour. Range Mangt., 22(2): 102-107.

Pearse, C. K., and S. B. Woolley. 1936. The influence of range plant cover on the rate of absorption of surface water by soil. Jour. Forestry, 34(12):844-847.

Philip, J. R. 1957. The theory of infiltration: three moisture profiles and relation to experiment. Soil Science, 84(2): 163-178.

Philip, J. R. 1957a. The theory of infiltration: 1. The infiltration equation and its solution. Soil Science, 83:345-357.

Philip, J. R. 1957b. The theory of infiltration: 2. The profile of infinity. Soil Science, 83:435-448.

Philip, J. R. 1957c. The theory of infiltration: 3. Moisture profiles and relation to experiment. Soil Science, 84:163-178.

Philip, J. R. 1957d. The theory of infiltration: 4. Sorptivity and algebraic infiltration equations. Soil Science, 84:257-264.

Philip, J. R. 1957e. The theory of infiltration: 5. The influence of the initial moisture content. Soil Science, 84:329-339.

Philip, J. R. 1968. Steady infiltration from buried point sources and spherical cavities. Water Resources Research, 4(5): 1039-1047.

Powers, W. L. 1934. Soil water movement as affected by confined air. Jour. Agr. Research, 49:1125-1133.

Rauzi, F. 1960. Water intake studies on range soils at three locations in the Northern Plains. Jour. Range Mangt., 13(4):179-184.

Rauzi, F. 1963. Water intake and plant composition as affected by differential grazing on rangeland. Jour. Soil and Water Conserv., 18(3):114-116.

Rauzi, F., C. L. Fly, and E. J. Dyksterhuis. 1968. Water intake on midcontinental rangelands as influenced by soil and plant cover. U. S. Dept. Agr. Tech. Bull. No. 1390, 58 pp.

Rauzi, F., and C. L. Hanson. 1966. Water intake and runoff as affected by intensity of grazing. Jour. Range Mangt., 19(6):351-356.

Rauzi, F., and A. R. Kuhlman. 1961. Water intake as affected by soil and vegetation on certain western South Dakota rangelands. Jour. Range Mangt., 14(5):267-271.

Rauzi, F., and R. L. Lang. 1956. Improving short grass range by pitting. Wyo. Agr. Expt. Sta. Bull. No. 344, 11 pp.

Rauzi, R., and D. E. Smika. 1963. Water intake on rangeland as affected by simulated grazing and fertilization. Jour. Range Mangt., 16(3):125-128.

Reed, M. J., and R. A. Peterson. 1961. Vegetation, soil, and cattle responses to grazing on Northern Great Plains range. U. S. Dept. Agr. Tech. Bull. No. 1252, 79 pp.

Reinhart, K. G., and R. E. Taylor. 1954. Infiltration and available water storage capacity in the soil. Trans. Am. Geophys. Union, 35(5):791-795.

Rhoades, E. D., L. F. Locke, H. M. Taylor, and E. H. McIlvain. 1964. Water intake on a sandy range as affected by twenty years of differential cattle stocking rates. Jour. Range Mangt., 17(4):185-190.

Rice, W. L., and F. J. Dragoun. 1965. Effects of runoff volume from perennial prairie grass seeded on cultivated land. Jour. Soil and Water Conserv., 20(2):63-64.

Richards, L. A. 1952. Report of the subcommittee on permeability and infiltration, committee terminology. Proc. Soil Sci. Soc. Am., 16(1):85-88.

Rogers, J. S., L. C. Johnson, D. M. Jones, and B. A. Jones, Jr. 1967. Sources of error in calculating the kinetic energy of rainfall. Jour. Soil and Water Conserv., 22(4):140-142.

Russel, J. C. 1946. The movement of water in soil columns and the theory of the control section. Proc. Soil Sci. Soc. Am., 11:119-123.

Schiff, L. 1953. The effect of surface head on infiltration rates based on the performance of ring infiltrometers and ponds. Trans. Am. Geophys. Union, 34(2):257-265.

Schumm, S. A., and G. C. Lusby. 1963. Seasonal variation of infiltration capacity and runoff on hillslopes in western Colorado. Jour. Geophys. Research, 68(12):3655-3666.

Scott, V. J. 1956. Relative infiltration rates on burned and unburned upland soils. Trans. Am. Geophys. Union, 37(1):67-69.

Sharp, A. L., J. J. Bond, J. W. Neuberger, A. R. Kuhlman, and J. K. Lewis. 1964. Runoff as affected by intensity of grazing on rangeland. Jour. Soil and Water Conserv., 19(3):103-106.

Sherman, L. K. 1938. Determination of infiltration-rates from surface-runoff. Trans. Am. Geophys. Union, 19(1):430-435.

Shull, H. 1964. Influence of installation depth on infiltration from unbuffered cylinder infiltrometers. Soil Science, 97:279-280.

Skaggs, R. W., L. F. Huggins, E. J. Monke, and G. R. Foster. 1968. Experimental evaluation of infiltration equations. Presented at Annual Meeting of Am. Soc. Agr. Engin., Logan, Utah,- Paper No. 68-213, 21 pp.

Slater, C. C. 1957. Cylinder infiltrometers for determining rates of infiltration. Proc. Soil Sci. Soc. Am., 21(4):457-460.

Slater, C. S., and H. G. Byers. 1931. A laboratory study of the field percolation rates of soils. U. S. Dept. Agr. Tech. Bull. No. 232, 23 pp.

Smith, W. O. 1949. Pedological relations of infiltration phenomena. Trans. Am. Geophys. Union, 30(4):555-562.

Smith, W. O., H. W. Olsen, R. A. Bagnold, and J. C. Rice. 1966. Certain flows of air and water in sands during infiltration. Soil Science, 101(6):441-449.

Stuaffer, R. S. 1938. Infiltration capacity of some Illinois soils. Jour. Am. Soc. Agron., 30:493-500.

Stoeckeler, J. H., and S. Weitzman. 1960. Infiltration rates in frozen soils in northern Minnesota. Proc. Soil Sci. Soc. Am., 24(2):137-139.

Storey, H. C. 1955. Frozen soil and spring and winter floods. in Water: 1955 Yearbook of Agriculture, pp. 179-184.

Swanson, C. L. 1950. A portable soil core sampler and penterometer. Agron. Jour., 42(9):447-451.

Swanson, N. P., and A. R. Dedrick. 1966. Simulation of increased slope length on small runoff plots. Proc. Am. Soc. Agr. Engin., 59th Annual Meeting.

Swartzendruber, D., and T. C. Olson. 1961. Sand-model study of buffer effects in the double-ring infiltrometer. Proc. Soil Sci. Soc. Am., 25(1):5-8.

Tackett, J. L., and R. W. Pearson. 1965. Some characteristics of soil crusts formed by simulated rainfall. Soil Science, 99(6):407-413.

Tanner, C. B., and C. P. Mamaril. 1959. Pasture soil compaction by animal traffic. Agron. Jour., 51(6):329-331.

Taylor, S. A., and N. C. Heuser. 1953. Water entry and downward movement in undisturbed soil cores. Proc. Soil Sci. Soc. Am., 17(2):195-201.

Thomas, G. W., and V. A. Young. 1954. Relation of soils, rainfall, and grazing management to vegetation, Western Edwards Plateau of Texas. Texas Agr. Expt. Sta. Bull. No. 786, 22 pp.

Thompson, J. R. 1968. Effect of grazing on infiltration in a western watershed. Jour. Soil and Water Conserv., 23(2):63-65.

Tisdall, A. L. 1951. Antecedent soil moisture and its relation to infiltration. Australian Jour. Agr. Res., 2:342-348.

Trimble, G. R., Jr., R. S. Sartz, and R. S. Pierce. 1958. How type of soil frost affects infiltration. Jour. Soil and Water Conserv., 13(2):81-82.

Turner, G. T., and E. J. Dortignac. 1954. Infiltration, erosion, and herbage production of some mountain grasslands in western Colorado. Jour. Forestry, 52:858-860.

U. S. Weather Bureau. 1961. Rainfall frequency atlas of the United States. Weather Bureau Technical Paper No. 40, May 1961, pp. 61.

Watson, K. K. 1965. A statistical treatment of the factors affecting the infiltration capacity of a field soil. Jour. Hydrology, 3:58-65.

Weaver, J. E. 1954. North American Prairie. Johnsen Publishing Co., Lincoln, Nebraska, 348 pp.

Weaver, J. E., and F. W. Albertson. 1956. Grasslands of the Great Plains. Johnsen Publishing Co., Lincoln, Nebraska, 395 pp.

Wilm, H. G. 1941. Methods for the measurement of infiltration. Trans. Am. Geophys. Union, 22(3):678-686.

Wilm, H. G. 1943. The application and measurement of artificial rainfall on types FA and F infiltrometers. Trans. Am. Geophys. Union, 24(2):480-484.

Wischmeier, W. H. 1966. Relation of field-plot runoff to management and physical factors. Proc. Soil Sci. Soc. Am., 30(2): 272-277.

Wischmeier, W. H., and J. V. Mannering. 1965. Effect of organic matter content of the soil on infiltration. Jour. Soil and Water Conserv., 20(4):150-152.

Wischmeier, W. H., and D. D. Smith. 1958. Rainfall energy and its relationship to soil loss. Trans. Am. Geophys. Union, 39(2):285-291.

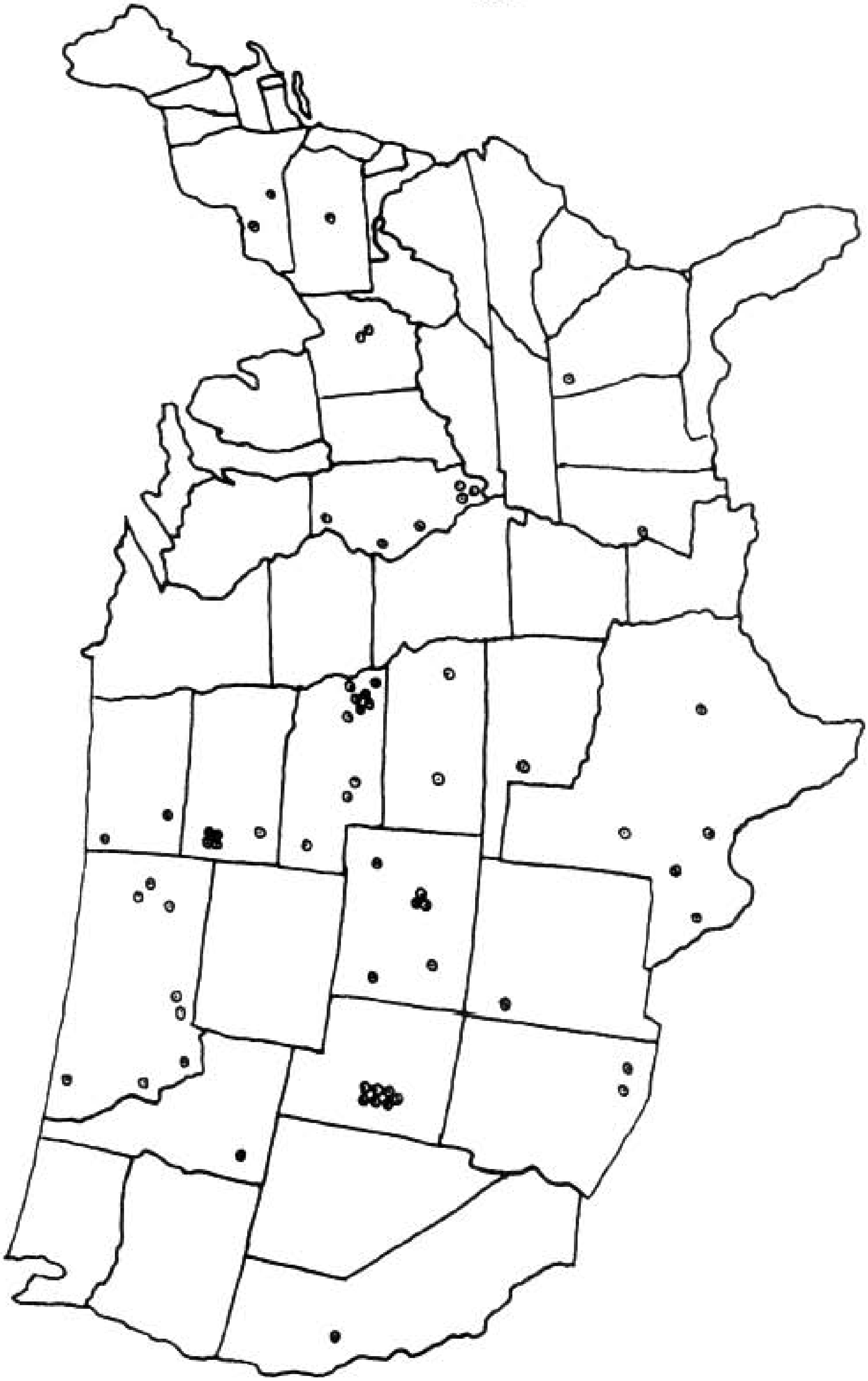
Woodward, L. 1943. Infiltration-capacities of some plant-soil complexes on Utah range watershed lands. Trans. Am. Geophys. Union, 24(2):468-475.

Zwerman, P. J. 1947. The value of improved land use as measured by preliminary data on relative infiltration rates. Jour. Am. Soc. Agron., 39:135-140.

APPENDIX

APPENDIX A

SKETCH MAP SHOWING APPROXIMATE LOCATIONS OF INFILTRATION EXPERIMENTS



Sketch map showing approximate locations of infiltration experiments

APPENDIX B

TABLE 3

INFILTRATION DATA SUMMARY SHEET

TABLE 3

INFILTRATION DATA SUMMARY SHEET

EXPLANATION OF CODES USED ON SUMMARY SHEET

UNDER INFILTRATION RATE, ONLY THOSE INFILTRATION VALUES PRECEDED BY AN ASTERISK (*) ARE USED IN THE FINAL DATA ANALYSIS.

UNDER HEADINGS---EXPERIMENT LOCATION, SOIL, RANGE CONDITION---SITES FROM WHICH INFILTRATION DATA ARE USED IN THE ANALYSIS ARE CODED BY LETTERS:

GEOGRAPHIC REGIONS RECOGNIZED UNDER EXPERIMENT LOCATION INCLUDE:

HIGHLANDS	(H)
SEMI-ARID	(S)
MIXED PRAIRIE	(M)
TRUE PRAIRIE	(T)

UNDER SOIL, THE BROAD CLASSIFICATIONS OF SOIL FACTORS ARE KEYED BY:

HEAVY INDEX SOILS	(H)
MEDIUM INDEX SOILS	(M)
LIGHT INDEX SOILS	(L)

THE NOTATIONS USED TO DESIGNATE RELATIVE RANGE CONDITIONS ARE

EXCELLENT	(E)
GOOD	(G)
FAIR	(F)
POOR	(P)

THE FOLLOWING IS A LIST OF COMMON AND BOTANICAL NAMES OF PLANTS REFERRED TO IN THE SUMMARY SHEET.

ASPEN	POPULUS TREMULOIDES
BIG BLUESTEM	ANDROPOGON GERARDI
BLUE GRAMA	BOUTELOUA GRACILIS
BLUEGRASS	POA SPP.
BLUESTEM	ANDROPOGON SPP.
BROOMSEDGE	ANDROPOGON VIRGINICUS
BUCKBRUSH	CEANOTHUS SPP.
BUFFALOGRASS	BUCHLOE DACTYLOIDES
CHAMISE	ADENOSTOMA FASCICULATUM
CLOVER	TRIFOLIUM SPP.
CURLY MESQUITE	HILARIA BELANGERI
DALLIS GRASS	PASPALUM DILATATUM
FESCUE	FESTUCA SPP.
GRAMA	BOUTELOUA SPP.
GREEN NEEDLEGRASS	STIPA VIRIDULA
IDAHO FESCUE	FESTUCA IDAHOENSIS
JAPANESE BROME	BROMUS JAPONICUS
JUNEGRASS	KOELERIA CRISTATA
JUNIPER	JUNIPERUS SPP.
KUDZU	PUERARIA THUNBERGIANA
LESPEDEZA	LESPEDEZA STRIATA
MANZANITA	ARCTOSTAPHYLOS UVA-URSI
MOUNTAIN BUNCHGRASS TYPE:	
ARIZONA FESCUE	FESTUCA ARIZONICA
MANZANITA	ARCTOSTAPHYLOS UVA-URSI
MOUNTAIN MUHLY	MUHLENBERGIA MONTANA
MUHLY	MUHLENBERGIA SPP.
NEEDLE AND THREAD	STIPA COMATA
NEEDLEGRASS	STIPA SPP.
OAK	QUERCUS SPP.
ORCHARD GRASS	DACTYLIS GLOMERATA
PADDOCK LOVE GRASS	ERAGROSTIS LEPTOSTACHYA
PARRAMATTA GRASS	SPOROBOLUS CAPENSIS
PINYON PINE	PINUS EDULIS
PRAIRIE SANDREED	CALAMOVILFA LONGIFOLIA
REEDGRASS	CALAMAGROSTIS SPP.
ROUGH FESCUE	FESTUCA SCABRELLA
RUSSIAN WILDRYE	ELYMUS JUNCEUS
SAGEBRUSH	ARTEMISIA SPP.
SANDBERG BLUEGRASS	POA SECUNDA
SAND DROPSEED	SPOROBOLUS CRYPTANDRUS
SAND SAGEBRUSH	ARTEMISIA FILIFOLIA
SEDGE	CAREX SPP.
SILVER BLUESTEM	BOTHRIOCHLOA SACCHAROIDES
SMOOTH BROMEGRASS	BROMUS INERMUS
THREAD LEAF SEDGE	CAREX FILIFOLIA
THURBER FESCUE	FESTUCA THURBERI
TIMOTHY	PHLEUM PRATENSE
TOBOSAGRASS	HILARIA MUTICA
VALLEY BUNCHGRASS TYPE:	
ARIZONA FESCUE	FESTUCA ARIZONICA
FRINGED SAGEBRUSH	ARTEMISIA FRIGIDA
MOUNTAIN MUHLY	MUHLENBERGIA MONTANA
VETCH	VICIA SPP.
WESTERN WHEATGRASS	AGROPYRON SMITHII
WHEATGRASS	AGROPYRON SPP.
WILD BARLEY	HORDEUM SPP.

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
ALDERFER AND ROBINSON 1947	(T) NEAR STATE COLLEGE PENNA. 40-45 IN.		(H) CLAY LOAM	PASTURE--50 PERCENT COVER	(P) HEAVILY GRAZED	TYPE-F INFILTROMETER ON 6 X 12 FT PLOTS. WATER APPLICATION RATE WAS 1.4 IN/HR FOR ONE HOUR	30	*0.78	RATES ARE AVERAGES FOR ONE HOUR DURATION. WET RUNS MADE 24 HOURS AFTER PREWETTING.
				PASTURE--90 PERCENT COVER	(G) MODERATELY GRAZED		27	*1.13	
					(F) MODERATELY GRAZED--AREA TRAMPLED		27	*0.46	
				PERENNIAL GRASS --100 PERCENT COVER	(E) UNGRAZED FOR 5 YEARS		25	*1.40	
				PASTURE--85 PERCENT COVER	(P) HEAVILY GRAZED		21	*0.77	
				PASTURE--100 PERCENT COVER	(E) LIGHTLY GRAZED		20	*1.39	
				PASTURE--75 PERCENT COVER	(G) MODERATELY GRAZED		23	*1.04	
				PERENNIAL GRASS --100 PERCENT COVER	(E) UNGRAZED		15	*1.40	
							12	*1.40	
			(H) SANDY LOAM	PASTURE--50 PERCENT COVER	(G) MODERATELY GRAZED		17	*0.70	
				PASTURE--85 PERCENT COVER	(P) HEAVILY GRAZED		17	*0.83	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
BEUTNER ET AL. 1940	(S) SOIL CONS. EXP. STATION NEAR TUCSON ARIZONA	THROUGH-OUT YEAR	(L) GRAVELLY	NONE EXCEPT FOR VERY LITTLE PLANT LITTER	(P)	FOUR 1.5 MULSIFYRE NOZZLES MOUNTED OVERHEAD.. PLOTS WERE 6 X 24 FEET.	5.3	*0.92 AT 0.35 HR. 0.42 AT 0.16 HR.	DRY WET
			(L) SANDY LOAM		(P)		8.9	*1.42 AT 0.47 HR. 0.71 AT 0.18 HR.	DRY WET
	10-12 IN.		(L) SANDY LOAM		(P)	WET RUNS WERE MADE WITHIN 24 HOURS OF DRY RUNS.	13.7	*1.36 AT 0.36 HR. 0.65 AT 0.20 HR.	DRY WET
			(M) FINE SANDY LOAM	NONE	(P)	WATER APPLIED AT CONSTANT RATE.	2.0	*0.63 AT 0.28 HR. 0.44 AT 0.20 HR.	DRY WET
			(M) FINE SANDY LOAM	VERY SPARSE FEW WEEDS	(P)		2.1	*0.83 AT 0.69 HR.	DRY
							1.4	*0.75 AT 0.70 HR.	DRY
			(M) SILT LOAM	SOME ANNUAL PLANTS AND LITTER	(F)		0.8	*0.60 AT 0.70 HR. 0.34 AT 0.46 HR.	DRY WET
			(L) SAND	SOME LITTER	(F)		1.3	*2.22 AT 0.78 HR. 1.29 AT 0.58 HR.	DRY WET
			(M) SANDY CLAY LOAM	NONE	(F)		1.3	*0.28 AT 0.17 HR. 0.18 AT 0.21 HR.	DRY WET
				SOME ANNUAL PLANTS AND LITTER	(G)		2.9	*1.78 AT 0.48 HR. 1.05 AT 0.39 HR.	DRY WET
				SPARSE WEEDS	(F)		3.3	*0.97 AT 0.78 HR. 0.69 AT 0.23 HR.	DRY WET
			(L) STONY LOAM	NONE	(P)		2.3	*0.87 AT 0.54 HR. 0.62 AT 0.28 HR.	DRY WET
				SPARSE GRASS	(F)		4.9	*1.52 AT 0.26 HR. 1.08 AT 0.26 HR.	DRY WET
			(L) SANDY LOAM	SPARSE ANNUAL PLANTS AND LITTER	(F)		2.6	*1.15 AT 0.28 HR. 0.70 AT 0.16 HR.	DRY WET
BRANSON, ET AL. 1962	(M) 20 MI. WEST OF FT. PECK, MONT.	07/58	(M) SILTY CLAY ALLUVIUM	BARE SEMI-SLICK AREAS	(P) LIGHTLY GRAZED	MOBILE RAINDROP SIMULATOR	NEARLY LEVEL	*0.17	RATES ARE AVE. FOR SINGLE DRY RUNS OF 1 HOUR AT A CONSTANT APPLICATION RATE.
	12-14 IN.				(P) HEAVILY GRAZED			*0.55	
		07/59			(P) LIGHTLY GRAZED			*0.44	
					(P) HEAVILY GRAZED			*0.10	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
BROWN AND SCHUSTER 1949	(M) FLAT TOP MT., 20 MI. NW OF SNYDER, TEXAS		(M) CLAYEY TO CLAY LOAM	BUFFALOGRASS AND TOBOSAGRASS	(F) UNRESTRICTED GRAZING	DOUBLE RING INFILTROMETER	8 - 10	*3.9	RATES ARE AVE. FOR 4 TEST RUNS ON EACH SITE.
	20 IN.		(M) CLAYEY	BUFFALOGRASS, TOBOSAGRASS AND GRAMA	(E) UNGRAZED			*15.3	
DEE ET AL. 1966	(M) TEXAS TECH. COLLEGE RESEARCH FARM AT PANTEX, TEXAS	SUMMERS 1963 AND 1964	(H) SILTY CLAY LOAM	BUFFALOGRASS HERBAGE AND LITTER	(P)	DOUBLE RING INFILTROMETER		*0.84	WATER LEVEL WAS HELD AT A CONTANT HEAD OF ABOUT 2 IN. RATES ARE FOR FIRST ONE HOUR OF TWO HOUR TEST RUNS.
				BLUE GRAMA HERBAGE AND LITTER	(F)			*2.56	
	20-22 IN.			SILVER BLUESTEM HERBAGE AND LITTER	(E)			*2.51	
				SAND DROPSEED HERBAGE AND LITTER	(G)			*2.08	
				ANNUAL WEEDS	(F)			*1.9	
				EARLY STAGE PERENNIAL GRASS	(G)			*2.8	
				LATE STAGE PERENNIAL GRASS	(E)			*4.2	
				REGRESSING STAGE PERENNIAL GRASSES	(P)			*1.05	
DIEPOLD 1951	(M) U.S. DRY LANDS EXP. STA., AKRON COLORADO	09/49	(M) LOAMY	GRAMA-BUFFALO-GRASS SOD	(G) PASTURE	PORTABLE INFILTROMETER USING TYPE-F NOZZLES SPRINKLING A 5 FT 1 IN X 6 FT PLOT	0.5-2.0	*1.85 AT 1.0 HR. 1.1 AT 0.6 HR. 0.85 AT 1.0 HR.	DRY WET WET
	15 IN.			FALLOW CRUSTED	CULTIVATED	APPLICATION RATE WAS 2 IN/HR FOR ONE HOUR		0.90 AT 0.6 HR. 0.80 AT 1.0 HR. 0.45 AT 0.6 HR. 0.40 AT 1.0 HR.	DRY DRY WET WET
DORTIGNAC AND LOVE [illegible]	(M) MANITOU EXP. FOREST COLORADO	SUMMERS 1946 AND 1952	(M) SANDY LOAM OR GRAVELLY	PINE-LITTER	(G) CONTROLLED SUMMER GRAZING	ROCKY MOUNTAIN INFILTROMETER	0.5 TO 50; AV. 9	2.37	RATES ARE FOR FINAL 20 MIN. OF 50 MIN. WET RUNS.
				PINE-GRASS				*1.94	
	16-18 IN.			GRASS PASTURE				*1.57	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
DULEY AND DOMINGO 1949	(T)AGRONOMY FARM, LINCOLN,NEB.	11/07/39	(M) SILTY CLAY LOAM	NATIVE GRASSES	(G) MOWED TO 1 INCH IN HEIGHT	INFILTRATION MEASURED IN A FRAME 16 X 72 IN., WATER APPLIED BY MANUALLY SWINGING A SMALL SPRINKLER NOZZLE OVER THE PLOT.	10	*1.40	WATER WAS APPLIED FOR 1.5 HOUR PERIODS ON DRY SOIL. RATES INDICATED WERE CONSIDERED TO BE CONSTANT.
	(T) 15 MI. SW OF LINCOLN,NEB.	07/02/40	(M) SILTY CLAY LOAM	MOSTLY BLUE GRAMA, DENSITY 0.4	(F) GRAZED		8	*1.75	
25-30 IN. APPLIES TO ALL EAST NEB. LOCATIONS		07/09/40		MIXED GRASSES	(F) OVERGRAZED BUT WITH GOOD LITTER COVER		7	*2.40	
		07/11/40		GRASSES 6 TO 10 INCHES TALL	(E) UNGRAZED, GOOD LITTER COVER		7	*2.55	
		07/09/40		BUFFALOGRASS, DENSITY 0.5	(G)		13	*2.00	
	(T) 30 MI. NE OF LINCOLN,NEB.	06/19/41	(M) SILTY CLAY LOAM	BLUEGRASS ,VERY LITTLE LITTER	(P) OVERGRAZED AND TRAMPLED		3	*0.14	
		06/21/41		BIG BLUESTEM 1.5 - 2 FT HIGH	(G)		3	*2.02	
	(T) ABOUT 100 MI. NW OF LINCOLN, NEBRASKA IN MERRACK CO.	08/25/39	(L) SANDY	NATIVE GRASSES 18 IN. HIGH	(G)		4	*5.20	
		08/29/39		NATIVE GRASSES	(G) GRASS MOWED AT SURFACE AND REMOVED		8	*2.34	
		08/25/39			ALL VEGETATION REMOVED AND SPADED 6 IN. DEEP		4	4.02	
DULEY AND KELLY 1939	(T) SOUTH-EASTERN NEB. 25-30 IN.	SUMMER 1938	(H) SILT LOAM WITH HEAVY SUB-SOIL	NATIVE SOD	(E) NONE	6.6 X 33 FOOT (1/200 AC.) PLOT SPRINKLED WITH OVERHEAD GARDEN NOZZLES	5	*3.30	RATES WERE MEASURED AT END OF 1.5 HR. APPLICATION RATE WAS 3 IN. PER HOUR.
				NATIVE SOD	(F) CLIPPED CLOSELY AND SURFACE LITTER REMOVED			*0.65	
				NONE	CULTIVATED			0.49	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
DULEY AND KELLY 1941	(T) SOUTH-EASTERN NEB. 25-30 IN.	09/38	(M) SILT LOAM TO SILTY CLAY LOAM	SOD, GRASS 18 INCHES HIGH	(E) VIRGIN, NEVER PLOWED	GARDEN SPRINKLER NOZZLES	4	*1.43	RATES ARE AVE. FOR 3 HOURS AT SPRINKLING RATE OF 3.5 INCHES PER HOUR.
				MIXED GRASS SOD			10	*1.49	
		04/38		BARE	CULTIVATED		5.0	0.44	
EVANKO AND PETERSON 1955	(M) NEAR VIGILANTE EXP. RANGE ON BEAVER-HEAD NAT. FOREST 14 IN.	JULY AND AUGUST 1949	(M) CLAY LOAM	FORBS, WESTERN WHEATGRASS, BLUE-GRASS, JUNEGRASS AND FESCUE	(E) UNGRAZED	FLOODING TYPE INFILTROMETER	GENTLY ROLLING	10.9 FOR 1ST IN. WATER *3.5 FOR 2ND IN. WATER	
					(P) HEAVILY GRAZED			7.5 FOR 1ST IN. WATER *2.7 FOR 2ND IN. WATER	
			(M) SANDY LOAM	REEDGRASS, FESCUE AND FORBS	(E) UNGRAZED			6.3 FOR 1ST IN. WATER *2.1 FOR 2ND IN. WATER	
					(G) LIGHTLY GRAZED			6.2 FOR 1ST IN. WATER *2.4 FOR 2ND IN. WATER	
			(M) CLAY LOAM WITH GRAVEL	FORBS, FESCUE, AND BLUEGRASS	(E) UNGRAZED			12.0 FOR 1ST IN. WATER *4.0 FOR 2ND IN. WATER	
					(P) HEAVILY GRAZED			7.5 FOR 1ST IN. WATER *2.7 FOR 2ND IN. WATER	
			(M) CLAYEY WITH GRAVEL	FORBS, FESCUE, AND BLUEGRASS	(E) UNGRAZED			6.0 FOR 1ST IN. WATER *2.6 FOR 2ND IN. WATER	
					(F) MODERATELY GRAZED			3.3 FOR 1ST IN. WATER *1.6 FOR 2ND IN. WATER	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
FREE ET AL. 1940	NATION WIDE 68 SITES	1937 AND 1938	SILT LOAMS	VARIED	VARIED	9 INCH DIAMETER CYLINDER JACKED INTO SOIL. CYLINDERS WERE EITHER 18 OR 24 INCHES LONG AND INSERTED UNTIL ONLY 2 OR 3 INCHES PROTRUDED ABOVE THE SOIL SURFACE. CONSTANT HEAD OF 0.25 IN. MAINTAINED. RATES GIVEN ARE FOR 3RD HOUR OF WET RUNS.	VARIED	0.71	AVERAGE FOR 22 SITES
			CLAY AND CLAY LOAMS					0.23	AVERAGE FOR 17 SITES
			SANDY LOAMS					0.81	AVERAGE FOR 12 SITES
			GRAVELLY SILT LOAMS					2.57	AVERAGE FOR 11 SITES
			LOAMS					0.22	AVERAGE FOR 5 SITES
	(S) NAVAJO SOIL AND WATER EXP. STA. GALLUP NEW MEXICO	05/04/38	(L) SANDY LOAM		(F) RANGELAND			*2.9	
		05/02/38	(M) SANDY CLAY LOAM					*1.4	
	10-15 IN.	04/15/38	(H) CLAY					**0.1	
		04/28/38	(M) SANDY LOAM	SPARSE STAND OF GRASS				*1.7	
		04/25/38	(H) CLAY LOAM					*1.0	
	(T) SOIL AND WATER EXP. STA., MARCELLUS, NEW YORK	10/08/37	(M) GRAVELLY SILT LOAM	DENSE BLUEGRASS SOD	(E) UNDISTURBED FOR MANY YEARS			*4.7	
	35 IN.								
	(T) NEAR ITHACA,N.Y.	10/19/37	(M) STONY SILT LOAM	ORCHARD GRASS, TIMOTHY AND CLOVER	(F) PASTURE FOR 2 YEARS			*0.6	
	35-40 IN.								
	(T) NEAR ZANESVILLE OHIO	06/28/38	(M) SILT LOAM	TIMOTHY AND WEEDS	(F)			*0.4	
	35-40 IN.								
HANKS AND ANDERSON 1957	(T) FLINT HILLS OF EASTERN KANSAS	08/55	(M)	FULL COVER OF NATIVE BLUESTEM GRASS PASTURE	(G) UNBURNED PASTURE	PORTABLE INFILTROMETER USING TYPE-F NOZZLES SPRINKLING A 5 FT 1 IN X 6 FT PLOT	VERY GENTLY SLOPING	4.5 AT 0.5 HOURS *4.5 AT 1.0 HOUR 2.0 AT 1.5 HOURS	
	30-35 IN.				BURNED IN MID-SPRING			3.0 AT 0.5 HOURS 2.8 AT 1.0 HOUR 1.75 AT 1.5 HOURS	
					BURNED IN LATE FALL	APPLICATION RATE WAS 4.75 IN/HR		2.9 AT 0.5 HOURS 2.8 AT 1.0 HOUR 1.8 AT 1.5 HOURS	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
HOLTAN 1941	(T) NEAR EDWARDSVILLE ILLINOIS 35-40 IN.	05/25/40	(M) SILT LOAM	LESPEDEZA AND TIMOTHY PASTURE	(G) LIGHTLY GRAZED	6 X 12 FOOT PLOTS TYPE-F INFILTROMETER APPLICATION RATE WAS 1.78 IN/HR	1.36	1.18 AT 0.25 HOURS 0.83 AT 0.50 HOURS *0.58 AT 1.00 HOUR 0.52 AT 1.50 HOURS 0.46 AT 3.00 HOURS	
		07/29/40						1.53 AT 0.25 HOURS 1.32 AT 0.50 HOURS *1.04 AT 1.00 HOUR 0.82 AT 1.50 HOURS 0.51 AT 3.00 HOURS	
		09/18/40						1.29 AT 0.25 HOURS 0.99 AT 0.50 HOURS *0.63 AT 1.00 HOUR 0.52 AT 1.50 HOURS 0.36 AT 3.00 HOURS	
HOPKINS 1954	(M) 2.5 MI. WEST OF HAYS, KANSAS 20-22 IN.	06/53	(M)	UPLAND SHORT GRASSES	(E) UNGRAZED	6 INCH CYLINDERS. WATER LEVEL HELD AT CONSTANT LEVEL	HILLY	*8 AT 2 HR. 17 AT 0.5 HR.	
					(F) GRAZED			*1.5 AT 2 HR. 8 AT 0.5 HR.	
				WESTERN WHEAT-GRASS	(E) UNGRAZED			*8 AT 2 HR. 14 AT 0.5 HR.	
					(F) GRAZED			*1 AT 2 HR. 2 AT 0.5 HR.	
JOHNSON AND NIEDERHOF 1941	(H) MANITOU EXP. FOREST COLORADO 16-18 IN.	1937	(L) 66 PERCENT GRAVEL AND SAND	5 PERCENT PLANT COVER DENSITY	(G) ABANDONED FIELD	PEARSE SQUARE FOOT INFILTROMETER WATER APPLIED AT RATE NEEDED TO MAINTAIN RUNOFF. DURATION WAS 30 MINUTES.	10	*1.73 AV. FOR VEGETATION 1.81 BARE AREA	
		1938						*2.73 AV. FOR VEGETATION 2.67 BARE AREA	
		1937	(L) 76 PERCENT GRAVEL AND SAND	9 PERCENT PLANT COVER DENSITY	(G) VALLEY BUNCHGRASS TYPE		10	*2.12 AV. FOR VEGETATION 1.80 BARE AREA	
		1938	(L) 83 PERCENT GRAVEL AND SAND	7.5 PERCENT PLANT COVER DENSITY	(G) MOUNTAIN BUNCHGRASS TYPE		40	*5.28 AV. FOR VEGETATION	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
JOHNSTON 1962	(M) RANGE EXP.STATION STAVELY, ALBERTA,CAN. 24 IN.	06-08/60	(M) LOAMY	FESCUE GRASSES	(E) 12 AC. PER AUM	MOBILE RAINDROP SIMULATOR	ROLLING TOPO., SLOPES UP TO 10 PERCENT	*2.24	RATES ARE FOR 2ND 30 MIN. OF 1 HOUR RUN AT APPLICATION RATE OF 3.2 TO 3.5 IN/HR
					(G) 9 AC. PER AUM			*1.60	
					(G) 6 AC. PER AUM			*1.63	
					(F) 3 AC. PER AUM			*1.39	
KINCAID ET AL. 1966	(S) WALNUT GULCH EXP. WATERSHED, ARIZONA 12-14 IN.	WINTERS OF 1962 AND 1963	(L) SANDY, GRAVELLY WITH SOME LOAM	1.65 PERCENT LITTER COVER; 42.9 PERCENT CROWN SPREAD	(F)	TYPE-F INFILTROMETER USING 12 NOZZLES TO SPRINKLE 6 X 12 FT PLOTS. APPLICATION RATE WAS 4 IN/HR. RATES GIVEN ARE FOR DRY RUNS.		2.88 AT 10 MINUTES 2.42 AT 20 MINUTES 2.16 AT 30 MINUTES *1.67 AT 60 MINUTES	
				1.58 PERCENT LITTER COVER; 32.7 PERCENT CROWN SPREAD	(F)			1.93 AT 10 MINUTES 1.35 AT 20 MINUTES 1.22 AT 30 MINUTES *0.68 AT 60 MINUTES	
				1.73 PERCENT LITTER COVER; 31.7 PERCENT CROWN SPREAD	(F)			1.25 AT 10 MINUTES 1.00 AT 20 MINUTES 0.86 AT 30 MINUTES *0.80 AT 60 MINUTES	
				1.72 PERCENT LITTER COVER; 19.2 PERCENT CROWN SPREAD	(F)			0.96 AT 10 MINUTES 0.73 AT 20 MINUTES 0.60 AT 30 MINUTES *0.58 AT 60 MINUTES	
				1.92 PERCENT LITTER COVER; 24.0 PERCENT CROWN SPREAD	(F)			1.10 AT 10 MINUTES 0.78 AT 20 MINUTES 0.78 AT 30 MINUTES *0.67 AT 60 MINUTES	
			(H) CLAYEY OR CLAY LOAM SURFACE SOIL	SOME GRASS; 2.07 PERCENT LITTER COVER; 5.7 PERCENT CROWN SPREAD	(F)			0.97 AT 10 MINUTES 0.64 AT 20 MINUTES 0.59 AT 30 MINUTES *0.52 AT 60 MINUTES	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
KOHNKE 1938	(T) NEAR COSHOCTON, OHIO 35 IN.	06/06/38	(M) SILTY LOAM WITH SLIGHT EROSION	PERENNIAL GRASSES	(E) UNGRAZED MEADOW	16 COMPARTMENTS AND EACH EQUIPPED WITH A BURETTE. COMPARTMENTS WERE 20 CM. X 10 CM. SETUP CONSISTED OF 4 INSIDE AND 12 OUTSIDE COMPTS.	3 - 5	*2.65	RATES ARE AVERAGES FOR 1 HOUR RUNS. DATA TAKEN ONLY FROM THE INSIDE FOUR COMPARTMENTS.
		07/11/38	(M) LOAM WITH MOD. EROSION		(G) PASTURE		20 - 25	*3.17	
		08/09/38	(M) SILT LOAM WITH MOD. EROSION				15 - 24	*2.39	
		08/29/38	(M) SILT LOAM WITH SEVERE EROSION		(E) UNGRAZED MEADOW		7 - 26	*2.02	
			(M) SILT LOAM WITH MOD. EROSION				10 - 28	*2.34	
LAURITZEN AND STOLTENBERG 1940	(T) BLACKLANDS EXP. WATERSHED PROJECT, WACO, TEXAS 30-35 IN.		(M) CLAYEY TO 3 - 4 FEET DEPTH	NATIVE PRAIRIE GRASSES	(E) UNGRAZED	SINGLE RING INFILTROMETER SIX INCHES IN DIAMETER FORCED INTO SOIL TO THE B HORIZON (A DEPTH OF ABOUT 17 INCHES). WATER WAS HELD AT A CONSTANT HEAD.	GENTLY ROLLING	20 *15 11 9	AT ONE HALF HOUR AT ONE HOUR AT TWO HOURS AT THREE HOURS
				BARE	CULTIVATED			1.5 0.75 0.01 0.00	AT ONE HALF HOUR AT ONE HOUR AT TWO HOURS AT THREE HOURS
LEITHEAD 1950	NEAR MARFA, TEXAS 15-20 IN.	08/47	4.6 PERCENT ORGANIC CONTENT	VEGETATIVE AND LITTER COVER OF 1791 LBS. PER ACRE	EXCELLENT	DOUBLE RING INFILTROMETER	ROLLING HILLS	9.5	WATER LEVEL WAS HELD AT A CONSTANT HEAD OF ABOUT 2 IN. RATES ARE CALCULATED FROM TOTAL WATER INTAKE DURING A 30 MINUTE PERIOD.
			3.8 PERCENT ORGANIC CONTENT	VEGETATIVE AND LITTER COVER OF 1076 LBS. PER ACRE	GOOD			5.8	
			3.6 PERCENT ORGANIC CONTENT	VEGETATIVE AND LITTER COVER OF 783 LBS. PER ACRE	FAIR			4.25	
			2.1 PERCENT ORGANIC CONTENT	VEGETATIVE AND LITTER COVER OF 477 LBS. PER ACRE	POOR			2.75	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
MAZURAK AND CONARD 1959	(T) LINCOLN NEBRASKA 25-30 IN.	08/50	(M) SILTY CLAY LOAM	BIG BLUESTEM, WHEATGRASSES, BUFFALOGRASS, AND GRAMAS	(E) UNGRAZED FOR 7 YEARS	DOULBE RING INFILTROMETER USING 12 AND 18 INCH DIAMETER CYLINDERS. WATER LEVEL HELD AT A CONSTANT HEAD OF ONE INCH.		4.70 AV. 3.89 AV. *3.52 AV. 2.94 AV.	FOR 20 MINUTES FOR 40 MINUTES FOR 60 MINUTES FOR 2 HOURS
				WHEAT-OATS ROTATION	CULTIVATED CROPS			5.98 AV. 4.88 AV. 4.25 AV. 2.95 AV.	FOR 20 MINUTES FOR 40 MINUTES FOR 60 MINUTES FOR 2 HOURS
	(M) NORTH PLATTE, NEB. 20 IN.	08/54	(M) VERY FINE SANDY LOAM	BUFFALOGRASS, BIG BLUESTEM, WHEATGRASSES, AND GRAMAS	(E) UNGRAZED FOR 7 YEARS			1.87 AV. *1.69 AV. 1.73 AV.	FOR 20 MINUTES FOR 60 MINUTES FOR 2 HOURS
				WHEAT-FALLOW ROTATION	CULTIVATED CROPS			2.52 AV. 1.57 AV. 1.26 AV.	FOR 20 MINUTES FOR 60 MINUTES FOR 2 HOURS
	(M) ALLIANCE NEBRASKA 15-20 IN.	08/52	(M) VERY FINE SANDY LOAM	WHEATGRASSES, SMOOTH BROME-GRASS AND RUSSIAN WILDRYE	(E) UNGRAZED FOR 7 YEARS			2.79 AV. 1.91 AV. *1.69 AV. 1.49 AV.	FOR 20 MINUTES FOR 40 MINUTES FOR 60 MINUTES FOR 2 HOURS
				WHEAT-FALLOW ROTATION	CULTIVATED CROPS			3.03 AV. 2.13 AV. 1.73 AV. 1.30 AV.	FOR 20 MINUTES FOR 40 MINUTES FOR 60 MINUTES FOR 2 HOURS
PEARSE AND WOOLLEY 1936	(H) INTER-MOUNTAIN REGION		(M) BARE VERSUS VEGETATED PLOTS WERE COMPARED ON PAIRED BASIS TO ELIMINATE THE EFFECTS OF SOIL, ASPECT, OR SLOPE.						
				ALL SPECIES	(E)	PEARSE ONE SQUARE FOOT APPARATUS		*3.97 2.32	VEGETATATED PLOT BARE PLOT
				FIBROUS-ROOTED SPECIES	(E)			*4.85 2.14	VEGETATED PLOT BARE PLOT
				TAP-ROOTED SPECIES	(E)			*3.64 2.40	VEGETATED PLOT BARE PLOT

REFFRENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
RAUZI 1960	(M) NEAR WILLISTON, N. DAKOTA 10-14 IN.	SUMMER 1956	(M) LOAM	WESTERN WHEAT-GRASS,NEEDLE---THREAD,AND BLUE GRAMA	(G) RANGE CONDITION HIGH 2820 LBS. FORAGE PER ACRE	MOBILE RAINDROP SIMULATOR. WATER APPLIED AT RATES OF 3.0 TO 4.5 IN/HR FOR ONE HOUR PERIODS.	ROLLING TOPO.	*3.02 2.88	AV. FOR 2ND 30 MIN AV. FOR 4TH 15 MIN
					(P) RANGE CONDITION LOW 770 LBS. FORAGE PER ACRE			*1.14 0.96	AV. FOR 2ND 30 MIN AV. FOR 4TH 15 MIN
	(M) MCCONE COUNTY, MONTANA 10-14 IN.		(M) SILT LOAM		(G) RANGE CONDITION HIGH 1740 LBS. FORAGE PER ACRE			*1.41 1.36	AV. FOR 2ND 30 MIN AV. FOR 4TH 15 MIN
					(P) RANGE CONDITION LOW 620 LBS. FORAGE PER ACRE			*0.90 0.76	AV. FOR 2ND 30 MIN AV. FOR 4TH 15 MIN
	(M) GLACIER COUNTY MONTANA 15-19 IN.		(M) LOAM	WESTERN WHEAT-GRASS,IDAHO FESCUE,AND ROUGH FESCUE	(G) RANGE CONDITION HIGH 4135 LBS. FORAGE PER ACRE			*2.19 2.04	AV. FOR 2ND 30 MIN AV. FOR 4TH 15 MIN
					(P) RANGE CONDITION LOW 1870 LBS. FORAGE PER ACRE			*0.88 0.76	AV. FOR 2ND 30 MIN AV. FOR 4TH 15 MIN
RAUZI 1963	(M) NORTH-ERN GREAT PLAINS FIELD STA. NEAR MANDAN N. DAKOTA 16-18 IN.	07/61	(M) SILT LOAM	WESTERN WHEAT-GRASS,NEEDLE---THREAD, THREAD LEAF SEDGE, AND BLUE GRAMA	(P) HEAVILY GRAZED: 1.25 AUM PER ACRE	MOBILE RAINDROP SIMULATOR. WATER APPLIED AT RATES OF FROM 3 TO 4.5 IN/HOUR FOR A PERIOD OF ONE HOUR.	0 - 3	1.81 1.16 *1.48	AV. FOR 1ST 30 MIN AV. FOR 2ND 30 MIN AV. FOR 1 HOUR
					(F)MODERATELY GRAZED: 0.50 AUM PER ACRE			2.78 2.15 *2.40	AV. FOR 1ST 30 MIN AV. FOR 2ND 30 MIN AV. FOR 1 HOUR
					(E) UNGRAZED			4.27 4.27 *4.27	AV. FOR 1ST 30 MIN AV. FOR 2ND 30 MIN AV. FOR 1 HOUR

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
RAUZI ET AL. 1968	(M) NEAR COLUMBUS, MONTANA		(M) LOAM	1450 LBS. TOTAL VEGETATION PER ACRE	(E)	MOBILE RAINDROP INFILTROMETER	ROLLING	*2.45	RATES GIVEN ARE FOR 2ND 30 MINUTES OF ONE HOUR TEST RUNS. RATES OF APPLICATION WERE APPROX. 3 IN/HOUR.
	15-19 IN.			700 LBS. TOTAL VEGETATION PER ACRE	(F)			*1.30	
	(M) NEAR PHILLIPSBURG, MONTANA		(M) SILTY LOAM	3400 LBS. TOTAL VEGETATION PER ACRE	(E)			*2.08	
	15-19 IN.			900 LBS. TOTAL VEGETATION PER ACRE	(F)			*1.17	
	(M) NEAR CHICO, MONT.		(M) LOAM	1550 LBS. TOTAL VEGETATION PER ACRE	(E)			*2.56	
	5-9 IN.			400 LBS. TOTAL VEGETATION PER ACRE	(F)			*1.53	
	(M) NEAR HAYS CENTER, NEBRASKA		(M) SILT LOAM	4200 LBS. TOTAL VEGETATION PER ACRE	(E)			*3.37	
	20-24 IN.			750 LBS. TOTAL VEGETATION PER ACRE	(P)			*0.95	
RAUZI AND HANSON 1966	(M) COTTON-WOOD EXP. STATION, S. DAKOTA	07/64	(M) SILTY CLAY OVER SILTY CLAY LOAM	WESTERN WHEAT AND JAPANESE BROME GRASSES	(G) 3.25 ACRES PER AUM	MOBILE RAINDROP SIMULATOR	7.8	*1.26	RATES ARE TOTALS FOR ONE HOUR WET RUNS. APPLICATION RATE VARIED FROM 2.90 TO 4.12 IN/HOUR.
	15 IN.			BLUE GRAMA AND BUFFALOGRASS	(F) 2.42 ACRES PER AUM		7.6	*0.69	
					(P) 1.38 ACRES PER AUM		7.9	*0.51	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
BAUZI AND KUHLMAN 1961 14-18 IN. APPLIES TO ALL LOCATIONS	(M) ABOUT 45 MILES NE OF NEWELL, S. DAKOTA	SUMMERS OF 1957 AND 1958	(L) FINE SANDY LOAM	WESTERN WHEAT-GRASS,PRAIRIE SANDREED,SEDGE, AND BLUE GRAMA	(G) RANGE CONDITION GOOD 1422 LBS. FORAGE PER ACRE	MOBILE RAINDROP SIMULATOR. WATER APPLIED AT RATES OF 2.0 TO 3.0 IN/HR FOR ONE HOUR PERIODS.	GENTLY ROLLING	1.69 AV. 1.52 AV. *1.69 AV.	FOR 2ND 30 MIN FOR 4TH 15 MIN FOR 1 HOUR
	(M) ABOUT 50 MILES NE OF NEWELL, S. DAKOTA		(M) LOAMY SURFACE, DENSE SUBSURFACE	WESTERN WHEAT-GRASS,NEEDLE-+-THREAD,SANDBERG BLUEGRASS AND BLUE GRAMA	(P) PANSPOTS WITH 896 LBS. FORAGE PER ACRE			0.51 AV. 0.36 AV. *0.80 AV.	FOR 2ND 30 MIN FOR 4TH 15 MIN FOR 1 HOUR
	(M) ABOUT 12 MILES E. OF NEWELL, S. DAKOTA		(M) CLAYEY	WESTERN WHEAT-GRASS AND FORBS	(G)RANGE CONDITION GOOD 1491 LBS. FORAGE PER ACRE			0.57 AV. 0.40 AV. *0.99 AV.	FOR 2ND 30 MIN FOR 4TH 15 MIN FOR 1 HOUR
	(M) ABOUT 33 MILES E. OF NEWELL, S. DAKOTA		(M) CLAYEY	WESTERN WHEAT-GRASS AND BUFFALOGRASS	(F) RANGE CONDITION FAIR 1105 LBS. FORAGE PER ACRE			1.41 AV. 1.26 AV. *1.55 AV.	FOR 2ND 30 MIN FOR 4TH 15 MIN FOR 1 HOUR
REED AND PETERSON 1961	(M) ABOUT 5 MILES SW OF MILES CITY, MONTANA 12-14 IN.		(M) SANDY LOAM TO SANDY CLAY EXCELLENT DRAINAGE	BLUE GRAMA, WESTERN WHEAT-GRASS AND NEEDLE-+-THREAD GRASS	(P) HEAVY SUMMER GRAZING	FLOODING TYPE	GENTLY ROLLING	*2.8	RATES GIVEN ARE BASED ON THE TIME REQUIRED FOR THE SITE TO INFILTRATE ONE INCH OF WATER.
					(F) INTER-MEDIATELY GRAZED			*4.3	
					(G) LIGHT GRAZING			*4.3	
					(E) UNGRAZED			*7.3	
			(M) CLAYEY GOOD DRAINAGE	WESTERN WHEAT-GRASS	(F) HEAVY SUMMER GRAZING		VERY GENTLE SLOPE	*2.2	
					(G) LIGHT GRAZING			*4.8	
			(M) SILTY CLAY, FAIR DRAINAGE	WESTERN WHEAT-GRASS AND GREEN NEEDLE GRASS	(F) HEAVY SUMMER GRAZING			*2.6	
					(G) LIGHT GRAZING			*6.7	
REINHART AND TAYLOR 1954	(T) EAST BLUFF OF MISSISSIPPI RIVER AT VICKSBURG, MISSISSIPPI 50-55 IN.	SPRING	(M) SILT LOAM	WILD BARLEY, VETCH AND DALLIS GRASS	(F) NOT GIVEN	ROCKY MOUNTAIN INFILTROMETER. WATER APPLIED AT RATE OF 5 IN/HOUR. DATA ARE FOR WET TEST RUNS CONDUCTED ONE TO THREE DAYS AFTER INITIAL WETTING.		1.2 AT 15 MINUTES 0.7 AT 20 MINUTES 0.4 AT 30 MINUTES *0.2 AT 60 MINUTES	
		SUMMER						3.8 AT 15 MINUTES 3.0 AT 20 MINUTES 1.7 AT 30 MINUTES *0.4 AT 60 MINUTES	

REFFRENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
RHOADES, ET AL. 1964	(M) SOUTHERN PLAINS EXP. RANGE STA., WOODWARD, OKLAHOMA	FALL 61 AND SPRING 62	(M) FINE SANDY LOAM	SAND SAGEBRUSH WITH PARTIAL GRASS COVER	(E) NON-GRAZED	MOBILE RAINDROP SIMULATOR	1 - 4	*10.58	RATES ARE AVE. FOR 2 HOUR RUNS AT CONSTANT APPLICATION RATE.
					(G) LIGHTLY GRAZED 22 AC. PER AUM			*4.41	
	23 IN.				(F) MODERATELY GRAZED 17 AC. PER AUM			*3.64	
					(P) HEAVILY GRAZED 12 AC. PER AUM			*2.27	
SCOTT 1956	NAPA COUNTY CALIFORNIA	SUMMER 1952	PARENT MATERIAL OF GRANITE, IGNEOUS AND SEDIMENTARY ROCK	VARIABLE DENSITY OF COVER TYPES AND PERCENT. GRASS, CHAMISE, OAK, BUCKBRUSH, AND MANZANITA	UNBURNED	SINGLE CYLINDER 6 INCH DIAMETER AND 20 INCHES HIGH. INFILTROMETER DRIVEN 2 INCHES INTO GROUND AND FILLED ONLY ONCE.		1.85 AT 0.25 HOURS 1.16 AT 1.00 HOUR	
					BURNED			2.34 AT 0.25 HOURS 2.02 AT 1.00 HOUR	
		SUMMER 1953			UNBURNED			5.28 AT 0.25 HOURS 3.95 AT 1.00 HOUR	
					BURNED			3.98 AT 0.25 HOURS 2.02 AT 1.00 HOUR	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
STAUFFER 1938	(T) SOUTH-WEST ILLINOIS		(H) SILT LOAM ON CLAY	100 PERCENT GRASS COVER	(G) NOT PLOWED BUT MOWED FOR SEVERAL YEARS	SINGLE RING INFILTROMETER FORCED INTO THE SOIL TO THE DEPTH OF THE B HORIZON. WATER LEVEL WAS HELD AT A CONSTANT HEAD OF ABOUT 0.3 INCHES.	NEARLY LEVEL	*0.78 AT 1 HOUR 0.61 AT 2 HOURS	
32-40 IN. APPLIES TO ALL LOCATIONS			(H) SLICKS					*0.37 AT 1 HOUR 0.27 AT 2 HOURS	
								*0.15 AT 1 HOUR 0.09 AT 2 HOURS	
	(T) SOUTHERN ILLINOIS		(H) COMPACTED SILT LOAMS	SEEDED TO GRASS DURING PREVIOUS YEAR	NOT GIVEN		8	0.60 AT 1 HOUR 0.53 AT 2 HOURS	
								0.73 AT 1 HOUR 0.53 AT 2 HOURS	
							5	0.45 AT 1 HOUR 0.33 AT 2 HOURS	
				100 PERCENT GRASS COVER	(G) NOT PLOWED BUT MOWED FOR SEVERAL YEARS		LEVEL	*0.34 AT 1 HOUR 0.28 AT 2 HOURS	
	(T) WEST CENTRAL ILLINOIS		(H) SILT OR CLAY ON CLAY	100 PERCENT GRASS COVER	(G) NOT PLOWED BUT MOWED FOR SEVERAL YEARS		NEARLY LEVEL	*0.96 AT 1 HOUR 0.68 AT 2 HOURS	
								*0.41 AT 1 HOUR 0.28 AT 2 HOURS	
	(T) NORTH-WEST ILLINOIS		(H) SILT LOAMS	100 PERCENT GRASS COVER	(G) NOT PLOWED BUT MOWED FOR SEVERAL YEARS		NEARLY LEVEL	*5.36 AT 1 HOUR 4.50 AT 2 HOURS	
							ROLLING	*5.91 AT 1 HOUR 5.29 AT 2 HOURS	
			(H) SILT LOAM ON COMPACTED SUB-SOIL					*0.71 AT 1 HOUR 0.39 AT 2 HOURS	
	(T) LOWER ILLINOIS PRAIRIE		(H) SILT LOAM ON CLAY	100 PERCENT GRASS COVER	(G) NOT PLOWED BUT MOWED FOR SEVERAL YEARS		NEARLY LEVEL	*0.34 AT 1 HOUR 0.22 AT 2 HOURS	
			(L) SILT LOAM ON TILL				ROLLING	*3.70 AT 1 HOUR 3.34 AT 2 HOURS	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
THOMAS AND YOUNG 1954	(M) TEXAS RANGE STA., CROCKETT CO., TEXAS	SUMMERS OF 1950, 1951, AND 1952	(H) CLAYEY	TOBOSA SOD	(E) GRAZED VERY LIGHTLY	DOUBLE RING INFILTROMETER. WATER LEVEL HELD AT A CONSTANT HEAD OF 2 INCHES.	NEARLY LEVEL	*9.8 *3.6 *11.1 *6.3	RATES GIVEN ARE BASED ON TWO HOUR TEST PERIODS. ALL DATA ARE AVERAGE RATES FOR THE THREE YEARS OF EXPERIMENTING.
	16-18 IN.			BUFFALOGRASS AND CURLY MESQUITE SOD	(F) GRAZED			*2.7 *2.6 *3.5 *2.3	
				BARE GROUND				9.0 7.9 4.9 7.0	
THOMPSON 1968	(S) ABOUT 25 MILES W. OF GRAND JUNCTION, COLORADO AT BADGER WASH	OCT. AND NOV. OF 1953 AND 1954	(M) SILTY CLAY LOAM TO LOAM	SALT DESERT SHRUB TYPE; 29 PERCENT COVER	(F) GRAZED FAIRLY HEAVILY	ROCKY MOUNTAIN INFILTROMETER	VARIED	*0.84	WATER APPLIED AT RATE OF 5 IN/HOUR. RATES ARE FOR LAST 20 MIN. OF A 50 MIN. TEST RUN UNDER DRY CONDITIONS
	8-10 IN.			SALT DESERT SHRUB TYPE; 26 PERCENT COVER	(E) UNGRAZED			*0.74	
		AUG. AND SEPT. OF 1958		SALT DESERT SHRUB TYPE	(F) GRAZED FAIRLY HEAVILY			*1.12	
				SALT DESERT SHRUB TYPE; 26 PERCENT COVER	(F) UNGRAZED			*0.93	
		SEPT. OF 1963		SALT DESERT SHRUB TYPE; 20 PERCENT COVER	(F) GRAZED FAIRLY HEAVILY			*0.83	
				SALT DESERT SHRUB TYPE; 26 PERCENT COVER	(F) UNGRAZED			*0.67	

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
TURNER AND DORTIGNAC 1954	(H) N.F. LANDS OF WESTERN COLORADO		(M)	DENSE THURBER FESCUE, 6 PER-CENT BARE SOIL	(E) VERY LIGHT GRAZING, 2460 LBS. FORAGE PER ACRE	ROCKY MOUNTAIN INFILTROMETER		*4.7	WATER APPLIED AT 5 INCHES PER HOUR FOR A PERIOD OF 50 MINUTES. DATA IS FROM LAST 20 MINUTES OF THE WET RUN.
	25-35 IN.			OPEN THURBER FESCUE, 19 PER-CENT BARE SOIL	(G) LIGHTLY GRAZED, 1938 LBS. FORAGE PER ACRE			*3.6	
			(H) FINE TEXTURED	BLUEGRASS, 14 PERCENT BARE SOIL	(F) 1562 LBS. FORAGE PER ACRE			*1.5	
			(L) COARSE TEXTURED	NEEDLE GRASS AND IDAHO FESCUE. 38 PERCENT BARE SOIL	(F) 1078 LBS. FORAGE PER ACRE			*3.2	
			(M)	LUSH WEED TYPE AND FORBS, 28 PERCENT BARE SOIL	(G) 1890 LBS. FORAGE PER ACRE			*4.4	
			(M)	POOR WEED TYPE, 58 PERCENT BARE SOIL	(F) 1301 LBS. FORAGE PER ACRE			*2.9	
WATSON 1965	(M) ABOUT 26 MILES W. OF SYDNEY, AUSTRALIA ON MCGARVIE-SMITH FARM	DURING DROUGHT SEASON	(M) LIGHT TEXTURE OVER A HEAVY TEXTURED PLASTIC SUB-SOIL	PRACTICALLY A COMPLETE COVER OF PADDOCK LOVE GRASS AND PARRAMATTA GRASS	(G)	TYPE-F NOZZLES USED TO SPRINKLE A 4 X 2 FOOT PLOT. DATA ARE FOR CONSTANT INFILTRATION RATES AND ARE AVERAGES FOR FIVE PLOTS. TEST RUNS WERE MADE AT TWO LEVELS OF INTENSITY: 3.53 AND 1.83 IN/HOUR.	UNIFORM BUT PERCENT NOT GIVEN	*1.30	DRY RUN AT HIGH RAINFALL RATE
	28 IN.							0.83	DRY RUN AT LOW RAINFALL RATE
								0.61	MEDIUM SOIL MOISTURE CONTENT AT HIGH RAINFALL RATE
								0.67	MEDIUM SOIL MOISTURE CONTENT AT LOW RAINFALL RATE
								0.24	HIGH SOIL MOISTURE CONTENT AT HIGH RAINFALL RATE
								0.38	HIGH SOIL MOISTURE CONTENT AT LOW RAINFALL RATE

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
WILM 1941	(M) MANITOU EXP. FOREST NEAR WOODLAND PARK, COLO. 16-18 IN.	SUMMER 1940	(L) COARSE TEXTURE	MUHLY AND FESCUE; BUNCHGRASS TYPE AND ABANDONED AGRIC. FIELD	(G) GRAZED	ROCKY MOUNTAIN INFILTROMETER	15	*1.75	RATES GIVEN ARE AVERAGES FOR 6 SITES ON EACH OF THE 2 COVER TYPES; ALL TEST RUNS WERE MADE ON PREWETTED SOIL. WATER APPLICATION RATES WERE 4 IN/HR. DATA TAKEN FROM LAST 20 MIN. OF 50 MIN.TEST RUN.
						MODIFIED NORTH FORK EQUIPMENT USING TWO TYPE-F NOZZLES TO SPRINKLE A 2.5 SQUARE FOOT AREA.		*1.93	
						PEARSE SQUARE FOOT APPARATUS		*1.54	
WOODWARD 1943 10-35 IN. VARYING WITH ELEV.	(S) SEVIER LAKE WATER-SHED IN SOUTHCENTRAL UTAH	1941	(L) MEDIUM TEXTURE WITH WELL DEVELOPED POROUS STRUCTURE	SAGEBRUSH-PINYON PINE-JUNIPER-DESERT SHRUB TYPE; GRASSES AND FORBS PRESENT BUT LITTER LACKING	(G) DENSITY 25 PERCENT;GRAZED	TYPE-F INFILTROMETER SPRINKLING AN AREA OF 6 X 12 FEET. WATER WAS APPLIED AT RATES OF 2 OR 4 IN/HR DEPENDING ON OBSERVED INFILTRATION RATES. RATES GIVEN ARE CONSTANT RATES FOR PREWETTED SOILS.	25	3.7 AT 30 MINUTES *3.5 AT 60 MINUTES 3.45 AT 90 MINUTES	
					(F) DENSITY 15 PERCENT;GRAZED			2.6 AT 30 MINUTES *2.3 AT 60 MINUTES 2.3 AT 90 MINUTES	
					(P) DENSITY 5 PERCENT;GRAZED			1.3 AT 30 MINUTES *1.25 AT 60 MINUTES 1.2 AT 90 MINUTES	
			(M) MEDIUM TEXTURE		(E) DENSITY 35 PERCENT;GRAZED VERY LIGHTLY			1.95 AT 30 MINUTES *1.2 AT 60 MINUTES 0.95 AT 90 MINUTES	
					(G) DENSITY 25 PERCENT;GRAZED			1.6 AT 30 MINUTES *0.9 AT 60 MINUTES 0.8 AT 90 MINUTES	
					(F) DENSITY 15 PERCENT;GRAZED			1.15 AT 30 MINUTES *0.7 AT 60 MINUTES 0.6 AT 90 MINUTES	
					(P) DENSITY 5 PERCENT;GRAZED			0.7 AT 30 MINUTES *0.5 AT 60 MINUTES 0.5 AT 90 MINUTES	

CONTINUED ON NEXT PAGE

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
WOODWARD CONTINUED	(S) SEVIER LAKE WATER-SHED IN SOUTHCENTRAL UTAH		(M) TEXTURE VARIED BUT SOIL STRUCTURE WAS GOOD		(G) DENSITY 25 PERCENT:GRAZED			2.0 *1.25 1.0	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(F) DENSITY 15 PERCENT:GRAZED			1.5 *1.0 1.85	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(P) DENSITY 5 PERCENT:GRAZED			0.85 *0.7 1.6	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
	(H) SEVIER LAKE WATER-SHED IN SOUTHCENTRAL UTAH		(L) MEDIUM TEXTURE WITH WELL DEVELOPED POROUS STRUCTURE	MOUNTAIN BRUSH-WOODLAND: GRASSES WITH WEEDS OCCURRING AS UNDERSTORY AND SOME SURFACE LITTER	(G) DENSITY 25 PERCENT:GRAZED			3.9 *3.15 2.9	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(F) DENSITY 15 PERCENT:GRAZED			2.6 *2.05 2.0	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(P) DENSITY 5 PERCENT:GRAZED			1.25 *1.05 1.05	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
			(M) MEDIUM TEXTURE WITH POORLY DEVELOPED STRUCTURE		(E) DENSITY 35 PERCENT:GRAZED VERY LIGHTLY			2.2 *1.8 1.75	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(G) DENSITY 25 PERCENT:GRAZED			1.85 *1.5 1.4	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(F) DENSITY 15 PERCENT:GRAZED			1.5 *1.2 1.1	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(P) DENSITY 5 PERCENT:GRAZED			1.1 *0.8 0.8	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES

CONTINURED ON NEXT PAGE

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
WOODWARD CONTINUED	(H) SEVIER LAKE WATER-SHED IN SOUTHCENTRAL UTAH		(H) HEAVY TEXTURE WITH WELL DEVELOPED POROUS STRUCTURE		(E) DENSITY 35 PERCENT:GRAZED VERY LIGHTLY			3.85 *3.5 3.3	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(G) DENSITY 25 PERCENT:GRAZED			3.3 *2.9 2.8	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(F) DENSITY 15 PERCENT:GRAZED			2.65 *2.3 2.25	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(D) DENSITY 5 PERCENT:GRAZED			1.9 *1.85 1.85	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
	(H) SEVIER LAKE WATER-SHED IN SOUTHCENTRAL UTAH		(M) MEDIUM TEXTURE	ASPEN-CONIFER-OPEN GRASSLAND: SHRUB AND GRASS UNDERSTORY WITH DENSE MAT OF LITTER	(E) DENSITY 45 PERCENT:GRAZED VERY LIGHTLY			1.3 *1.25 1.25	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(E) DENSITY 35 PERCENT:GRAZED VERY LIGHTLY			1.1 *1.05 1.05	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(G) DENSITY 25 PERCENT:GRAZED			0.9 *0.8 0.8	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(F) DENSITY 15 PERCENT:GRAZED			0.6 *0.6 0.6	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(F) DENSITY 5 PERCENT:GRAZED			0.4 *0.4 0.4	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
	(H) SEVIER LAKE WATER-SHED IN SOUTHCENTRAL UTAH		(H) MEDIUM TEXTURE WITH POORLY DEVELOPED STRUCTURE		(E) DENSITY 35 PERCENT:GRAZED VERY LIGHTLY			0.35 *0.35 0.35	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(G) DENSITY 25 PERCENT:GRAZED			0.3 *0.3 0.3	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(F) DENSITY 15 PERCENT:GRAZED			0.25 *0.25 0.25	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(P) DENSITY 5 PERCENT:GRAZED			0.2 *0.2 0.2	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES

CONTINUED ON NEXT PAGE

REFERENCE	EXPERIMENT LOCATION	TIME	SOIL	COVER	RANGE CONDITION	INFILTROMETER APPARATUS	PERCENT SLOPE	INFILT. RATE (IN/HR)	COMMENTS
WOODWARD CONTINUED	(H) SEVIER LAKE WATER-SHED IN SOUTHCENTRAL UTAH		(H) HEAVY TEXTURE		(E) DENSITY 35 PERCENT:GRAZED VERY LIGHTLY			1.65 *1.1 1.05	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(G) DENSITY 25 PERCENT:GRAZED			1.05 *0.8 0.75	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(F) DENSITY 15 PERCENT:GRAZED			0.65 *0.5 0.5	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
					(P) DENSITY 5 PERCENT:GRAZED			0.3 *0.3 0.3	AT 30 MINUTES AT 60 MINUTES AT 90 MINUTES
ZWERMAN 1947	(T) NEAR ROME, GA. IN COOSA RIVER WATER-SHED	01/15/41 TO 04/15/41	(H) SILTY CLAY LOAMS AND CLAY LOAMS	KUDZU	(G) IMPROVED LAND BUT NOT SUITABLE FOR CULTIVATION	TYPE-FA INFILTROMETER USING FOUR NOZZLES TO SPRINKLE A 1 X 1.25 FT PLOT. SUFFICIENT WATER APPLIED TO CAUSE RUNOFF. TESTS WERE CONDUCTED FOR 1.5 HOURS.	MODERATE TO STEEPLY SLOPING	*4.06 2.92	DRY RUN AVERAGE WET RUN AVERAGE
	50-55 IN.			BROOMSEDGE AND WEEDS	(P) UNIMPROVED LAND UNSUITED FOR CULTIVATION			*0.38 0.24	DRY RUN AVERAGE WET RUN AVERAGE