FACT SHEET **No. 37**

Rangeland Watershed Program

U.C. Cooperative Extension and USDA Natural Resources Conservation Service

Infiltration and Overland Flow

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Infiltration is the process of rainwater, or any water, crossing the soil surface and entering the soil profile. There is a maximum rate at which a given soil can absorb water. This maximum potential rate is the *infiltration capacity* and is expressed as a depth of water per unit time (in/hr or mm/hr). *Infiltration rate* is the actual amount of water crossing the soil surface per unit time at any point in time (in/hr or mm/hr). Infiltration should not be confused with percolation, the downward movement of water already in the soil.

Infiltration plays a major role in a watershed's hydrologic cycle. Infiltration influences the source, timing, volume, and peak rate of storm runoff. Infiltration can be thought of as a diverting gate at the soil surface which determines the path by which rainwater or snow melt reaches a stream channel. Water which enters the soil can be used by plants, evaporated, percolate to ground water aquifers, or become stream flow by means of lateral subsurface flow and/or ground water discharge. Water which does not infiltrate will pond on the soil surface and run off as *overland flow*. Overland flow may travel down slope to be infiltrated on another portion of the hillslope, or it may flow directly to a stream channel.

Overland flow has the potential to erode soil and transport nonpoint source pollution directly to waterbodies. Certainly sediment, and possibly nutrients, pathogens, etc., can be filtered from overland flow if the storm water has an opportunity to enter the soil before it reaches a stream. Infiltration of flood waters on floodplains and riparian areas serves to recharge local aquifers as well as reduce flood flows. Any management activity which impacts the process of infiltration will impact overland flow, stream flow, nonpoint source pollution generation, and overall watershed response. Maintaining or increasing infiltration rates, thus minimizing overland flow, should be an objective of every rangeland watershed manager.

The Process

Although soil seems solid, it is actually porous. The spaces between soil particles as well as root channels, worm holes, rodent tunnels, and shrinkage cracks, create porosity within a soil profile. It is through the *soil pores* that water moves into and through the soil profile. Water enters the soil via soil pores due to the forces of *gravity* and *capillary attraction*. Gravity is easily understood, capillarity is more complex and will only be briefly defined here. Capillarity is the physical attraction of soil particles to water, generally referred to as *matric potential*. Matric potential is not constant through time and is dependent upon how moist the soil is. Dry soil has a greater matric potential than wet soil. Capillarity in soils is much the same as a sponge absorbing spilled water. Gravity and capillarity combine to determine the ability of a soil to absorb water at any given point in time. The following discussion focuses on infiltration under non-ponded conditions, but the reader should realize that ponded water on the soil surface will cause increased infiltration rates due to the head of water.

Infiltration is not constant through time. Figure 1 illustrates the general decrease in infiltration rate on an initially dry soil throughout a rainfall event. The initial high infiltration rate is due to dry soil conditions creating high matric potential (Point A). Dry soil strongly attracts water. Thus, infiltration rate is controlled by rainfall intensity. As the storm progresses, the soil pores become filled with water and the matric potential decreases. Just as a sponge stops absorbing the spilled water when it becomes soaked, soil stops actively absorbing water when it become *saturated*. The final infiltration rate reached in Figure 1 represents the rate at which water moves into the soil under the force of gravity alone (point B). The relationship between rainfall intensity and infiltration rate is important in determining the generation of overland flow. If rainfall intensity (in/hr) is below the infiltration capacity, then the infiltration rate equals the rainfall intensity and all the rainwater passes the soil surface to become soil water (Figure 2). If rainfall intensity is greater than the infiltration capacity, then infiltration rate equals the infiltration capacity and the *excess* rainfall becomes overland flow (Figure 3).

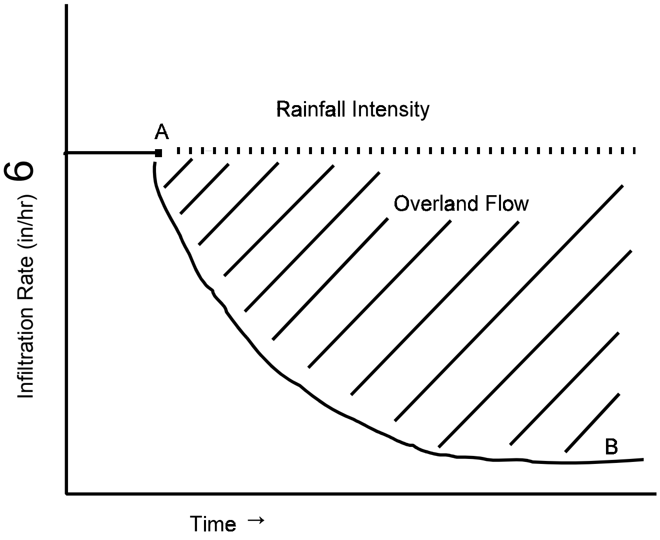

Figure 1. Generalized infiltration curve through time under constant rainfall intensity (in/hr).

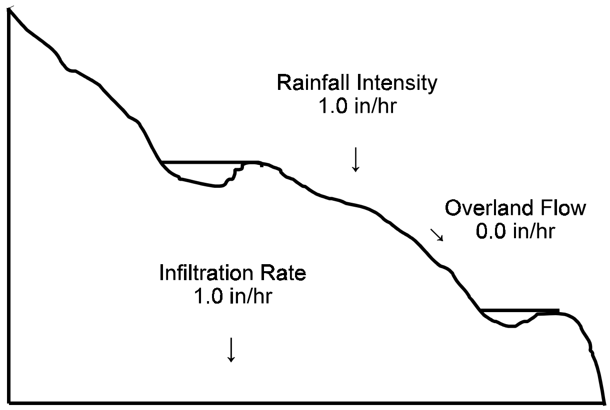

Figure 2. Rainfall intensity is less than infiltration capacity.

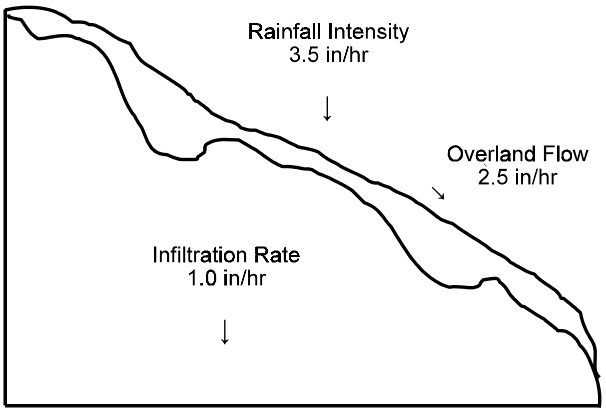

Figure 3. Rainfall intensity is greater than infiltration capacity.

Rainfall intensity will vary throughout a storm event, having short periods of very intense downpours followed by less intense showers. Rainfall intensity may exceed infiltration capacity during the downpours, but not during the showers. During the periods of light or no rainfall, the soil can actually recover some of its infiltration capacity as the soil drains and soil storage capacity is returned. The type, timing, and spatial pattern of rainfall over a watershed will greatly influence how much overland flow is generated during a storm. The reader is referred to Rangeland Watershed Program Fact Sheet #34 for further information on rainfall intensity, storm types, etc.

Factors Controlling Infiltration

Many factors influence the shape of the infiltration curve shown in Figure 1. These factors can generally be grouped as rainfall characteristics, soil properties, vegetation, and land use. Rainfall intensity is a major factor determining infiltration rate and overland flow. This was covered sufficiently in the previous section.
The ***water storage capacity*** and ***percolation rate*** of the soil profile operate together to influence infiltration rate. Think of the sponge which is absorbing spilled water. There is some finite amount of water the sponge can hold before one must ring it out in the sink. The amount of water a sponge can hold depends upon the size of the sponge and how porous it is. Soil is essentially the same. The amount of water a soil can hold depends basically upon how deep and how porous it is. The deeper and more porous a soil profile is, the more pore space available for storing water. Thus, ***initial soil water content***, the amount of water in the soil when rainfall begins, plays a large role in determining infiltration rates during a storm. A soil which is half full of water only has half of its storage capacity available. A 3 inch storm falling on saturated soil will generate much more overland flow than the same storm falling on dry soil.

Recall that ***percolation rate*** is the rate at which water is removed vertically from the soil via gravity flow. The greater the percolation rate, the faster the soil is drained, the faster storage capacity is recovered, and the more soil pore space available for infiltrating rainwater. The presence of an impervious soil layer, such as a clay layer at 3 feet, can reduce percolation rates within a soil profile.

Soil texture is the percent of sand, silt, and clay in a given soil. ***Soil structure*** refers to how the soil particles in a soil profile are arranged into soil colloids or aggregates. Sands have the largest individual pore spaces, while clays have the largest total pore volume. Although clays are more porous than sands, clays have much smaller individual pores than sands, resulting in smaller pathways for water to flow through. Thus, sands will have greater infiltration rates than clays. Soils with a loose, friable structure have high infiltration rates.

Soil porosity is generally defined as the percentage of the soil profile composed of pore space. The ***interconectivity of soil pores*** as well as total porosity determine the pathway available for water to enter and pass through a soil profile. As porosity and soil pore interconectivity increase, infiltration rate increases.

Soil bulk density is related to porosity and hydrologic condition. Bulk density is often used to assess if and how *compacted* a soil has become due to some land use or other disturbance. Soil bulk density is the mass or weight of dry soil per unit soil, usually expressed as grams per cubic centimeter (g/cm^3). Soil bulk density is determined by taking a soil sample of known volume, drying and weighing the sample. A soil with a low bulk density will generally have "better" hydrologic condition than a soil with a high bulk density.

Soil organic matter is instrumental in building and maintaining soil structure which in turn improves infiltration. Soil structure is crucial to maintaining soil porosity and the connectivity of soil pores. In general, as organic matter content increases, infiltration rate increases.

Many soils contain ***macropores***. Macropores are large, connected pathways through the soil. They can be rodent tunnels, worm holes, root channels, shrinkage cracks, fissures between rocks, etc. Macropores can lead to extremely high infiltration rates and rapid soil water transport.

Vegetative cover over the soil surface is extremely important in maintaining and improving infiltration rates. Cover can take the form of tree canopy, brush, grass, or litter. Litter covering the soil surface can be viewed as two distinct layers, the top which is undecomposed plant material and the bottom which is decomposed material behaving much like mineral soil. The lower layer can have a substantial storage capacity, over 200% by weight in some cases.

Raindrops impact the soil surface with some level of energy. When the soil surface is bare this raindrop energy detaches soil particles and reduces soil structure. Detachment of soil particles and loss of soil structure at the soil surface reduces the number and size of pores at the soil surface available to infiltrate water. The process of interception is further explained in Rangeland Watershed Program Fact Sheet #36.

All Soils are not Equal

It is important to note that all soils are not naturally created equal. Some soils will have naturally high infiltration rates, while others will have naturally low infiltration rates. Deep, well-drained, well-covered, coarse-textured soils with large organic matter content and marcopores will have higher infiltration rates than shallow, poorly-drained, poorly-covered, fine-textured soils with low organic matter content and no marcopores.

Grazing Impacts

In general, any land use which changes the soil and vegetation properties of a site can change infiltration at that site. **Over**-grazing can reduce infiltration capacity (in/hr) by excessive removal of vegetative cover and hoof impacts on soil structure. **Over-**grazing occurs when the stocking rate (animals/unit land/unit time) exceeds the carrying capacity of the pasture or ranch, or when livestock are not properly distributed across a ranch or pasture. Carrying capacity varies from pasture to pasture and from year to year.

Over-grazing tends to reduce protective vegetative cover and compact the soil (hoof impact) causing a deterioration in soil structure. This effect is often evaluated by measuring soil bulk density (see Rangeland Watershed Program Fact Sheet #30). Thus, **over**-grazing can lead to reduced infiltration, increased overland flow, and increased potential for nonpoint source pollution generation and transport.

There have been several very thorough reviews of the state of our **scientific** understanding of grazing impacts on infiltration (Gifford and Hawkins 1978, Blackburn 1984, and Spaeth et al. 1996). Several general conclusions can be made from this work:

1. Researchers have done a very poor job of defining and quantifying the grazing treatment employed for experiments on the impact of "grazing" on infiltration. Grazing treatment are commonly reported as "heavy," "moderate," or "light." What is described as moderate in one study may be heavy in another. This makes it very difficult to interpret or extrapolate the results of the work. (Blackburn 1984).

2. The majority of studies have compared heavy (over) grazing with no grazing. Few studies have addressed the ability of **proper** grazing (stocking rate in balance with carrying capacity) to sustain the hydrologic function of rangeland soils (Blackburn 1984, Spaeth et al. 1996). There is no scientific evidence that a soil's hydrologic function cannot be maintained under **proper** grazing management. The definition of proper will vary from site to site depending upon how climate, vegetation, soil, topographic, and grazing management factors interact.

3. Grazing at any intensity does influence infiltration. Infiltration rates on grazed sites are statistically lower than on ungrazed sites (Gifford and Hawkins 1978, Blackburn 1984).

4. There is no significant difference in infiltration between light and moderate grazing. Thus, there is no benefit to infiltration by grazing lightly rather than moderately (Gifford and Hawkins 1978, Blackburn 1984, and Spaeth et al. 1996).

5. Heavy (over) grazing does significantly reduce infiltration rates compared to light and moderate grazing (Gifford and Hawkins 1978, Blackburn 1984, and Spaeth et al. 1996).

6. There is a substantial body of scientific evidence indicating that intensive rotational grazing systems do not improve infiltration rates when compared to continuous light or moderate grazing (Spaeth et al. 1996).

7. Future research needs to be focused on the “best” known grazing management practices, not the worst.

Literature Cited

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Gifford, G.F., and R.H. Hawkins. 1978. Hydrologic impact of grazing on infiltration: a critical review. Water Resources Research. 14:305-313.