Ode to Green and Ampt’s f

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Authors’ note:

Green and Apt’s f represents the infiltration rate in one of the first widely used infiltration equations (1911).

In the equation, \( f = \frac{1}{k} \left( 1 - \psi f \right) \) where \( f \) is the infiltration rate, \( k \) is hydraulic conductivity, \( n \) is available porosity, \( \psi f \) is capillary or wetting front pressure head, and \( F \) is infiltration amount.

W. Heber Green was “Lecturer and Demonstrator in Chemistry” at the University of Melbourne and G.A. Ampt was a graduate “Research Scholar.” Several other infiltration equations also have been used worldwide, but this equation has been given the most attention in the past decade because the variables in the equation can be related to physical properties of the soil. This story can be considered a companion to the article “Ode to Manning’s n” found in the August 1991 issue of Rangelands.

The professor looked more like a cowboy than an academic as he stood quietly in front of the desks. The new class filed in, talking quietly among themselves.

“Good morning,” said the prof brightly. “Welcome to Range Watershed Management. I know you are all from across the campus where you normally study everything from land classification in the natural sciences to empirical constants in engineering.” The class stirred uneasily.

“Today I’m going to introduce you to several new concepts. But first, let’s get acquainted. John Bush, you’re a range major. How does your major relate to watershed management?”

“Well Doc, rangelands are located on watersheds and their management cannot be thought of separately.”

“Fawn Meredith, what will you do when you become a wildlife manager?”

“We develop soil, water, and plants for food and cover for all wildlife species,” answered Fawn.

“How does your major relate to watershed management?” the prof asked.

“Wildlife cannot live without water. All drink it, many live in it, and their food and cover depends on it,” replied Fawn.

“Jennifer Camp, tell us what an outdoor recreation major will do after graduation.”

“We try to provide opportunities for pleasure, play, and fun. Our courses include landscape architecture, forestry, wildlife management, range management, physical education, conservation, and civil engineering. Watershed management is very important for providing water-related recreation opportunities and providing high-quality drinking water for all outdoor recreation activities,” replied Jennifer.

“Joe Gates, you are a civil engineering major. Why is watershed management important to you?” asked the prof.

“Knowledge of watershed management helps us predict floods, plan for sediment deposits in our reservoirs, and design tanks, ponds, and erosion control structures.”

“Hoss Thomas, why does a major in animal science need to take a course in watershed management?”

Hoss replied, “All animals drink water, prof—up to several gallons a day, and we need to know where this water is coming from and how pure it is.”

The prof was silent for a minute and then said, “I’m pleased to see that each of you knows at least some of the importance of watershed management to your major and career. For much of the rest of the semester we will learn the processes within the hydrologic cycle and how to manipulate them.

At the second lecture, the prof explained that today the class would consider the hydrologic cycle.

“The hydrologic cycle,” said the prof, “is the one you learned back in about fourth grade. But even today, we still don’t know all of its parts or processes in all ecosystems. Where should we start?”

“How about the ocean?” declared the student wearing a t-shirt that said “Ski Diamond Head.”

“Okay, and what happens in the ocean other than spring break recreation?” asked the prof.

“Evaporation takes place and moisture accumulates in the atmosphere which eventually moves over land,” said Joe Gates from civil engineering.

“Right. And how pure is that evaporated water?”

“It should be simon-pure,” said another student.

“Evaporated water from the oceans is nearly pure, but it does contain some chlorides and sulfates of sodium, magnesium, calcium, and potassium. The atmospheric moisture is carried by winds over land masses where it condenses and falls as precipitation. Can we control this evaporation from the oceans and the resultant precipitation?” asked the prof.

Hoss Thomas, an animal science major declared, “My granddaddy and some other ranchers once tried to increase rainfall in the Great Basin by burning brush, which would put a lot of dirt into the clouds and cause condensation. All they got was a 2-year drought and some mad folks in Colorado.”

“Yes,” said the prof, “Some efforts have been made to modify precipitation, but all they got were mixed results and controversy. What happens when precipitation falls to the earth?”

“It lands in a tree, hits a rock, strikes the ground, or falls on someone’s back,” answered Jennifer, the outdoor recreation major.
"When it comes in contact with anything but soils, it is called interception," commented the prof. "Interception is initially very great, but as the interception capacity is reached, throughfall and stemflow equal the amount of precipitation."

"Last year on a hunting trip, I crawled under a big tree when it started to rain. It was dry for a few minutes, but eventually it was raining as much under the tree as out in the open, and the raindrops were huge," said John Bush.

"Okay what happens when rainfall and throughfall reach the soil surface?"

"It may run into the soil, pond, evaporate, or run off," said Fawn.

"Yes, we call this process of water ‘running into the soil’ infiltration. This bit that ponds, evaporates, or runs off is what is left after infiltration."

"What, then, is a key process in managing land?" asked the prof. "Which process of the hydrologic cycle, including evaporation, condensation, interception, infiltration, and runoff does managing the land have the most influence and control over?"

"Every activity on land affects the infiltration rate," exclaimed Hoss. "It doesn’t matter if it is hikers, horses, motorcycles, or grasshoppers."

"I think you are right," agreed the prof. "Infiltration is the process of the hydrologic cycle that can be most manipulated by management. The hydrologic cycle is completed as the runoff and spring flow enter rivers that return to the ocean. Let’s stop here for today."

At the start of the next lecture, the prof passed out a diagram and explained how infiltration was most influenced by land management. "The interactions of management with an ecosystem and how they relate to each other can be seen in the conceptual model," said the prof. (Figure 1)

"We know from infiltration studies over a few decades that infiltration is very complex on rangelands, varying greatly in space and time. The effect of a component on infiltration varies between different environments. Now let’s look at each component individually and assess its influence."

"What do we mean by ‘components’?" asked Jennifer. "Components or variables are different parts of an ecosystem, such as plant cover or soil organic matter content, that influence infiltration rates," explained the prof. "How would plant cover affect infiltration rates?"

"That’s easy," said Truss Walton from civil engineering. "As the amount of cover goes up, so does the infiltration rate."

"Are we talking about foliar cover or basal cover?" asked John Bush, the range major. "My range con supervisor where I worked as a co-op student said basal cover was more dependable from one year to the next."

The prof answered, "Foliar cover shows a stronger correlation than basal cover with infiltration rates. Infiltration rates may decrease instead of increasing as basal cover of some plants such as blue grama increases from overgrazing."

"Boy, that would make a mess of the output from a hydrologic model that only considers a positive influence," remarked Jennifer.

"Wouldn’t infiltration decrease as interception increases?" asked Hoss.

"That relates infiltration to interception, does it not?" asked the prof.

Fawn Meredith, the wildlife major, stated, "It seems to me that the total amount of plants would also be important."

"Well, it’s not that simple," said the prof. "Would an area with 60% cover of buffalo grass have the same infiltration rate as one with 60% cover of big bluestem?"

"Probably not," said Fawn. "The big bluestem is much taller and therefore adds more litter to the soil."

"The literature is full of comparisons of infiltration rates for all different types and combinations of plants and soils, even cryptogams. Infiltration rates will differ between sites because of differences in plant cover, phytomass, and density," answered the prof.

"What is a cryptogam?" asked Joe. "Cryptogams are nonflowering plants such as algae, mosses, and lichens. Because they are so small, their importance to the hydrologic cycle is probably not fully understood," answered the prof.

"Density is important too?" asked Hoss. "This is getting complicated."

"Studies report that when large trees exist in a stand of pinyon-juniper, infiltration rates directly beneath the trees may be very high, but between the trees are often low," said the prof.

"Why would infiltration rates between trees be low?" asked Jennifer.

"This is because trees produce massive amounts of small roots. Soil protection between tree crowns is often not enough to sustain the site, and subsequent low infiltration rates result in increased erosion."

"Why would infiltration rates be higher with smaller and more dense plants?" asked Marcia Tukey, an agriculture statistics major.

"That’s because water would have to take a tortuous path across the site, which slows it down and increases infiltration," answered Joe Gates.

"Yes, we call this the ‘time of concentration’," remarked the prof. "Now how would infiltration rates compare for 2 identical sites if one was covered by a sod-forming grass and the other by a bunchgrass?"

"The sod-former would have the highest infiltration rate because it has rhizomes," speculated a student with a bit of confidence.

"We used to think that," answered the prof. "but several studies have shown no differences if cover, phytomass, and density were equal."

"Okay, this spaghetti bowl-looking diagram (Figure 1) includes animal trampling and burrowing. Are they good for infiltration or bad?" asked Hoss, the animal science major.
Rangeland management influences on infiltration rates

Diagram showing the relationships between land management practices, animal trampling and burrowing, plant and rock cover, plant mass, soil surface roughness, soil configuration, soil moisture evaporative loss, soil organic matter content, soil particle sizes, soil structure, soil bulk density and porosity, and infiltration rates.
"Trampling wet soils would increase surface roughness, but trampling dry soils would tend to flatten soils out."

"In my hydraulics course we learned that roughness is expressed as a coefficient or n in a popular runoff equation called Manning’s, where V = (1.49/n)R^{0.6}S^{0.5}," claimed Joe Gates, the civil engineering major. "How does roughness affect infiltration then?" asked the prof.

Joe continued, "Roughness lengthens the path and decreases the velocity of runoff by friction. The high spots act like chimneys, and as a given volume of air escapes, an nearly equal volume of water infiltrates."

"What effects do my wildlife have?" asked Fawn.

"Large ungulates would reduce cover and phytomass by trampling," answered the prof. "The effects of burrowing are not well known."

"Don’t burrow holes open up and offer a huge pore for water entry?" asked Fawn.

"That’s right," answered the prof, "some burrowed areas have mounds of loosened, structureless soil that covers the holes of critters like pocket gophers. What other animals are found on rangelands?"

Fawn commented, "In biology we learned that ants and termites may be more abundant in total mass than all other animals including elk and cows. They must have an impact on infiltration rates too."

"Yes," said the prof, "They increase soil porosity but bring small soil particles which seal surface pores to the surface. Ant hills reduce infiltration, but redistribute water and contribute to patchiness in the landscape."

Gerald Awn, a plant team member, asked, "Can soil surface roughness be influenced by plants as well as by animals? Our deserts didn’t have large ungulates after the Pleistocene era until the introduction of livestock by Europeans."

"Good point," said the prof, "Many shrubs, grasses, and forbs are found in areas that experience wind-borne soil movement. When wind velocity is reduced, especially near shrubs, sand is deposited to form cobbles of dunes. These dunes may have very high infiltration rates, but the interspaces often have finer soil particles and sparse vegetation. Conversion from a shrub- to a grass-dominated rangeland may mitigate the low infiltration problem between shrubs."

"What is soil surface configuration?" asked Jennifer.

"It relates to topographic patterns or land forms," answered the prof. "Terraces forming behind plants and dead trees can be observed on many slopes. These shorten the slope lengths and increase detention storage. It relates to whether a surface is rough across the slope or up and down the slope, or a combination of both. As we come down in what Mr. Thomas called a bowl of spaghetti (Figure 1), we find soil moisture. How is it affected by plant cover and mass, rock cover, and soil surface roughness?"

"Well," said Gerald, "a lot of plants use a lot of water, which leaves the soil drier than soil with few plants, so that the soils with the most plants have the highest filtration rates."

"Let’s now move on to the next component, which is soil organic matter," said the prof. "The main source of organic matter comes from decomposed litter on the soil surface and decomposition of roots. How is organic matter important to infiltration rates?"

"It is sort like the glue that holds the soil all together," said a student.

"That’s right," added the prof. "Organic matter is broken down to colloidal size and then becomes a glue for building stable soil aggregates. There are other forms of soil structure too. Large, stable aggregates have large pores between them and therefore have higher infiltration. As you might have guessed, infiltration increases with increases in organic matter."

"Are there any exceptions, Doc?" asked John.

"Yes John," answered the prof. "Infiltration rates may be reduced in shrub-dominated areas where organic matter and coarse soils lead to a hydrophobic layer."

"Now, what do we mean by soil texture?" asked Joe.

"Soil texture relates to the size of the soil particles and the relative proportions of different sizes," said Clay, a soil science major.

The prof continued, "Soils with particles larger than clay and with high silt contents may be very low in organic matter, and they have lower infiltration rates than clay soils that are high in organic matter."

"And are you saying that the largest particles or sand can have low infiltration rates?" asked a student.

"Yes, coarse sandy soils may have high organic matter contents resulting in hydrophobic conditions," said the prof. "What happens to infiltration rates if we have a fine-textured soil like lay loam over a coarse-textured gravelly soil?"

"In my soil physics class, we watched some wetting fronts move downward," said Clay. "When the front reached the coarse layer, it slowed down until the coarse layer was saturated. Then it continued at the same rate as it did through the fine surface layer."

"We still have not discussed bulk density and porosity. What is bulk density, and how does it relate to porosity and infiltration rates?"

"Bulk density is the weight of a given volume of soil, which includes the solids and pores," answered Clay. "It is directly related to porosity and is sometimes called ‘compaction’."

"Okay, and how does it relate to infiltration rates?" asked the prof.

Hoss Thomas commented, "Around water holes and corrals on our ranch, the soils get pretty hard, and water tends to stand and run off."

"That’s right," said the prof. "Bulk density of soil is usually negatively associated with infiltration rates and is influenced by organic matter, soil particle size, and animal trampling and burrowing. As Clay mentioned, porosity is inversely related to bulk density. Infiltration rates usually increase with decreases in bulk density. Can
you think of any exceptions?"
The class remained silent. "Well, some arid, silty soils possess little organic matter and a vesicular structure, or crust, near the surface. These crusts have spherical pores that are not continuous, but impede the downward movement of water."
"What effects do the kind, amount, intensity, and duration of precipitation have on infiltration rates?" asked Joe.
"Energy, associated with raindrops, compacts the soil surface, destroying and eroding aggregates. Small soil particles then seal up the pores between remaining aggregates. The best management defense is to maintain a vegetal cover."
"Haven't we forgotten slope?" asked Joe.
"We actually ignored it," said the prof. "Apart from small differences in depression storage, slope itself has been found to have little effect."
"I have noticed on our ranch that water goes into the soil differently at different seasons," remarked Hoss. "Why is that?"
"Plants, animals, soils, and climate change with the seasons," explained the Prof.
"And as soil dries from one season to another, infiltration rates should increase and vice versa," replied Jennifer. The prof added, "There is often much shrinking and swelling of the soil surface during winter. This may mitigate any increased bulk density from the previous year."

"I think we can conclude this discussion by saying that the infiltration process on rangelands is complicated and spatially and temporally variable, with variables changing in importance during a rainfall event," added the prof. "Plant, animal, and soil variables have a differential effect on infiltration rates so that modeling may be very difficult. Infiltration rates can vary greatly for an area depending on the management of animals, plants, and soils. Mismanagement can be disastrous. What can we now say about Green and Ampt's formula."
"The formula looks pretty simple," remarked Joe. "Where are all the components that influence infiltration?" asked Jennifer. "I think some of those letters in the formula have hidden meanings."
"That's right," admitted the prof. "Porosity, capillary pressure head, and saturated hydraulic conductivity are key components. Other variables and their influences were not known in 1911. Organic matter is related to bulk density and porosity. Cover is used to adjust the hydraulic conductivity. Evaluation and incorporation of plant, soil, water, and animal variables into infiltration equations is a continuing process. Let's stop here for today."