Subsurface Drainage Revealed:
How Drainage Affects Water Balance

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1. Introduction

The growing use of subsurface drainage in Minnesota has sparked much debate about its impacts on local hydrology and water quality. Discussions are typically focused on questions such as: Does subsurface drainage lessen or worsen localized flooding?; Are catastrophic floods more frequent because of subsurface drainage?; Does subsurface drainage alter the quantity of flow in a river basin?; Do subsurface-drained soils respond more like a "sponge" to excess rainfall, as compared to poorly drained soils?; How do surface inlets (intakes) affect the quantity and quality of drainage flow; and, How do artificially drained lands impact water quality? Answers to these questions have important policy implications for local and state decision makers.

2. Drainage and the Water Balance

The water balance, as applied to a crop/soil system, describes the fate of precipitation and the various components of water flow in and around the soil profile. Because drainage alters soil water, other components of the water balance are also affected by drainage. With an understanding of soil water and drainable porosity, we can now consider these effects. Consider first, a simple water balance on a soil profile <u>with good natural drainage</u>, as pictured in Figure 1. In the typical case, precipitation (P) (rainfall, snowmelt, irrigation—if practiced) is

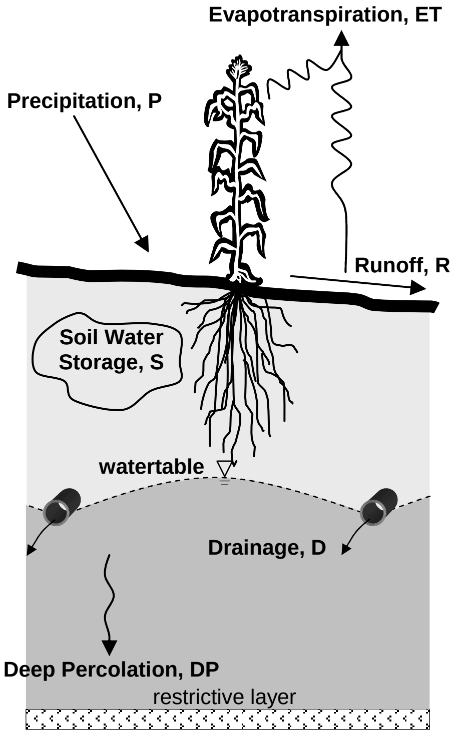

Fig. 2. Illustration of the water balance with artificial drainage.

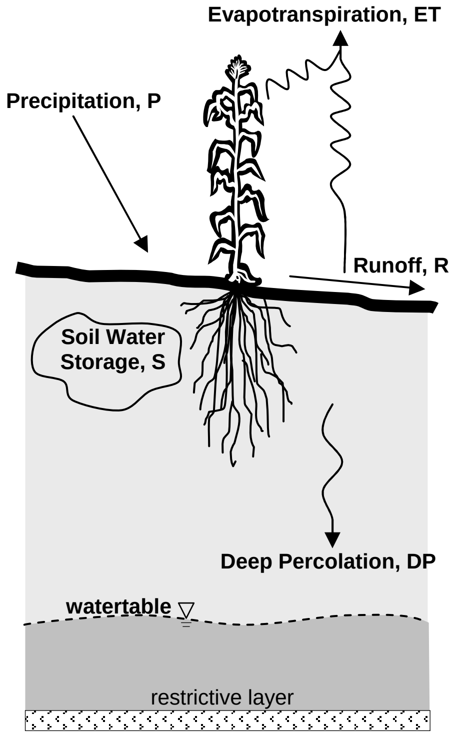

Fig. 1. Components of the water balance with good natural drainage.

the major water input to the crop/soil system: surface runoff water (R), crop evapotranspiration (ET), deep percolation (DP), and changes in soil water storage (S) emanate from precipitation. In the case of Figure 1 we assume that no water enters the soil from adjacent areas by horizontal flow (an assumption that won't be true in some cases). Mathematically, the water balance can be written as follows:

$$P = R + ET + DP + S$$

When the watertable is relatively deep as shown in Figure 1 (3 to 15 feet), deep percolation provides recharge to the watertable. If deep percolation occurs and continues, there is an opportunity for the watertable to rise. The water balance demonstrates that the amount of deep percolation depends on the extent to which the precipitation input to the soil is reduced by runoff, ET, and changes in soil water storage.

The same water balance relationship holds true in an artificially drained soil profile, as depicted in Figure 2. Now, however, drainage flow, D, becomes a major component of water leaving the system. As before, the amount of drainage is dependent on how much precipitation is lost to runoff, ET and changes in soil moisture. Simply put, the quantity of drainage flow is driven by precipitation and the relative proportion of the other components of the water balance. This implies that the impact of drainage will vary on an annual basis and from region to region in Minnesota, with a 13- to 15-inch variation in rainfall across the state.

Let’s compare the water balance of a poorly drained, high water table soil with an artificially drained soil—in effect, a before and after scenario—without considering the influence of a growing crop. Figure 3 shows the distribution of water- and air-filled pores above a shallow watertable in a poorly drained soil (right portion), and, above a deep watertable in a subsurface-drained soil profile (left portion). The lighter-shaded area indicates the empty (air-filled) pore space (or volume) for each case. The drained soil has more pore volume available for infiltration during the next rainfall event because it has a larger volume of empty pores. Consequently, ***more infiltration*** and ***less runoff*** will likely occur on the drained soil compared to the undrained soil, depending on the nature and timing of the next rainfall event (a very intense rainfall event may not produce much infiltration in either case). How much more infiltration could occur? This depends on many factors, but the amount of infiltration will be greater when: the difference between the shallow and deep watertable levels is greater (i.e., very high initial watertable drained to a greater depth); the undrained watertable is closer to the soil surface; and, soil textures are coarser.

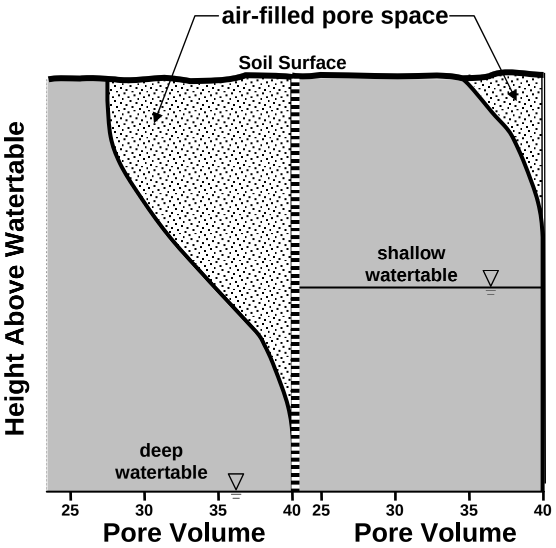

Fig. 3. Illustration of drainable porosity when the watertable is lowered by drainage.

An Example with Numbers:

How might a drained and undrained soil differ during a rainfall event? Consider two soils, both with a drainable porosity of 3 percent: the undrained soil has a watertable at 6 inches below the surface, and the drained soil has a watertable at the level of the drain, or 48 inches. The undrained soil has a total of **0.18 inches** (6 inches × 3% ÷ 100) of available pore space between the watertable and the surface, and the drained soil has a total of **1.44 inches** (48 × 3% ÷ 100). Hence, the drained soil has **1.26 inches** (1.44 – 0.18 in) more of available (empty) pore space than the undrained soil. If a low-intensity 1.5-inch rain occurred, our simple water balance would lead us to expect 0.06 inches runoff from the drained soil (the soil can hold 1.44 inches) and 1.32 inches of runoff from the undrained soil (the soil can hold only 0.18 inches).

Following the rainfall, both soils are saturated to the soil surface. Additionally, we would expect 1.44 inches of drainage from the drained soil over the following 24 to 48 hours to bring the watertable back to the 48-inch depth mark.

With this simple example we estimate that we lose about 1.32 inches of water, as surface runoff, from the undrained soil, compared to 1.44 inches of water over the next 24 to 48 hours, as drainage, from the drained soil. The real difference between the drained and undrained cases, in terms of water loss, is one of timing. The 1.32 inches of surface runoff from drained soil will occur relatively rapidly compared (perhaps over several hours) to the 1.44 inches of water outflow from the drained soil. The drained soil's water must first pass through the soil before it reaches the drainage system. Thus, the resultant flow at the drainage outlet will occur over a longer period of time, and with a lower peak flow, than surface runoff from the undrained soil. Consequently the total runoff ***rate*** (surface runoff + drainage flow) of the drained soil is reduced. The magnitude of this reduction depends on the depth and intensity of the rainfall event. Smaller events of low intensity will reduce the total runoff rate more dramatically because proportionally more water will have an opportunity to infiltrate and pass through the drainage system. In addition, smaller rainfall events may cause surface runoff on the undrained soil and no surface runoff at all on the drained soil. However, if another rainfall event(s) occur before the drained soil has had time to drain adequately, water balance differences between the drained and undrained soils will be diminished. Based on this analysis—without the influence of a growing crop—we see that drainage can, to some degree, enhance the soil profile's ability to store water and alter runoff rates and volumes. This effect is known to some as the "sponge effect" of subsurface drainage. The reader should bear in mind that these simple calculations are volume balances only and do not take into account the dynamic nature of rainfall, and other factors associated with the rainfall-runoff process. Nevertheless, they are useful in understanding the potential influence of drainage on the water balance of a soil and how this affects hydrology.

3. Seasonal Water Balance

Finally, we must consider the influence of a growing crop on the water balance. We previously included crop ET in the water balance but have not yet explored the changes in the soil profile that take place over the growing season in response to drainage. The undrained condition shown in Figure 4 (left portion) is characterized by a shallow watertable. This condition will almost always exist in poorly drained soils in the spring, and may extend into, or recur later in the growing season, depending on seasonal precipitation patterns. Because of saturated conditions near the soil surface, the depth of crop root development may be severely restricted, if not effectively eliminated (in the most poorly drained soils). Hence, the effective rootzone depth will be a fraction of what it could potentially be in a well-drained or artificially-drained soil. The deep root structure of the drained condition in Figure 4 (right portion) plays an important role in the water balance and the health and production of the crop. Drainage may even be advantageous in unseasonably dry years. When dry summer conditions follow a wet spring, the crop may have an increased tolerance to drought by being able to access deeper and moister soil in the profile.

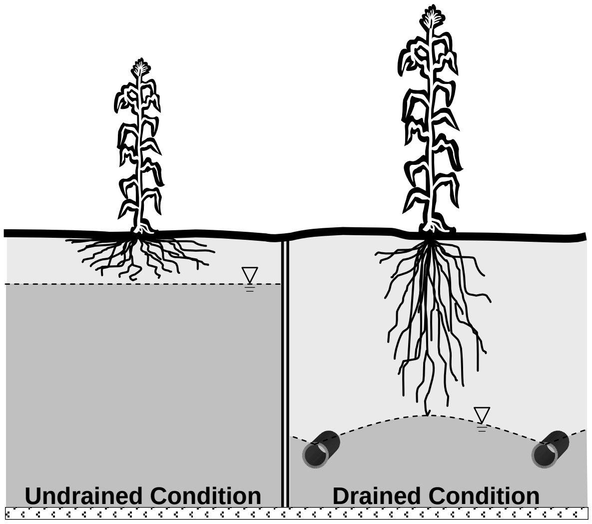

Fig. 4. Comparison of watertable and root development with drained and undrained conditions.

The presence of a vigorously growing crop increases the “sponge effect” in a drained soil in the following way. As the growing season progresses and crop ET increases, crop water uptake will further dry the rootzone causing upward flow of water to occur from below the rootzone. By drying out the soil profile in and below the rootzone, the crop creates yet more empty (air-filled) pore space compared to drained soil with no crop. This effect can be illustrated by the soil air/water percentage curve shifting to the left (drier) as shown in Figure 5. The shaded area between the curves in Figure 5 represents the additional empty pore space created by crop-induced drying of the rootzone and upward flow of water to the rootzone. The deeper and healthier the root system is, the larger this effect will be, for a given crop, with the maximum effect occurring later in the growing season (late July, August, early September) as the crop and its root system matures. The shifted curve in Figure 5 represents the extreme case where the soil moisture in the rootzone has been depleted to the wilting point.

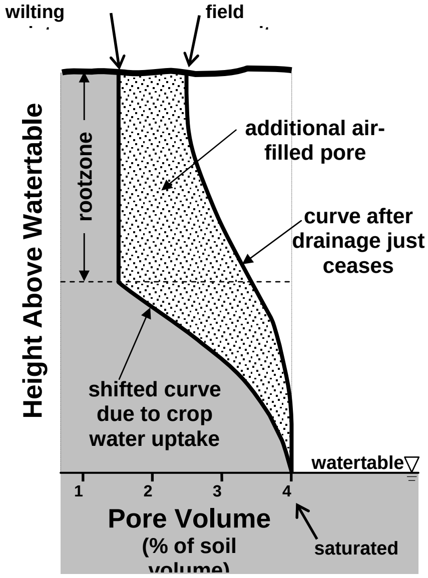

Fig. 5. Crop-induced increase in empty (air-filled) pore space in a drained soil.

4. An Illustration with Field Data

The graph shown in Figure 6 provides a visual display of how water balance dynamics can change over the growing season due to subsurface drainage and crop growth. Shown are daily subsurface drainage flow and precipitation over the 1998 growing season for corn, on a Webster clay loam soil. Precipitation for the season was 36.4 inches, of which 26.4 inches occurred between February 22nd and November 1st, the period shown at left. The data were collected by Dr. Gyles Randall, at the University of Minnesota Southern Research and Outreach Center at Waseca, Minnesota. The highest drainage flow corresponds to the period just following soil thaw, in late March and early April. From this point on, the subsurface flows decreased throughout the growing season. After mid-July, no more subsurface flow occurred, despite rainfall events as large or larger that those of the early season (note the rainfalls of nearly 1 inch and 1.7 inches in September and October).

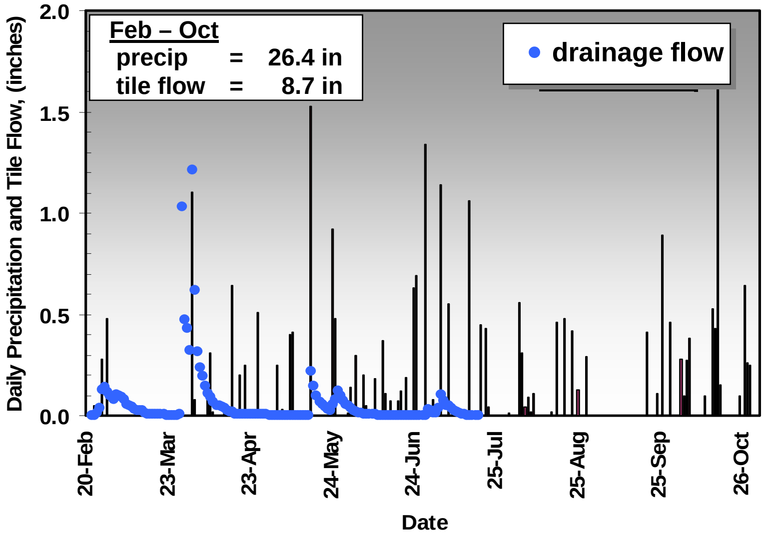

Fig. 6. 1998 daily precipitation and drainage flow for corn on a Webster clay loam soil at Waseca, MN.

In the absence of surface runoff data, there are two possible explanations for the absence of subsurface flow later in the growing season, either: (1) all the late-season rainfall events were of very high intensity, generating mostly surface runoff and little infiltration; or (2) the combination of subsurface drainage and crop growth produced a drier soil profile and more available pore space for absorbing the rainfall events. While it is likely that *some* of the late-season rainfall events were of high intensity, it is equally likely that many were not. What are not evident from the above data are the proportions of the drainage and crop effects, relative to one another. These data illustrate however, that together, subsurface drainage and crop growth create a buffering capacity or sponge effect as the growing season progresses, which would otherwise not be present on a poorly drained soil. It is hoped that results from current drainage research in Minnesota will strengthen our understanding of drainage and the water balance for this region of the U.S.

5. Summary Questions and Answers

How does subsurface drainage promote better plant growth on poorly drained soils?

Subsurface, or “tile” drainage removes excess water from the soil—water that prevents air and oxygen from getting to plant roots. Without artificial drainage, plants have difficulty establishing a health root system on poorly drained soils. Subsurface drainage provides the mechanism for poorly drained soils to drain to field capacity in a reasonably short period of time so that plant growth is not significantly impaired. In addition, drainage often permits spring field operations (e.g., tillage, planting) to take place in a more efficient and timely way. Depending on seasonal rainfall, this can have the effect of adding days, to a week or more, to the length of the growing season, providing another source of potential crop yield improvement.

Does subsurface drainage remove plant available water from the soil?

No, drainage does not increase or decrease plant available water in the soil profile. Drainage removes “drainable” water from the soil, just like the water that drains from the bottom of a potted plant when watered. Upward flow can occur, however, from the watertable to the rootzone, providing an important source of moisture for crop growth.

Is the source of subsurface drainage water groundwater or rainfall?

In most situations, flow from drainage systems is shallow groundwater that is replenished by rainfall—the less rainfall there is, the less drainage flow there can be. In some cases drainage systems intercept lateral flow, and hence, are not fed exclusively by rainfall occurring at the drainage site.

Does subsurface drainage cause more water to leave the field compared to undrained conditions?

While not true for all cases and locations, in general, subsurface drainage causes less that 10 percent more water to leave the field as compared to agricultural land with surface drainage only. This number is based on drainage simulation models because variations this small are difficult to measure in the field due to high seasonal variability.

How does drainage influence surface runoff and flooding?

Local rainfall is the source of surface runoff and water that enters the soil. The route that water takes as it flows through the landscape plays a very important role in the amount and rate of total runoff, and this is affected greatly by land use. When natural vegetation is disturbed or converted into field crops and pasture, peak runoff rates at the field edge can increase dramatically (often these conversions are accompanied by some surface drainage practices). In general, subsurface drainage tends to *decrease* surface runoff (sometimes by one- to three-fold) and decrease peak surface runoff rates when compared to surface-drained or undrained land.

The decrease occurs because water flows more slowly through the soil to reach the drainage system (and eventually the outlet) than it would as surface runoff. The later arrival of drainage flow may cause the overall peak outflow (surface + drainage) to decrease. Moreover, when the amount of runoff is reduced, the speed of its flow may also decrease. While these processes are well understood at field and farm scales—flooding is a watershed-scale phenomenon. As we look at larger and larger landscapes, the complexity of watershed hydrology makes it more difficult to make summary statements about drainage that hold true for all watersheds, at all scales, at all times. It can be said, however, that the potential for subsurface drainage to reduce peak flowrates at the field scale, does not support the argument that subsurface drainage exacerbates flooding at larger scales. It should also be noted that most researchers agree that large-scale, basin-wide flood events such as those of 1993 and 1997 are largely attributable to catastrophic precipitation events, and not the presence of subsurface or surface drainage systems.

What is meant by the "sponge effect" of subsurface drainage?

The combined effect of subsurface drainage and a healthy, deep-rooted crop provides for an increased storage capacity for water infiltration into the soil, compared to an undrained, high watertable soil. Depending on the timing, depth and intensity of rainfall, more water has a chance to infiltrate on a drained soil as compared to a poorly drained soil. This increased storage capacity is often referred to as the "sponge effect". The extent to which the effect is realized depends on soil type, crop, time of year, and both rainfall and soil moisture characteristics prior to, and during precipitation. In poorly drained, high watertable soils, subsurface drainage lowers the watertable and increases the empty (air-filled) pore space available for infiltrating rainfall. The deeper, healthier crop root structure that is promoted by drainage further enhances this effect by removing still more water from the soil profile, which creates more empty pore space. The combined effect of subsurface drainage and crop growth is most apparent in middle to late growing season.