Memorandum

To: MIDS Work Group
From: Barr Engineering Company
Subject: Abstractions (Interception and Depression Storage) (Item 5, Work Order 1)
Date: December 14, 2010
Project: 23/62 1050 MIDS

The hydrologic cycle dictates that precipitation either directly generates surface runoff or is abstracted, which includes infiltration into groundwater or interflow, evapotranspiration through plants, interception by vegetation, or depression storage. The Federal Highway Administration (FHWA) defines abstractions as "the collective term given to the various processes which act to remove water from the incoming precipitation before it leaves the watershed as runoff. These processes are **evaporation**, **transpiration**, **interception**, **infiltration**, **depression storage** and **detention storage**." (FHWA 1984, emphasis added).

- Evaporation is the when solar energy vaporizes water from water bodies, soil, and other source of water.
- Transpiration or evapotranspiration is the process by which plants remove soil moisture through roots and release it back to the atmosphere. Evapotranspiration is discussed in another companion memo, Item 3: Regional Hydrologic Metrics- Precipitation.
- Infiltration is a significant abstraction; infiltration is discussed in a companion memo, Item 4: Infiltration. While evapotranspiration is an important part of the hydrologic cycle and is critical to reducing the antecedent moisture content of soil, thereby promoting infiltration, evapotranspiration does not have a direct effect on abstraction during a precipitation event.
- Detention storage, as defined above by FHWA, is storage required to generate overland flow, and is generally treated as part of depression storage.

This paper focuses on the two types of abstractions used in analyzing single-event precipitation: interception and depression storage.

Interception

Interception is the process by which water is captured on vegetation (leaves, bark, grasses, crops, etc.) during a precipitation event. Intercepted precipitation is not available for runoff or infiltration, but instead is returned to the atmosphere through evaporation. Interception losses generally occur during the first part of a precipitation event and the interception loss rate trends toward zero rather quickly (Figure 1). Interception losses are described by the following equation (Horton reprinted by Viessman 1996):

$$L_i = S + KEt$$

In the above equation, L_i is the total volume of water intercepted, S is the interception storage, K is the ratio of the surface area of the leaves to the area of the entire canopy, E is the rate of evaporation during the precipitation event and t is time. This equation assumes that the precipitation is enough to satisfy the storage on the vegetation.

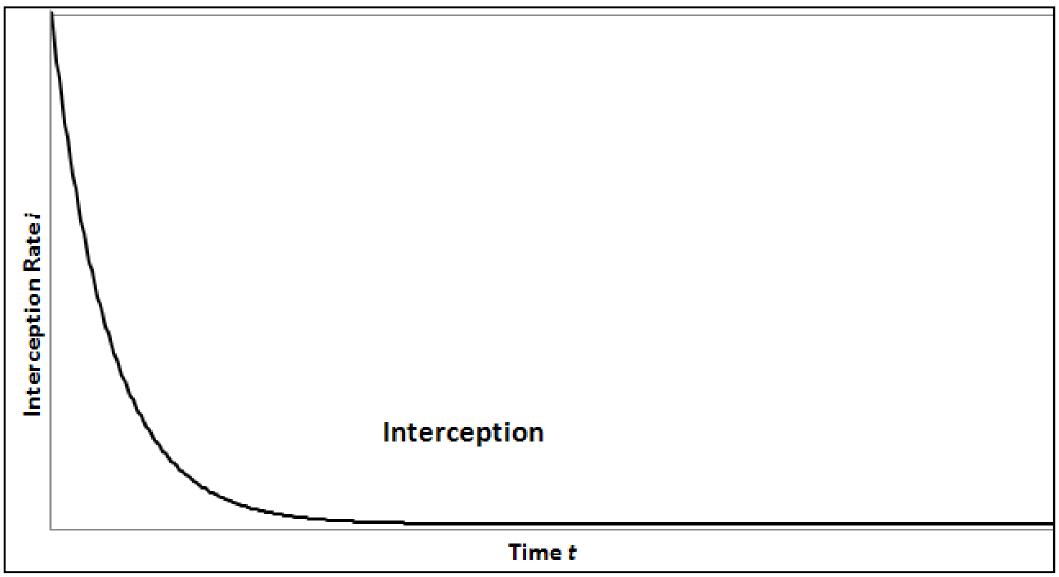

Figure 1. Interception Rate versus Time (Viessman 1996)

Interception can also be related back to the precipitation event with the following equation (Brooks 2003):

$$L_i = P_g - T_h - S_f$$

In the above equation, L_i is the canopy interception loss, P_g is the gross precipitation, L_h is the throughfall and S_f is the stemflow. Stemflow is the portion of precipitation that is slowed by leaves and branches and then slowly flows to the ground along the tree itself. Stemflow is not an abstraction itself; however, stemflow can be abstracted through infiltration or depression storage.

As the Horton equation suggests, the total interception is dependent on the storm duration, as longer duration storms allow more evaporation from the canopy during the storm event. The intensity of the storm also plays a role in canopy interception (Viessman 1996); however, there is debate as to whether intensity increases or decreases interception storage in canopy (Keim 2003).

There are many other factors that influence interception potential. Interception varies widely by season as deciduous trees lose much of their canopy storage potential during winter months. Xiao demonstrated that for the deciduous sweetgum tree, interception decreased from 70.5% during summer months to only 5.5% of total rainfall during winter months (Xiao 2003). The age, size and density of trees are also important factors in determining interception potential.

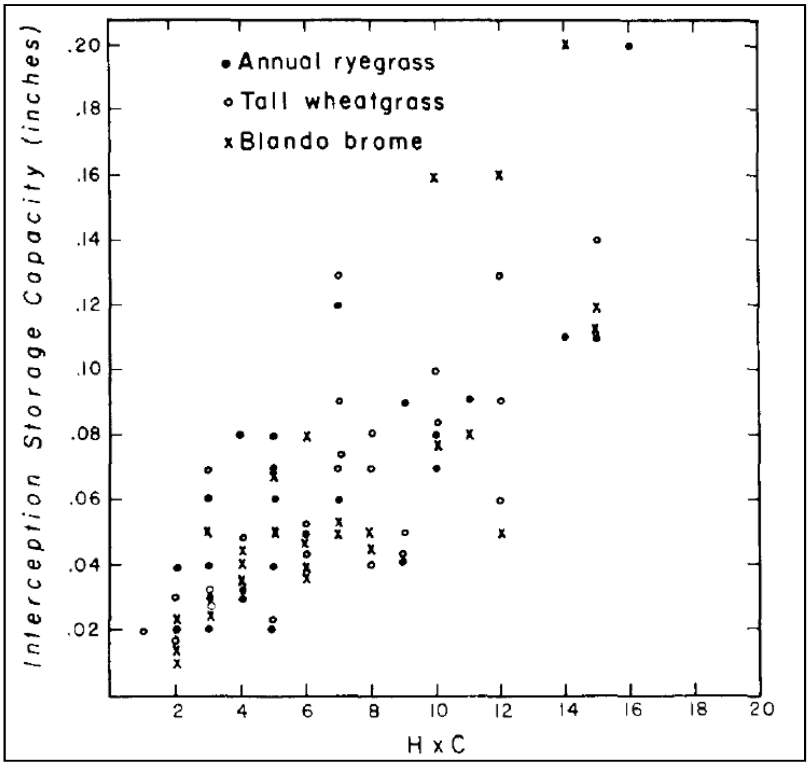

Figure 2 Interception Capacity of Grasses vs. Height x Cover (Corbett 1968)

Grasses also can intercept a substantial percentage of gross precipitation, up to 60% of annual rainfall (Viessman 1996). The interception storage capacity of grasses is most directly related to the height of the grasses and density of the vegetative cover. The US Forest Service (USFS) demonstrated that this relationship between interception, grass height and grass cover holds fairly constant for different types of grasses (Figure 2).

In Figure 2, H is the height of the grasses in inches and C is the percent cover of the grasses. Generally, the percent cover was rather high so the H x C value on the graph is approximately the height of the grasses. The results of their experiments demonstrated clearly that the interception potential of grasses varies widely over a growing season, with shorter grasses in the spring intercepting less water than longer grasses in the fall.

Extensive research has been conducted to quantify interception for different types of vegetation. The following table summarizes findings for different types of vegetation:

Table 1. Interception for Selected Vegetation Types

Vegetation Type	Interception (in.)	Region Data Collected	Source
Coniferous Trees	0.11 – 0.17	Douglas-fir-western hemlock ecosystem in SW Washington State	Link, et. al. 2004
Deciduous Trees	0.09 – 0.14*	Oak Tree in Davis, CA	Xiao, et. al. 2000
Meadows – 1-foot	0.08	**	Linsley 1982
Cropland – Corn – 6 feet	0.03	**	Linsley 1982
Cropland – Small Grains – 3 feet	0.16	**	Linsley 1982

*Interception values are valid for full-leaf canopy. Xiao found that leaf-off interception was 0.04 inches for pear trees.
**Linsley used Horton's equations for crop interception, which are based on experiments made in Seneca Falls, NY in 1914.

While the interception values listed above for single events may seem rather small, on an annual basis, vegetative interception is a large abstraction. Studies suggest that forests and meadows can remove, through interception, between 10 and 60 percent of annual precipitation (Viessman 1996, Xiao 2000).

A related abstraction is the water that is stored in ground litter (dead leaves, grasses, etc.) that can be found under trees or in grasslands. Studies suggest that ground litter can contribute as much as or more to abstractions than actual canopy interception. The USFS experiments demonstrated that one year of ground litter accumulation could store an average of 0.046 inches of precipitation, in addition to the vegetative interception of the grasses themselves (Corbett 1968). Ground litter, however, varies considerably based on the type of forest or grassland, and the type of management practices used on the land cover.

Depression Storage

Depression storage refers to small low points in undulating terrain that can store precipitation that otherwise would become runoff. The precipitation stored in these depressions is then either removed through infiltration into the ground or by evaporation. Depression storage exists on pervious and impervious surfaces alike; however, depression storage is much greater on undisturbed, pervious surfaces. Standard design and construction practices remove these natural depressions in order to promote drainage, which reduces depression storage.

The volume of water in depression storage at any time during a precipitation event can be approximated as:

$$V = S_d(1 - e^{-kP_e}) \text{ (Linsley 1982)}$$

Where V is the volume of water in depression storage, S_d is the maximum storage capacity of the depression, P_e is the rainfall excess, and k is a constant equal to $1/S_d$.

Depression storage assumes that all water has had a chance to infiltrate or evaporate. As shown on Figure 3, Turner demonstrated that depression storage intensity decreases by nearly half when there is an antecedent rainfall.

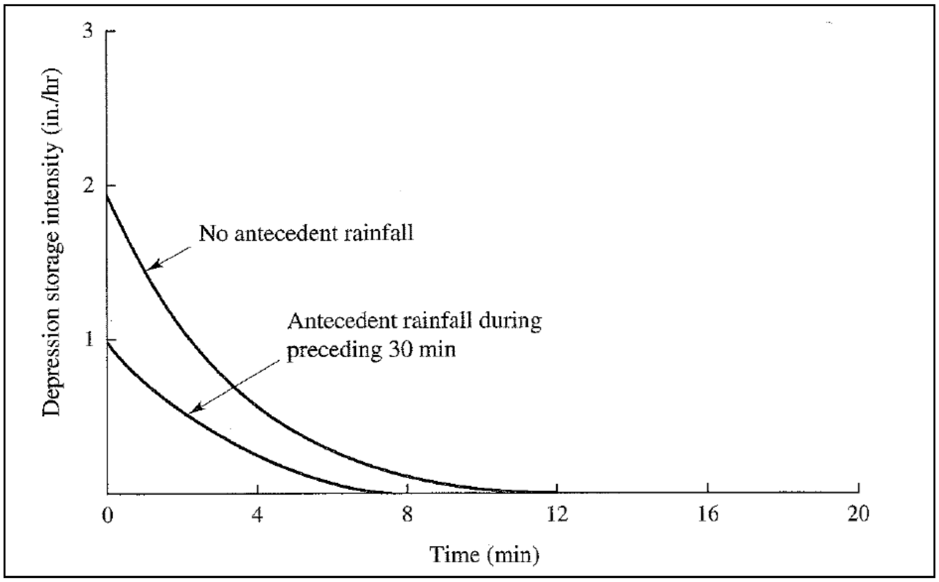

Figure 3. Depression Storage Loss Rate versus Time for Impervious Surfaces (Turner reprinted by Viessman 1996)

Slope also impacts the potential depression storage of a land cover. Viessman determined a relationship between slope on an impervious surface and depression storage. As the slope increases and approaches four percent, the depression storage may approach zero (Figure 4).

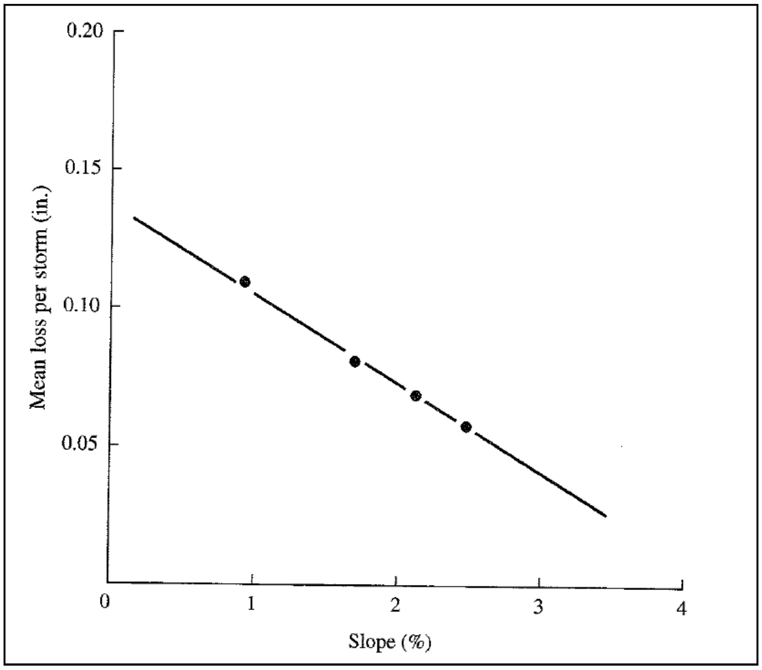

Figure 4. Depression Storage Loss versus Slope for Impervious Surfaces (Viessman 1996)

Many studies have attempted to determine depression storage for different land covers. The following table presents depression storage values for different land covers:

Table 2. Depression Storage for Selected Land Covers

Land Covers	Depression Storage (inches)	Source
Impervious, 1 percent slope, flat roofs, parking lots, roads	0.0625 – 0.125	Tholin and Kiefer 1960
Impervious, 2.5 percent slope and sloped roofs	0.05	Viessman 1996
Turfgrass	0.25	Tholin and Kiefer 1960
Open Fields	0.40*	Urban Drainage and Flood Control District 2008
Wooded Areas	0.40*	Urban Drainage and Flood Control District 2008

*These values include interception losses by vegetation

Application of Interception and Depression Storage Losses

The abstractions listed above in Tables 1 and 2 can be used in hydrological modeling to predict runoff for different storm events (or multiple events) and land covers. The abstraction values can be used throughout the entire state of Minnesota and across all ecoregions, but some values may not be relevant to every part of the state. For example, the interception loss potential of coniferous forests is probably of little interest to southwestern Minnesota; however, impervious surfaces and meadows (to name a couple) are land covers that are relevant to every part of the state. These losses are site-specific so that the designer can consider the expected abstractions from each distinct land cover on a site.

The abstraction values listed in Tables 1 and 2 are particularly well-suited for infiltration-based modeling approaches, such as those employed by the Horton and Green-Ampt infiltration methodologies as opposed to Curve Number methodology, which does not allow for the direct adjustment of initial abstractions (see the companion memo, Item 6: Regional Hydrologic Metrics – Curve Numbers, for further discussion on this topic). The abstractions are also the best-suited for continuous hydrologic modeling due to the methods' consideration of the antecedent moisture content and infiltration capacity regeneration during inter-event periods. As previously mentioned, the interception losses are small when considering large, individual storm events (such as the 5- or 100-year precipitation events); however, on an annual basis, these abstractions from interception and depression storage can account for up to 60% or more of annual mean precipitation.

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