

Issue

Percolation is defined as the slow movement of water through the pores in soil or permeable rock. Currently, the Federal Emergency Management Agency (FEMA) does not have specific guidance on percolation-related issues, such as conditions under which percolation should be considered, data needed to support the computation, and acceptable methodology. The Southwest Florida Water Management District and several counties in Florida proposed to incorporate percolation loss computation into Flood Insurance Study modeling. This guidance paper reviews the physical processes of infiltration and percolation and outlines procedures to determine percolation rate, evaluate the impact of percolation, and estimate percolation losses through hydrologic modeling.

Infiltration and Percolation

Infiltration and percolation are two related but different processes describing the movement of moisture through soil. Infiltration is defined as the downward entry of water into the soil or rock surface (SSSA, 1975) and percolation is the flow of water through soil and porous or fractured rock. In hydrologic modeling, these two processes are usually modeled separately. Infiltration rate is the rate at which a soil under specified conditions absorbs falling rain, melting snow, or surface water expressed in depth of water per unit time (ASCE, 1985). Percolation rate, although more difficult to measure directly, represents the rate at which soil moisture moves down through the soil or permeable rock.

Infiltration rate usually demonstrates a rather rapid decline with time from the beginning of infiltration and reaches a steady state as the soil eventually becomes saturated. At this stage, the infiltration rate would be approximately equal to the percolation rate, which in general is much lower than the initial surface infiltration rate. Therefore, in practice the steady state infiltration rate can be considered as a good representation of the percolation rate when soil texture and characteristics are similar between upper layers of soil where the infiltration rate is measured and lower layers where percolation occurs. If the underlain soil layers are different from upper soil layers, the steady state infiltration rate may vary significantly from the percolation rate. The percolation rate in a karst terrain usually has high spatial variability both horizontally and vertically; therefore, the steady state infiltration rate is often unable to accurately represent the rate of percolation in such terrain.

Estimation of the Percolation Rate

The infiltration rate can be estimated from field tests. The Double Ring Infiltrometer test is the most commonly used method. Other field testing methods approved by responsible Federal and State agencies or Water Management Districts are also acceptable. Laboratory determinations are usually not sufficient because even an undisturbed soil core may provide highly variable rates.

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Lysimeters, a commonly used field method, may be used to determine percolation rates as they provide direct and accurate measurement. Other field methods approved by responsible Federal and State agencies or Water Management Districts where the site is located are also acceptable.

To reflect uncertainties associated with the soil, water, measurement methods, and circumstances of infiltration and percolation, values as measured by the above methods should be multiplied by an appropriate factor of safety to determine the design infiltration and percolation rates. A safety factor for the project site/region established by Federal and State agencies or Water Management District is generally acceptable; otherwise, a safety factor should be determined by a Professional Geotechnical Engineer, Certified Professional Soil Scientist, or Certified Hydrologist with groundwater experience to account for the above factors.

Copies of the field test report, the calculations used to obtain the designed infiltration and/or percolation rate, and safety factor must be submitted to FEMA. All copies must be certified by a Professional Geotechnical Engineer, Certified Professional Soil Scientist, or Certified Hydrologist with relevant experience who performed or directly supervised the field tests and calculations.

Impact of Percolation

While infiltration is important in estimating flood peaks and volumes for all watersheds, percolation has significant impact on watersheds with very sandy soil or karst terrains.

Simulate Infiltration and Percolation Losses in Hydrologic Modeling

Infiltration and percolation are components of hydrologic cycle and are affected by other components. For example, for areas with a high groundwater table, the total amount of infiltration and percolation would be rather low even though the soil matrix is capable of higher infiltration and percolation rates. A hydrologic model used for simulating infiltration and percolation losses must account for all the flows entering, moving within, and leaving the system, as well as storage changes within the system. Inflow may constitute infiltration resulting from rainfall and, if applicable, interflow. Outflow may constitute evaporation, transpiration, percolation and/or deep percolation, and groundwater outflow. The system may be modeled as multiple layers of soil extending from the ground surface to the permanent groundwater table. The model must perform mass balance calculations to assure that all water movements are accounted for and storage changes within the systems reflect the differences between inflow and outflow. It must also show any change in groundwater table elevation that occurred during the simulation process and its impact on percolation. It is not acceptable to simply model the percolation as the amount of water disappearing from the system. If a perched groundwater table

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exists at or near an impermeable layer, it must be reflected in the model setup or parameter determination.

A good example of such a model is the U.S. Army Corps of Engineers HEC-HMS program, which includes a soil moisture accounting (SMA) model. The SMA model divides the soil into several layers based on the soil moisture content and dominant hydrologic processes. For example, infiltration and evaporation processes are modeled in the upper unsaturated layer of soil, whereas percolation in the lower layer occurs under mostly saturated conditions. Layers can also be modeled as different nodes in a nodal system model.

Because of inherent uncertainties and variability associated with the determination of various model input parameters, the determined model parameters must be refined by calibration with observed data. The calibration process and the source of observed data must be documented. Detailed guidance for calibrating model parameters is provided in the Technical Reference Manual of HEC-HMS.

Percolation is a relatively slow process compared to surface runoff. An event-based model, typically simulating surface runoff hydrographs for a rainfall duration of 24 hours or shorter, is usually not sufficient to reflect the impact of percolation, especially changes of groundwater level. To fully simulate the impacts of percolation, the simulation period should be determined by physical conditions such as the watershed size and soil characteristics. It must be at least 48 hours longer than the surface runoff hydrograph associated with the design rainfall event.

Special Considerations

Some special considerations that are relevant are discussed below, including: coastal areas, karst terrain, and lakes and ponds.

Watersheds in Coastal Areas

For watersheds located in areas where the groundwater table is likely to be influenced by coastal factors, the hydrologic model must consider the worst case scenario of the highest groundwater table that may occur as a result of the interaction between ground and coastal waters.

Watersheds with Karst Terrain

Karst terrain is characterized by a wide range of closed depressions, well developed underground drainages, and a paucity of surface streams. Water movement in karst terrain is especially unpredictable. Karst terrain can also have true underground streams with high rates of flow (USGS 1998). It is not unusual for surface streams to disappear into rock openings and reappear at the surface, often as a spring,

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at locations beyond the watershed boundary defined by surface topography. Large amounts of rainfall could become “lost” to such underground drainages.

Modeling work that involves the simulation of infiltration and percolation losses in karst terrain must be performed by or under the direct supervision of a professional hydrogeologist. Relevant hydrologic and hydrogeologic reports and studies performed by Federal, State, or local agencies in the area should be reviewed and, if applicable, incorporated into the modeling framework. In addition to modeling all inflow and outflow from the system and performing mass balance calculations, the flow pathways, sources, and sinks must be clearly described and supported by adequate documentation/technical evidence. Model parameters must be refined by calibration with observed data. Step-by-step documentation of the calibration process and the source of observed data must be provided.

Lakes and Ponds

Percolation rates for natural lakes and man-made ponds that are not designed for specific percolation rates decrease significantly over time due to the build up of layers of organic muck caused by sediment deposition and other physical, chemical, and biological processes, such as the growth and decomposition of nuisance plants. Percolation rates at the bottom of such a lake or pond may be different from that of their floodplains. Therefore, each lake, pond, or depression area for which percolation loss is accounted during the Base Flood Elevation determination process must be carefully evaluated by a competent professional to ensure that the percolation rate used in the simulation will be representative of the long-term percolation rate.

Conclusions and Recommendations

- Percolation losses can be estimated through hydrologic modeling.
- Field data collected must be representative of the percolation or steady-state infiltration rate. A Double-Ring Infiltrometer or equivalent is recommended.
- Subsurface variability must be incorporated in the modeling or sufficient calibration using observed data must be completed.
- The interaction between surface water and groundwater must be accounted for in the model because this can control the percolation rate regardless of the capacity of the soil matrix.

As a result of the complex nature of the variables involved (i.e., soil, groundwater, subsurface geology), no one methodology will work for all situations. This document provides general guidance; use of percolation in modeling the 1-percent-annual-chance flood will be evaluated and approved on a case by case basis. The FEMA Regional office should be contacted if any methodologies not described are planned to be used.

References

American Society of Civil Engineers (ASCE), 1985, Manual 40 - Ground Water Management

Soil Science Society of America (SSSA), 1975, Glossary of Soil Science Terms

USGS, 1998, Ground Water and Surface Water - A Single Resource, USGS Circular 1139, Winter, T.C., J.W. Harvey, O. L. Franke, and W. M. Alley