Rain-on-Snow Simulation Enhancements within HEC-HMS

Travis Dahl, Research Hydraulic Engineer, USACE ERDC-CHL, Vicksburg, MS, Travis.A.Dahl@usace.army.mil
Michael Bartles, Hydraulic Engineer, USACE IWR-HEC, Davis, CA, Michael.D.Bartles@usace.army.mil
Jeremy Giovando, Research Hydraulic Engineer, USACE ERDC-CRREL, Hanover, NH, Jeremy.J.Giovando@usace.army.mil
Daniel Hamill, Hydraulic Engineer, USACE Sacramento District, Sacramento, CA, Daniel.D.Hamill@usace.army.mil

Extended Abstract

Rain-on-snow events are a common occurrence in the winter months throughout the United States including large portions of the Mid-Atlantic, Midwest, and Pacific Northwest regions. This is especially true for rivers in the mountainous West, which typically experience their largest floods when warm winter storms interact with extensive snow cover. In many of these watersheds, rain-on-snow events are the primary driver of flood hazards and the Federal Government has constructed numerous projects in order to mitigate flooding risks due to these events. The nonlinear effects of rain falling on snowmelt can be difficult to simulate accurately within hydrologic models.

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS; Bartles et al., 2022) has recently been modified to include three methods for accumulating and melting snow: Temperature Index (TI), Hybrid/Radiation-derived Temperature Index (RTI), and Energy Balance (EB). These three methods range from being relatively simple with only a few required boundary conditions (TI) to intricate with numerous required meteorological inputs (EB). All three methods include mechanisms to discriminate between precipitation falling as rain or snow, form a snowpack, melt the snowpack, reformulate the snowpack when temperatures drop, and eventually melt the entire snowpack. Users can employ these methods at either a subbasin scale (i.e., lumped) or within gridded (i.e., distributed) implementations.

Snowmelt Methods

Temperature Index

The simplest snowmelt method available in HEC-HMS is Temperature Index (TI). This method uses an air temperature gradient as a proxy for the energy available to heat and melt the snowpack. The implementation in HEC-HMS is based on the Streamflow Synthesis and Reservoir Regulation (SSARR) model (USACE 1987) and SNOW-17 (Anderson, 2006). SSAR, in turn, relied heavily on U.S. Army Corps of Engineers (USACE) snow hydrology studies from the 1950s (USACE, 1956). While simple, this method has proven effective for modeling snow hydrology across a wide range of environments, especially for application in operational contexts (e.g., USACE, 1998; Hock, 2003; Jonsell et al, 2012; Dahl and Selegean, 2018; Geck et al. 2021).

During days without liquid precipitation, TI estimates snowmelt (mm/day) as

$$Snowmelt = Dry\ Melt\ Rate * (T_A - T_B)$$

where Dry Melt Rate is in (mm/°C –day), T_A is the air temperature (°C), and T_B is the base temperature, a model input parameter often assumed to be 0 °C. For time steps with liquid precipitation (rain-on-snow), TI uses

$$Snowmelt = (Wet\ Melt\ Rate + 0.168 * Precipitation\ Intensity) * (T_A - T_B)$$

where Wet Melt Rate is in (mm/°C –day), Precipitation Intensity is in (mm/hr), and the constant term is 0.168 (hrs/°C –day).

HEC-HMS also provides a Gridded Temperature Index method that distributes the TI calculations across individual grid cells instead of performing them at the subbasin scale.

Hybrid (Radiation-Derived) Temperature Index

The Radiation-Derived Temperature Index (RTI) method was developed to increase model fidelity without dramatically increasing input data requirements (Follum et al., 2015). As implemented in HEC-HMS, the primary difference from the TI method is the addition of topographic shading. HEC-HMS calculates the shortwave radiation input based on day-of-year, location, and digital elevation models of the terrain. The model formulation has a rain threshold of 1.5 mm/6 hrs that triggers a set of radiation-derived calculations for rain-on-snow events.

Energy Balance

The highest fidelity snowmelt method for use in HEC-HMS is the Energy Balance (EB). This name is somewhat misleading because all of the methods perform energy balances; however, the EB method in HEC-HMS simulates as many of the energy flows into and out of the snowpack as possible. This includes shortwave and longwave radiation, complete with the effects mitigating variables such as snow albedo. The EB implementation in HEC-HMS is based on the Utah Energy Balance Model of Tarboton and Luce (1996). Due to the large number of parameters included in the model calculations, the EB method is both data and computationally intensive.

Validation

The HEC-HMS is committed to ensuring that publicly available software features are fully validated and documented. As of HEC-HMS version 4.10, the RTI and EB methods are still only available when the program runs in debug mode. Considerable effort has been expended over the last year to confirm that the RTI method in HEC-HMS produces the same results as the original work of the method developer (Hamill et al. 2021). A similar effort has also been initiated for the EB method.

Related HEC-HMS Features and Enhancements

In the past, HEC-HMS required the same snowmelt method and parameters to be used for the entire model basin. The HEC-HMS team reorganized the model architecture in version 4.10 so that snowmelt parameters are associated with specific subbasins rather than the meteorology of the entire model. This will allow modelers greater ability to calibrate models that cover widely varying topography and elevation.

The HEC-HMS has also improved the output related to snowmelt, including the ability to display and animate gridded outputs of Snow Water Equivalent (SWE).

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