Snow Melt with the Land Climate Boundary Condition

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Introduction

The land-climate interaction (LCI) boundary condition in SEEP/W is used to model the water balance at the ground surface. The water balance includes rainfall, snowmelt, actual evaporation, and runoff. The behavior of the boundary condition during solve-time depends partly on the air temperature. This example demonstrates how to interpret the net infiltration during a snow melt event when the air temperature is transitioning across the 0°C freezing threshold.

Background

The water flux boundary condition required to solve the water transfer equation can be calculated from a mass balance equation at the ground surface, which is given by:

$$(q_P + q_M)cos\alpha + q_E + q_R = q_I \qquad \text{Equation 1}$$

where superscripts on the water fluxes (q) indicate rainfall (P), snow melt (M), infiltration (I), evaporation (E) and runoff (R) and α is the slope angle. The evaporation and runoff fluxes are negative; that is, out of the domain. The infiltration is deemed the residual of the mass balance equation and therefore forms the boundary condition of the water transfer equation. Transpiration does not appear in Equation 1 because root water uptake occurs below the ground surface.

The land-climate interaction boundary condition in SEEP/W requires a time-based function for precipitation and snow depth. Climate stations generally measure precipitation, but snow depth is often absent and needs to be estimated. The following sections discuss how a snow depth function can be generated using a precipitation and air-temperature data.

Snow Accumulation

The snow depth on the ground surface at any instant in time h_s is the summation of all incremental snow depth accumulations minus snow melt:

$$h_s = \sum_0^t (\Delta h_s - \Delta h_{melt})$$ Equation 2

where the incremental snow depth accumulation Δh_s is corrected for ablation. There are essentially two approaches for estimating snow accumulation and melt: an energy-balance approach and a temperature-index approach. Dingman (2002) notes that the temperature-index method is used in most models to predict or forecast snowmelt because the data requirements are not realistic for the energy-balance approach. Anderson (2006) notes that many studies have found air temperature to be a good indicator for snow melt and that index models are more realistic for operational forecasting.

The snow depth accumulated over the interval is calculated as:

$$\Delta h_s = \Delta h_m \frac{\rho_w}{\rho_s}$$ Equation 3

where Δh_m is the height of snow accumulated over the interval as a snow-water-equivalent (SWE). The height of snow accumulated over the interval is corrected for ablation, which can include processes such as canopy interception, wind redistribution, and sublimation.

The height of snow accumulated over the interval can be approximated as:

$$\Delta h_m = \Delta P \times f_s \times MF$$ Equation 4

where

Δh_m	Height of snow over the interval [m SWE]
ΔP	Precipitation over the interval [m]
f_s	Fraction of precipitation as snow
MF	Multiplier factor

The fraction f_s is set to either 0 or 1 depending on the air temperature relative to the threshold temperature. The multiplier factor can be used to account for various factors contributing to ablation. The multiplier factor can be calculated from an ablation constant as:

$$MF = 1 - Ablation\ Constant$$ Equation 5

The multiplier factor MF is ultimately used for site-specific calibration. For example, an ablation constant of 0.3 implies that only 70% of the snowpack remains.

Snow Melt

In order to estimate a snow depth verses time function (Equation 2), the snow melt must also be calculated. The process of snow melt estimation involves a very complex energy balance that requires high quality data. As such, a temperature-index approach is an accepted method for estimating snow melt. A daily melt verses daily average temperature function would take the form shown Figure 1. In general, snow melt begins as the average daily air temperature approaches a threshold, typically around 0°C. The slope of the line on the positive side of the melt threshold represents the daily melt rate (cm/day). In order to use this approach, a maximum melt rate is usually required.

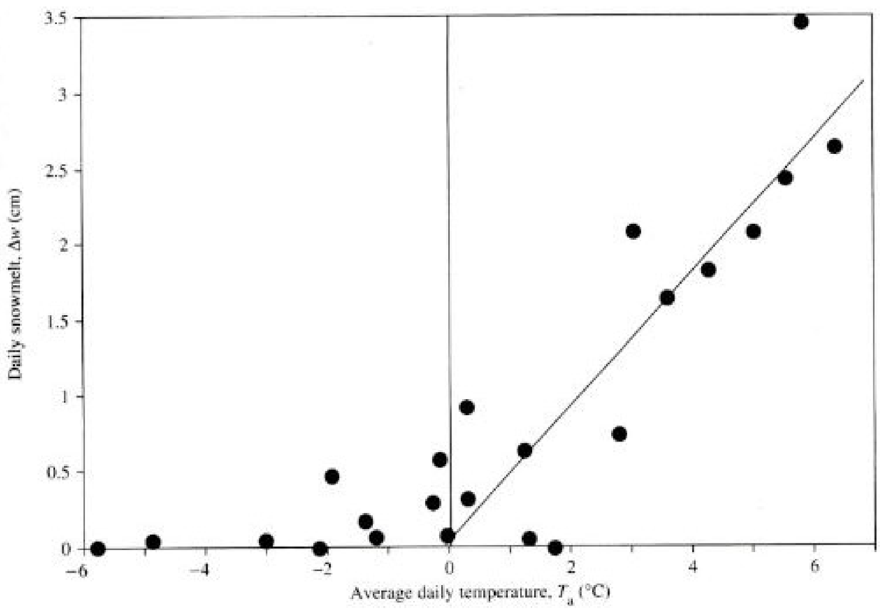

Figure 1. Daily snow melt as a function of average air temperature (Anderson et al., 1977).

Calculation of Snow Melt Flux in SEEP/W

The land-climate interaction boundary condition in SEEP/W calculates snow melt based on the change in snow pack depth between time steps. For example, assume that the snow pack depth on Day 1 and Day 2 was 10 cm and 5 cm, respectively. During solve time for Day 2, the boundary condition would determine a decrement of 5 cm between time steps and calculate the snow melt as:

$$\Delta h_m = \Delta h_s \frac{\rho_s}{\rho_w} = 50\ mm \frac{50 kg/m3}{1000 kg/m3} = 2.5 mm \quad \text{Equation 6}$$

assuming a snow density of 50 kg/m^3. It should be noted, however, that the snow melt is automatically set to zero if the air temperature is below 0°C because other processes likely altered the snow pack.

Numerical Simulation

The model domain comprises a column of silt that is 5 m in height. The silt is modeled using a saturated-unsaturated model. The initial condition is defined using a water table at the base of the column. This lower boundary is set to a pressure head of 0 m. The upper boundary is modeled using the mass land-climate interaction (LCI) condition. By default, a SEEP/W analysis considers liquid water transfer. The water transfer physical processes, including isothermal and thermally-driven vapor flow, are not selected for this example because evaporative drying is not involved.

Figure 2 presents the inputs for the mass LCI boundary condition. The three requirements include climate data, an evapotranspiration method, and vegetation data. The vegetation data only needs to be defined if root water uptake is modeled and/or the Penman-Monteith evapotranspiration method is selected. In this case, the user-defined potential evapotranspiration (PET) method has been selected and the PET set to zero for the duration of the analysis. The toggles (i.e. check-boxes) indicate the required climate inputs. Snow depth is optional and wind speed and radiation are not required for the User Defined PET method. There are two options to define the snow depth function: (1) From Climate Data; or, 2) Calculated. The former option implies that a snow depth verses time function will be defined as part of the climate data. The latter option uses the precipitation and air temperature climate data to automatically generate a snow depth function.

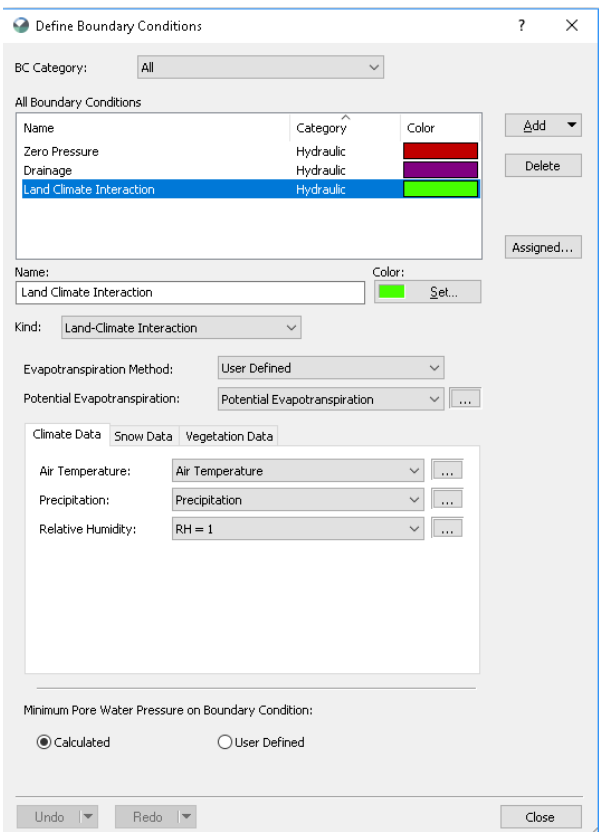

Figure 2. Mass land-climate interaction boundary inputs.

Figure 3 presents the climate data inputs for the analysis. The relative humidity (RH) function was set to 1.0 for the duration of the analysis. The RH does not affect the analysis because the PET has been set to zero. The air temperature and precipitation functions are devised to demonstrate the behavior of the LCI boundary condition during precipitation and snowmelt. The snow density was assumed to be 50 kg/m³.

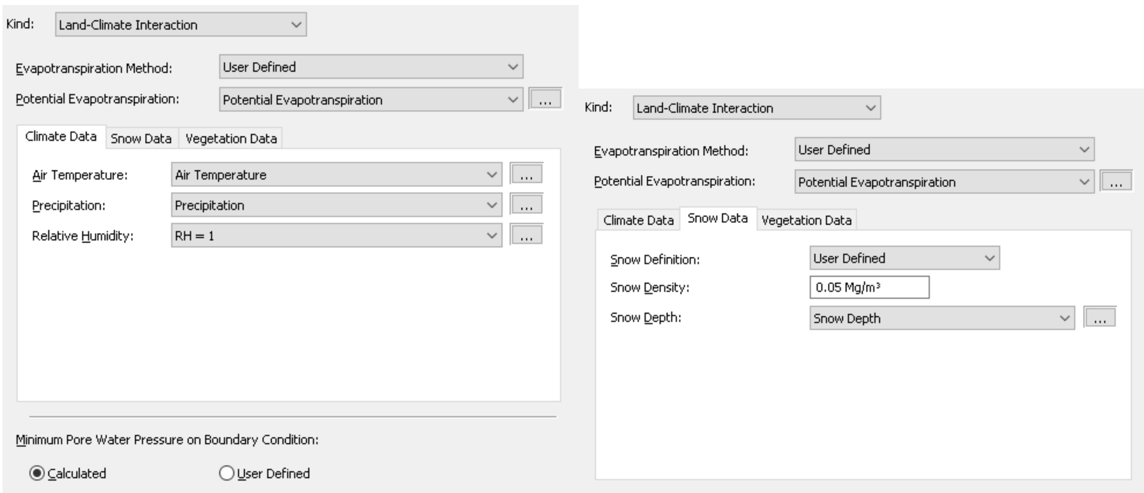

Figure 3. Climate data inputs.

The snow depth function (Figure 4) was calculated using the temperature-index approach discussed above (Figure 5). This approach is used automatically in SEEP/W when the snow depth is set to 'Calculated'. The ablation constant was set to 0.20 and the daily snow melt rate was assumed to be 0.00125 mm when the air temperature was above 0°C.

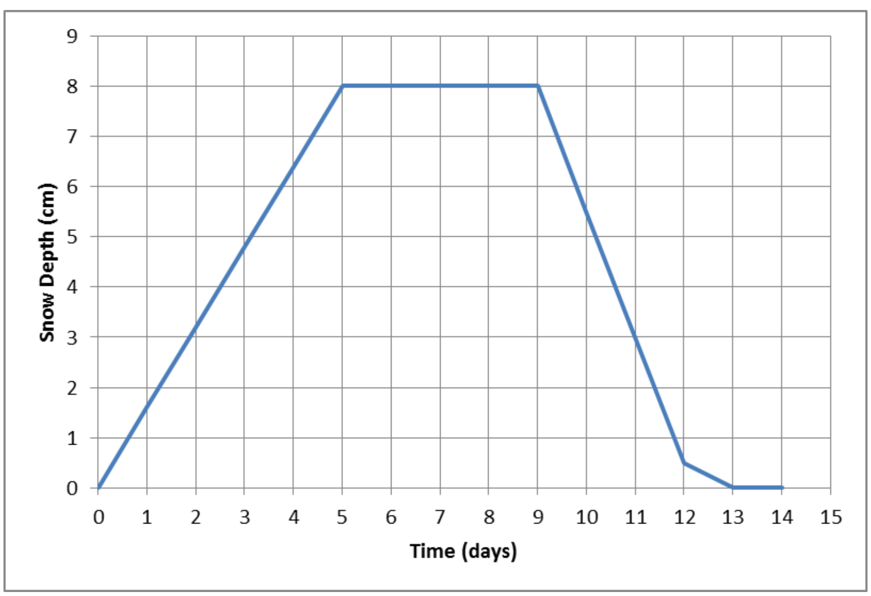

Figure 4. Snow depth function calculated using the temperature-index approach.

Inputs

Threshold Melt Temp.	0	
Snow Ablation Constant	0.2	
Snow Density	50	kg/m3
Water Density	1000	kg/m3
Integration Interval	1	day

Elapsed Time	Date	Avg. Air Temp	Precip.	Snow Fall mm SWE	Snow Melt Rate mm SWE	Accumulated Snow mm SWE	Accumulated Snow cm
0	01/01/2004	-5	1	0	0	0	0
1	02/01/2004	-5	1	0.8	0	0.8	1.6
2	03/01/2004	-5	1	0.8	0	1.6	3.2
3	04/01/2004	-5	1	0.8	0	2.4	4.8
4	05/01/2004	-5	1	0.8	0	3.2	6.4
5	06/01/2004	-5	0	0.8	0	4	8
6	07/01/2004	-5	0	0	0	4	8
7	08/01/2004	-5	0	0	0	4	8
8	09/01/2004	-5	0	0	0	4	8
9	10/01/2004	0.5	0	0	0	4	8
10	11/01/2004	0.5	0	0	1.25	2.75	5.5
11	12/01/2004	0.5	0	0	1.25	1.5	3
12	13/01/2004	0.5	0	0	1.25	0.25	0.5
13	14/01/2004	0.5	0	0	1.25	0	0
14	15/01/2004	0.5	0	0	1.25	0	0

Figure 5. Example of snow accumulation and snow melt calculations.

SEEP/W integrates the precipitation and air temperature verses time functions over the day to determine the rainfall and average temperature, respectively. If the average air temperature is below freezing, snow is accumulated using Equation 4 with the user-input ablation constant and assuming that f_s is 1. In this case, there was 1 mm/day of precipitation in the first five days of the climate record. Given the ablation constant of 0.2, the snow accumulates at 0.8 mm per day, yielding a maximum of 4 mm SWE on Day 5. At a snow density of 50 kg/m^3, the accumulated snow depth equals 8.0 cm. The air temperature increases to 0.5°C on Day 9. As such, the snow disappears at 1.25 mm SWE per day, which is equal to 2.5 cm of snow given a density of 50 kg/m3. Only 0.5 cm of snow remains on Day 11, so the snow melt is set to zero on Day 12 to ensure that the snow depth does not become negative.

Results and Discussion

Figure 6 presents the net infiltration into the top of the column. Snowmelt infiltration started at an elapsed time of 9.0 days. The total infiltration is 0.004 m^3, which is equal to 4.0 mm per m^2. The total change in snow depth from the function was 4.0 mm SWE (8.0 cm snow; Figure 5). The snow melt infiltration is also in-keeping with the air temperature function (Figure 7). At an elapsed time of 9 day, the air temperature function is integrated across the time step (8.5 to 9 days), yielding an air temperature of -0.5 °C.

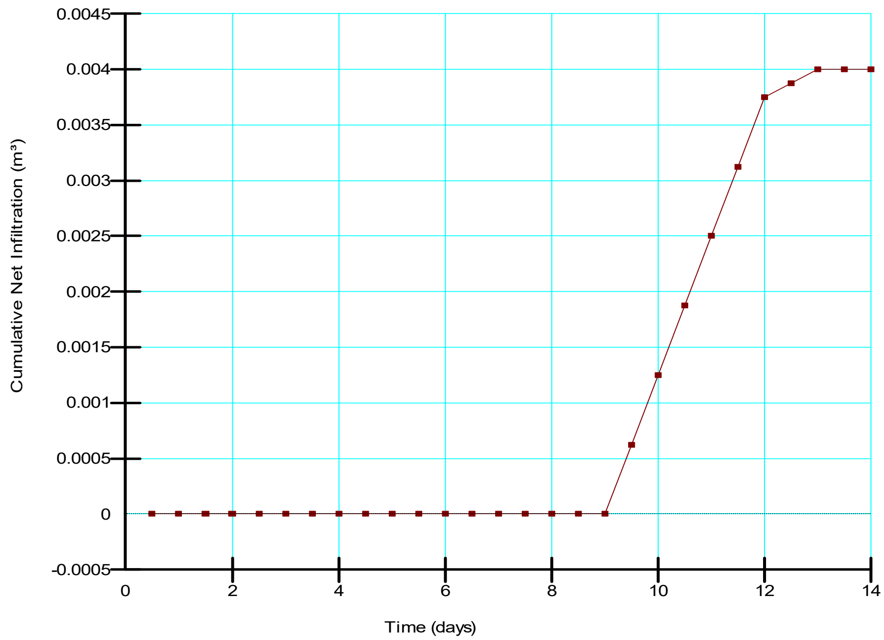

Figure 6. Net infiltration verses time.

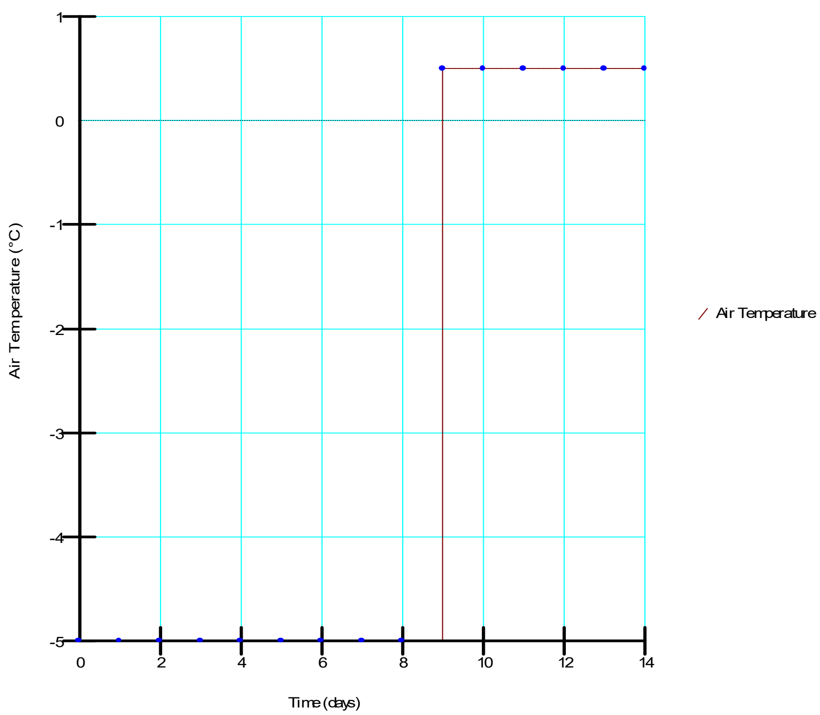

Figure 7. Air temperature vs time function.

Figure 8 presents the water rate for the top node over the duration of the analysis. The infiltration rate decreases from 1.25 mm/day (1.45e-8 m/s) to 0.25 mm/day (2.9e-9 m/s) on Day 12.5. This occurs because there is only 0.25 mm SWE of snow remaining on Day 12. As such, the incremental change from Day 12 to 12.5 and 12.5 to 13 is 0.125 mm, which equates to a flux of 0.25 mm/day for a time step duration of 0.5 day (i.e. 0.125 mm/0.5 day). It should also be noted that the net infiltration from Day 0 to Day 5 was zero, despite 5 mm of rainfall during this period. This occurs because the air temperature was below 0°C.

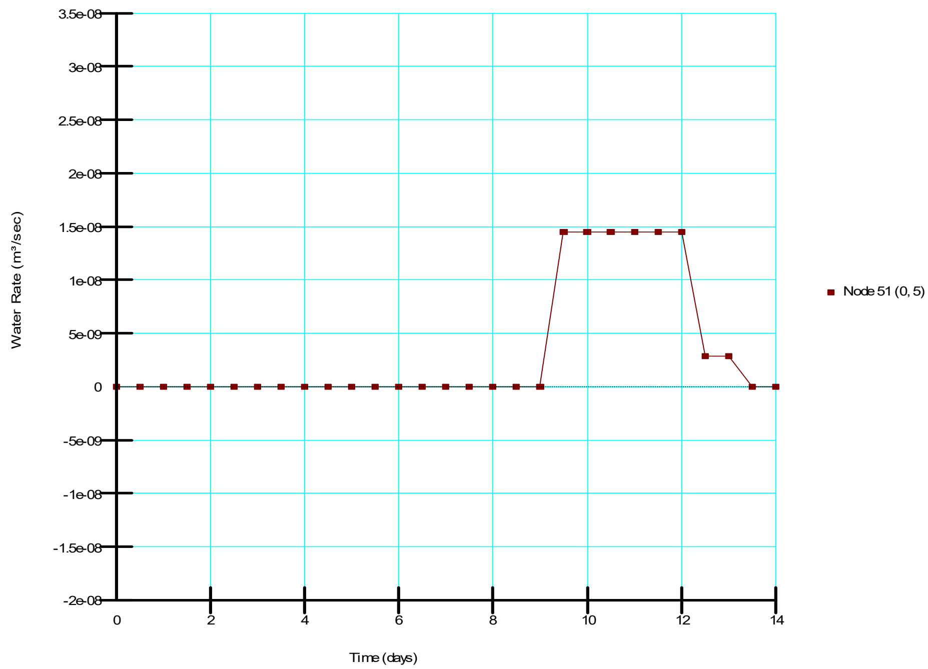

Figure 8. Recharge rate verses time.

Summary and Conclusions

The land-climate boundary condition in SEEP/W is used to model the water balance at the ground surface. The boundary condition requires a snow depth function, which can be defined using measured data or using the built-in SEEP/W temperature-index estimation approach. During solve-time, snow melt is included in the surface water balance calculation if there is a decrement is snow depth and the air temperature is above freezing. Rainfall from the precipitation verses time function is ignored if the air temperature is below 0°C.

References

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