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Holistic Research to Support Resilient Water Management
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Flow Below Channels

Removing Problematic Flow Routing Assumption in DHSVM

I. Abstract

The Distributed Hydrology Soil Vegetation Model (DHSVM) channel network routing scheme was developed in a very humid coastal climate, leading to assumptions that may be invalid in more arid environments. Specifically, the legacy version of DHSVM assumes that the soil beneath the user-specified stream network is always saturated, i.e., the water table cannot fall below the channel cut depth. In arid environments, many stream channels are ephemeral and/or losing, which invalidates this assumption. As a side effect of this assumption, the legacy DHSVM routing architecture prohibits lateral subsurface flow beneath channels. Consequentially, water can get stuck below stream channels despite a strong hydraulic gradient, causing unphysical streamflow simulations. Removing a single "if" statement from the DHSVM code largely ameliorates this problem, permitting reasonable streamflow simulation in arid environments. The paper provides a cursory examination of the issue, and a planned journal publication will detail a fully revised coupled surface-groundwater interaction scheme.

II. Background

The original implementation of DHSVM (Wigmosta et al. 1994) does not include stream network routing; rather, saturated groundwater exfiltrates when the water table intersects the land surface, and is assumed to exit the basin as streamflow on the same day. Wigmosta and Perkins (2001) introduced network flow routing to DHSVM for both stream channels and road cuts. In the revised model, a user-defined stream network extends across the two-dimensional model grid, with network routing defined by a lookup table of stream segment confluences. In addition to various other parameters, each channel segment requires specification of a bank cut depth; when the water table is shallower than this depth, saturated groundwater from a given grid cell is added to the respective channel segment.

The DHSVM stream network scheme was developed and initially applied in the very humid Carnation Creek watershed on Vancouver Island (BC, Canada). Consistent with this environment, the original implementation assumes that all stream channels are effectively perennial, and the water table never falls below the channel bank cut depth (Figure 1).

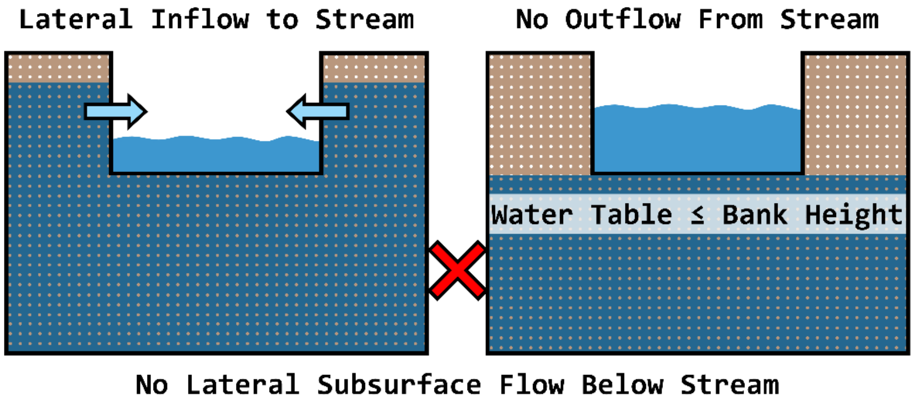

Figure 1. Original conceptual model for DHSVM stream channel intersections with grid cells.

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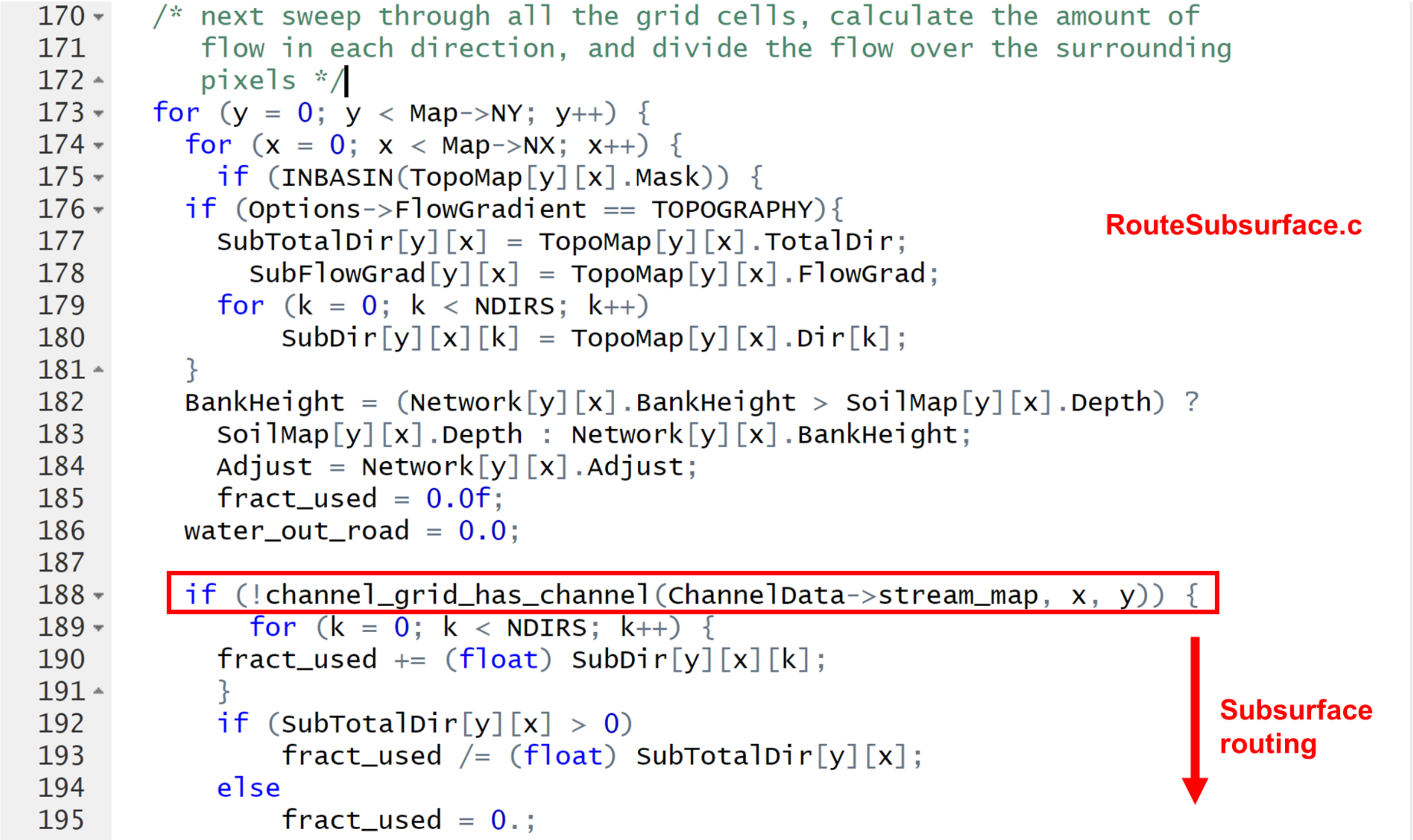
III. Code Implementation

When the stream network functionality was added, the original DHSVM subsurface routing module (RouteSubsurface.c) was modified to only operate on cells that do NOT have stream channels:



```c
/* next sweep through all the grid cells, calculate the amount of
   flow in each direction, and divide the flow over the surrounding
   pixels */
for (y = 0; y < Map->NY; y++) {
  for (x = 0; x < Map->NX; x++) {
    if (INBASIN(TopoMap[y][x].Mask)) {
  if (Options->FlowGradient == TOPOGRAPHY){
    SubTotalDir[y][x] = TopoMap[y][x].TotalDir;
      SubFlowGrad[y][x] = TopoMap[y][x].FlowGrad;
    for (k = 0; k < NDIRS; k++)
        SubDir[y][x][k] = TopoMap[y][x].Dir[k];
  }
  BankHeight = (Network[y][x].BankHeight > SoilMap[y][x].Depth) ?
    SoilMap[y][x].Depth : Network[y][x].BankHeight;
    Adjust = Network[y][x].Adjust;
    fract_used = 0.0f;
  water_out_road = 0.0;

  if (!channel_grid_has_channel(ChannelData->stream_map, x, y)) {
      for (k = 0; k < NDIRS; k++) {
    fract_used += (float) SubDir[y][x][k];
    }
    if (SubTotalDir[y][x] > 0)
        fract_used /= (float) SubTotalDir[y][x];
    else
        fract_used = 0.;
```

Figure 2. DHSVM routing code, showing “if” statement that excludes cells with stream channels.

Removing the highlighted “if” statement (and the corresponding closing bracket) enables groundwater flow below stream channels. This was likely implemented originally to avoid a more complicated treatment of bidirectional hyporheic flow between channels and riparian groundwater. In humid environments, anecdotal testing suggests that groundwater remains near the surface year-round in grid cells with channels; since surface flow is much faster than groundwater flow, the latter can reasonably neglected below perennial streams.

However, in arid environments, streams can remain dry most of the year, with a deep water table even in topographic convergence zones. In this case, channels specified in the user-defined network files should be ignored during subsurface routing calculations, because dry channels do not affect the underlying groundwater.

An initial implementation of DHSVM with groundwater flow enabled below streams (simply by removing the exclusionary “if” statement) is available here: https://github.com/eli-mtnhydro/DHSVM-MtnHydro/commit/f43d723f53fa1275a7c811eef422c1df03ecb905

A more sophisticated treatment of coupled surface-groundwater interactions and hyporheic flow in DHSVM will be described in a forthcoming journal article, but in the meantime, relevant code and notes are available here: https://github.com/eli-mtnhydro/DHSVM-MtnHydro/releases/tag/DHSVM_X.1

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IV. Demonstration

For demonstration purposes, consider the arid Pecos River watershed in New Mexico. The user-defined channel network is shown here, but most of these channels are ephemeral.

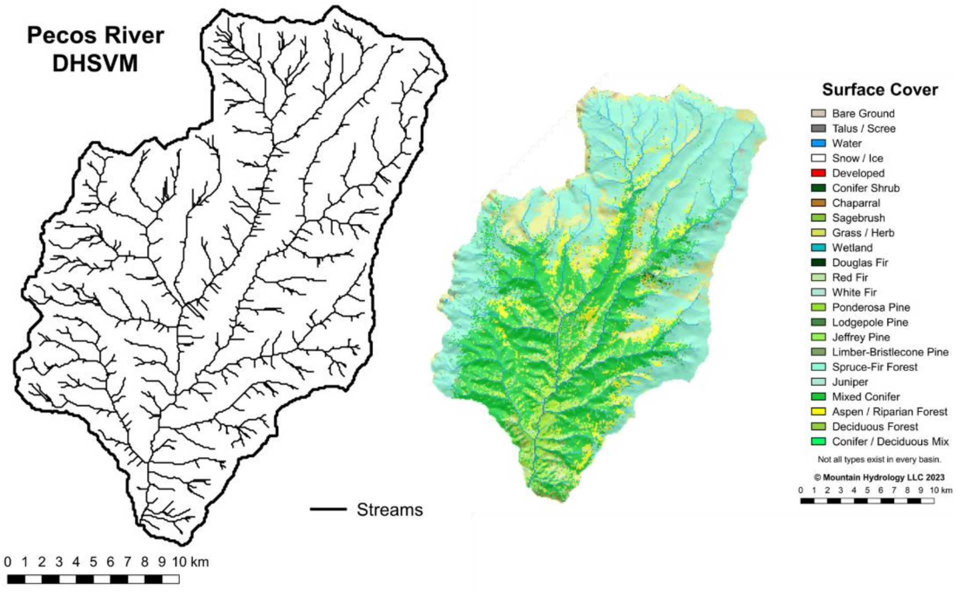

Figure 3. Example DHSVM setup in the Pecos River.

With the original code, the water table cannot fall below the channel cut depth, so groundwater gets stuck at high elevations when it intersects a channel network and can no longer flow downhill. Removing the "if" statement highlighted in Figure 2 enables groundwater flow and reduces the water table in many areas because the groundwater is allowed to continue flowing downhill.

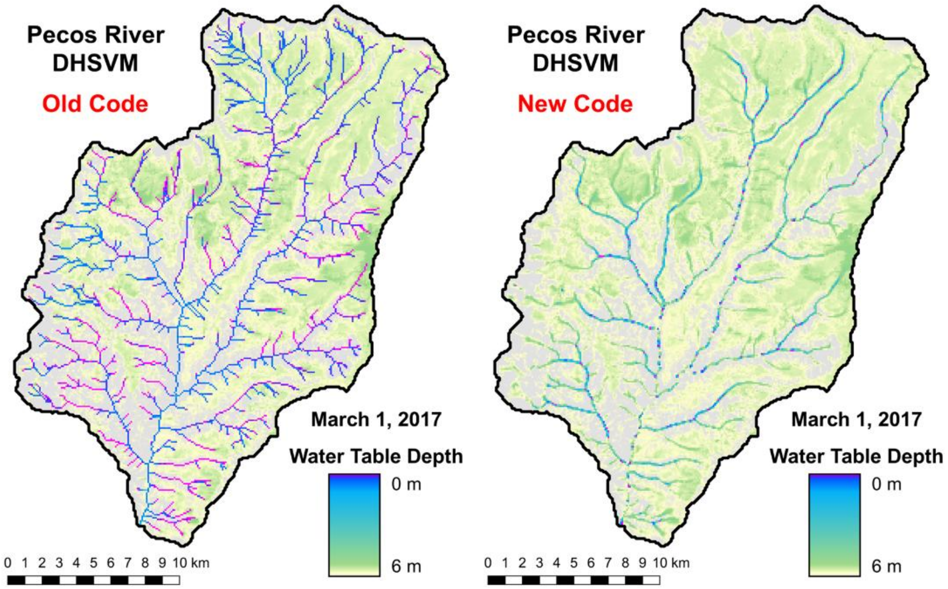

Figure 4. DHSVM water table depth with the original routing (left) and with sub-channel flow enabled (right).

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I originally diagnosed this issue by comparing the modeled timeseries of soil volumetric water content to the model field capacity. As shown in Figure 5, the original model (without sub-channel groundwater flow) did not enable drawdown of soil moisture, because the sub-channel water was stuck and could not flow. With sub-channel flow enabled, the soil moisture is reduced appropriately and approaches the landscape-average field capacity during dry periods. Similarly, the modified sub-channel flow-permitting code produces more realistic streamflow during low-flow periods (Figure 6).

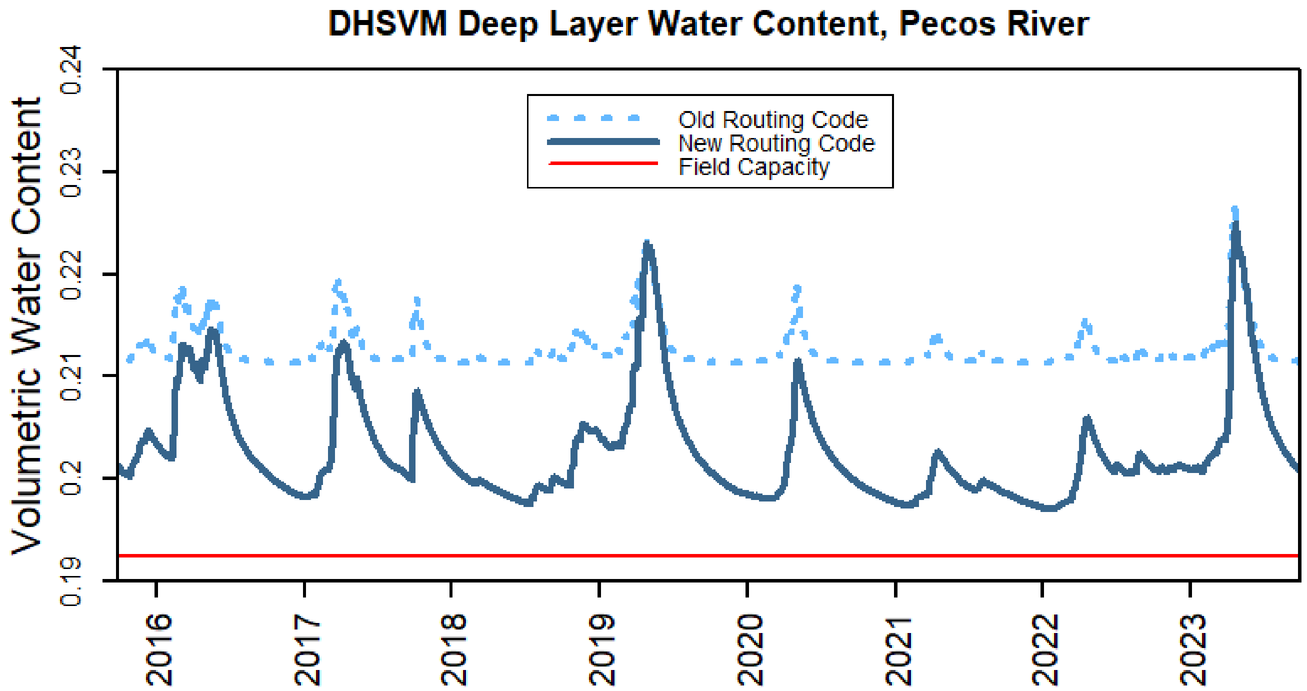

Figure 5. Modeled timeseries of landscape-average volumetric water content for the deepest soil layer compared to the respective field capacity value. Note that the deepest soil layer represents a shallow aquifer below the deepest rooting depth, and as such, it cannot fall below field capacity.

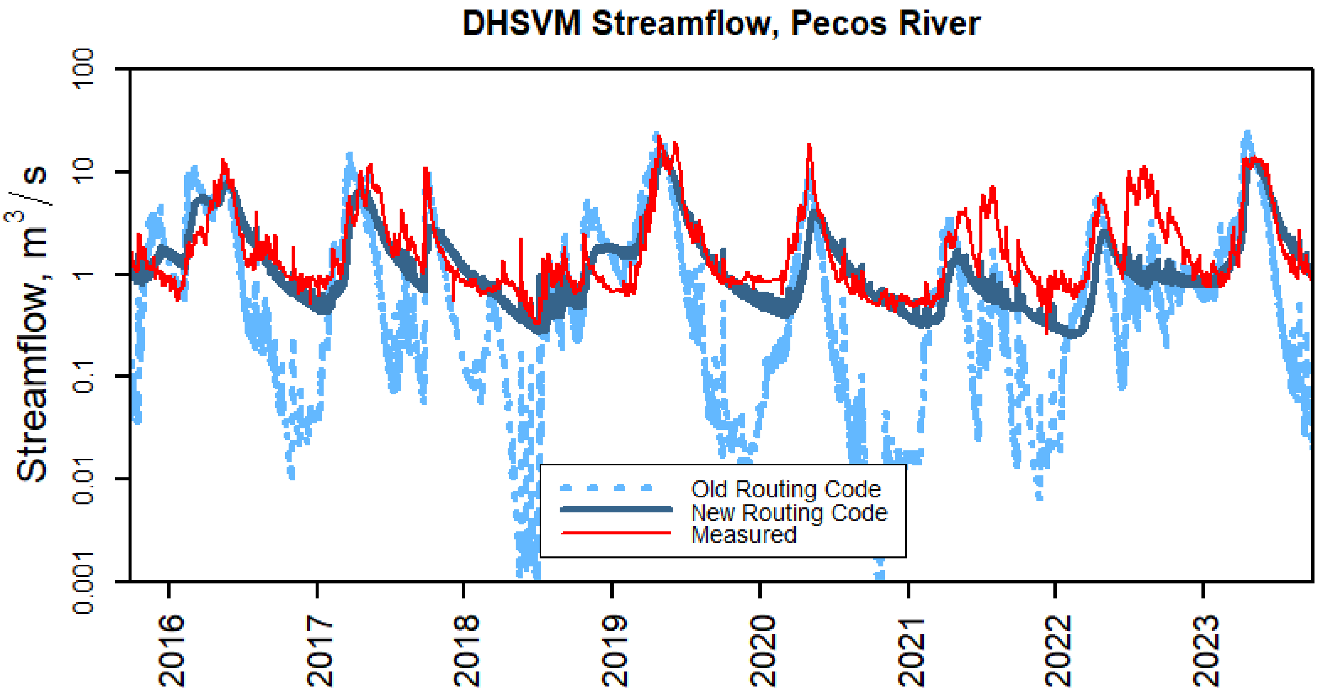

Figure 6. Streamflow hydrographs for the Pecos River, showing improved low-flow simulation (note logarithmic scale).

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References

Wigmosta, M. S., & Perkins, W. A. (2001). Simulating the Effects of Forest Roads on Watershed Hydrology. In *Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas* (pp. 127–143). American Geophysical Union (AGU). https://doi.org/10.1029/WS002p0127

Wigmosta, M. S., Vail, L. W., & Lettenmaier, D. P. (1994). A distributed hydrology-vegetation model for complex terrain. *Water Resources Research*, 30(6), 1665–1679. https://doi.org/10.1029/94WR00436

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