Discrepancies between RSM and Hydraulic Theory in Calculating Velocity

Summary: Building on our substantial previous experience using RSM, we have been applying the model to ridge-and-slough landscapes to test ecohydrological hypotheses. However, we have encountered several issues with RSM that, after careful study, we believe are related to errors in how RSM calculates velocity. We found three discrepancies between RSM-computed velocities and those expected based on hydraulic theory. We were able to develop workarounds for two of the issues, but the third was sufficiently limiting that we were unable to obtain accurate results with RSM.

This document summarizes our findings from the past six months with the hopes that these results will either: a) point to conceptual or user errors on our part (which might be easily resolved) or, b) inform refinements to RSM for future applications.

Methods: We applied RSM (Revision: 2379) to a series of hypothetical 2 x 4 km landscapes. Mesh geometries were built in GMS 7.1 and had 6400 evenly spaced elements, with uniformly sloping bathymetries of -3e-5 m/m (y-direction) and 0 m/m (x-direction) (Fig. 1). Our hypothetical scenarios assume uniform flow, requiring bed slope and water slopes to be equal. Constant head (*h*) BCs were applied at top and bottom boundaries (Fig. 2) to avoid backwater issues (simulations with flow boundaries resulted in significant backwater, despite identical inlet/outlet flow). Here we focus on results from two scenarios: a uniformly sloped plane (Fig. 1a) and a uniformly-sloped plane with parallel ridges of varying heights (Fig. 1b).

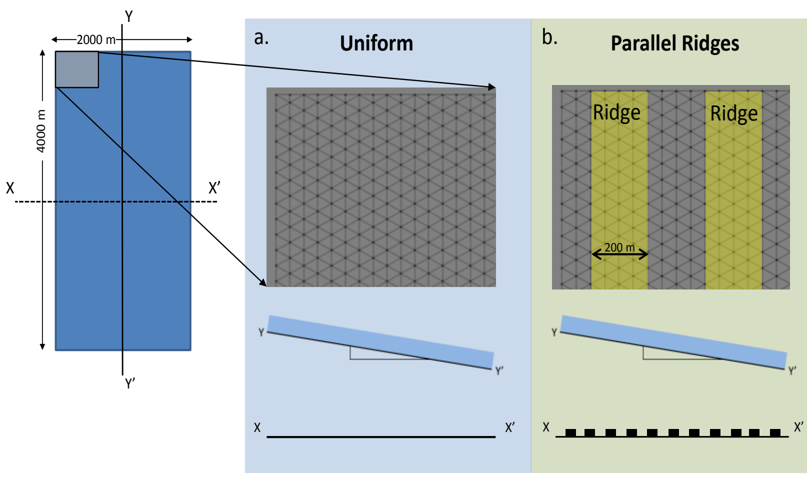


Fig. 1. Schematic of model domain/geometry. Both head (*h*) and flow (*Q*) boundary conditions (BCs) were investigated (applied at top and bottom boundaries), with no-flow BCs on left and right boundaries.

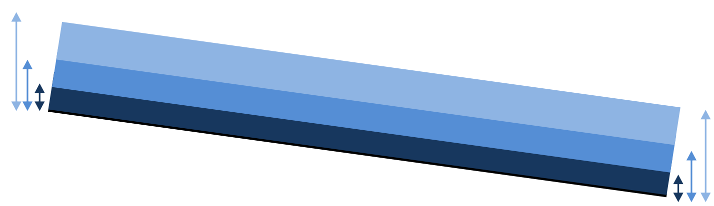


Fig. 2. Different *Q* was achieved by raising and lowering inlet and outlet *h* while maintaining equal water surface and bed slopes.

Results:

The model was run to steady state, and constant *Q* was confirmed across the domain at multiple cross-sections.

Issue 1: When benchmarking the <u>Uniform</u> scenario, RSM matched Manning's (within ~5%; Fig. 3a) when using a constant *n*-value, but not when using the depth-dependent formulation $n = Ad^B$ (we used *A*=0.17 and *B*=-0.77), where RSM appeared to over-predict flow by ~3x (Fig. 3b).

Proposed Solution: We confirmed RSM-calculated depths and slopes were correct, leading us to look at how RSM was applying specified *n*, *A*, and *B* parameters. We back-calculated the value of *n* that would be required to produce the observed flows and re-fit the depth-*n* relationship using these values. It appears that RSM *does* apply the specified form of the power relationship, but assigns an incorrect *A* coefficient (Fig. 3c). Iterating this process over a range of *A* values yielded a consistent relationship between assigned and apparent *A* (Fig. 3d), allowing us to correct for this effect.

Outcome: Required *A* values can be achieved by multiplying target *A* by 1/0.3791 = 2.638.

Issue 2: In both the <u>Uniform</u> and <u>Parallel Ridges</u> scenarios (Fig. 1), RSM appears to report incorrect velocities (*v*) in the outvect.dat file. Velocity calculated from Manning's equation (*v*_Manning) and *v* = *Q*/A agree (Fig. 4), but the velocities calculated by RSM do not follow either of these.

Proposed Solution: We calculated the ratio of *v* computed using *v*=*Q*/A to *v* from the outvect.dat file, regressed this ratio against flow depth, and found a very consistent relationship (Fig. 5). It appears that *v* values reported in outvect are scaled (multiplied by) flow depth. In other words, the *v* values reported in outvect seem to really be *v***d*.

Outcome: Velocities can be calculated by dividing *v* reported in outvect by depth in each cell.

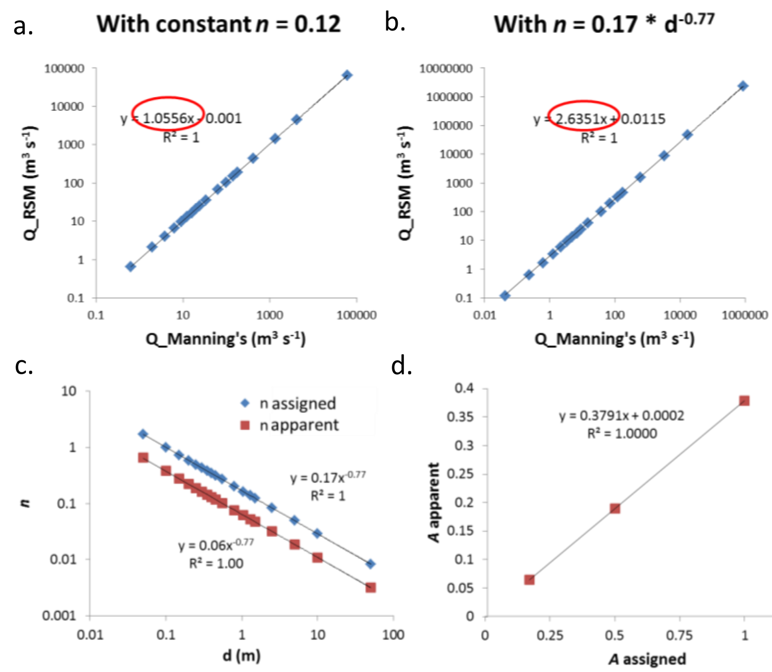


Fig. 3. Q calculated with constant vs. depth-dependent *n* (a-b). Comparison of expected vs. apparent *n* and *A* values (c-d).

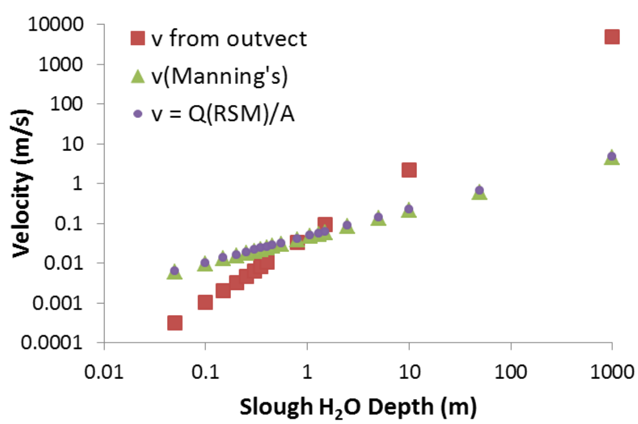


Fig. 4. Comparison of *v* values reported in outvect.dat, calculated with v=Q/A (where Q is calculated by RSM), and calculated directly with Manning's equation.

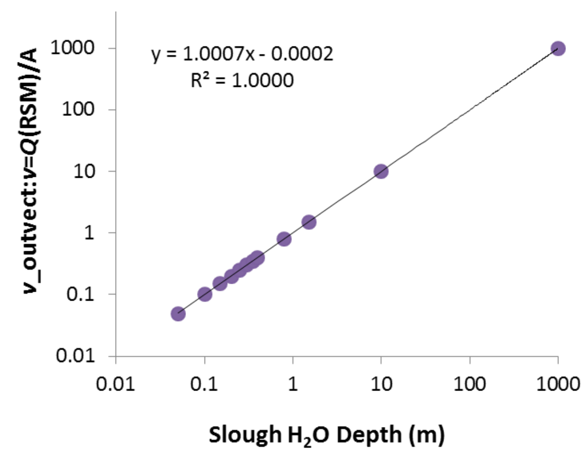


Fig. 5.Dividing the velocity from outvect by velocity calculated with v =Q/A yields depth.

Issue 3: When testing the <u>Parallel Ridges</u> case, we observed very low velocities in mesh elements where cell bathymetry changes (in this case at Ridge/Slough boundaries), resulting in unexpectedly low flows through the domain (Fig. 6). This effect was consistent across a wide range of flow depths (e.g., from 0.05 to 1000 m). We also found this effect to be persistent through disparate mesh configurations (e.g., equilateral, right, and irregular triangular meshes), and topographic differences (e.g., effect was apparent even when neighboring cells had topographic differences of only 1 cm). Note that all model elements had the same resistance parameters and the effect was observed when using both constant and depth-dependent formulations for *n*. Velocities presented below are values from outvect.dat, corrected by dividing by depth.

Proposed Solutions: After trying an assortment of mesh configurations and BCs, we next attempted to avoid this "edge effect" by using a very fine model mesh to minimize the number of elements with low *v*. With 10-m node spacing (and 160,000 mesh elements) the model still yielded low velocities at edge ridge/slough interfaces. Although the overall effect on flow through the domain was diminished when using a finer mesh (since only edge cells were affected), the relative reduction in velocity in edge cells was increased (as was the required computational time). We investigated the effect of cell size on the edge effect and found the velocity-reduction in edge cells was well predicted by mesh size, following a power relationship (Fig. 7). Additionally, further investigation of the fine mesh with other landscape configurations (not shown here), revealed strong reductions in flow (vs. expected), even at very high depths.

Next, we explored the use of time-varying (instead of constant) BCs, but results were similar. Finally, we explored whether the edge effect was still apparent when the model domain was irregularly aligned and made up of irregular elements (hypothesizing that the effect might be reduced or masked by irregular x and y velocity vectors), but the effect remained (Fig. 8).

Outcome: This request for input from SFWMD model developers.

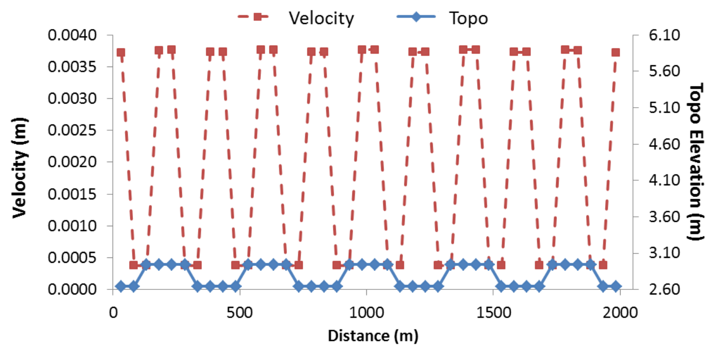


Fig. 6. Velocity (red) and topography (blue) along an X-X' cross section of the Parallel Ridge scenario. Each "ridge" and "slough" is 4 elements wide and their topographic difference is 0.30 m. Note that *v* in the centers of Ridges and Sloughs are high and those at the edges are low. High *v* values match calculated Manning's closely; low *v* values are off by 10x.

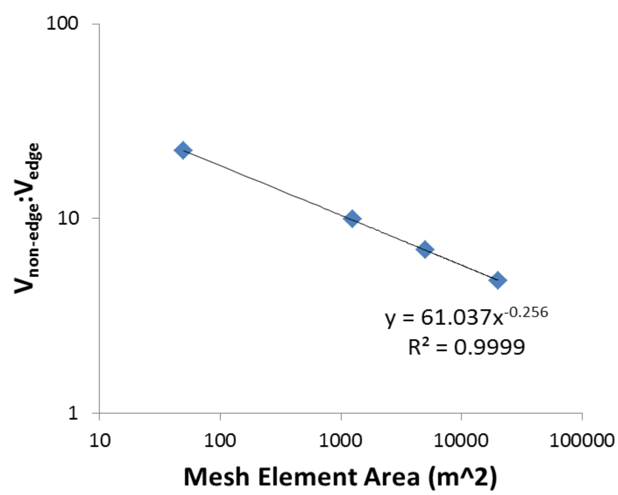
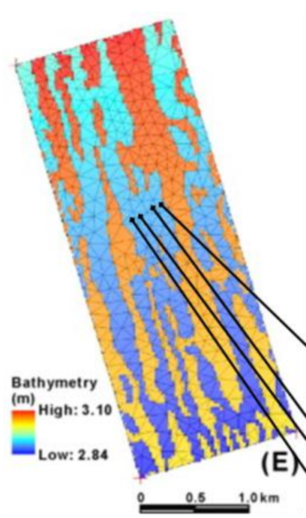


Fig. 7. Impact of cell size on the reduction in velocities observed in edge cells (where topography changes).



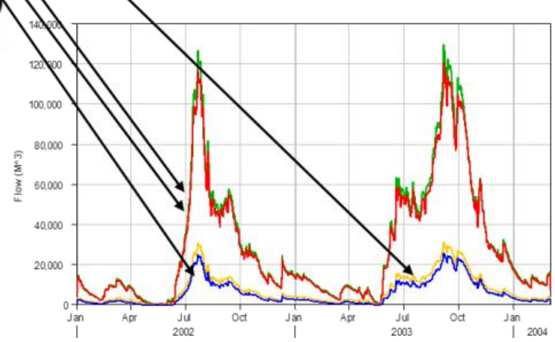


Fig. 8. Even with time-varying BCs and irregular mesh, flow through edge cells was much reduced compared with center cells.