New modeling capabilities with the SWMM5+ parallel hydraulic solver

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Highlights

- The SWMM5+ hydraulic solver adds finite-volume algorithms to the EPA-SWMM model.
- The new model is a plug-in that works with existing EPA-SWMM code.
- A beta (experimental) version of SWMM5+ is being released, and we hope beta users will provide feedback prior to the formal release of version 1.0 later in 2022.

Introduction

The EPA funded the National Center for Infrastructure Modeling and Management to build next-generation capabilities for SWMM. The focus of this effort has been a new parallel-processing hydraulics solver being released under the name "SWMM5+". The new solver works as a plug-in to the existing EPA-SWMM5.1 code and makes use of multi-core/multi-thread computer architecture. State-of-the-art finite-volume algorithms have been introduced to replace the link-node finite-difference methods that were shown to have limited potential for parallelization (Burger et al. 2014).

Our presentation at UDM 2022 will describe the capabilities of the new hydraulic solver and its behaviors, including mass conservation, near-surcharge conditions, transient behaviors under surcharge, hydraulic jumps, and changes to the representation of hydrologic inflows. The new SWMM5+ hydraulic solver is being released in a Beta version (pre-release development version) for testing by the community. As this is the first general-public release of the code, we expect the community will find inventive ways to crash the code and uncover latent bugs. Indeed, we are particularly interested in the experiences of a variety of users as they work with the new model. The new code is being released as open-source public domain software, which allows users, developers, and vendors to freely modify the code and incorporate into other software packages.

Methodology

Integration with SWMM5

The SWMM5+ code is compiled alongside EPA-SWMM. The models work seamlessly together with the SWMM5+ hydraulics replacing the traditional link-node solver in EPA-SWMM. Existing SWMM input files can be used. A wide variety of controls for the new numerical algorithms are available, which users can change through a secondary SWMM5+ input file. For many users, the default values this file will be acceptable. In the Beta code release, this file uses JavaScript Object notation standards (*JSON*). Although SWMM5+ solves with sub-discretization of links, this high-resolution data is pushed back into the link-node standard so that the standard SWMM output file remains unchanged. Two important caveats on backwards compatibility are: (i) finite-volume water quality transport is not slated to be included in either the Beta or v1.0 of SWMM5+, and (ii) the new model runs entirely at the command line, with further development effort and testing required to run using the EPA SWMM GUI.

Parallel operation using CoArray Fortran

Solution of hydraulics has been the slowest part of the algorithm within EPA-SWMM and the least amenable to speed-up through parallelization. The SWMM5+ hydraulic solver is written to efficiently parallelize the hydraulic solution for large systems. The new hydraulics engine is written using the Fortran 2008 standard that includes coarrays for Single Program Multiple Data (SPMD) parallel processing. Combining the C code of EPA-SWMM and the Fortran code of SWMM5+ is seamless through application of tools for multi-language programming. The key advantages of using CoArray Fortran (CAF) are that (i) the parallel code portions are much simpler to write than MPI or OpenMP, and (ii) Fortran allows vector processing that eliminates most "do-loops" and simplifies the code.

Finite-volume algorithms

Development goals for the SWMM5+ hydraulic solver include improving mass conservation and stability --- particularly where open-channel flow crosses into surcharged flow along a link. For open-channel flow, SWMM5+ uses an explicit Runge-Kutta 2nd order time-marching scheme with a "no-neighbor" finite-volume algorithm (Hodges and Liu, 2020). The finite-volume scheme subdivides each of the links in a SWMM link-node system into "elements" based on a nominal size selected by the user. Although this approach substantially increases the number of computations over the link-node system, the resulting model provides better control over stability and mass conservation across transitions between surcharged and open-channel flow. The finite-volume system is capable of representing hydraulic jumps and transitions from subcritical to supercritical flow as they occur along the length of the pipe or in an open channel.

Artificial compressibility algorithm for surcharged flow

A new approach to handling surcharged flow has been introduced --- Artificial Compressibility (AC) --- which is an approach to solving the incompressible Navier-Stokes equations that treats the flow as slightly more compressible than water to create a hyperbolic equation that is marched in pseudo-time to approximate the incompressible Navier-Stokes equations (Chorin, 1967). The SWMM5+ solver uses an approach called "dual time-stepping" developed by Rogers et al. (1991), which is well adapted to the finite-volume method and handling the bores and hydraulic jumps that can occur at a transition to surcharge (Hodges, 2020). The principal motivation behind using the AC method is that its hyperbolic equation is easily time-marched using a no-neighbor discrete system, which minimizes communications overhead in massively parallel computers.

The future of cloud computing

The parallel solution approach to SWMM5+ is designed for use on computers ranging from everyday laptops with one or two computational cores to the largest parallel supercomputers with tens of thousands of cores. We are testing across an array of platforms so that developers can have confidence that the code will port to their particular platform. We will be testing the limits of parallel scaling so that users will have an understanding of what performance speed-ups can be expected for different numbers of cores. In the future, we hope to partner with developers interested in porting the code to various vendor cloud-computing systems.

Results and discussion

SWMM5+ Beta is undergoing testing, with quantitative results to be presented at the conference. Tests are designed to examine the stability, mass conservation, and parallel performance of the new code across a wide range of systems. Because SWMM5+ uses a finite-volume algorithm that subdivides links and nodes, the new code must solve more operations in each time step than the original link-node approach of EPA-SWMM. Furthermore, the time step in the explicit time-marching scheme must be below a Courant-Friedrichs-Lewy (CFL) limit, which prevents the hydraulic scheme from taking the larger time steps that can sometimes be used in the implicit solver of EPA-SWMM. Thus, SWMM5+ will generally run slower than EPA-SWMM on a single-processor computer. Indeed, because small systems often cannot be easily parallelized, we expect that EPA-SWMM will remain preferred to SWMM5+ for many applications where parallelization cannot be efficiently applied. The key advantage of SWMM5+ will be in solving large networks, which have often proved intractable to EPA-SWMM because of the slower convergence of its iterative implicit solver as network size increases. SWMM5+ is being designed for deployment on supercomputers, so that porting to vendor cloud computing systems in the future will allow users to take advantage of massively parallel computational architecture for modeling large stormwater systems.

Conclusions and future work

The new SWMM5+ solver will provide new capabilities for the stormwater modeling community. The new finite-volume sub-discretization of the EPA-SWMM link-node system provides greater stability, mass-conservation, and representation of gradients throughout the system. For stormwater systems where unsteady transients in surcharged flows need to be resolved, the new model will complement the SWMM5.1 approaches tested in Pachaly et al. (2020). City managers who have found EPA-SWMM impractical for continuous modeling of large urban systems will be able to apply SWMM5+ on massively parallel computers. In the future, extension of the finite-volume approach to water quality transport will allow conservative transport with the advection-diffusion-reaction forms of the mass transport equations.

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