United States Environmental Protection Agency

Advancing the Stormwater Management Model for the Digital Water Transformation

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Disclaimer

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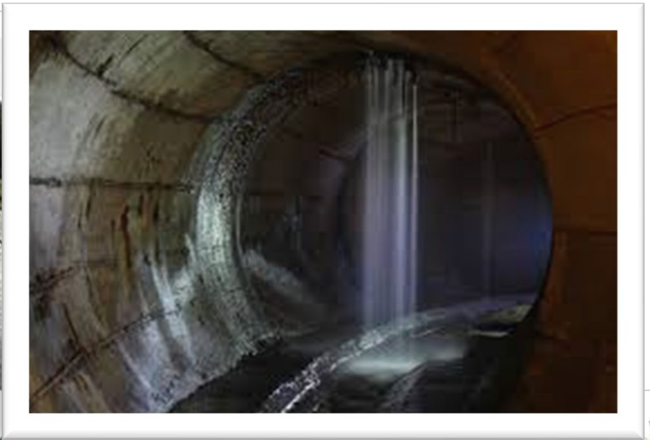
Legacy of SWMM

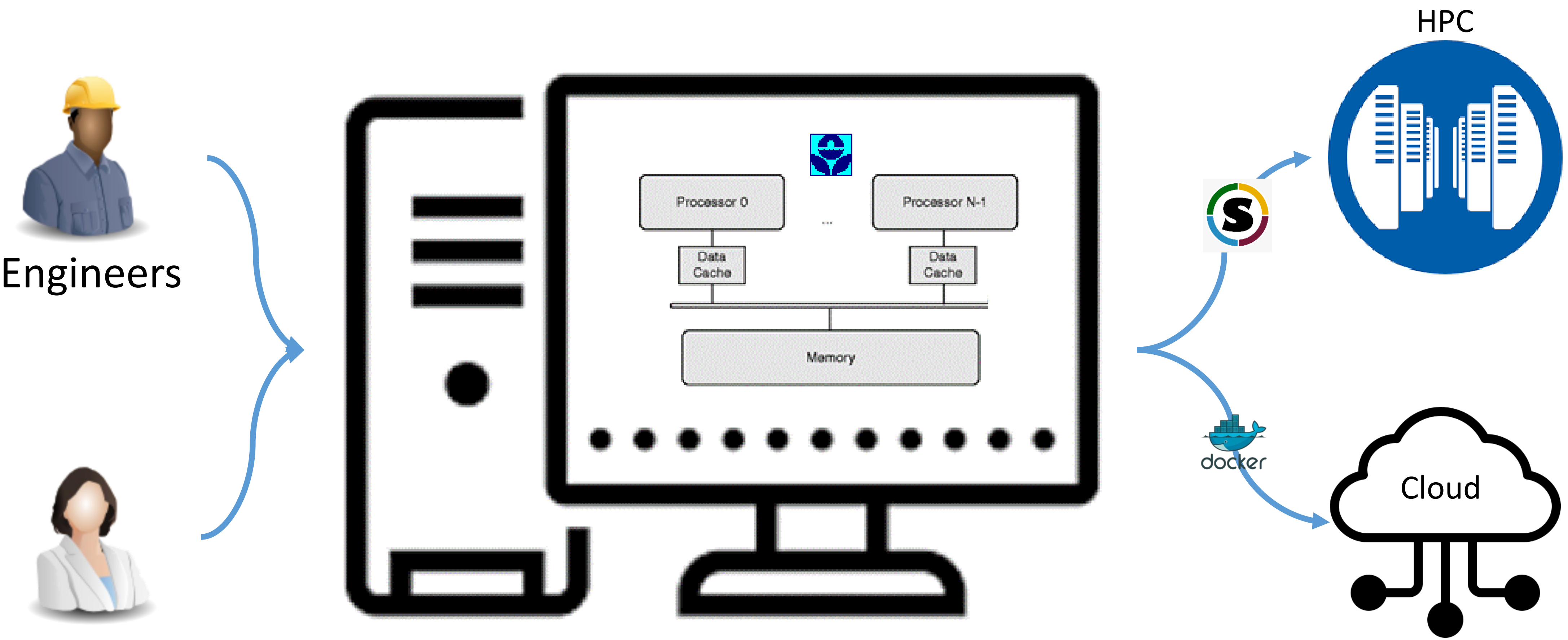
- Has played a crucial role in flow and pollution control in collection systems since its introduction
- Supports studies driven by regulatory imperatives e.g., LTCP, TMDL, MS4, NPDES, etc.
- Widely used and adapted by modeling practitioners and in scientific research efforts within the EPA, academia, third-party software vendors, consultants, etc.

Traditional Application Areas

- Traditional application scenarios
  - Design and sizing of drainage systems
  - Control of combined and sanitary sewer overflows
  - Pollutant load estimation and transport as well as BMP and treatment evaluation
  - Estimating inflow and infiltration in sanitary systems
  - Green infrastructure assessment
- Typically involves calibrating to historical records and evaluating on design/typical year storms for long term engineering design and planning purposes



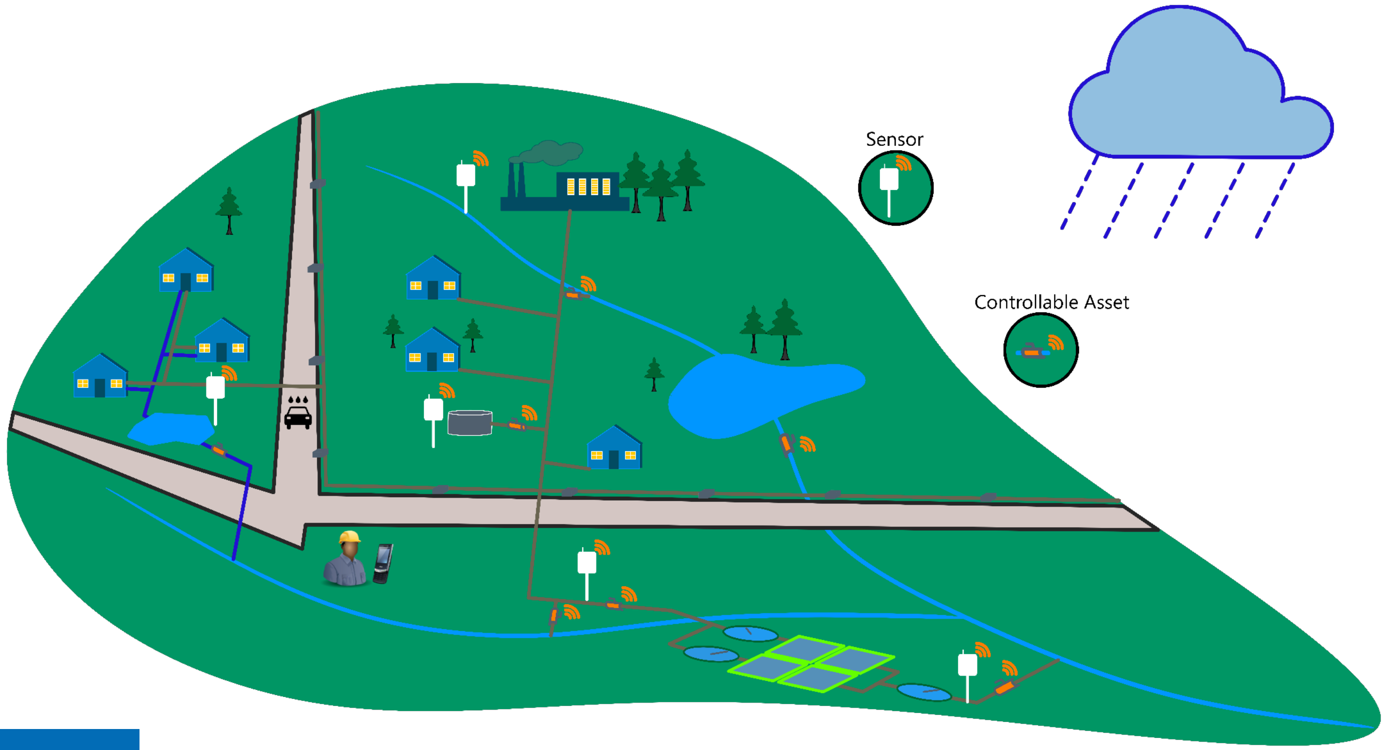
SWMM Core Users



(High-performance) Multicore and Multi-CPU shared memory systems

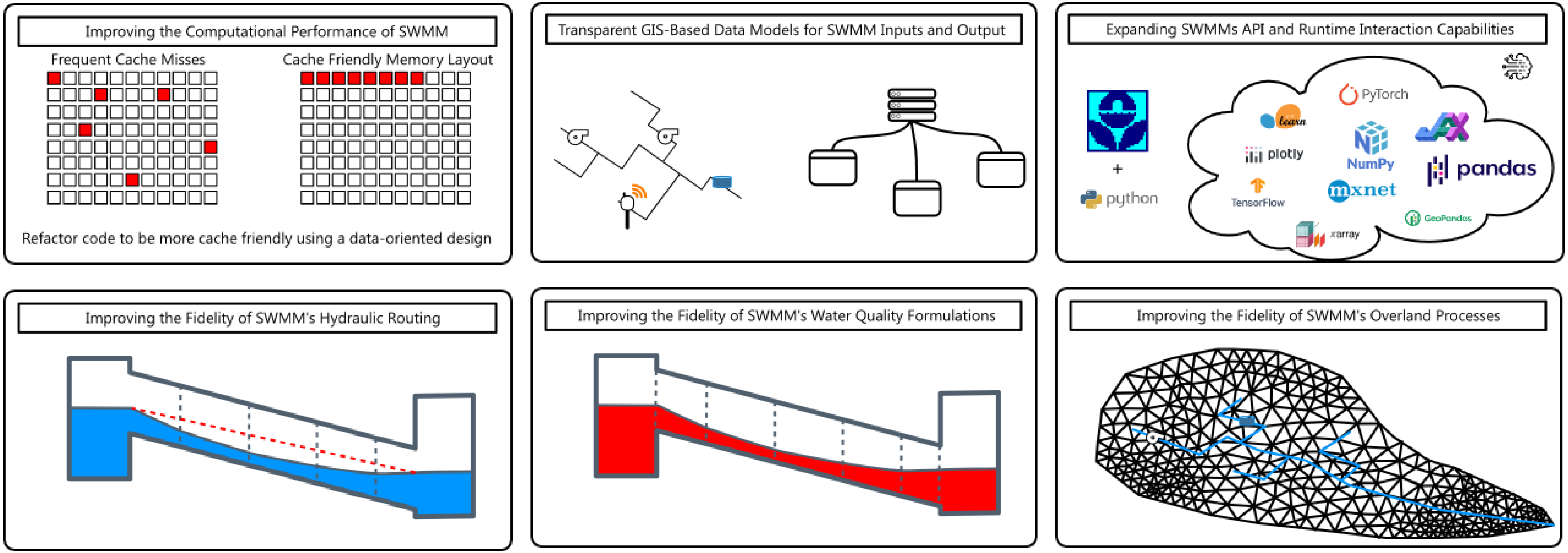
SWMM's Role in Advancing the Intelligent Collection Systems Paradigm

Multi-model sensing, actuatable assets (i.e., gates, weirs, pumps, etc.) and data communication infrastructure deployed at critical locations within collection



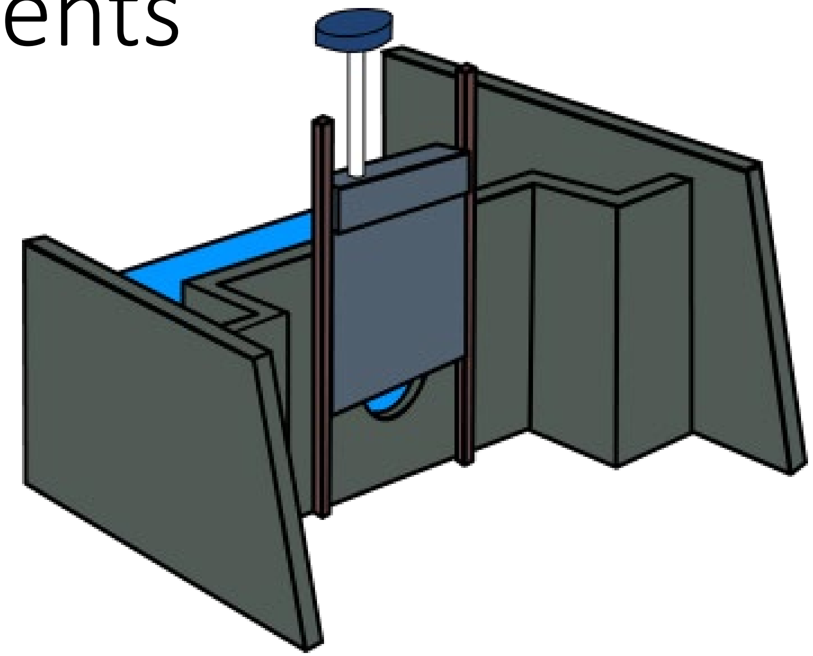
Virtual representation of collection system — digital twin — through fusion of real-time sensor data, models, AI/ML algorithms as an operational experimental frame

What SWMM advancements will facilitate this digital water transformation?



- These advancements align with many of the recommended priorities from the 2018 EWRI organized 2018 Visioning Summit

Recent SWMM Advancements Towards Realtime Control Enhancements



- Control rules premise clauses expanded to include:
  - Additional control rule parameters:
    - Current and next rainfall
    - Node attributes including full depth, head, and volume
    - Conduit attributes including length, slope, full depth, full flow and velocity
  - Named variable as aliases and math expressions for more sophisticated real time control implementations

-Variable D1 = Node Node1 Depth
-Variable D2 = Node Node2 Depth
-Expression HGL $= \frac{D1+D2}{2.0} + 23.7$
-If Expression HGL <> 24 THEN ORIFICE OR1 SETTING = PID 0.1 0.01 0.0

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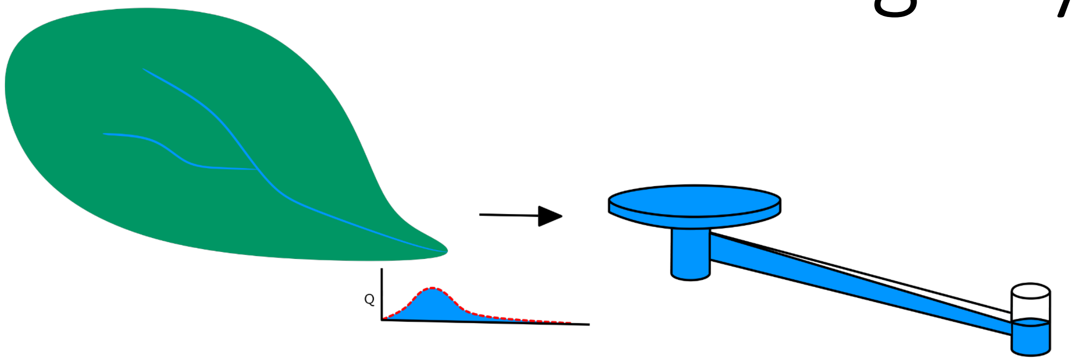
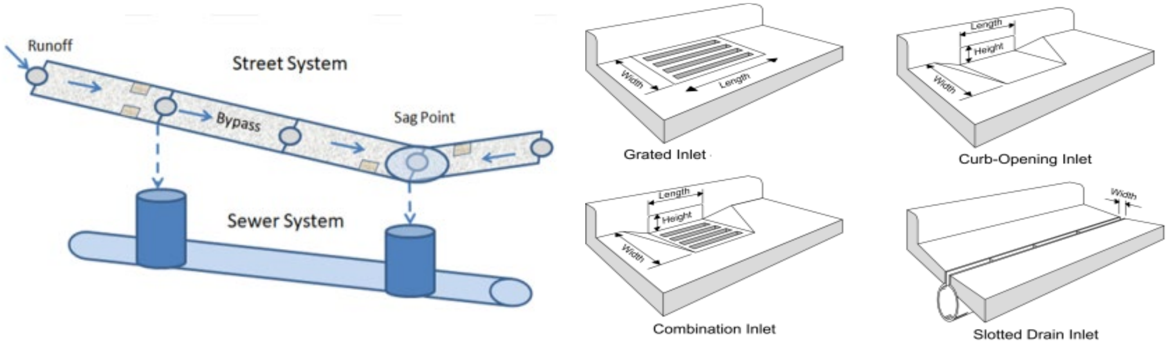
Recent SWMM Advancements Towards Dual Drainage System Modeling



- Runoff is applied as one-way inflow into downstream nodes
- Surcharges and flooding is accumulated over a user prescribed area on top nodes
- Poor approximation of reality, where water flows on streets and over the landscape and can reenter at downstream locations



- As a step towards coupling of the under drainage and streets, a new streets cross-section for links and inlet types are available in SWMM
- Adopts FHWA "Urban Drainage Design Manual" (HEC-22), which is the de-facto standard for inlet analysis has been implemented

Upcoming Advancements on Saving Model State (v5.3.0)

- Save several model state files at specified times
- API extended to save model state at runtime
- API extended to set system variables including:
  - Start, end, and report times
  - Timestep and report steps
  - Number of threads
  - Enabling and disabling hydrological and hydraulic processes
  - Returning meaningful error codes

```
[FILES]
;;Interfacing Files
USE  HOTSTART "tests2.hsf"
SAVE HOTSTART "tests1.hsf"
SAVE HOTSTART "tests2.hsf"  01/01/2024  12:00:00
SAVE HOTSTART "tests3.hsf"  01/01/2024  18:00:00
```

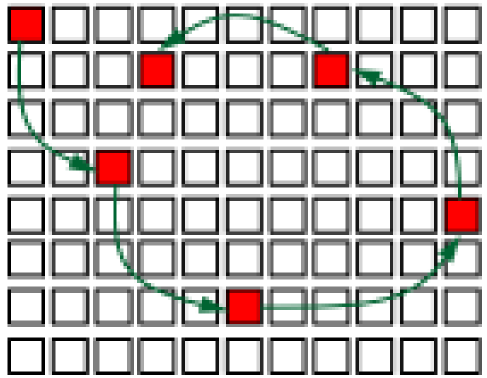
```
Int DLLEXPORT swmm_useHotStart(const char* hotStartFile);

int DLLEXPORT swmm_saveHotStart(const char* hotStartFile);
```

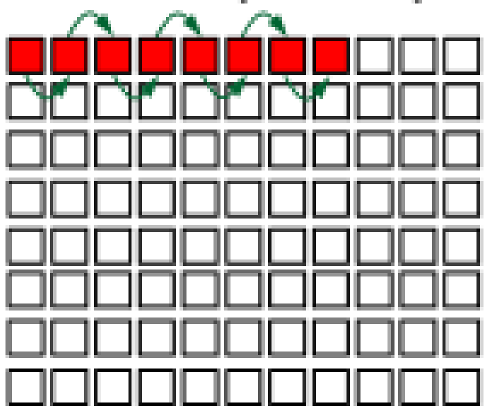
Upcoming Advancements to Improve SWMM's Computational Performance (v5.4.0)

- Digital twins developed with SWMM need to run fast!
- Modern efficient and high-performance computational codes emphasize spatial and temporal locality of data in memory for fast access and transformation (i.e., "cache friendly code")
- File IO optimizations
- Preliminary testing using these strategies for SWMM are promising showing about a 30% reduction in computation time
- We believe there are more optimizations left on the table

Frequent Cache Misses

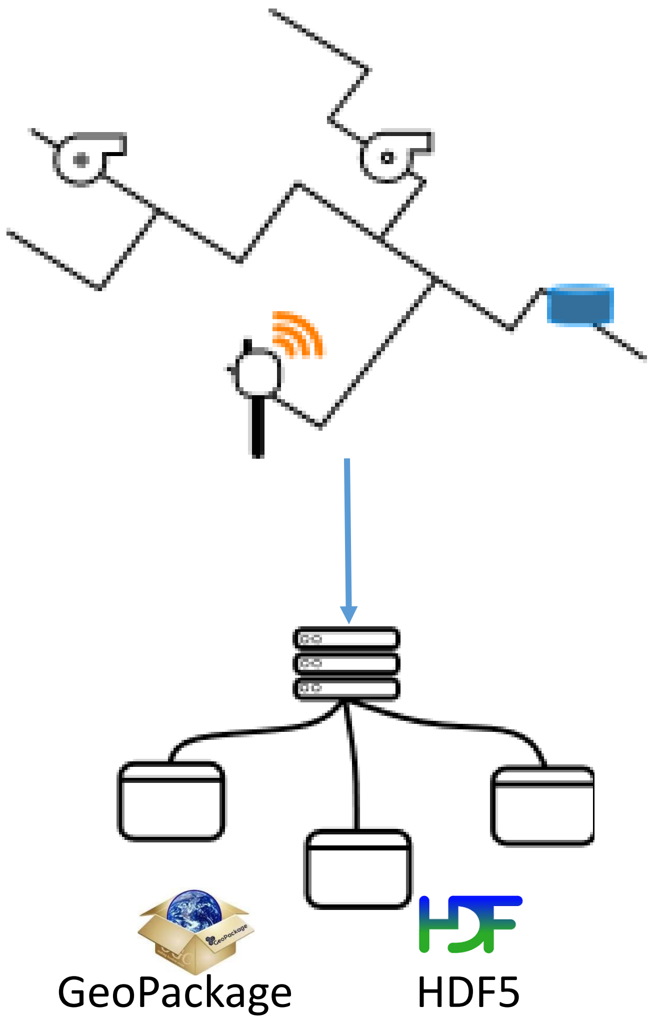


Cache Friendly Data Layout



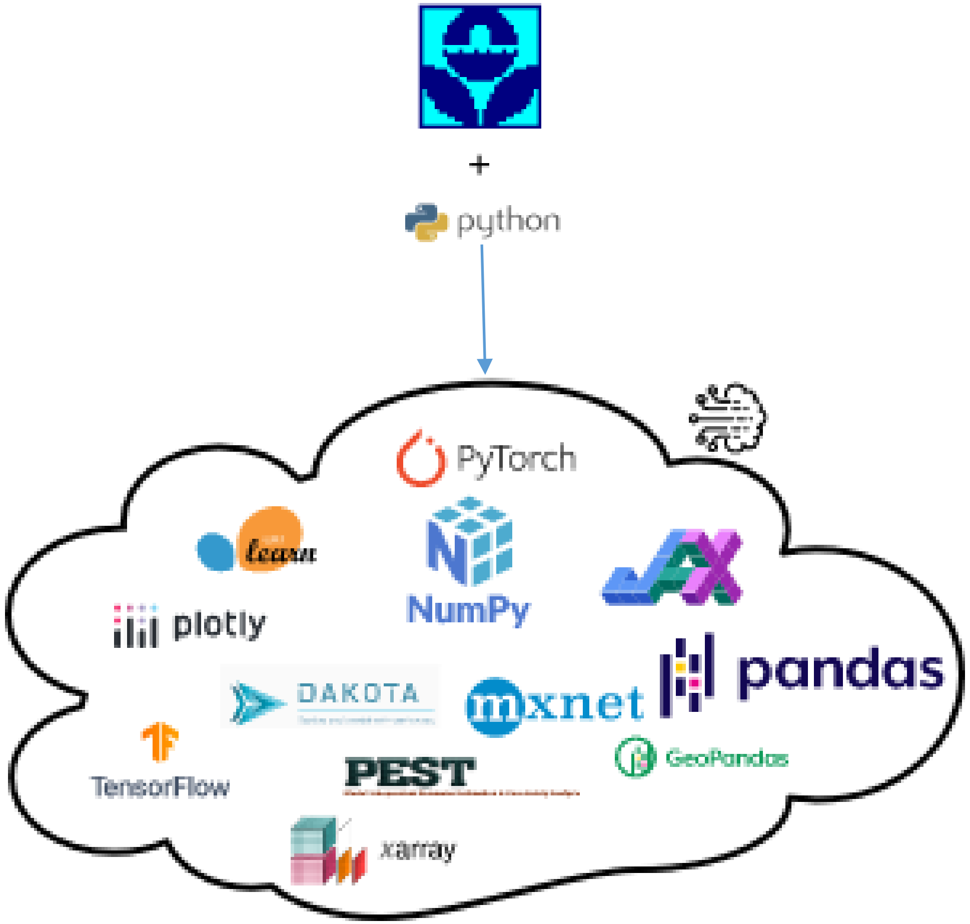
Future Advancements: A GIS Based Data Model for SWMM

- While GIS is ubiquitous in engineering, SWMM's engine disregards the geospatial frame
- SWMM's output and state persistence file formats (i.e., hotstart) are relatively opaque and inflexible
- All these elements are important for developing digital twins
- Develop and implement a GIS-based and topologically aware data model
- Implement flexible and transparent output and state persisting output format



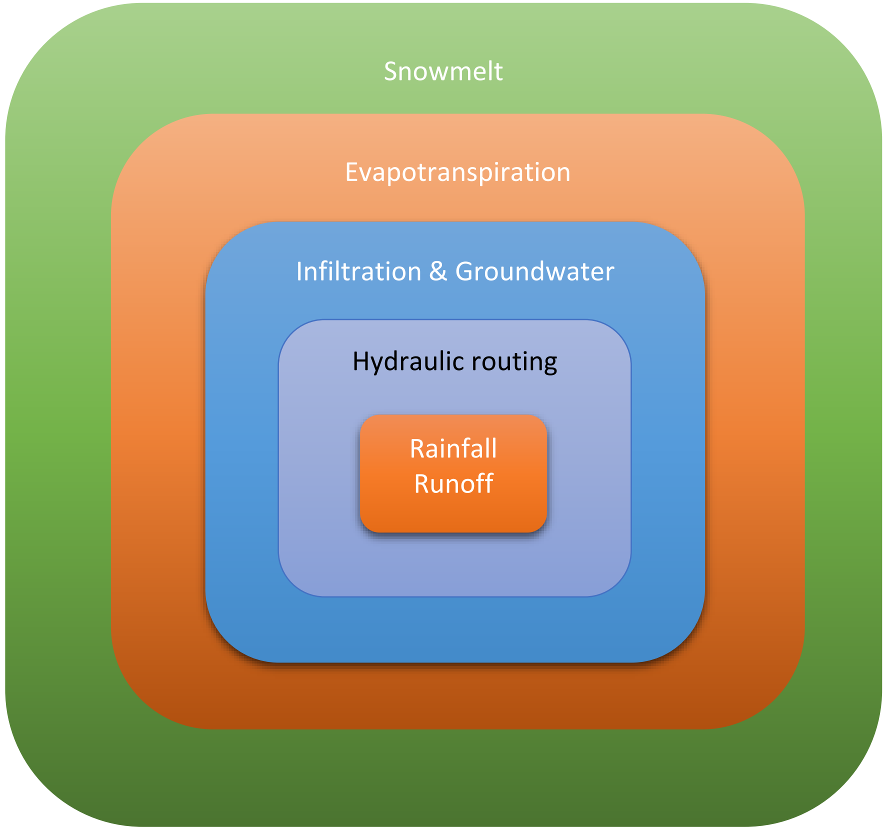
Future Advancements: Advancing SWMM's API and Runtime Interaction Capabilities

- With data model envisioned, a more extensive API will be implemented
- API will not allow not only allow reading and setting object attributes parameters, but also allow creating of objects while maintaining the topological integrity of the mode
- Python is arguably the lingua franca of big data and AI/ML approaches that are a critical component of developing digital twins and the intelligent/smart collection systems of the future
- Low level python bindings for the SWMM API is being developed to allow users harness the vast freely available libraries available in the python ecosystem



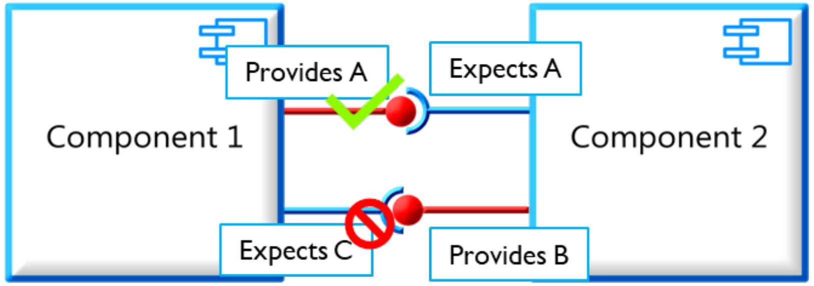
How do we advance the fidelity paid to hydrologic and hydraulic processes?

- We can continue to add new process formulations to core SWMM computational engine
- However, doing this leads to code accretion over several years and becomes unwieldy to manage
  - Few people are experts in all aspects of the code
  - Difficult for researchers to extend and add new formulations
  - Prone to bugs as errors in one part can cascade to other parts
  - Difficult to validate and write unit tests



Component-Based Modeling as a Potential Answer

- The component-based modeling paradigm is an alternative to managing these challenges
- Adopts the principle of separation of concerns by splitting process formulations into a set of independent components
- Each component simulates a single process or a group of related processes
- Standard interface definitions implemented by each component
- Standard interfaces define the when, where, what, and how of the data being exchanged between components



Object Modeling System

Community Surface Dynamics Modeling System, Basic Modeling Interface (BMI)

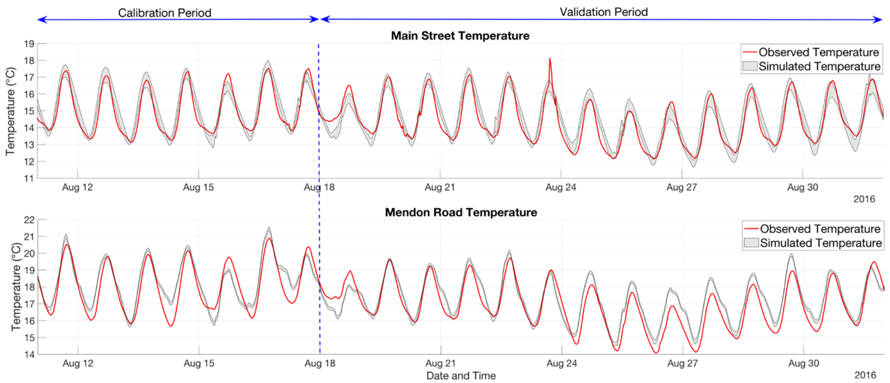
Earth Systems Modeling Framework

Open Modeling Interface

HydroCouple

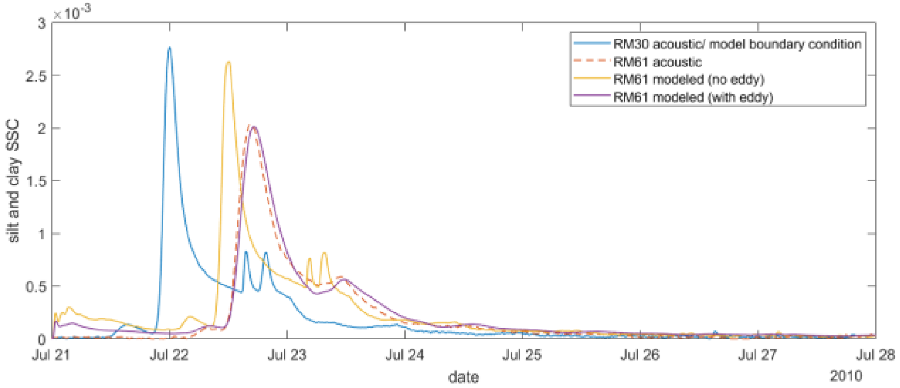
Example Coupled Modeling Applications Using SWMM with HydroCouple

Parameter estimation for a coupled stormwater heat transport model



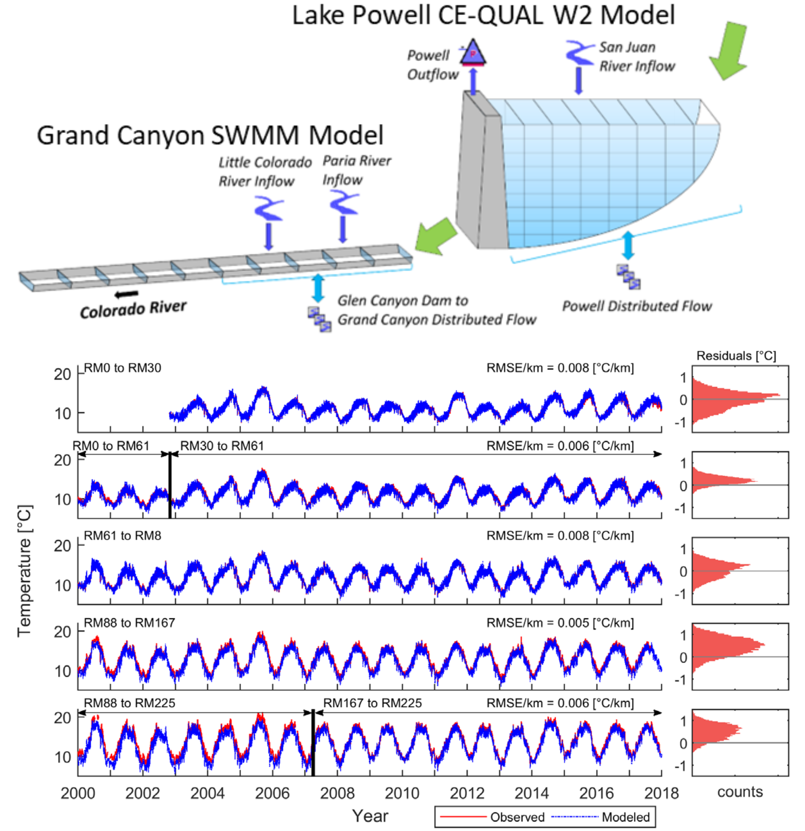
[Parallel multi-objective calibration of a component-based river temperature model]
CA Buahin, JS Horsburgh, BT Neilson - Environmental Modelling & Software, 2019

Numerical modeling of mud transport, storage, and release on the Colorado River



[Numerical modeling of mud transport, storage, and release on the Colorado River, Arizona]
Gerard Salter - SEDHYD Conference, 2023

Colorado River heat transport model



[Water temperature controls for regulated canyon-bound rivers]
BA Mihalevich, BT Neilson, CA Buahin, CB Yackulic… - Water Resources Research, 2020

Future Advancements: Improving the Fidelity of SWMM’s Hydraulic and Water Quality Formulations

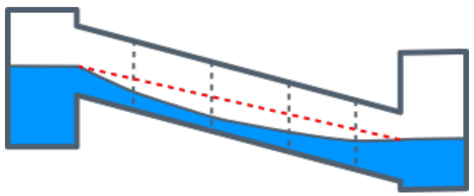
Goal

Advance SWMM’s formulation to improve the degree of fidelity paid to underlying routing and water quality processes in an efficient manner

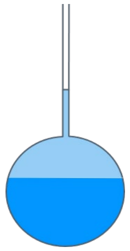
Approach

- Efficient and accurate numerical methods for hydraulics that resolve sub-pipe dynamics, handle transitions from open-channel to pressurized flows, and promote mass conservation and convergence
- Implementing full advection-reaction-dispersion formulations
- Advancing heat transport modeling and multi-species reaction capability for SWMM

Sub-grid discretization to resolving flow dynamics



Alternatives to the Preissmann Slot approximation to handle transitions from open channel to pressurized flow



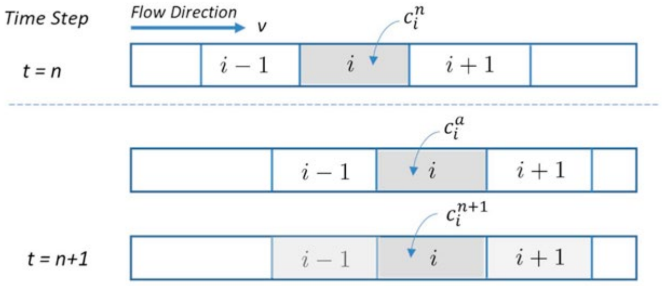


Fig. 1. Nonuniform pipe discretization and Lagrangian transport.

(Shang et al., 2021)

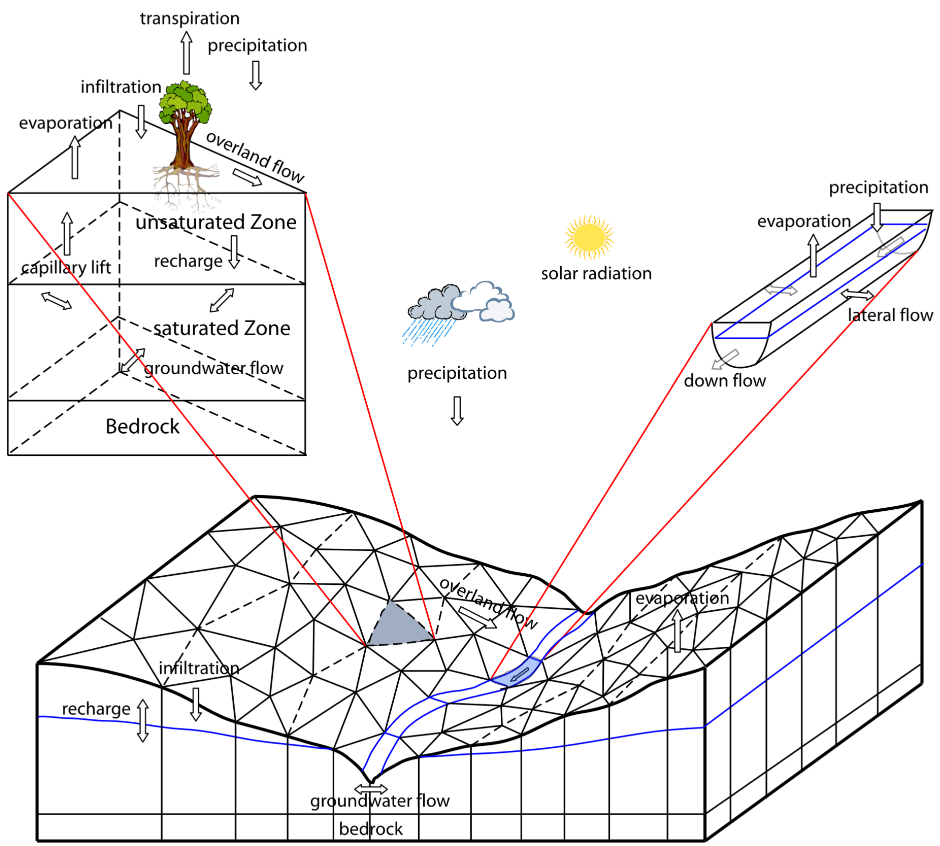
Future Advancements: Improving the Fidelity of SWMM's Overland Processes

Goal

- A spatially explicit multi-process and multi-scale overland flow quantity and quality model to facilitate coupled 1D/2D modeling studies

Approach

- Implement coupling infrastructure to allow coupling arbitrary 2D models to SWMM
- Implement a spatially explicit multi-scale and multi-process overland flow-infiltration 2D model
  - Among other models, the Penn State Integrated Hydrologic Model (PIHM) is being evaluated for adaptation and adoption



Qu, Y., Duffy, C.J., 2007. A semidiscrete finite volume formulation for multiprocess watershed simulation. Water Resources Research 43, 2006WR005752. https://doi.org/10.1029/2006WR005752

Conclusions

- EPA ORD will continue to maintain and advance SWMM for the digital water transformation
- We plan to expand the unit test coverage of the SWMM and regression tests to ensure continued accuracy and quality of the SWMM code
- Advancements will go through EPA's rigorous internal review process to ensure continued confidence in the use of SWMM
- We plan to continue conversations with our stakeholders throughout the development process to make sure their views are considered in this process
- We are excited about the future of SWMM and invite practitioners, researchers, to provide feedback and suggestions on future directions

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Contact

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GitHub

https://github.com/USEPA/Stormwater-Management-Model
https://github.com/USEPA/SWMM-GUI