Mesh Generation and Explicit Solver

RAS 2025

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RAS2025, the next major release of HEC-RAS, will include major changes to mesh generation, a new explicit solver, and a new user interface. An alpha version will be released at the end of September, 2024.

- **Mesh generation:** The new mesh generation approach aims to improve mesh quality, repeatability, and flexibility. While these goals and their implementation are tailored to HEC-RAS and its predominant use-cases, the mesh generation algorithms are applicable to most unstructured, mixed-element hydrodynamic models.
- **Explicit solver:** A new solver for 2D, unsteady problems has been implemented in RAS2025, with the goal of supporting better parallelization, GPU computations, and tighter integration with the user interface.

This poster outlines the features and design choices of the mesh generator and key features of the explicit solver.

Conceptual Mesh

Mesh generation in RAS2025 is based on a *conceptual mesh* — a blueprint for the mesh generation process (similar to SMS). It is composed of arcs and regions with attributes to control cell size, type, and quality.

Arcs delineate the boundary of the overall computational mesh and divide the domain into regions. An arc can also denote a breakline if it falls entirely within one region.

Regions are areas completely enclosed by arcs. Each region is meshed independently, according to the attributes of the region (e.g. quadrilateral vs triangular cells) and bounding arcs (e.g. cell size along boundary)

This "declarative" approach (compared to more "procedural" tools like Janet) brings several major advantages and some challenges.

- The computational mesh is fully described by the conceptual mesh (within a specific version of RAS).
- The conceptual mesh for this example is about 150kB, small enough to make backups every few minutes, and to keep in `git` or other versioning system.
- Meshes are effectively parametric with respect to resolution choices, making refinement studies and convergence studies more practical.

The declarative approach puts a greater burden on the mesh generation tools to sort out potential geometric conflicts, as the computational mesh cannot be directly edited. There is no longer a practice of fixing a mesh by manually editing cell centers or vertices, although it is possible to create regions which end up generating exactly one cell.

Laplacian-based Quad Discretization

Vertex locations around quad patches are generally determined by the solution contours of a pair of Laplace's equations. With suitable boundary conditions, these contours meet at right angles throughout the patch and lead to quads that are nearly orthogonal.

$$\nabla^2\phi = 0 \quad \phi(\text{left bank}) = 0, \phi(\text{right bank}) = 1$$
$$\nabla^2\psi = 0 \quad \psi(\text{upstream}) = 0, \psi(\text{downstream}) = 1$$

Stretching

When not adjacent to a quad patch, spacing along arcs is adjusted to avoid sharp changes in cell size. This is accomplished by computing a coarse triangulation of the conceptual mesh and propagating size constraints and stretching rates across the triangulation.

For example, a refined channel is often flanked by coarse overbank regions. The overbanks can be configured with arbitrarily coarse cell sizes. These values will be adjusted during the scale propagation phase to smoothly coarsen moving away from the channel. Propagation applies both to the spacing along arcs and within regions, with the option to coarsen or refine within triangle and cartesian regions.

Post-processing

After initial generation, region meshes are optimized through a configurable "recipe" of post-processing steps. The current implementation includes multiple smoothing algorithms, cell splitting/merging, and edge swapping. Upcoming releases will add algorithms for improving orthogonality and local mesh topology.

After all region meshes have been generated (typically in parallel), the global computational mesh is constructed by splicing the region meshes together. Another round of mesh optimizations can be applied to the global mesh. Conflicts between the computational mesh and sub-face geometry are also repaired at this stage.

An important feature of these post-processing steps is that they maintain the relationship between faces of the computational mesh and the arcs of the conceptual mesh. These faces are constrained to slide along the conceputal mesh arcs, ensuring that the optimization does not introduce "leaks" across levee-like features.

Explicit Solver

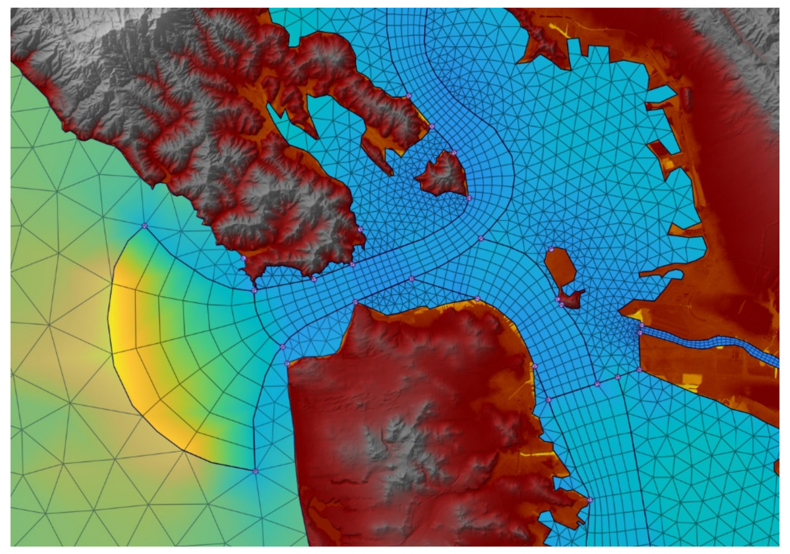
RAS2025 includes a new compute engine with explicit time stepping.

Compared to the semi-implicit solver in RAS 6.x, the explicit solver is more easily translated to GPU architectures and compatible with a broader range of parallelization approaches. RAS2025 also migrates the solver implementation to the same language as the user interface (C#), allowing the solver and UI to run in the same process. These changes allow a tighter integration between the interface and simulations than was possible in RAS 6.x.

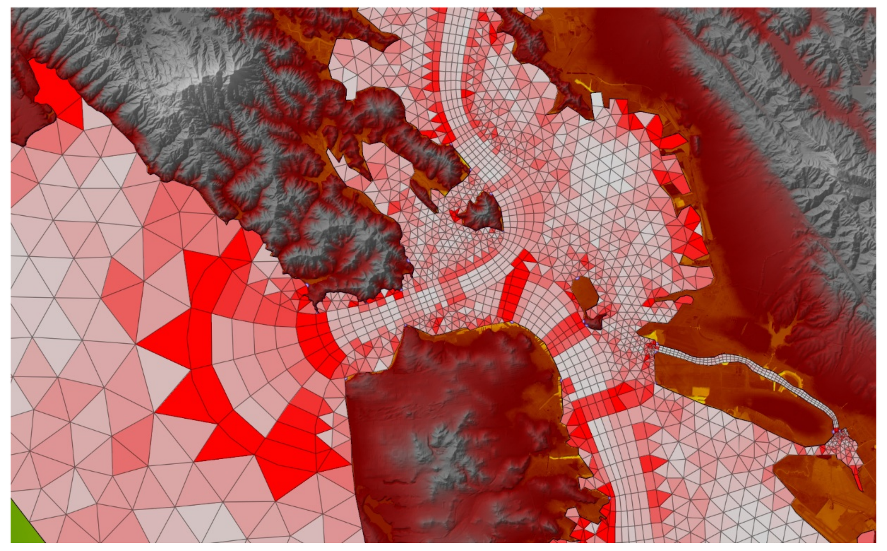
For common RAS use cases the explicit solver's performance is similar to the semi-implicit solver. Even though the explicit solver has more severe time-step restrictions, each step of the explicit solver is relatively cheap to compute. The solver also benefits from a combination of robust parallel scaling and local time stepping. Local time stepping assigns cell- and face-specific timesteps depending on the local courant number. Local time steps divide the global timestep by powers of two, with three to four levels typically most efficient.

The user interface provides several alternative views to aid the user while developing a new mesh:

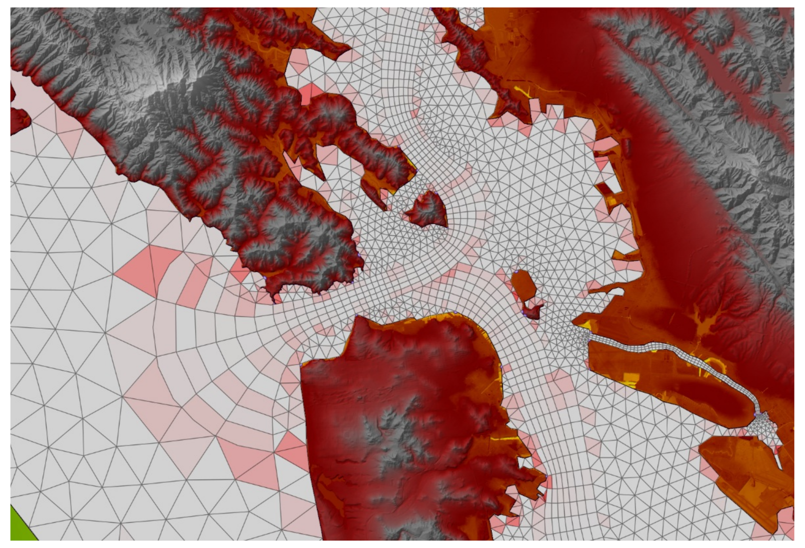
Size function



Mesh quality: area ratio



Mesh quality: orthogonality



San Francisco Estuary Demonstration Mesh

The mesh shown on this poster is intended as a testbed for the mesh generation features of RAS2025. Mesh types, resolutions, and parameters have been chosen more for demonstration purposes than for optimal simulation. Some features of the Delta and Suisun Bay have been omitted, especially when they would not exercise any additional features of the mesh generator.

Mesh details:

- 25,655 cells, 50,015 faces
- Approximately 9 seconds to generate
- 212 regions: 127 quads, 84 triangle, 1 cartesian
- Domain includes San Francisco Bay, with an ocean boundary near Point Reyes.