Does it Matter Doing 2D Flood Modeling 150 Times Faster?

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Chanhassen, MN

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Motivation

NOAA River Forecast Centers need faster models
Some regions require 2D models (flat areas, unconfined flow)
Using multiple-CPU processors is not enough
GPU parallelization
Red River of the North Floodplain, MN
Hydronia | NOAA CRADA
Research and Development Agreement

• Implement **RiverFlow2D GPU** on a 420-mile reach of the Red River of the North
• Improve forecast response times and accuracy with 2D modeling
RiverFlow2D Model

- Combined Hydrologic-Hydraulic model
- Flexible non-structured mesh
- Robust dry-wet bed algorithm
- Finite-Volume numerical engine
- Supercritical and subcritical regimes
- Extensively validated in a broad range of real-world projects
- Add-on Modules: ST, PL, MD
- Hydraulic structures (culverts, weirs, bridges, gates)
- Seamless integration with Aquaveo SMS GUI
- GPU module.
Flexible Mesh

$\eta, u, v, z_b$
Concerns about using 2D Models for Large Areas and Long River Reach Forecasting

Non-parallelized (or poorly parallelized) 2D models are very slow!

CPU Processors are not getting any faster

CPU’s (e.g. Intel i7, etc.) are optimized for a single thread

Parallelization is the way to go → Multiple Processors

Super-computers are not easy accessible.
Evolution of Processor Clock Frequency: CPU
Graphic Processing Units: GPU

- Designed to accelerate graphic rendering
- GPU’s are present on video cards
- GPU’s emphasize executing **many concurrent threads.**

<table>
<thead>
<tr>
<th></th>
<th>GTX 780</th>
<th>GTX Titan Black</th>
<th>Tesla c2075</th>
<th>Tesla k20</th>
<th>Tesla k40</th>
<th>Tesla k80</th>
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</thead>
<tbody>
<tr>
<td>CUDA cores</td>
<td>2,304</td>
<td>2,880</td>
<td>448</td>
<td>2,496</td>
<td>2,880</td>
<td>2 x 2,496</td>
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<tr>
<td>Memory</td>
<td>3 Gb</td>
<td>6 Gb</td>
<td>6 Gb</td>
<td>5 Gb</td>
<td>12 Gb</td>
<td>24 Gb</td>
</tr>
<tr>
<td>Cost US$</td>
<td>$500</td>
<td>$850</td>
<td>-</td>
<td>$2,000</td>
<td>$3,000</td>
<td>$4,500</td>
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</tbody>
</table>
Green River, USA

- Mesh1 19,079 cells
- Mesh2 154,880 cells
- Mesh3 1,878,607 cells
- 2-hr Hydrograph

Peak Inflow $Q = 44,000 \text{ ft}^3/\text{s}$
### Speed-up with respect to non-parallelized code

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Cells</th>
<th>Intel CPU</th>
<th>GTX 780</th>
<th>Tesla c2075</th>
<th>Tesla k20</th>
<th>Titan Black</th>
<th>tesla k40</th>
<th>tesla k80</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>19,079</td>
<td>00:00:08:14</td>
<td>00:00:00:41</td>
<td>00:00:00:23</td>
<td>00:00:00:24</td>
<td>00:00:00:32</td>
<td>00:00:00:18</td>
<td>00:00:00:18</td>
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<tr>
<td>2</td>
<td>154,880</td>
<td>00:03:23:47</td>
<td>00:00:04:36</td>
<td>00:00:05:12</td>
<td>00:00:03:38</td>
<td>00:00:03:19</td>
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<tr>
<td>3</td>
<td>1,878,607</td>
<td>08:23:17:47</td>
<td>00:02:41:46</td>
<td>00:04:17:00</td>
<td>00:02:32:06</td>
<td>00:01:54:58</td>
<td>00:01:49:04</td>
<td>00:01:28:04</td>
</tr>
</tbody>
</table>

Up to 150X Faster
Numerical model verification of a whitewater kayaking run with physical model results

Clark Barlow, P.E., CFM
Atkins Global
Royd Nelson, P.E.
Aquaveo, LLC
Scott Shipley, M.S., P.E.
S20 Design and Engineering, LLC

In cooperation with...

Cloward H2O
Mesh Generation

- Mesh Generated with Surface-water Modeling System (SMS)
- 602,619 triangular cells
Run Times

Computer Specifications:

- Processor: Intel® Core™ i7-3770 CPU @3.40GHz
- Cores: 8
- Speed: 3.40 GHz
- Installed memory (RAM): 24.0 GB

<table>
<thead>
<tr>
<th>Model</th>
<th>Time Step (s.)</th>
<th>Model Run Time</th>
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</thead>
<tbody>
<tr>
<td>SRH-2D</td>
<td>0.25</td>
<td>22 hr 05 min</td>
</tr>
<tr>
<td>TUFLOW FV</td>
<td>Variable</td>
<td>32 hr 51 min</td>
</tr>
<tr>
<td>RiverFlow2D CPU r2015</td>
<td>Variable</td>
<td>29 hr 16 min</td>
</tr>
<tr>
<td>RiverFlow2D GPU r2015</td>
<td>Variable</td>
<td>2 hr 13 min</td>
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</tbody>
</table>

NVIDIA GEFORCE Titan Black
Test 5 UK Benchmarks

Objective:
This tests a model’s capability to simulate major flood inundation and predict flood hazard arising from dam failure (peak levels, velocities, and travel times).

Description:
This test is designed to simulate flood wave propagation down a river valley following the failure of a dam.

Inflow hydrograph applied
Test 5 UK Benchmarks

Test 6B - Velocity - Point 1

Test 6B - Water Level - Point 1

Test 5 - Velocity - Point 5

Test 5 - Water Level - Point 5
Test 5 UK Benchmarks

35X Faster than RAS 2D
57X Faster than SRH-2D
Test 6A UK Benchmarks

Objective:
This tests the model capability to correctly simulate hydraulic jumps and wake zones behind buildings using high-resolution modelling.

Description:
Test 6A is the original test proposed in Soares-Frazao and Zech 2002, where the physical dimensions are those of the laboratory model.
Test 6A UK Benchmarks

Test 6A - Velocity - Point 3

Test 6A - Water Level - Point 3

Test 6A - Velocity - Point 4

Test 6A - Water Level - Point 4
Test 6A UK Benchmarks

89X Faster than RAS 2D
23X Faster than SRH-2D
Test 6B UK Benchmarks

Objective:
This tests the model capability to correctly simulate hydraulic jumps and wake zones behind buildings using high-resolution modelling.

Description:
Test 6B is identical to Test 6A although all physical dimensions have been multiplied by 20 to reflect realistic dimensions encountered in practical flood inundation modelling applications.
Test 6B UK Benchmarks
Test 6B UK Benchmarks

163X Faster than RAS 2D
31X Faster than SRH-2D

Bar chart showing runtimes in hours for different models:
- RiverFlow2D 1 CPU: 0.060
- RiverFlow2D 8 CPU: 0.033
- GPU GTX 970 Model: 0.004
- SRH-2D: 0.124
- HEC-RAS: 0.652
Red River of the North
NOAA-North Central River Forecast Center NCRFC

Forecast Point Locations

- 426 Forecast Points
- 1173 Sub-watersheds

Major drainages:
- Hudson Bay
- Mississippi
- Great Lakes

Map showing Hudson Bay Drainage, Great Lakes Drainage, and Mississippi R. Drainage.
Hydraulic Challenges

• Low accuracy of 1-D approach
• Complex overland flow
• Excessive computational times: 1D model requires 3-9 hours!
• Ideally run times should be less than 2 hours
Test A: Uniform mesh 1,070,000 cells

Test B: Refined mesh 590,000 cells

420 miles
Comparison with field data. Flood of 2011.

- Measurement locations
- USGS Gauges and HWM

420 miles
$R^2 = 0.9986$
Comparison of RiverFlow2D GPU Model with Aerial Images
2011 Flood
Comparison of RiverFlow2D GPU Model with Aerial Images
2011 Flood
Summary of RRN Performance Tests

420 river miles
1,070,000 cells
50 day hydrograph
4-ft LiDAR (90Gb)
RiverFlow2D GPU
1 hour setup time

<table>
<thead>
<tr>
<th>RiverFlow2D Mesh (cells)</th>
<th>GPU Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,070,000</td>
<td>2.2 h</td>
</tr>
<tr>
<td>590,000</td>
<td>36 min</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HEC-RAS 1D Run Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-day hydrograph</td>
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</tbody>
</table>
Summary

• Speedups of 150X with respect to 1-processor model

• RiverFlow2D GPU is faster than existing RAS 1D model of the Red River of the North

• In the test performed, RiverFlow2D is up to 163X faster than RAS2D and 57X faster than SRH-2D

• GPU parallelization is the cost effective way to speed up hydraulic models
Modeling Process

- Modeling process costs depend on many factors
- Free software is not necessarily more cost effective
- Model robustness and speed is the most important factor
- Days ➔ Hours and Hours ➔ Seconds
Questions?
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