Two Dimensional Hydrodynamic and Sediment Transport Model for Surface Flow Routing (CHRE2D)

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1. Introduction

Background

- There is no defined drainage path in urban watershed resided in alluvial fan.
- Modeling surface flow over watershed needs to simulate both overland flow and channel flow.
- The depth of overland flow is much shallower than that of channel flow.

CHRE2D Model

- CHRE2D is a two-dimensional Hydrodynamic and Sediment transport model that simulates surface flow routing and sediment transport using numerical solutions of shallow water equations and the kinematic or diffusion wave approximation.
- The shallow water equations are discretized by the first-order Godunov-type finite volume method. An approximate solution to the momentum equation, kinematic or diffusion wave approximation, was introduced to overcome the difficulties in simulating very shallow overland (e.g. 10^{-10} m).
- The resulted CHRE2D model is capable of simulating both hydrological flow (e.g. surface flow routing) and hydraulic flow (e.g. dam break), which has not been achieved in similar commercial software, such as FLO2D, ARM2D.
- Additionally, the CHRE2D model implemented the Grass-type sediment transport formula to simulate the total sediment load in both overland flow and channel flow.

2. Governing Equations and Numerical Methods

Flow Model,: shallow water equations - Mass and Momentum Conservations. The integral form of thee equations were solved using HLL Riemann solver.

$$\frac{\partial h}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}=i_0 \qquad \begin{cases} \dfrac{\partial (hu)}{\partial t}+\dfrac{\partial}{\partial x}(hu^2+\dfrac{1}{2}gh^2)+\dfrac{\partial (huv)}{\partial y}=ghS_{0x}-C_f\|\mathbf{u}\|u \\ \dfrac{\partial (hv)}{\partial t}+\dfrac{\partial (huv)}{\partial x}+\dfrac{\partial}{\partial y}(hv^2+\dfrac{1}{2}gh^2)=ghS_{0y}-C_f\|\mathbf{u}\|v \end{cases}$$

Sediment Model: The governing equations for variable density flow model is based on the two-phrase flow theory and treated sediment-laden flow density as a spatial and temporal variable.

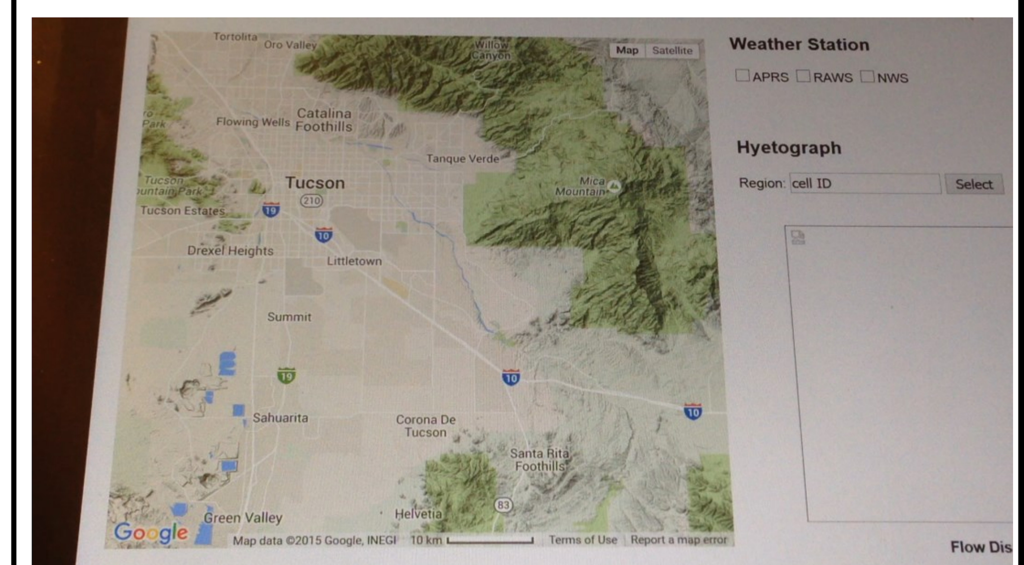
$$\frac{\partial h}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}=S_b \qquad \frac{\partial (\rho hu)}{\partial t}+\frac{\partial}{\partial x}(\rho huu+\frac{1}{2}\rho gh^2)+\frac{\partial (\rho huv)}{\partial y}=\rho ghS_{0x}-\rho C_f\|\mathbf{u}\|u$$

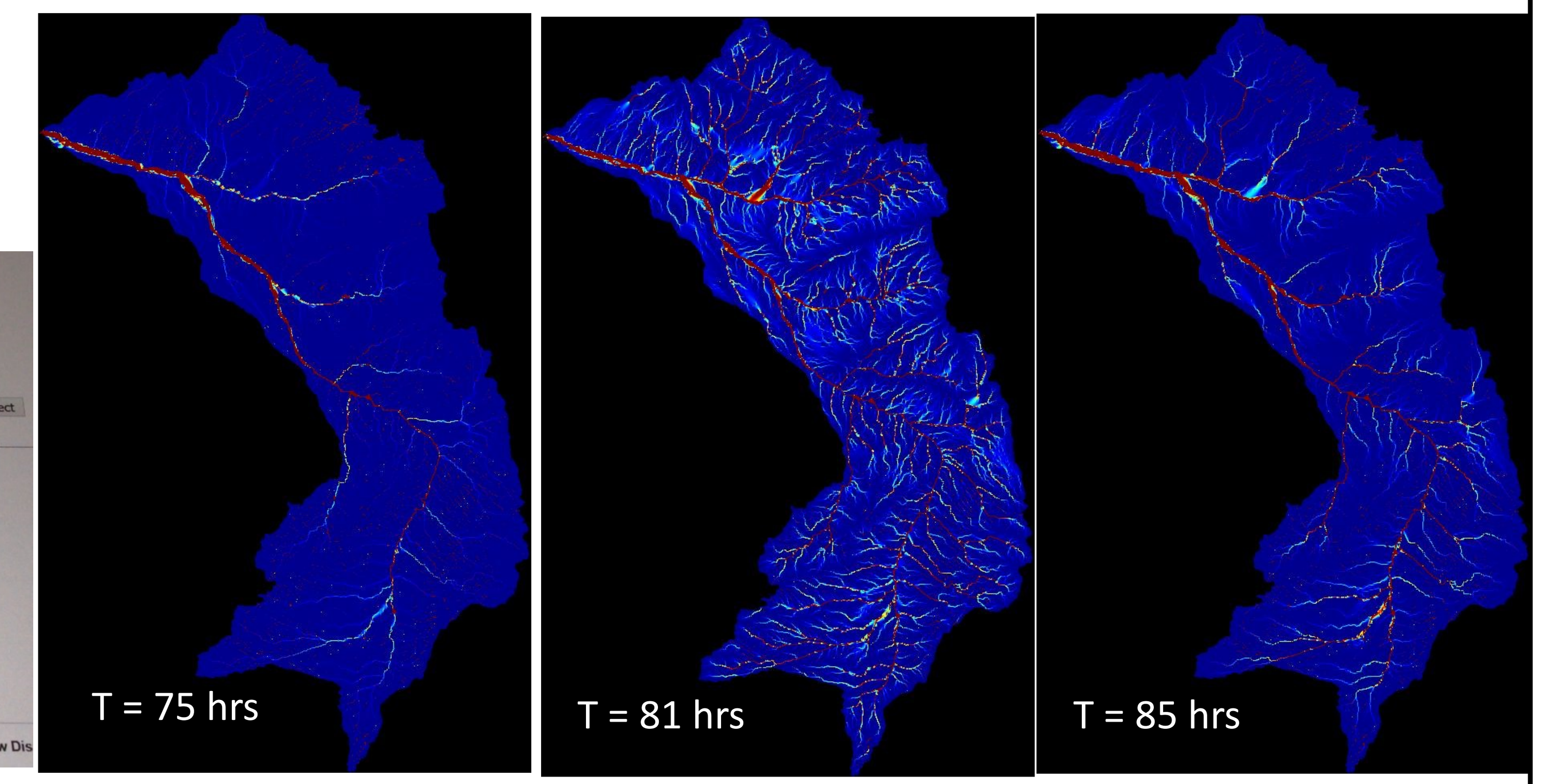
$$\frac{\partial (\rho h)}{\partial t}+\frac{\partial (\rho hu)}{\partial x}+\frac{\partial (\rho hv)}{\partial y}=\rho_b S_b \qquad \frac{\partial (\rho hv)}{\partial t}+\frac{\partial (\rho hvu)}{\partial x}+\frac{\partial}{\partial y}(\rho hvv+\frac{1}{2}\rho gh^2)=\rho ghS_{0y}-\rho C_f\|\mathbf{u}\|v$$

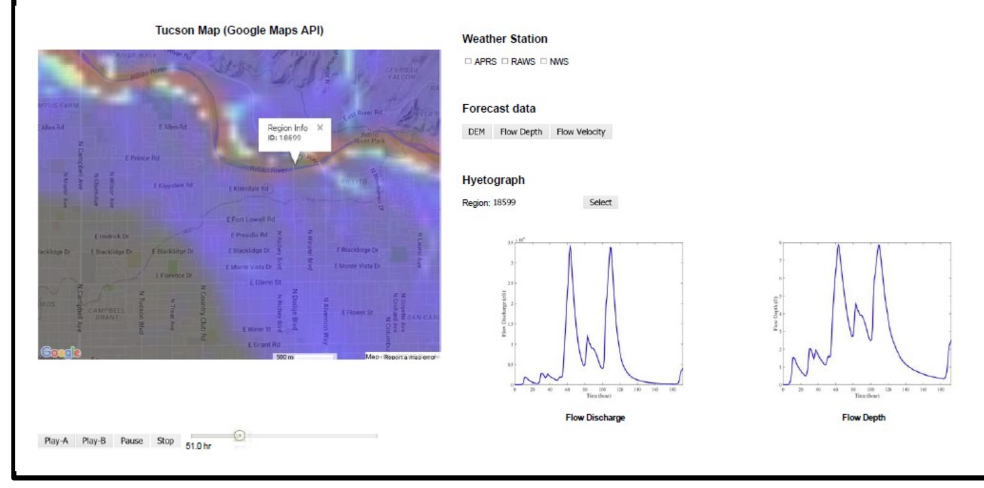
Watershed ID

3. Flood Inundation Simulation in Tucson, Arizona

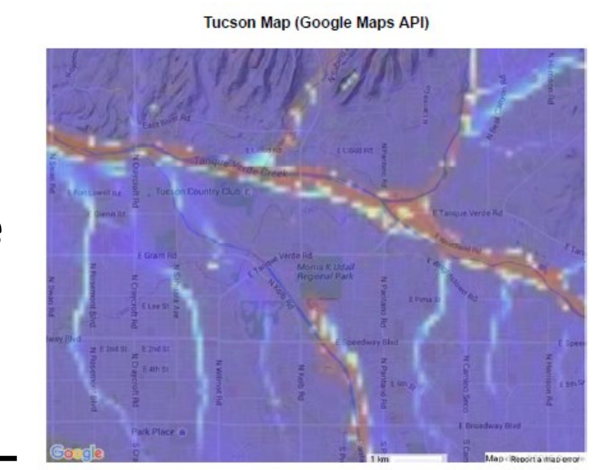
Time: Precipitation included flash flood from July 27th to Aug. 4rd, 2006, 192 hours, in Rillito Basin, about 60 x 40 mile
Total Cells: 400,000

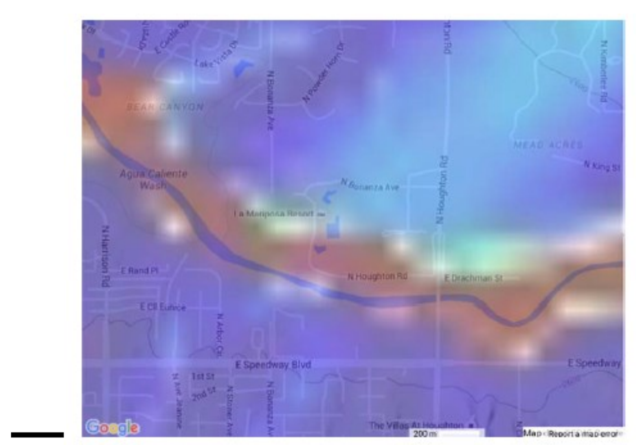




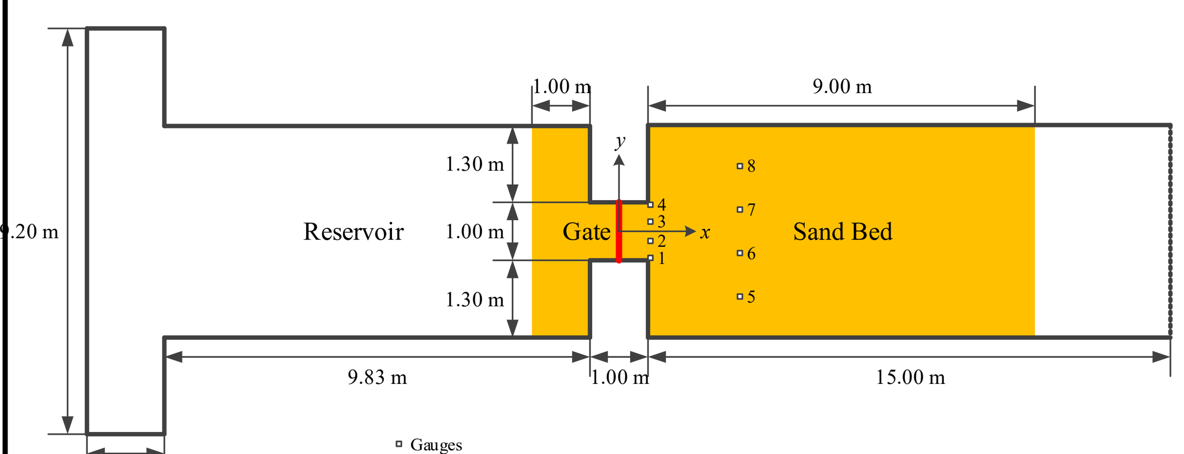


Internet enabled flood flow real-time forecast in street level.

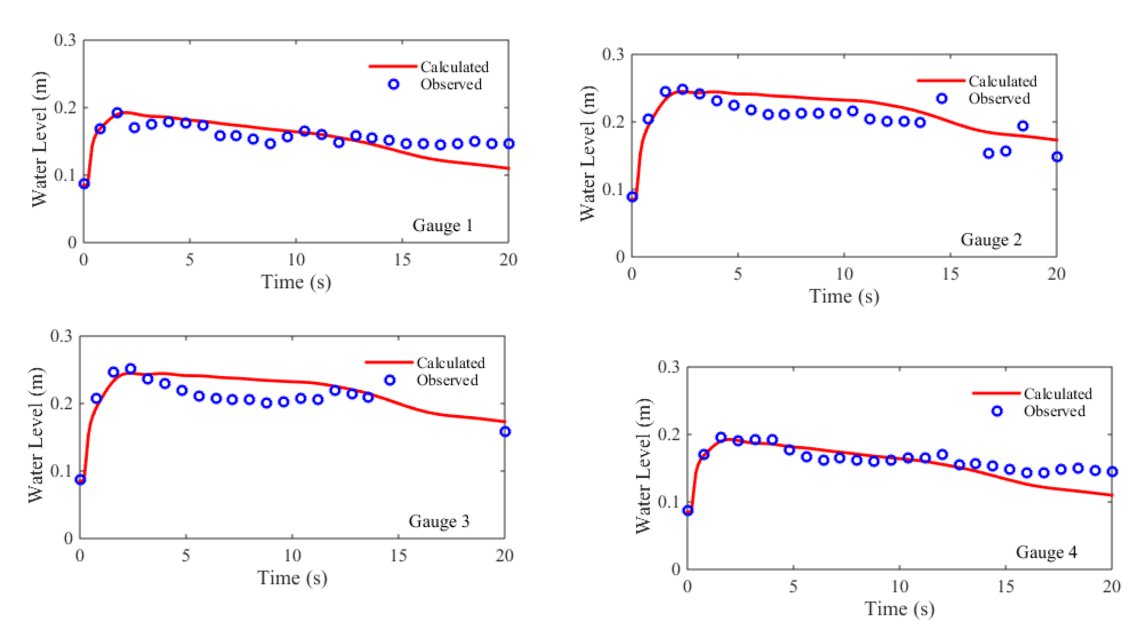




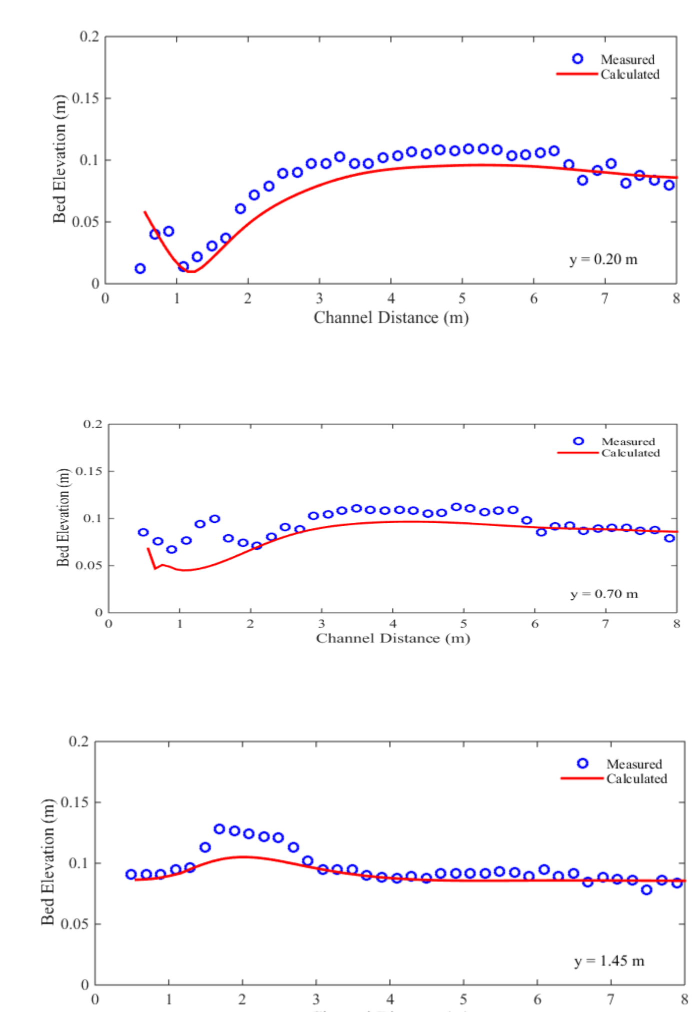
4. Sediment Modeling Results



Experimental Set-up



Comparison of Simulated and Observed Water Surface



Comparison of Simulated and Observed Bed Elevation

Conclusions

- CHRE2D model is a robust surface flow routing and sediment transport model, which is capable of simulating hydrodynamics of unsteady flow, surface flow over watershed, and sediment transport processes.
- The performance of the model was verified by many laboratory and field cases.
- For flow simulation, the model predicted accurately peak flows and flow hydrographs.
- The sediment module predicted reasonable changes of river cross sections and thalweg caused by a realistic dam break flow.
- The accuracy and simplicity of the proposed model, together with the robust implementation of well-balanced numerical scheme, makes this model suitable for practical hydraulic engineering applications.