The following is my TWRI Pre-Proposal application, specifically for the USGS Research Program.

Title:

Modeling and predicting Texas flooding events with the Shallow Water model

Student Contact Information:

Eric Joseph Tovar
ejtovar@math.tamu.edu
Texas A&M University
Department of Mathematics
PhD, 2016 - 2021

Advisor Contact Information:

Dr. Jean-Luc Guermond
Professor of Mathematics
FAX: (979) 862-4190
guermond@math.tamu.edu
Texas A&M University
Department of Mathematics

Current Research:

The funds will support ongoing research and the start of a recently developed timeline that will incorporate a new application of the current research. Our research has been focusing on developing and implementing a new mathematical model that better predicts the behavior of water waves. We are in the process of validating our model with numerical benchmark tests with relevant literature and hope to complete this by the end of the 2018 year. We will then begin to explore real-world applications such as large-scale flooding and tsunami propagation.

Abstract:

When Hurricane Harvey hit Texas in 2017, the Colorado River overflowed into the towns of Wharton County causing devastating flooding. The water reached historic levels, causing damage that is still in the process of being repaired. It is said that some of the flooding was unforeseen due to the redirection of the flow of water over the banks of the river, caused by the major rainfall (Foxhall, 2017). With the use of Mathematics and Computer Science, our goal is to model possible flooding scenarios to help predict future catastrophic events and explore possible solutions accordingly.

Our mathematical model, which is a dispersive Shallow Water model (Guermond, *et al.*, 2019), can help simulate various flooding events such as river flooding, storm surge flooding or dam breaks. We numerically implement the model using finite elements and use real topographical data (obtained by the U.S. Geological Survey (USGS), Google Elevation or other open source datasets such

OpenStreetMap). Incorporating rain and friction effects, we can accurately simulate the level and flow of water. Through thorough analysis of these simulations, we can provide input on possible solutions, such as creating levees or artificial river channels, that will help prevent catastrophic flooding.

Description:

The major bodies of water within and alongside the state of Texas are ubiquitous. Some notable areas include the Rio Grande River, Colorado River, Lake Travis, and of course, the Gulf of Mexico. These bodies of water provide sources for drinking water, water for agricultural use, and ecosystems for wildlife. However, with the size and ubiquity of these bodies, the possibility of flooding is always a concern for the state of Texas. Flooding events can be a result of natural disasters, structural failures, and often severe thunderstorms. Our goal is to use Mathematics and Computer Science to accurately simulate past and possible future Texas flooding events for the use of forecasting and prevention. We believe applying our dispersive Shallow Water model[1] (Guermond, *et al*, 2019) to simulate flooding can be of great assistance to city officials, engineers, and the people of Texas in general in helping them to understand the effects and risks of future flooding events.

We will be using finite elements to numerically implement our 2D model for the creation of our simulations, similar to methods proposed in (Guermond, et al., 2018). Our goal is to simulate three different types of flooding scenarios: river flooding, dam break flooding, and storm surge flooding. Specifically, we will model the flooding of the Colorado River in Wharton County during Hurricane Harvey, the breaking of a Texas dam (where data is available), and storm surge flooding near the Gulf of Mexico. If possible, we will compare our simulations to data from past events. Our timeline consists of the following: two months of gathering topographical data and fine-tuning the data, one month of collecting appropriate rain data and terrain roughness data (used for friction approximation), one month of running initial test simulations (without considering possible solutions), one month of considering possible simple solutions to the flooding events, followed by a period where we will optimize our simulations and comparing to real data. We give more details on each below.

We can obtain elevation (or topographical) data from sources such as U.S. Geological Survey (USGS), Google Elevation or other open-sourced options. The data is a digital representation of cartographic information taken from radar or satellite images. It is common for the elevation data to contain errors such as peaks, sinks, or even integer values of the data (such as jump from 1 meters to 2 meters without the values in between). To correct these errors, we can fine-tune the data by applying what's called a smoothing technique or, mathematically, a discrete laplacian. Elevation data can also lack detailed descriptions for areas such as river beds and ocean floors. We can try to correct this error by exploring methods such as surface reconstruction seen in (Dobrev, et al., 2010).

For more accurate simulations, we can implement rain and friction effects into our model. The Shallow Water model has been shown to accurately reproduce the Malpasset dam break that occurred

[1] The Shallow Water model is a set of non-linear partial differential equations used to describes the time and space evolution of a body of water evolving in time under the action of gravity assuming that the deformations of the free surface are small compared to the water elevation and the bottom topography varies slowly.

in France in 1959 when the proper friction coefficient is chosen (Guermond, et al., 2018). We can follow similar methods with the appropriate friction coefficient accounting for the different terrains in Texas. We will also consider the appropriate rainfall rate for the simulations concerning Hurricane Harvey using the data that was recorded during that time.

After finding the best data that closely matches the physical world, we will then begin to run initial simulations. This consists of running simple tests that verify our numerical code is behaving appropriately; that is, it is not exhibiting un-physical behaviors such negative water height, water height blow-up, etc. Once we have a solid foundation, we can move forward and fully utilize our method to try to recreate large-scale simulations over a long period of time. The aim is to piece together all the information and closely match the past events mentioned above. At the moment, we believe the Colorado River flooding will be our key subject. Once we are satisfied with our results, we can then implement potential solutions to the flooding events. We want to create artificial levees, river channels and seawalls (for storm surge waves), to simulate the prevention and redirection of the flow of water.

After completing the above tasks, we hope to apply the model to different flooding scenarios that have yet to occur. This will aid engineers when building new structures and city officials who make flood evacuation decisions during natural disasters.

Intended career path:

I am currently a third-year PhD student working towards a career in applied mathematics research. I recently began an internship with the U.S. Army Engineer Research and Development Center (ERDC) developing and implementing numerical methods for modeling water waves. I would like to continue working for ERDC after I graduate as a full-time research scientist to continue gaining experience outside an academic setting.

Eventually, I would like to return to academia as a professor in the Rio Grande Valley to give back to the community where I was raised and obtained my undergraduate and master’s degrees. Working in a university will also give me the opportunity and resources to continue significant research projects.

After recently meeting two deputy directors from Los Alamos National Lab, I am also considering the option of pursuing an administrative position in an established research facility once I have established my career as a researcher.

References

Foxhall, E. (2017, September 14). Residents of flood-ravaged Wharton County feel forgotten in Harvey's wake. Retrieved from https://www.houstonchronicle.com/news/houston-texas/texas/article/Residents-of-flood-ravaged-Wharton-County-feel-12199385.php

Guermond, J-L., Popov, B., Tovar, E. (2019). Robust Explicit Relaxation Technique For Solving The Green-Naghdi Equations. Manuscript in preparation.

Guermond, J., Luna, M. Q., Popov, B., Kees, C. E., & Farthing, M. W. (2018). Well-Balanced Second-Order Finite Element Approximation of the Shallow Water Equations with Friction. SIAM Journal on Scientific Computing, 40(6). doi:10.1137/17m1156162

Dobrev, V., Guermond, J., & Popov, B. (2010). Surface Reconstruction and Image Enhancement via L^1-Minimization. SIAM Journal on Scientific Computing, 32(3), 1591-1616. doi:10.1137/09075408x