Calibrating the Shiono Knight Model for Inbank Flow by Means of Evolutionary Algorithms

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Introduction

Modeling of inbank and overbank flow is a technically challenging task due to the complexity of the 3D flow structures that are present in most rivers especially during the flood events. As a result, there is a certain level of uncertainty in flood levels predicted by many numerical models.

The Shiono & Knight Method (SKM) is a simple depth-averaged flow model, based on the RANS equations, which can afford a novel way of determining the lateral distributions of depth averaged velocity and boundary shear stress across rivers and channels. The main goal of this research is to study and interpret the physical meaning of three parameters within this model: Friction factor \((f)\), dimensionless eddy viscosity \((\lambda)\) and Secondary current term \((\Gamma)\). This work is going to be done by calibrating the three parameters in the model based on data from experimental studies in the UK Flood Channel Facility and University of Birmingham. Various classic and novel search techniques including multi-objective Genetic Algorithms will be tested in calibrating this model. The SKM model is then going to be applied to validate the stage-discharge relationships at a number of key gauging stations around the UK.

What is the Shiono-Knight Method (SKM)?

The SKM is a 1D model with 2D parameters which take account of 3D effects and takes the form:

\[
\frac{\partial}{\partial y} \left[ H \left( \rho \bar{U} \bar{V} \right) \right] = \frac{\rho g}{8} \frac{\rho f U_d^2}{s} \left( 1 + \frac{1}{s} \right)^{1/2} + \frac{\partial}{\partial y} \left[ \rho \lambda H^2 \left( \frac{f}{8} \right) \frac{1}{2} U_d \frac{\partial U_d}{\partial y} \right]
\]

Where; \(H=\)Depth of water in channel, \(U\) and \(V=\)velocity components, \(S_0=\)longitudinal slope, \(f=\)Darcy-Weisbach friction factor, \(s=\)channel side slopes, \(\rho=\)fluid density, \(g=\)acceleration due to gravity and \(\lambda=\)dimensionless eddy viscosity. Sub-script ‘d’ signifies that it is depth-averaged. However, this simplifies to:

\[
\tau_b \left( 1 + \frac{1}{s} \right)^{1/2} = \rho g H S_0 + \frac{\partial}{\partial y} \left( H \bar{r}_{xx} \right) - \Gamma
\]

Where \(\Gamma\) represents the transverse gradient of secondary flow cells. Secondary currents develop due to a change in momentum.

How can the SKM be used to model a river?

In brief, the river is divided into a number of representative panels and then the equations are applied to each panel. Considering the boundary conditions between the panels, the equations are solved and the depth-averaged velocity and local boundary shear stress are calculated at various sections along the cross-section.
What is the main difficulty in using this model?

As it can be seen, this model has three parameters in it:
\( f \): representing the boundary friction
\( \lambda \): representing the lateral mixing and turbulence
\( \Gamma \): representing the secondary flows

The value of these parameters should be defined for each panel before applying the SKM. The calibration of the model for different types of channels is going to be done by using some search techniques including Genetic Algorithms.

What are Genetic Algorithms?

Genetic Algorithms (GAs) are a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology to solve a problem. The idea in all these evolutionary algorithms is to evolve a population of candidate solutions to a given problem, using operators inspired by natural genetic variation and natural selection such as inheritance, mutation, selection, and crossover.

Genetic algorithms (GAs) were invented by John Holland in the 1960s and were developed by Holland and his students and colleagues at the University of Michigan in the 1960s and the 1970s. Holland's GA is a method for moving from one population of "chromosomes" (e.g., strings of ones and zeros, or "bits") to a new population by using a kind of "natural selection" together with the genetics inspired operators of crossover, mutation, and inversion. Each chromosome consists of "genes" (e.g., bits), each gene being an instance of a particular "allele" (e.g., 0 or 1). The selection operator chooses those chromosomes in the population that will be allowed to reproduce, and on average the fitter chromosomes produce more offspring than the less fit ones.

Crossover exchanges subparts of two chromosomes, roughly mimicking biological recombination between two single chromosome ("haploid") organisms; mutation randomly changes the allele values of some locations in the chromosome; and inversion reverses the order of a contiguous section of the chromosome, thus rearranging the order in which genes are arrayed.

What are the Elements of Genetic Algorithms?

In GA, search starts with an initial set of random solutions known as population. Each chromosome of population is evaluated using some measure of fitness function which represents a measure of the success of the chromosome. Based on the value of the fitness functions, a set of chromosomes is selected for breeding. In order to simulate a new generation, genetic operators such as crossover and mutation are applied. According to the fitness value, parents and offsprings are selected, while rejecting some of them so as to keep the population size constant for new generation. The cycle of evaluation–selection–reproduction is continued until an optimal or a near-optimal solution is found.

**Selection** attempts to apply pressure upon the population in a manner similar to that of natural selection found in biological systems. Poorer performing individuals (evaluated by a fitness function) are weeded out and better performing, or fitter, individuals have a greater than average chance of promoting the information they contain to the next generation.

**Crossover** allows solutions to exchange information in a way similar to that used by a natural organism undergoing reproduction. This operator randomly chooses a locus and exchanges the subsequences before and after that locus between two chromosomes to create two offspring.
**Mutation** is used to randomly change (flip) the value of single bits within individual strings to keep the diversity of a population and help a genetic algorithm to get out of a local optimum. It is typically used sparingly.

![A chromosome with 5 genes](image1)

![Single point Crossover operator](image2)

![Mutation operator](image3)
Aims and Objectives

The main goals of the research are as follows:

1- **Calibrating the SKM model for inbank flow**: Before applying a model to a specific case, it should be calibrated with the available experimental data. The SKM has been calibrated for compound channels with overbank flow (Abril & Knight, 2004) considering large panels and relating the floodplain parameters to the main channel characteristics, but no major attempt has yet been made to calibrate the model for inbank flow.

2- **Interpreting the physical meaning of the three parameters within the SKM model**: Once the model is calibrated for various simple channels with inbank flow, the three parameters in the model (\( f, \lambda, \Gamma \)) can be expressed in mathematical terms. This would assist us in proposing a physical interpretation of each parameter and explain how they vary laterally across the channel, as well as with stage.

3- **Revising the model calibration for compound channels with overbank flow**: After finding the physical meaning of each parameter, the calibration would be continued for cases with overbank flow. This work would be a revision of Abril & Knight’s (2004) work. At the end of this stage we would have the ability to apply the model to any river with any cross-section with great certainty about the results.

4- **Validating the stage-discharge relationships at a number of UK’s key gauging stations**: Being able to estimate the values of the three parameters of the SKM model for any
kind of channel, this model can be used to rationally calculate the H vs. Q relationship at any point of a channel or river.

In order to reach these main goals I intend to use river data and data collated in flumes, such as the United Kingdom Flood Channel Facility (FCF) to carry out various simulations and compare the results to current modelling packages.

If you have any questions, please email me, Soroosh Sharifi, at SXS650@bham.ac.uk.