Hydrodynamic Modelling of Rivers with Floodplains

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Introduction

Rivers are all too often reported to have caused widespread flooding resulting in loss of life and property but without them we would be up the creek without a paddle. Rivers provide flood, water and energy and not to mention their recreational uses such as canoeing and fishing.

My project concentrates on trying to model rivers better. Currently, shear stress and velocities calculations are often neglected by river modellers as no widely used modelling package can determine them at specific points, they usually calculate an average value for the whole cross-section. Knowing shear stress and velocities at specific points can improve flow and sediment transport calculations. In order to model the river I am going to be using an existing model; the Shiono-Knight Method, and where necessary adapt it.

Rivers and Their Characteristics

Flow in a river is not as simple as it may seem—there are many factors which influence the ability of a channel to carry a flow. Such characteristics include:

- Slope of the channel
- Bed friction which can be caused by bed material (e.g. sand, gravel, rock etc), vegetation, debris, etc.
- Bank friction again, caused by vegetation, debris, etc.
- Size of the channel and its shape

However, rivers also have secondary flows which circulate across the river and these affect the flow, velocity and shear stresses within a channel and in turn can affect the plan form of a river. The figure below shows a possible river cross-section.

Due to their circulatory nature they are difficult to model and as a result they have often been neglected from widely used equations.

What is the Shiono-Knight Method (SKM)?

This model has been developed over the past 20 years, but significant progress has been made in the last few years owing to increased funding and interest. Flooding is a contentious issue of late as current modelling methods are failing somewhere along the line, therefore an improved method is required.
The SKM is a 1D model with 2D parameters which take account of 3D effects and takes the form:

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

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

\[
\tau_s \left( 1 + \frac{1}{s^2} \right)^{1/2} = \rho g H S_o + \frac{\partial}{\partial y} \left[ H \left( \frac{f}{8} \right)^{1/2} U_d \right] - \Gamma
\]

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

**FIGURE 1: HYDRAULIC PARAMETERS ASSOCIATED WITH OVERBANK FLOW IN A STRAIGHT CHANNEL**

Secondary currents influence sediment transport within a river system. Being able to model the better may allow for:

~calculation of bank erosion and deposition which over time alters the rivers morphology
~habitat restoration,

**How can the SKM be used to model a river?**

In brief, the river is divided into a number of representative panels. These panels are the subdivided and the model applied to each of these slivers. This gives the depth-averaged velocity and local boundary shear stress at various sections along the cross-section which can then be summed to give the overall velocity and shear stress in the river at any cross-section.

**What has already been done?**

There are many river models out there and the SKM in comparison is in its infancy. So far it can only be applied to straight, prismatic channels (i.e. no change in cross-section); this is because the SKM cannot be applied to a river reach only to a cross-section. In addition, it hasn’t quite made it to the ‘main stream’ yet and has largely been confined to the corridors of academia, with one exception—see later. In 2000, Ervine et al developed the SKM so that it could be applied to meandering channels with some degree of success. Their equation takes the form:

\[
\rho g H S_o - \frac{1}{8} \rho f U_d^2 \left( 1 + \frac{1}{s^2} \right)^{1/2} + \frac{\partial}{\partial y} \left[ \rho \lambda H \left( \frac{f}{8} \right)^{1/2} U_d \frac{\partial U_d}{\partial y} - H \rho K U_d^2 \right] = 0
\]
Where \( \bar{U} = K_1 U_d \) and \( \bar{V} = K_2 U_d \)

This has been found to predict the discharge, velocities and shear stresses in the channel well, however there isn’t a lot of velocity field measurements of overbank flows (Ervine et al, 2000), the Universities of Glasgow and Lancaster are hoping to remedy this situation. The main bone of contention with this model is that \( K \) is an empirical co-efficient and has little theoretical basis.

**Current Uses**

As stated, so far the uses of the SKM have been limited to largely academic studies, with one exception-the Conveyance Estimation System (CES). This has been developed by HR Wallingford, academics and industrial partners and is due for launch this year (2005). CES does not model a river but can provide the user guidance on the conveyance of the channel and its roughness. Although some assumptions and simplifications have been made in order that anyone with a small degree of knowledge can run the software, it is believed that this could be a major advancement in river engineering.

**Aims and Objectives**

The major aim of my project is to make this model more accessible and to develop it in such a way that it can be applied to any river anywhere in the world by any river engineer with a relative degree of knowledge. I have given my aims as a series of questions as I feel that by answering these I will have met my ultimate aim, the questions I intend to answer are:

- How do I model a straight river reach?
- Should energy losses or momentum losses be considered?
- How can this be transferred onto a meandering river?
- Are there going to be differing methods due to varying sinuosity?
- Should there be specific locations where cross-sections should be taken during surveys of rivers, such as at the apex, cross-over regions, how many are required?
- As this model is based on finding a flow for a specific water depth how do you decide what is going to be the worst case scenario? Currently, most modellers will take a given 'worst case' flow and calculate the water level, therefore a clear set of guidelines will be required.
- Currently the model is calibrated based on field data, how can it be used if there is little to no field data?

In order to answer these questions 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 or are having difficulties with this website please email me, Jennifer Chlebek, at JXC449@bham.ac.uk. All images, unless otherwise stated are copyright of Jennifer Chlebek.