Assignment 1

Gradually Varied Flow Profiles and Numerical Solution of the Kinematic Equations:

Examiner: Jahangir Alam

Due Date: 27 Apr 2017

Weighting: 15%

Objectives

1. Evaluate and apply the equations available for the description of open channel flow
2. Solve the equations governing unsteady open channel flow
3. Apply the equations of unsteady flow to practical flow problems

Rationale

This assignment is based on the material covered in this course. As such you will be directed to attempt tutorial questions from modules 1-5 before starting this assignment

Important Information

Before starting please review the USQ's Academic Integrity Policy and Procedure:

> "*All assessable work in a course is to be the individual student's own work, unless advised otherwise in the Course Specification. It is unacceptable for students to share solutions to assessable work on this Study Desk site, or in any other manner. Violations of this principle are regarded as Academic Misconduct and will be dealt with under the USQ Academic Regulations.*"

For guidance on what constitutes Academic Misconduct and its various categories, at USQ refer to the USQ Student Academic Misconduct Policy available at: http://policy.usq.edu.au/documents/13752PL

By submitting this assignment you hereby certify that:

The submission is entirely my own work except where due acknowledgement is made in the text and that no part has been copied from any other person's work.

Special Instructions

a. Computer programs or spreadsheets **must be the work of the individual student**.

b. Assignments submitted without adequate proof of program validation will not be eligible for greater than a C grading.

c. A proportion of the marks is allocated to the communication aspects of the assignment. Marks will be deducted for untidy and poorly presented work, poor English expression, and failure to cite sources of information.

d. Plagiarism is taken seriously in this course, as such your assignment report will be checked using Turnitin and your spreadsheets (if you have chosen to use Excel or equivalent) will be checked for plagiarism using Excel-Smash

Instructions for Submission

Submission for this assignment is in two parts:

- Report introducing the problem, providing background in all relevant theory, descriptions of methods and equations used and discussion of results.
- Electronic copy of all computer code or spreadsheets used so the examiner can validate the models

The report should be compiled in such a manner that assessment can be completed without access to the electronic copies of the code/spreadsheet files. It is normal practice to include technical details (e.g. computer code) as an appendix.

The assignment is to be submitted electronically via study desk. The link is available on the course studydesk.

Please note that hand written equations within the body of the report are permitted*. In many cases they are preferred as they are simpler to produce and easier to read than poorly set out computer produced equations*

Late Submissions

If students submit assignments after the due date without (prior) approval of the examiner then a penalty of 20% of the total marks gained by the student for the assignment may apply for each working day late up to 5 working days at which time a mark of zero may be recorded. No assignments will be accepted after model answers have been posted

Assessment Task

This assignment is comprised of two questions with the marks allocated as follows

Question 1 – Gradually Varied Flow Profile 40 marks

Question 2 – Kinematic Wave Model 110 marks

Question 1 – Gradually Varied Flow Profiles

Water is flowing in a long prismatic channel of trapezoidal cross section with base width 3.5m and the side slope 2.2 (Hor.): 1 (Ver.). The channel is made of rough concrete whose Manning roughness is 0.018.

The channel is conveying a steady flow rate of $5+(2\times n_1)$ m³/s

The bed slope of the channel is $0.00035+(0.0001\times n_2)$

Where, n_1 is the second last digit and n_2 is the last digit in your student number.

*For example if your student number is 100050076**48** then*

$Q = 5+(2\times 4) = 13\,\mathrm{m^3/s}$

$S_0 = 0.00035+0.0001\times 8 = 0.0012$

The downstream end of the channel drops vertically into a reservoir (discharges freely into the air). Note that for a free outfall the water depth closely approximates critical flow depth. Take alpha as being 1.1 (α =1.1).

Your task:

a) Use the direct step method, and the equation below to compute the water surface profile upstream of the outfall.

$$\frac{\Delta y}{\Delta x} = \frac{S_0 - \overline{S_f}}{1-\overline{F_R}^2} \qquad \text{where } F_R = \frac{\sqrt{\alpha}\ V}{\sqrt{g\bar{y}}}$$

b) Plot the water depth against distance

c) Plot the longitudinal bed, normal depth, critical depth, water surface and energy line over the length of this profile. (All on the same set of axis e.g. Fig 5.22 Chadwick)

d) Include sample hand calculation in the report

Hints:

- The size of the step is up to you.
- Use of computers for this task (Matlab, Excel etc is encouraged)
- When computing the water surface profile you should stop just short of normal depth
- The Froude number and critical depth for a trapezoidal channel are different to that of a rectangular channel (e.g. need average depth ($\bar{y}$) instead of max depth (y) in F_R)

Marking Scheme- Question 1

<table>
<tr><th></th><th>Requirements</th><th>Marks</th></tr>
<tr><td>Calculation of Normal Flow</td><td>• Area Correct
• Perimeter Correct
• Value is correct</td><td>5</td></tr>
<tr><td>Calculation of Critical Depth</td><td>• Used equation for non-rectangular channel
• Value is correct</td><td>5</td></tr>
<tr><td>Direct step Method</td><td>• Started at correct end of the profile
• Appropriate Delta Y (at least 10 steps)
• Calculations are correct</td><td rowspan="2">25</td></tr>
<tr><td>Plots of profile</td><td>• Water depth vs distance

The following plotted on the same set of axes and corrected for height of the bed

• Bed with distance
• Normal depth with distance
• Critical depth with distance
• Energy line with distance</td></tr>
<tr><td>Sample Calculations</td><td>Showing at least one row of the table as sample calculations</td><td>5</td></tr>
<tr><td>Total</td><td></td><td>40</td></tr>
</table>

Question 2 – Kinematic Wave Model

Background

You have been asked to investigate the flow behaviour of a large sporting field subjected to a short duration high intensity storm rainfall event.

As part of the process you will develop a computer simulation of the water depths and flow rates for a specified rainfall pattern. The kinematic wave approximation is a simple form of one dimensional flow model, which is deemed sufficient for this task.

The Sporting Field

For study purposes it has been deemed sufficient to represent the behaviour of the sporting field with a one dimensional hydraulic model, in effect reducing the two dimensional sporting field to a unit flow width running down the predominant slope direction. Basically, you will estimate water depth and flow rate per unit width at constant interval.

The length of the carpark area is determined by the last digit of your student number:

$$L = 120 + N_1 \times 10$$

For example if your student number was 01121584

$$L = 120 + N_{Last} \times 10$$
$$L = 90 + 4 \times 10$$
$$L = 160 \quad m$$

For the purpose of this study you may assume a constant value of Manning roughness ***n*** across the sporting field. You should justify your choice.

The specifications of the car park are as follows:

Manning ***n*** = based on your research

Field slope is uniform with 0.1% drop over length L

Freely draining at the downstream end.

Design Inflow

The model will be used to simulate the flood behaviour subjected to an extreme rainfall event. An example of such event is as below which occurred in Toowoomba on 10^{th} of January 2011. The rainfall hyetograph chosen for this study (Figure1) is from the weather station at Eastern Valley.

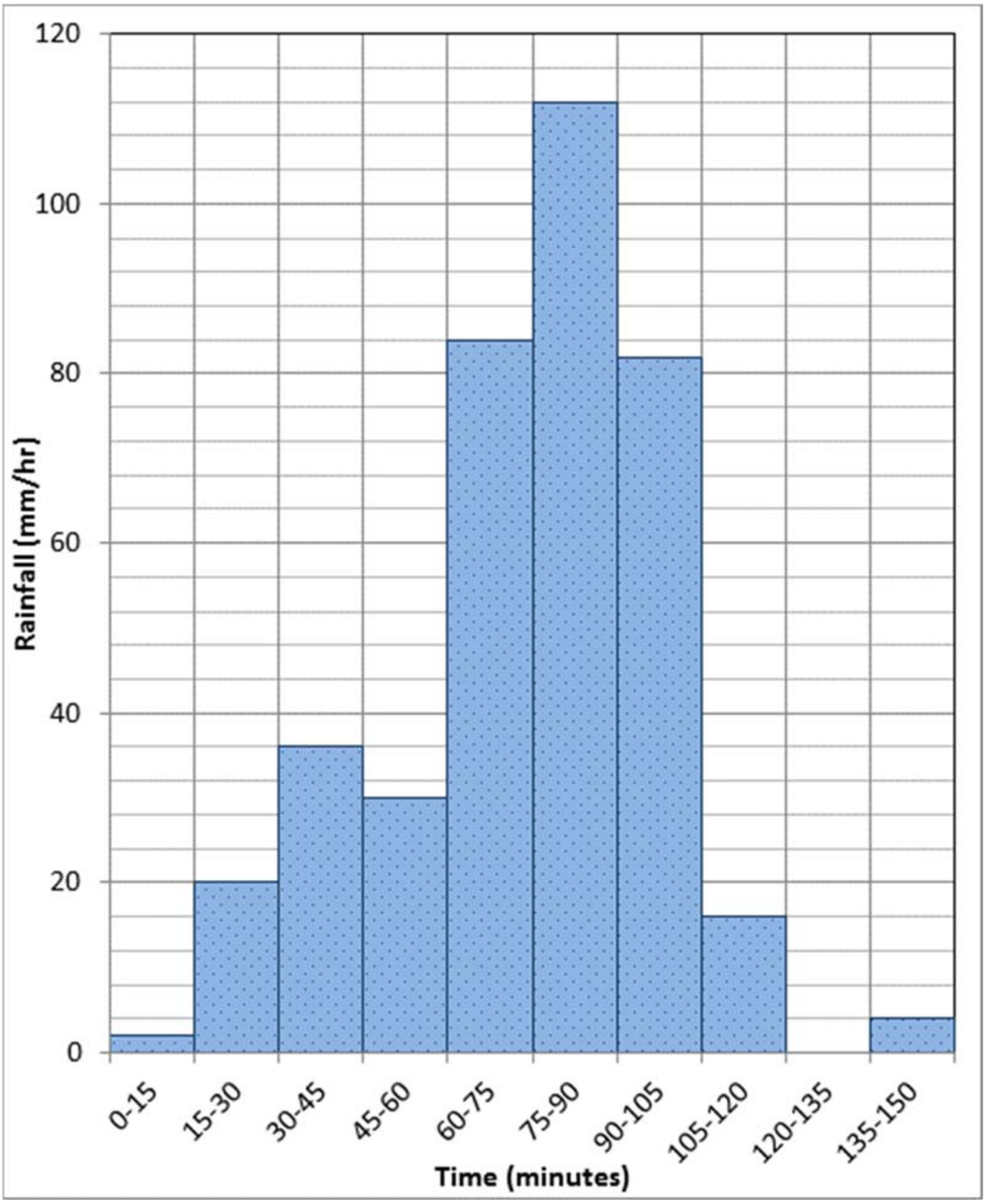

Figure 1: Example Rainfall Hyetograph from Eastern Valley (Source ICA 2011)

For simplicity it will be assumed in this study that the surface was already saturated at the start of the storm and that the continuing rainfall loss will be zero.

Model Specifications

Model Type: 1-dimensional kinematic wave approximation
Backward difference in *x* and **Forward** difference in time *t*

Boundary Conditions:

Initial condition ($t = 0$): $q = 0$ and $y = 0$ for all x

Upper boundary ($x = 0$) $q = 0$ for all *t*.

Grid Step Sizes

Maximum distance step $\Delta x <= 10$ m

Time step: Must satisfy Courant stability condition

Your Task

1) Complete the tutorial problems 5.1, 5.2, 5.3 and 5.4 in Module 5. You will find full solutions of first three questions in the study book that will help you to solve 5.4.

2) OPTIONAL: If you are not confident about your answer to 5.4 you may submit your working (formulas/equations) to the examiner using the link provided on studydesk before proceeding with the numerical scheme. Your examiner will be able to guide you through.

3) Build your model (using any programming language or spreadsheet) for solving the kinematic wave equations for computing depth and flow rate resulting from the storm events. You must configure your model according to the specifications above.

4) Validate your mathematical model by modelling the runoff under steady rainfall (constant rainfall depth) and compare results with the theoretical results for steady rainfall. The analytical procedure for theoretical results has been discussed at the end of this problem (The section Model Validation)

   You are required to check all three conditions

5) Modify the model to accommodate the design storm hyetograph. Then use this program to calculate water depth and flow rate at uniform distance interval dx along the unit width channel for the given storm event.

6) Write up all equations, model development, validation, results and discussion in a report format

Presentation of Results

The final report should include as a minimum:

- Introduction and background, a description of the problem
- Formulation of the finite difference solution,
- Basic description of model;
- Validation of the model for a constant slope by:
  - – plot of steady depth profile for a constant lateral inflow of sufficiently long duration, and
  - – comparison of your program output with the results from the analytic solutions of the kinematic equations given below
- Evidence that the Courant condition for stability has been satisfied for both the steady inflow simulation and the simulation of the example storm.
- Plots (for the given variable rainfall) of:
  - – the runoff hydrograph (q vs t) at the lower end of the channel (taken to at least 30 min after the cessation of rainfall), and
  - – the water surface profile (y vs x) when the discharge from the end of the channel is a maximum. Also note the time at which this maximum discharge occurs.
- Appropriate discussion. Some points that you should cover include:
  - i. What are your assumptions and how they might impact on the ability of your results to replicate flow in the real world?
  - ii. Your results for the runoff hydrograph and depth profiles.
  - iii. General conclusions of the practical use of your model.
- Acknowledgement of any sources of information in a reference list

Model Validation

A useful aide in the validation of your program is to run it with a steady rainfall of duration sufficiently long for steady state conditions to be reached.

Your results for this case can be compared to the analytic solutions as derived below based on the concept from Stephenson and Meadows (1986).

For a steady rainfall these are:

1. The rising limb of the hydrograph should initially follow the relationship:

$$q = a(rt)^m$$

where r is lateral inflow, and a and m are constants, which can be derived from the Manning equation and have the values:

$$a = \frac{S_0^{0.5}}{n} \qquad \text{and} \qquad m = \frac{5}{3}$$

2. The steady state discharge is given by:

$$q_{\max} = rL$$

where L is the length of the channel. **Your modelled *q* should converge on this result exactly.**

(you should check this at the downstream end of the channel)

3. The steady state depth profile (y vs x) can be determined by:

$$y(x) = \left(\frac{rx}{a}\right)^{\frac{1}{m}}$$

where x is the distance from the upstream end of the plane, and a and m are constants as defined above. **Your model should give an identical water surface profile for a steady rainfall.**

Note: In order to use these validations, (particularly 1 & 3) you will need to model a simple plane surface with a **single constant slope** and constant **Manning roughness** subject to a **steady rainfall** rate.

Marking Scheme - Question 2

Marks

Formulation of equations and model	Derivation of equations & implementation of the equations in the model: • Kinematic wave equations and diagram (10) • Boundary Condition (5) • Model code (15)	30
Validation of program (steady rain)	• Modelled steady state (5) • Validated Q_{max} (5) • Validated depth profile (8) • Validated rising limbs (7)	25
Courant Check	Selection of appropriate step sizes that satisfy courant for both the steady and unsteady system	5
Solution for 2011 storm	• Correctly interpreted rainfall (5) • Justified Manning *n* with reference (3) • Plot of *q* vs time (10) • Time of Max *q* (2) • Depth vs distance at Max *q* (10)	30
Introduction/Discussion/Conclusion	• Report structure • Introduction/Background • Assumption, results, limitations of model • Conclusions	20
Total		**110**

References

ICA, 2011, *The Nature and Causes of Flooding in Toowoomba 10 January 2011*, Insurance Council of Australia (ICA) Hydrology Panel.

Lai Y. 2009. Watershed Runoff and Erosion Modeling with a Hybrid Mesh Model. *Journal of Hydrologic Engineering* 14(1).

Readings 5.1 to 5.4 in the Book of Readings (taken from Stephenson, D. & Meadows, M.E. (1986) *Kinematic Hydrology and Modelling.* Elsevier, Amsterdam)