How to Build a Hydraulic Model

Headstart Summer School
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What’s engineering?

- It is the practical application of science,
- It is everything you are standing on, you are working in,
- It is the entire infrastructure of life,
- It is making something practical,
- It is finding solutions to problems
- It is the application of knowledge, to design, build, and maintain structures, machines, devices, etc.
Civil Engineering at Bristol

- Earthquake Engineering
- Geotechnical Engineering
- Dynamics and Control
- Systems
- Advance composites
- Water and Environment
Flooding
How can we model floods?

What is a model?

- A model is a representation of a physical system that may be used to predict the behavior of the system of interest.

- There is not a perfect model.
Model Types

• **Physical**: scaled laboratory model
  + Highly visual
  + Complicated flow patterns
  + Non-standard structures
  - Size
  - Speed £’s

The principles of ‘Dimensional Analysis’ and model Similarity’ are key to translate model results to prototypes
Model Types

• **Numerical**: computer software
  + Cheap and quick
  + Long reaches
  + Re-usability
  + Results at any position
  + Improving technology
  - 1 dimensional
  - Standard, aligned structures
  - Beware default values.

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Need for Hydraulic Modelling

- Sources of flooding: fluvial, coastal, pluvial (surface & sewer), groundwater, & reservoir.
- Flood risk mapping & assessment
  - development & flood risk
  - Scheme appraisal & design
  - Operation & maintenance
- Effects of actions / scenarios simulated virtually
Risk of Flooding from Rivers and Sea

Risk of Flooding from Reservoirs

Thames river and Thames barrier
The Importance of Thames Barrier

- Thames barrier used to protect London from flooding
- If barrier fails projected £30billion in damages plus economic knock-on
‘The purpose of the barrier is to protect London from flooding by an exceptionally high tide moving up from the sea, often exacerbated by a **storm surge**’
What is a Storm Surge?

- Difference in observed water levels to those predicted, due to meteorological effects

- Can affect the water level in estuary regions by +/- 1m or more
How to build the Thames river model in HEC-RAS?

\[ Q(t) = \text{river flow in m}^3/\text{s} \]
\[ y(t) = \text{river water level in meters} \]

The model also requires the roughness of the river channel \('n'\) (also named the Manning coefficient).

**River Flood Routing**

Upstream boundary: \(Q(t)\) or \(y(t)\)

Downstream boundary: \(Q(t)\) or \(y(t)\)

Initial conditions: \(Q(t_0)\) or \(y(t_0)\)
Values of the Manning Coefficient (water is the flowing fluid)

<table>
<thead>
<tr>
<th>Wetted Perimeter</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Natural channels</strong></td>
<td></td>
</tr>
<tr>
<td>Clean and straight</td>
<td>0.030</td>
</tr>
<tr>
<td>Sluggish with deep pools</td>
<td>0.040</td>
</tr>
<tr>
<td>Major rivers</td>
<td><strong>0.035</strong></td>
</tr>
<tr>
<td><strong>B. Floodplains</strong></td>
<td></td>
</tr>
<tr>
<td>Pasture, farmland</td>
<td>0.035</td>
</tr>
<tr>
<td>Light brush</td>
<td>0.050</td>
</tr>
<tr>
<td>Heavy brush</td>
<td>0.075</td>
</tr>
<tr>
<td>Trees</td>
<td>0.15</td>
</tr>
<tr>
<td><strong>C. Excavated earth channels</strong></td>
<td></td>
</tr>
<tr>
<td>Clean</td>
<td>0.022</td>
</tr>
<tr>
<td>Gravelly</td>
<td>0.025</td>
</tr>
<tr>
<td>Weedy</td>
<td>0.030</td>
</tr>
<tr>
<td>Stony, cobbles</td>
<td>0.035</td>
</tr>
<tr>
<td><strong>D. Artificially lined channels</strong></td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>0.010</td>
</tr>
<tr>
<td>Brass</td>
<td>0.011</td>
</tr>
<tr>
<td>Steel, smooth</td>
<td>0.012</td>
</tr>
<tr>
<td>Steel, painted</td>
<td>0.014</td>
</tr>
<tr>
<td>Steel, riveted</td>
<td>0.015</td>
</tr>
<tr>
<td>Cast iron</td>
<td>0.013</td>
</tr>
<tr>
<td>Concrete, finished</td>
<td>0.012</td>
</tr>
<tr>
<td>Concrete, unfinished</td>
<td>0.014</td>
</tr>
<tr>
<td>Planed wood</td>
<td>0.012</td>
</tr>
<tr>
<td>Clay tile</td>
<td>0.014</td>
</tr>
<tr>
<td>Brickwork</td>
<td>0.015</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0.016</td>
</tr>
<tr>
<td>Corrugated metal</td>
<td>0.022</td>
</tr>
<tr>
<td>Rubble masonry</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Munson et al. (2006)
Thames Tidal Barrier

Gate Heights: 5m 10m 20m 20m 20m 20m 10m 5m 5m

RS – Rising Sector Gate
FR – Falling Radial Gate

Gilbert and Horner (1984)
Thames Tidal Barrier Gates

Gilbert and Horner (1984)
HEC-RAS – main window

Run HEC-RAS (start -> All programs -> HEC -> HEC-RAS -> HEC-RAS 4.0 Beta)

The software is freely available at:
To save your project, click on ‘File’ -> ‘New Project’ and give a project title and specify file name and click OK.
Before starting building the model, change the unit system to the “Metric System”:

Click on Options -> Unit System -> System International -> OK
HEC-RAS – Geometry data editor

River reaches editor

Cross section editor

Hydraulic structures editor
Click on ‘River Reach’ and draw a line with the mouse. To finish the line press twice the left bottom of the mouse.

Type new names for the River and the Reach (e.g. Thames and allReaches respectively) and click OK.
HEC-RAS – River reaches editor

• Click on ‘GIS Tools’ -> ‘Reaches Invert Lines Table’

• On the new window ‘Edit reach lines …’, copy and paste your river network. Note that the default number of rows is 500. You may need to increase the number of rows (click on ‘Set number of rows in table’). Click OK.
• Click on ‘View’ -> ‘Set Schematic Plot Extents’

• On the ‘Geometry Extents’ box, click ‘Set to Computed Extents’. Click OK.
• Click on ‘Options’ -> ‘Add a new Cross Section’. Type ‘1’ to identify this X-section and click OK. This X-section is at the downstream end of the reach.

• Copy and paste X-section data and fill in ‘downstream reach lengths’, ‘manning values’ and ‘main channel bank stations’.

• Click on ‘Apply Data’
• Click on ‘Options’ -> ‘Add a new Cross Section’. Type ‘2’ to identify this X-section and click OK.

• Copy and paste X-section data and fill in ‘downstream reach lengths’, ‘manning values’ and ‘main channel bank stations’.

• Click on ‘Apply Data’

• **Repeat this process for all X-sections.**
HEC-RAS – Geometry data editor
HEC-RAS – Edit unsteady flow data (Boundary conditions)

- **Upstream boundary** (last X-section) - Click on ‘Boundary Condition Type’ (RS13) and then click on ‘Flow Hydrograph’. On the ‘Flow Hydrograph’ window, change the time interval to 15min and increase the number of ordinates to 700. Then copy and paste flow data. Click OK.

- **Downstream boundary** (1st X-section) - Click on ‘Boundary Condition Type’ (RS1) and then click on ‘Stage Hydrograph’. On the ‘Stage Hydrograph’ window, change the time interval to 15min and increase the number of ordinates to 700. Then copy and paste tide data. Click OK.
HEC-RAS – Edit unsteady flow data (Initial conditions)

• Initial conditions boundary (upstream X-section) – Set the initial flow to 1 m$^3$/s and click on ‘Apply Data’.

• Click on ‘File’ -> ‘Save Unsteady flow data’. Type ‘Thames’.
• Open the **unsteady flow simulation** window. On main window, click on ‘Run’ -> ‘Unsteady flow analysis’.

• On ‘short ID’, type ‘CIWEM’.

• Select the different options as shown here.

• Click on ‘File’ -> ‘Save Plan’. Type ‘Thames’.

• Click on ‘Compute’.
HEC-RAS – Display animation results
The Thames barrier can be simulated using ‘overflow gates’.
A weir or embankment has to be created to locate the gates.
The gates will be embedded in the embankment
HEC-RAS – Hydraulic Structures (Embankment)

- Open the **Geometry Data Editor**, and click on **Inline Structure Data** icon.

- Click ‘Options’ -> ‘Add an inline structure’. In the new box type ‘6.9’ as the new river station for the new inline structure. This structure should be close to X-section ‘7’.

- Click on ‘Weir Embankment’ and type the values shown here.
HEC-RAS – Hydraulic Structures (Embankment)
HEC-RAS – Hydraulic Structures (Gates)

• Open the **Geometry Data Editor**, and click on **Inline Structure Data** icon.

• Click on ‘Gate’ and create all gates of the Thames barrier. Choose ‘overflow’ gates, sharp crested with a weir coefficient of 1.67. The widths and heights of gates are given below.

![Diagram of Thames barrier gates]

**Gate Heights:** 5m 10m 20m 20m 20m 20m 10m 5m 5m 5m

Gilbert and Horner (1984)
HEC-RAS – Hydraulic Structures

(Gates)

• For instance, see the configuration for the main gates (add 1cm to the height to avoid errors from HEC-RAS):

• Create every gate individually so that you can open/close that gate independently of the rest.

• If these gates are created as a group, then all gates in that group open/close at the same time.
HEC-RAS – Hydraulic Structures
(Thames Barrier)
HEC-RAS – Thames Barrier Gate Operation (boundary conditions)

- Open **Unsteady Flow Data Editor**. Select the Thames barrier structure ‘6.9 IS’ on ‘River Sta’. Click on ‘Add a Boundary Condition Location’ and then click on ‘T.S. Gate Openings’. Fill in the ‘Gate Opening Heights’ according to data provided. Do this for all gates.

- For overflow gates, and assuming a 20m height gate, a value of 20m means the gate is fully open, a value of 10m means the gate is half open and a value of 0m means the gate is closed.
Step 4: Calibration/Validation

- Change manning’s values to calibrate the model against measured data
- The weir/gate coefficients have to be obtained from lab experiments (use default values)
Thames barrier operation simulation

Thames Barrier

Sheerness

Teddington

Legend

EG 25OCT2007 0715
WS 25OCT2007 0715
Crit 25OCT2007 0715
Ground

Tide @ Sheerness

Gates operation

open

closed
Exercise in computing lab

• **Download this presentation** from my website: Type my surname in google ‘**Rico-Ramirez**’ and search for ‘**Summer School Presentation**’ under ‘Students -> Teaching’

• **Download data** for river Thames at:
  [https://dbms.ilrt.bris.ac.uk/media/user/20991/thamesdata-3.xls](https://dbms.ilrt.bris.ac.uk/media/user/20991/thamesdata-3.xls)

• **Build the hydraulic model** for the River Thames and select a manning coefficient of 0.035.

• If time allows, **Incorporate the Thames barrier** structure into your model and play with gate operation. How many hours in advance should the barrier be closed when an extreme tidal surge is forecasted?

• **HEC-RAS model** installed in this computer room. Use your login & password then click on **Start -> HEC -> HEC-RAS -> HEC-RAS 4.1.0**
Reflection questions:

• Why there is a need for hydraulic modelling?
• Which are the different sources of flooding?
• Why the Thames barrier was built?
• Which software is available to build river hydraulic models?
• How long takes for a high water level (e.g. tide+surge) to reach the upstream part of the river?
• How the water levels change upstream the Thames barrier when the barrier is closed?