Defra / Environment Agency
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Benchmarking Hydraulic River Modelling Software Packages

Results – Test C (Triangular Channels)

R&D Technical Report: W5-105/TR2C

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Statement of use
This document provides the results and findings from undertaking the Environment Agency's Benchmarking Test C (Triangular Channels) for hydraulic river modelling software. The results only relate to the ISIS, MIKE 11 and HEC-RAS software packages and inference to the likely performance to other software packages should not be made.

The findings are intended to be a supplementary resource for Defra and Agency staff, research contractors and consultants, academics and students for assessing the applicability of any one of these software packages for their own modelling requirements. This report should not be considered in isolation and should be read in conjunction with the other tests reports produced as part of this R&D project.

Keywords
Hydraulic Modelling, River Modelling, Benchmarking, Test Specifications, Triangular Channel, Subcritical Flow, Supercritical Flow

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EXECUTIVE SUMMARY

The test has successfully demonstrated that ISIS, MIKE 11 and HEC-RAS are all capable of modelling subcritical (Part 1) and supercritical (Part 2) flows in a triangular channel under both steady and quasi-steady flow regimes and by analogy unsteady flow conditions.

The difference in results when undertaking a steady state or quasi-steady calculation is marginal for each of the software packages.

All of the software packages have been shown to be capable of calculating a normal depth to within 0.01m of that determined by Manning's formula for both subcritical and supercritical flow.

MIKE 11 has two options for calculating cross section resistance. The choice of resistance radius or hydraulic radius is discussed in detail in the MIKE 11 Reference Manual ("Resistance Radius" vs "Hydraulic Radius"). The Resistance Radius option calculated a water level that was notably lower than that calculated when using the Hydraulic Radius option and it is therefore clear that the resistance radius formulation is not suited to this test. This difference, which is as much as 0.258m for the subcritical flows and 0.150m for the supercritical flows, has clearly highlighted that the selection of the most appropriate Radius option for a modelling study with MIKE 11 can be important.

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1 INTRODUCTION

1.1 Background

This report presents the results and findings from Test C (Triangular Channel) of the Environment Agency of England and Wales (EA), Benchmarking and Scoping Study (2004). The study, which encompasses a series of tests, is intended to be an independent research investigation into the accuracy, capability and suitability of the following one-dimensional hydraulic river modelling software packages:

Software	Version		Developer
ISIS	User Interface:	2.0 (13/01/01)	Halcrow /
	Flow Engine:	5.0.1 (27/06/01)	Wallingford Software
MIKE 11	User Interface:	Build 5-052 (2001b)	DHI Water and Environment
	Flow Engine:	5.0.5.5	
HEC-RAS	User Interface:	3.1.0 (Beta) (03/02)	US Corps of Engineers
	Pre-processor:	3.1.0 (Beta) (03/02)	
	Steady Flow Engine:	3.1.0 (Beta) (03/02)	
	Unsteady Flow Engine:	3.1.0 (Beta) (03/02)	
	Post-processor:	3.1.0 (Beta) (03/02)	

Each of the above software packages was tested in the previously undertaken benchmarking study (Crowder *et al*, 1997). They are currently on the EA's BIS-A list of software packages for one-dimensional hydraulic river modelling.

The test has been undertaken on behalf of the EA by the following team in accordance with the Benchmarking Test Specification: Test C (Triangular Channel), (Crowder *et al*, 2004):

	Role	Affiliation
Mr Andrew Pepper	EA Project Manager	ATPEC River Engineering
Dr Richard Crowder	Study Project Manager/ Tester	Bullen Consultants Ltd
Dr Nigel Wright	Advisor	University of Nottingham
Dr Chris Whitlow	Advisor	Eden Vale Modelling Services
Dr Andrew Sleigh	Advisor	University of Leeds
Dr Chris Tomlin	Advisor	Environment Agency

1.2 Aim of Test

The aim of the test is to:

- assess the ability of each software package to calculate the normal subcritical flow depth (Part 1) and the normal supercritical flow depth (Part 2) in a triangular channel with a side slope of 1:2 under steady state and quasi-steady boundary conditions; and

- present the particulars for developing and undertaking the tests (Model Build) with each of the software packages and the associated results so that others can repeat the test with their own software.

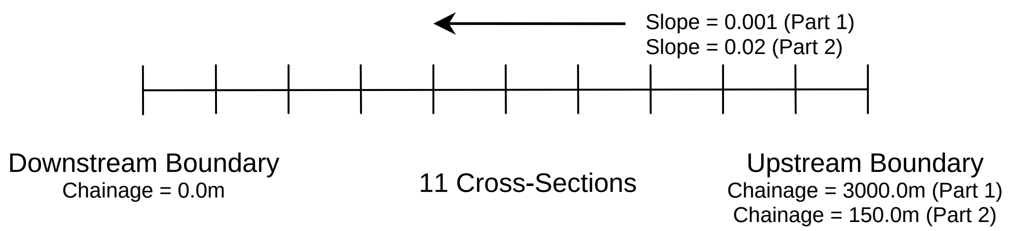
2 MODEL BUILD

2.1 Test Configuration

The test has been undertaken in accordance with the Benchmarking Test Specification – Test C (Crowder *et al*, 2004).

The test configuration is illustrated schematically in Figure 2.1.

Figure 2.1: Schematic Illustration of Test Configuration



For Part 1 the triangular channel has been defined by eleven cross-sections placed at 300m intervals each with a side slope of 1:2 (V:H), a constant bed slope of 0.001 and a constant Manning's n value of 0.035.

For Part 2 the triangular channel has been defined by eleven cross-sections placed at 15m intervals each with a side slope of 1:2, a constant bed slope of 0.02 and a constant Manning's n value of 0.035.

For Parts 1 and 2 each of the software packages has been tested with a steady state (SS) flow and water level boundary condition, as defined by Table 2.1 below.

Table 2.1: Boundary Conditions (Parts 1 and 2)

	Downstream Level (mAD)	Upstream Discharge (m^3/s)
Part 1: Subcritical Flow	3.0	20.0
Part 2: Supercritical Flow	1.7	20.0

The software packages have also been tested under quasi-steady (QS) boundary conditions. To form these boundary conditions the same steady state boundary conditions, as specified for Part 1 and Part 2, have been used at 00:00hrs and extended through to 01:00hrs.

In the supercritical runs it is noted that while a downstream boundary level should not be necessary needed for the calculations, a software package may require a downstream boundary as an input, even if it is not then used.

It is noted that it may be more appropriate to use the term ‘forewater’ instead of ‘backwater’ when referring to supercritical flows, however, for simplicity the term backwater has been used throughout.

2.2 Building the Model in ISIS, MIKE 11 and HEC-RAS

The model build with ISIS, MIKE 11 and HEC-RAS was undertaken in accordance with the test specification, as defined by the dataset.

The MIKE 11 model was tested with the default “Resistance Radius” option and also the “Hydraulic Radius (Effective Area)” option so as to enable a comparison of the results from the two options.

It should be noted that the Resistance Radius formulation in MIKE 11 has been developed for natural channels (as discussed in the software manuals), and in particular those, which incorporate floodplain sections. In such cases this formulation is intended to produce a smooth increase in the section conveyance, which the traditional hydraulic radius may not. However, for prismatic or steep sided channels, the Resistance Radius formulation may generate a section conveyance which is not consistent with user’s expectations of the Manning ‘n’ for the channel (which is based on the hydraulic radius, A/P). The default formulation can be changed in the cross section editor, under Settings/Miscellaneous.

3 RUNNING THE MODEL

3.1 Introduction

With the exception of HEC-RAS, which required the “mixed flow” option to be used when undertaking Part 2 of the test, each software package was run with the default calculation settings.

For consistency each of the software packages was run with a 20s time step when undertaking the quasi-steady simulations.

When undertaking the quasi-steady simulations, a steady-steady result from the respective software packages has been used for the initial conditions.

3.2 Running the Model in ISIS

When ISIS was run for Part 1 of the test with the steady and quasi-steady boundary conditions, the diagnostics file (zzd) indicated no errors or warnings.

When ISIS was run for Part 2 of the test with the steady and quasi-steady boundary conditions, the diagnostics file indicated that the simplified method had been used to compute the solution at every cross section.

3.3 Running the Model in MIKE 11

When running Parts 1 and 2 of the test, with either the steady state or quasi-steady boundary conditions, no errors or warnings were produced by MIKE 11.

3.4 Running the Model in HEC-RAS

When HEC-RAS was run for Parts 1 and 2 of the test with the steady state boundary conditions the following warning was produced at the chainage 300.0 and 2700.0m:

“The energy loss was greater than 1.0 ft (0.3 m) between the current and previous cross section. This may indicate the need for additional cross sections.”

When HEC-RAS was run for Part 1 of the test with the quasi-steady boundary conditions the same above warning was produced for the first 14 time steps, after which no warnings were given. However, for Part 2 of the test, no warnings were produced throughout the simulation.

4 RESULTS

4.1 Introduction

For each part of the test the results from all the software packages have been discussed, compared and presented in combination so as to provide a direct comparison.

For both the steady state and quasi-steady simulations results for water level have been reported upon in tabular format. The steady state results are also presented in graphical format.

For MIKE 11 additional analysis has been undertaken which compares results when using the default “Resistance Radius” cross section option with the alternative “Hydraulic Radius (Effective Area)” option.

The result from the quasi-steady simulations has been taken at 01:00hrs.

In analysing the results it is important to note that for both Parts 1 and 2 of the test the downstream water level boundary is set at a level below that of the normal depth, which has been determined based on Manning’s equation and the channel geometry:

$$h = 5^{\frac{1}{8}}\left(\frac{Q.n}{2\sqrt{S}}\right)^{\frac{3}{8}}$$

where: Q = flow (m^3/s)
n = Manning’s n
S = bed slope

4.2 Analysis of Results – Part 1 (Subcritical Flow)

The difference between the steady state and quasi-steady state results for Part 1 of the test are marginal for all of the software packages, as can be seen in Table 4.1. The differences can be summarised as follows:

- the results from ISIS for both the steady state and quasi-steady simulations are identical to the third decimal place at all cross sections except at chainage 300.0m which has a 0.001m difference;
- the results from HEC-RAS for both the steady state and quasi-steady simulations are almost identical. Between 300.0m and 600.0m the quasi-steady run consistently calculates a water level that is 0.001m lower than the subcritical normal depth. Furthermore, between 900.0m and 3000.0m the quasi-steady run consistently calculates a water level that is 0.002m lower;
- when using the “Resistance Radius” option in MIKE 11 the results for both the steady state and quasi-steady simulations are identical throughout; and
- when using the “Hydraulic Radius” option in MIKE 11 the results for both the steady state and quasi-steady simulations are identical between 1800.0m and 3000.0m. Between 0.0m and 1500.0m the results are within 0.001m of each other.

From Graphs 1 and 3, Appendix A, it can be seen that ISIS, HEC-RAS and MIKE 11 (Hydraulic Radius option) have all been able to calculate a subcritical normal depth that is identical to that determined by the Manning's formula. However, the point at which each software package produces an exact match to the third decimal place varies. For both ISIS and HEC-RAS an exact match is calculated from 1800m and above, whereas for MIKE 11 it is calculated from 1200m and above.

From Graph 3, Appendix A, and Table 4.1 it can be seen that when using the Resistance Radius option in MIKE 11 the water level is consistently below that of the subcritical normal depth. The difference between the calculated water level and the normal depth increases in the upstream direction and reaches a maximum difference of 0.258m.

Table 4.1: Part 1 Water level results

		Water Level (m)							
		ISIS		HEC-RAS		MIKE 11 (RR)		MIKE (HR)	
Chainage (m)	Normal Depth (m)	Steady State	Quasi Steady	Steady State	Quasi Steady	Steady State	Quasi Steady	Steady State	Quasi Steady
3000	16.012	16.012	16.012	16.012	16.010	15.754	15.754	16.012	16.012
2700	15.712	15.712	15.712	15.712	15.710	15.454	15.455	15.712	15.712
2400	15.412	15.412	15.412	15.412	15.410	15.154	15.155	15.412	15.412
2100	15.112	15.112	15.112	15.112	15.110	14.856	14.857	15.112	15.112
1800	14.812	14.812	14.812	14.812	14.810	14.559	14.560	14.812	14.812
1500	14.512	14.511	14.511	14.511	14.509	14.266	14.266	14.512	14.511
1200	14.212	14.211	14.211	14.211	14.209	13.977	13.977	14.212	14.211
900	13.912	13.910	13.910	13.910	13.908	13.698	13.698	13.911	13.910
600	13.612	13.608	13.608	13.608	13.607	13.436	13.436	13.610	13.608
300	13.312	13.305	13.306	13.306	13.305	13.201	13.201	13.306	13.305
0	13.012	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000

4.3 Analysis of Results – Part 2 (Supercritical Flow)

The difference between the steady state and quasi-steady state results for Part 2 of the test are marginal for all of the software packages, as can be seen in Table 4.2. The differences can be summarised as follows:

- the results from ISIS for both the steady state and quasi-steady simulations are identical to the third decimal place at all cross sections;
- the results from HEC-RAS for both the steady state and quasi-steady simulations are similar; the difference between the two results fluctuating between +0.014m and -0.023m;
- when using the "Resistance Radius" option in MIKE 11 the result for both the steady state and quasi-steady simulations is identical at all cross sections except at chainages 75.0m, 60.0m and 45.0m which have a 0.001m difference in water levels; and
- when using the "Hydraulic Radius" option in MIKE 11 the results for both the steady state and quasi-steady simulations are identical at all cross sections except at chainage 15.0m which has a 0.001m difference in water level.

From Graphs 2 and 4, Appendix A, and Table 4.2 it can be seen that both ISIS and MIKE 11 (Hydraulic Radius option) consistently underestimate the supercritical normal depth by up to 0.002m for both the steady and quasi-steady simulations. HEC-RAS exactly calculates the supercritical normal depth between 45.0m and 120.0m for the steady state simulation, however outside of this range the difference is as much as 0.019m.

From Graph 4, Appendix A and Table 4.1 it can be seen that when using the "Resistance Radius" option in MIKE 11 the water level is consistently below that of the supercritical normal depth. The difference between the calculated water level and the normal depth increases in the upstream direction and reaches a maximum difference of 0.150m.

Table 4.2: Part 2 Water level results

		Water Level (m)							
		ISIS		HEC-RAS		MIKE 11 (RR)		MIKE (HR)	
Chainage (m)	Normal Depth (m)	Steady State	Quasi Steady	Steady State	Quasi Steady	Steady State	Quasi Steady	Steady State	Quasi Steady
150	14.718	14.716	14.716	14.700	14.714	14.568	14.568	14.716	14.716
135	14.418	14.416	14.416	14.437	14.414	14.268	14.268	14.416	14.416
120	14.118	14.116	14.116	14.118	14.114	13.968	13.968	14.116	14.116
105	13.818	13.816	13.816	13.818	13.814	13.668	13.668	13.816	13.816
90	13.518	13.516	13.516	13.518	13.514	13.369	13.369	13.516	13.516
75	13.218	13.216	13.216	13.218	13.214	13.070	13.071	13.216	13.216
60	12.918	12.916	12.916	12.918	12.913	12.774	12.775	12.915	12.915
45	12.618	12.615	12.615	12.618	12.613	12.482	12.483	12.614	12.614
30	12.318	12.314	12.314	12.319	12.312	12.200	12.200	12.312	12.312
15	12.018	12.010	12.010	12.020	12.009	11.935	11.935	12.009	12.008
0	11.718	11.700	11.700	11.721	11.700	11.700	11.700	11.700	11.700

5 DISCUSSION AND CONCLUSIONS

It has been possible to set up the test for each of the software packages as specified by the test specification without the need for any adjustments in the configuration.

For both parts of the test the results from the software packages have been compared to a normal depth calculation as determined by Manning's formula to the third decimal place. For most engineering purposes it is recognised that this order of accuracy is more than sufficient and as such it is considered that two decimal places should suffice.

If the result from chainage 0.0m is not considered, so as not to take into account the impact of setting the downstream boundary water level below the normal depth, then all of the above software packages are capable of calculating a subcritical (Part 1) and supercritical (Part 2) normal depth to within 0.01m. Should calculation tolerances for each of the software packages be reduced then it is expected that this could be improved further; however, for most engineering applications and modelling studies this level of accuracy is considered to be appropriate, especially given other uncertainties that can be introduced in modelling studies.

The choice of cross section resistance method in MIKE 11 has a significant impact on the calculated water levels for both parts of the test. When using the "Resistance Radius" option the calculated water levels are notably lower than those when using the "Hydraulic Radius" option. This difference, which is as much as 0.258m for the subcritical flows (Part 1) and 0.150m for the supercritical flows (Part 2) clearly highlights the importance and impact of selecting the most appropriate Radius option for a modelling study with MIKE 11.

The difference in results when undertaking a steady state or quasi-steady calculation is marginal for ISIS and MIKE 11, however for HEC-RAS there is a more pronounced variance.

6 RECOMMENDATIONS

As a result of undertaking this test the testers recommend that the following improvements to the software packages would benefit the modeller.

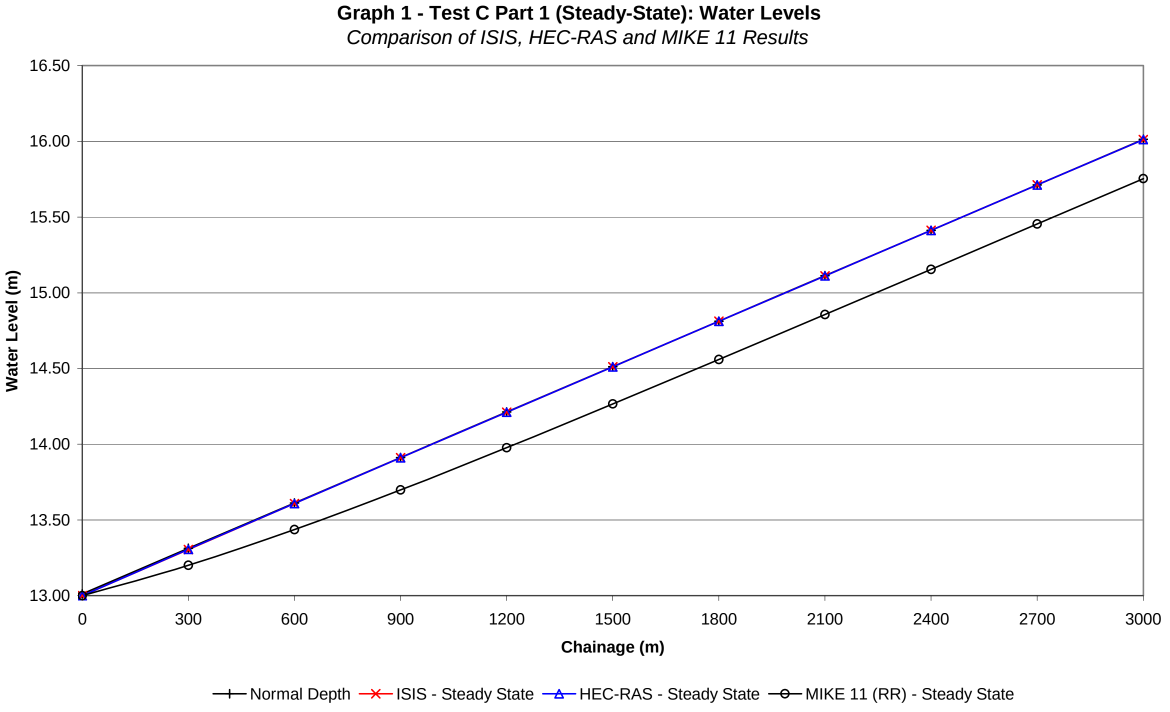
- Guidance within the MIKE 11 diagnostics file on which resistance method may be the most appropriate to use for a given channel cross section.

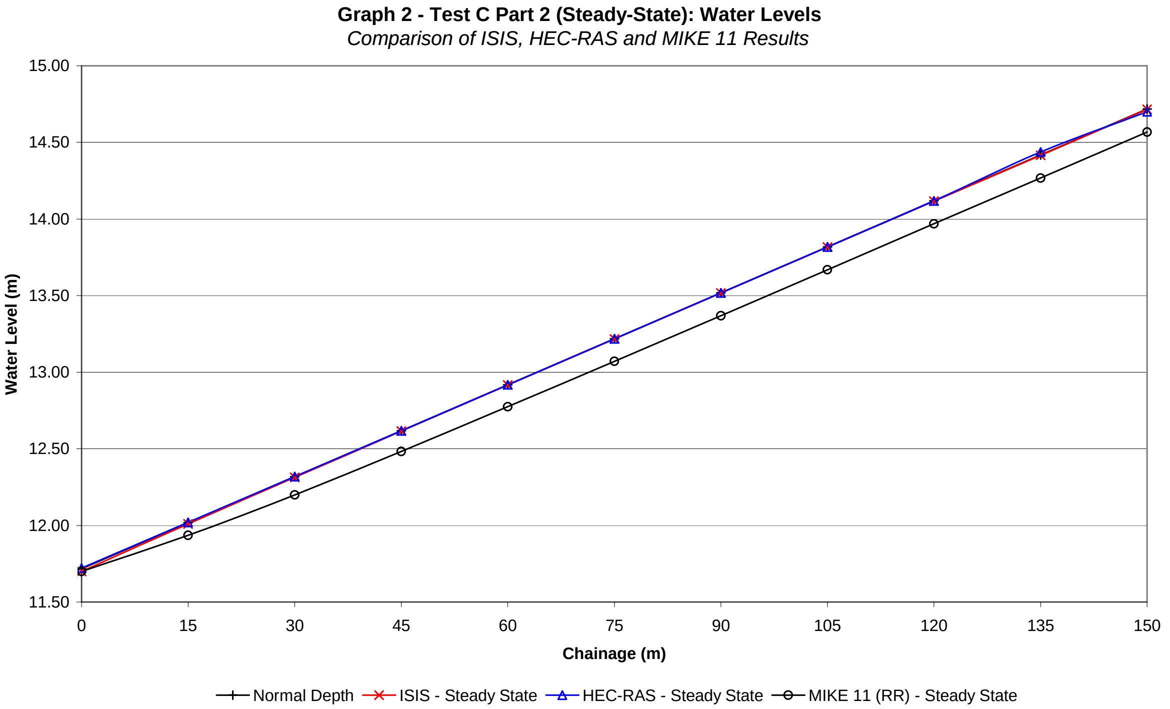
7 REFERENCES

Crowder, R.A., Chen, Y., Falconer, R.A., (1997) Benchmarking and Scoping of Hydraulic River Models, Environment Agency Research and Technical Report, W88, 1997

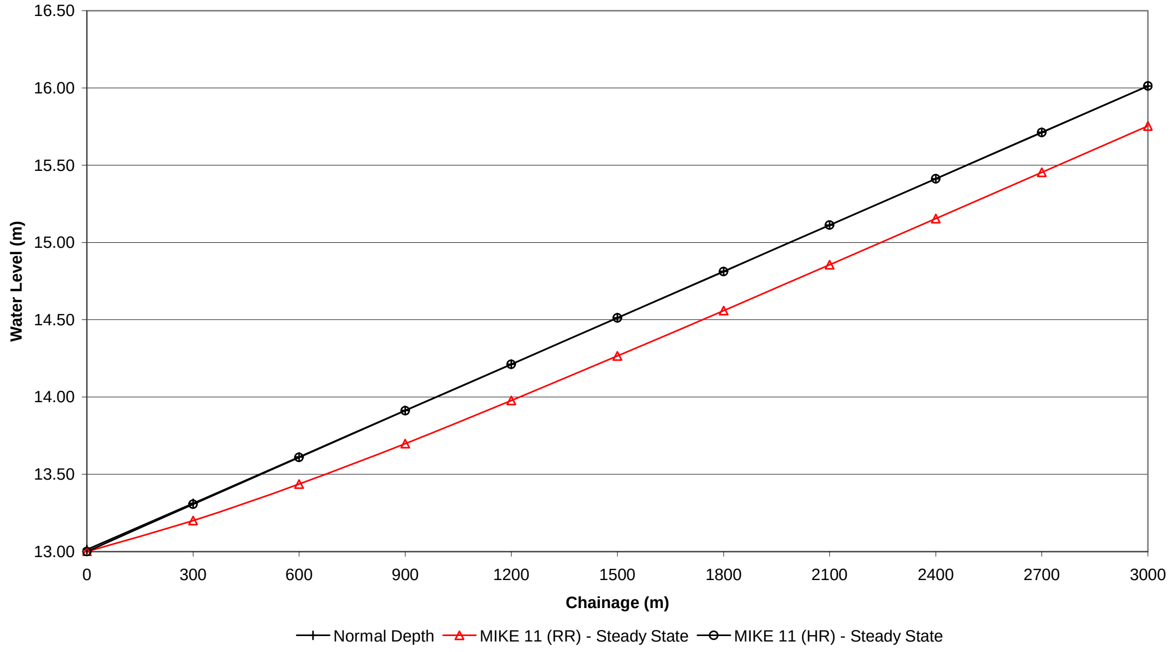
Crowder, R.A., Pepper, A.T., Whitlow, C., Wright, N., Sleigh, A., Tomlinson, C., (2004) Benchmarking and Scoping of 1D Hydraulic River Models, Environment Agency Research and Technical Report, W5-105/TR1, 2003

APPENDIX A RESULTS


Graph 1 - Test C Part 1 (Steady-State): Water Levels
Comparison of ISIS, HEC-RAS and MIKE 11 Results
Water Level (m)
Chainage (m)
Normal Depth
ISIS - Steady State
HEC-RAS - Steady State
MIKE 11 (RR) - Steady State


Graph 2 - Test C Part 2 (Steady-State): Water Levels
Comparison of ISIS, HEC-RAS and MIKE 11 Results
Water Level (m)
Chainage (m)
Normal Depth
ISIS - Steady State
HEC-RAS - Steady State
MIKE 11 (RR) - Steady State

Graph 3 - Test C Part 1 (Steady-Steady): Water Levels
Comparison of MIKE 11 Resistance Radius and Hydraulic Results



Graph 4 - Test C Part 2 (Quasi-Steady): Water Levels
Comparison of MIKE 11 Resistance Radius and Hydraulic Results