Defra / Environment Agency
Flood and Coastal Defence R&D Programme

Benchmarking Hydraulic River Modelling Software Packages

Results – Test D (Weirs)

R&D Technical Report: W5-105/TR2D

TECHNICAL REPORT W5-105/TR2D

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This document provides the results and findings from undertaking the Environment Agency's Benchmarking Test D (Weirs) 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, Broad Crested Weir, Crump Weir

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EXECUTIVE SUMMARY

The test has successfully demonstrated that ISIS, MIKE 11 and HEC-RAS are capable of modelling a Broad Crested weir and that ISIS and MIKE 11 are capable of modelling a Crump weir. The developers of HEC-RAS have suggested that trial and error methods be adopted for modelling a Crump weir (i.e. adjusting the weir coefficient to suite the weir shape), however, this has not been tested as part of this study due to this approach being considered to be outside the scope of the study. Furthermore, in modelling terms, this approach may not to be practicable.

For the Broad Crested weir in steady state conditions both MIKE 11 and HEC-RAS have produced the same upstream water level (to two decimal places) over the weir under both free and drowned flow conditions. Conversely, ISIS produces a slightly lower (0.01m) water level for free flow conditions and higher (0.02m) water level for drowned flow conditions, which equates to a 2% and 4% difference in water depths respectively. The unsteady calculations are consistent with the steady calculations and show a notable difference to the MIKE 11 and HEC-RAS results during the transition between free flow and drowned flow.

For the Crump weir in steady state conditions, both ISIS and MIKE 11 have produced the same results (to two decimal places) over the weir under both free and drowned flow conditions. For unsteady calculations there is a small but noticeable deviance in the results during the transition between free and drowned flow which is likely to be due to differences in the modular limit (point at which flow changes from free to drowned flow) that each software package uses.

The benefits of having support available direct from the software developer have been highlighted by this study. The ability to obtain direct support from DHI, the developers of MIKE 11, has been of significant benefit to this test, as without it MIKE 11 would not have been able to undertake the Crump weir part of the test. Similar support can be obtained from Wallingford Software the joint developers of ISIS. An equivalent is not available for HEC-RAS. Support for HEC-RAS is provided through third party vendors/agents, which may not be as extensive as support obtained direct from the developers, which has been possible in this study.

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1 INTRODUCTION

1.1 Background

This report presents the results and findings from Test D (Weirs) 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
MIKE11	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 D (Weirs), (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 model a Broad Crested Weir (Part 1) and Crump Weir (Part 2) under steady and unsteady boundary conditions;

- assess water level and head loss results for the respective weirs under both free flow and drowned flow 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

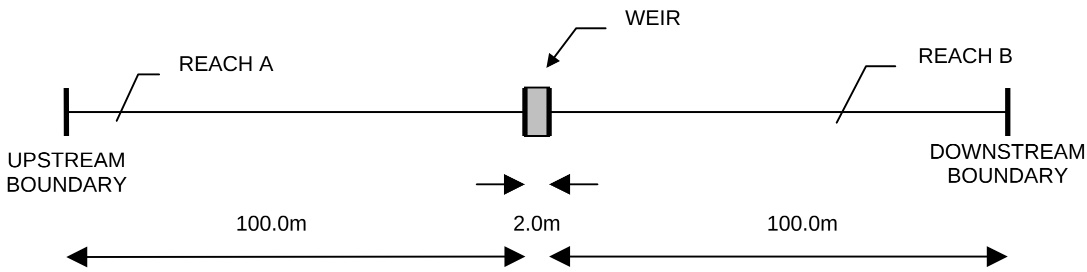
2.1 Test Configuration

The test has been undertaken in accordance with the Benchmarking Test Specification for Test D (Weirs).

The test configuration for both Parts 1 and 2, is illustrated schematically in Figure 2.1

There are two reaches: Reach A and Reach B, both of which have two cross sections at a spacing of 100m, a constant Manning's roughness of 0.014 and a bed slope of 0.005 and 0.001 respectively.

Figure 2.1: Schematic Illustration of Test Configuration



Between Reaches A and B there is a weir. For Part 1 of the test this is a Broad Crested and for Part 2 it is a Crump weir. The parameters defining the weirs are given in Tables 2.1 and 2.2 respectively.

For Parts 1 and 2 of the test, two steady flow boundary conditions have been used as follows:

(Free Flow)	SS1:	Upstream inflow boundary of 0.15m^{3}s-1 Downstream water level of 0.3m
(Drowned Flow)	SS2:	Upstream inflow boundary of 0. 15m^{3}s-1 Downstream water level of 0.8m

Table 2.1: Broad Crested Weir Parameters

Parameter	Broad Crested
Calibration coefficient (if required)	Default*
Coefficient of velocity (if required)	Default*
Coefficient of discharge (if required)	Default*
Modular Limit*	Default*
Height of weir crest above bed - upstream	0.45m
Height of weir crest above bed - downstream	0.45m
Elevation of crest	0.5m
Breadth (perpendicular to flow)	0.9m
Length (in direction of flow)	2.0m

*Default/Software recommended values to be used

Table 2.2: Crump Weir Parameters

Parameter	Crump
Calibration coefficient (if required)	Default*
Coefficient of velocity (if required)	Default*
Coefficient of discharge (if required)	Default*
Modular Limit*	Default*
Profile Shape	Triangular
Front Face Slope	1:2
Back Face Slope	1:5
Height of weir crest above bed - upstream	0.45m
Height of weir crest above bed - downstream	0.45m
Elevation of crest	0.5m
Breadth	0.9m
Length (in direction of flow)	2.0m

*Default/Software recommended values to be used

In addition, both parts of the test have been tested with unsteady boundary conditions. The upstream boundary has been fixed at 0.15m^3/s for a period of 24:00hrs. The downstream boundary has then been set at 0.3m for the first 06:00hrs and then linearly increased from 0.3m to 0.8m between 06:00hrs and 18:00hrs, after which remaining at this level for a further 06:00hrs.

2.2 Building the Model in ISIS

The model build with ISIS was undertaken in accordance with the test specification, as defined by the dataset, for both Parts 1 and 2 of the test.

In ISIS the cross sections were defined at the required locations and either the round nosed Broad Crested or Crump weir unit placed such that it connected Reaches A and B.

For the Broad Crested weir the following equation is used for free flow conditions:

$$Q = C_d C_v (2/3)^{1.5} \sqrt{g} b h_1^{1.5} \qquad \text{Equation (1)}$$

where:

$$C_d = [1 - \delta(L - r)/b]\,[1 - (\delta / 2h_1)(L - r)]^{1.5} \qquad \text{Equation (2)}$$

The on-line help and user manual for ISIS define the terms as follows:

- C_v Coefficient of velocity
- δ function of the boundary layer thickness which is set constant at 0.01
- G gravitational acceleration (ms-2)
- L Length of the weir in the direction of flow (m)
- B Breadth of weir at control section (normal to the flow direction) (m)
- h_1 Depth of water above the weir crest upstream of the flow control structure (m)
- R A constant (0.1m) used to define the round nose shape of the weir

The default value of 1.0 for C_v, the coefficient of velocity, was used in the test. No advice is provided in the ISIS on-line help or user manual with respect to this value, which is set by the user.

The default value of 0.7 for the modular limit of the Broad Crested weir unit was used in the study.

For drowned flow, the Broad Crested weir equation is based on the Bernoulli Equation with Cd, the coefficient of discharge, as for free flow. A smooth transition between free and drowned flow is assumed at the modular limit. The equation used in ISIS is as follows:

$$Q = C_d C_v (2/3)^{1.5} \sqrt{g} b h_1 \left[(h_1 - h_2)/(1-m) \right]^{0.5} \qquad \text{Equation (3)}$$

The on-line help and user manual for ISIS define the additional terms in the above equation as follows:

h_2 Depth of water above the weir crest downstream of the structure (m)
M Modular limit, which can be fixed by the user or calculated by ISIS

For the Crump weir ISIS uses the following equation developed White (1971):

$$Q = C_d C_v \sqrt{g} b H_1^{1.5} \qquad \text{Equation (4)}$$

The on-line help and user manual for ISIS defines the terms in the above equation as follows:

C_d Coefficient of discharge
C_c Coefficient of contraction
G gravitational acceleration (m/s2)
B Breadth of weir at control section (normal to the flow direction) (m)
H_1 Total head upstream of the flow control structure (m)

For drowned flow over a Crump weir ISIS uses the following equation:

$$Q = f_r C_c C_d \sqrt{g} b H_1^{1.5} \qquad \text{Equation (5)}$$

The on-line help and user manual for ISIS define f_r as the drowned flow reduction factor.

2.3 Building the Model in HEC-RAS

For the Broad Crested weir the model build was undertaken in accordance with the test specification, as defined by the dataset with a minor adjustment as described later. However, the Crump weir test has not been undertaken as there is no such structure unit within HEC-RAS. It is, however, suggested by the developers of HEC-RAS that any weir shape (and hence a Crump weir) can be modelled assuming the user can estimate an appropriate weir coefficient. The developers suggest, through trial and error methods, that a coefficient of 2.0 is appropriate for this test, however, the application of such trial and error procedures are beyond the scope of this study.

Although an internal rating curve approach could have been adopted for the Crump weir element of the test (analogous to the MIKE 11 approach – see Section 2.4), this was considered beyond the scope of the study, as the HEC-RAS manual does not provide appropriate details on this approach/method and no technical information is/was not available (to the typical modeller) direct from US Corps of Engineers as was the case from DHI for MIKE 11. Technical support on HEC-RAS can only be obtained from third party vendors/agents, as the US Corps of Engineers do not provide direct support to users.

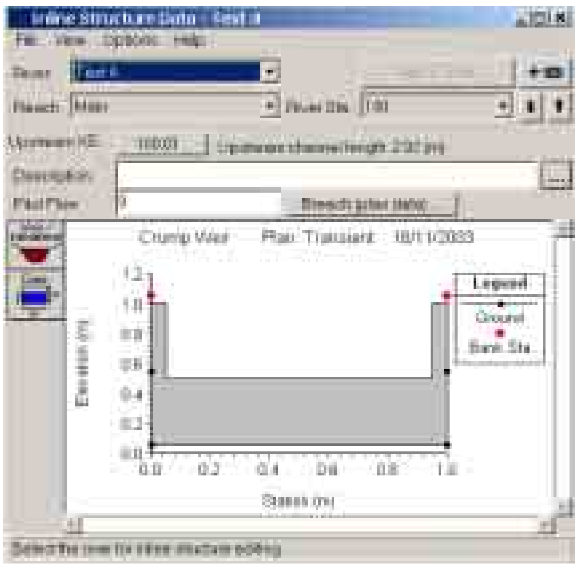
The modelling of a weir requires a reach with a minimum of four cross-sections, two downstream and two upstream of the structure. The first cross section should be located sufficiently downstream from the weir so that the flow is not affected by the structure (i.e. the flow has fully expanded). The second cross section should be a short distance downstream of the weir (i.e. within a few metres). This cross section should represent the effective flow just downstream of the structure. The third cross section should be located a short distance upstream of the weir and is intended to represent the effective flow area just upstream of the structure. The fourth cross section should be upstream of the weir where the flow lines are approximately parallel and the cross section is fully effective.

The distance between cross sections two and three must be greater than the length of the structure in the flow direction. As such, the distance between the cross-sections bounding the weir structure was set at 2.02m, 0.02m longer than that defined by the data set.

In defining the weir structure the distance between the most downstream cross section on Reach A and the upstream face of the structure was set at 0.01m. This has resulted in a distance of 0.01m between the downstream face of the structure and the most upstream cross section of Reach B.

When defining the dimensions of the weir in HEC-RAS it is important that the crest level/profile of the weir is fully defined along the complete width of the channel (i.e. the crest of the weir and any side embankment). For this test case, this has required an increase of the weir width from 0.9m to 1.0m; however, this has not resulted in an increase in the effective width of the weir, as illustrated below in Figure 2.2 (a HEC-RAS screen capture).

Figure 2.2: HEC-RAS Screen Capture of Weir Structure



For the Broad Crested weir the following standard weir equation is used:

$$Q = CLH_1^{1.5}$$ Equation (6)

The Hydraulic reference manual for HEC-RAS (pp 5-22 and 8-10) define the terms in the above equation as follows:

Q Total flow over the weir (m3s-1)
C Coefficient of discharge for weir flow
L Effective length of the weir (m)
H_1 Difference between energy upstream of the weir crest (m)

The default value for the coefficient of discharge is 1.44 when working in SI units. However, when using the tool tips with HEC-RAS (holding the curser over the data entry field) the user is given suggested values. It should be noted that these values are based on Imperial units and not SI units.

The Hydraulic reference manual for HEC-RAS suggests typical weir coefficient values of 2.6 to 4.0. The modeller should be aware that these only apply to US customary units (i.e. feet and inches). An equivalent metric value is also given in the manuals.

For high tail-waters HEC-RAS automatically reduces the amount of weir flow to account for the submergence on the weir. The reduction is achieved by reducing the weir coefficient based on the amount of submergence.

Submergence corrections are based on a trapezoidal weir shape, or optionally an ogee spillway, shape. The sharp option has been selected for this test. The total weir flow is then computed by subdividing the weir crest into segments, computing L, H, a submergence correction, and a Q for each section, then summing the incremental discharges. The submergence correction is then taken from “Hydraulics of Bridge Waterways” (Bradley, 1978).

When the weir becomes highly submerged the program automatically switches to calculating the upstream water surface by the energy equation.

2.4 Building the Model in MIKE 11

For the Broad Crested weir the model build was undertaken in accordance with the test specification, as defined by the dataset, with a minor adjustment as described below. However, to undertake the test with the compound Crump, a user-defined approach was required since MIKE 11 does not have a specific Crump Unit.

The modelling of a weir requires an upstream and downstream river cross section, which must be within the defined “maximum dx distance” for the branch in question. For the purpose of this test Reach A and B have been treated as a single branch with the cross sections defined at the appropriate locations.

The user adds a weir at a particular chainage (central chainage used i.e. 101.0m), and then the appropriate weir attributes need to be defined.

For the Broad Crested weir the following default parameter/weir unit settings were used:

Valve setting (used to limit the flow direction)	: None
Inflow head loss factors (used for determining the energy loss)	: 0.5
Outflow head loss factors (used for determining the energy loss)	: 1.0
Freeflow head loss factors (used for determining the energy loss)	: 1.0
Number of q/h relationships.	: 20

The geometry of the weir was defined by level and width dimensions. Further to defining these values the “calculate q/h relationships” button was pressed to automatically calculate a q/h table for the weir.

Neither the on-line help nor the user manual provides information on the method/formula adopted by MIKE 11 for calculating the q/h relationship table.

For the Crump weir a “special weir” unit was used. This enabled a unique q/h relationship to be defined for the weir structure.

The relationship for the Crump weir was generated using a MS Excel spreadsheet that was downloaded from the DHI website. The equations used within the spreadsheet to calculate the q/h relationship are the same as those used by ISIS for the free and drowned flow conditions.

When constructing the model in MIKE 11 the default “Resistance Radius” option in the cross section editor was initially used. The “Resistance Radius” formulation has been developed for use with natural channels, especially those incorporating floodplain sections. In such cases this formulation is designed to ensure a smooth increase in the section conveyance, which the hydraulic radius does 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). In these cases it is recommended, by the developers, that the user should select the hydraulic radius formulation. The default formulation can be changed in the cross section editor, under Settings/Miscellaneous. In addition, it is possible to switch formulations for any cross section and recompute the processed data. Full details on these formulations are provided in the MIKE 11 user manuals in pdf.

3 RUNNING THE MODEL

3.1 Running the Model in ISIS, HEC-RAS and MIKE 11

No errors or warnings were provided by any of the software packages when undertaking the steady and unsteady simulations.

When undertaking the unsteady simulations a time step of 20s was used along with default calculation settings for each of the software packages.

When undertaking the unsteady simulation in ISIS initial conditions from the SS1 steady backwater calculation were used for both Parts 1 and 2 of the test.

When undertaking the unsteady simulation in HEC-RAS initial conditions were automatically developed by the software package. HEC-RAS achieves this by undertaking a steady backwater calculation based on the initial flow in the system and the initial downstream water level. These values were the same as those used for the SS1 boundary conditions.

When undertaking the unsteady simulation in MIKE 11 initial conditions were automatically developed by the software package by using the steady state option. This produces initial conditions based on the initial flow in the system and the initial downstream water level. These values were the same as those used for the SS1 boundary conditions.

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.

The analysis of results for the steady state element of the test has been limited to a comparison of stage (water level) at the cross sections immediately upstream and downstream of the weir structure and the head loss over the structure.

The analysis of results for the unsteady (transient) element of the test has been limited to the stage (water level) verses time at the cross sections immediately upstream and downstream of the weir structure.

4.2 Analysis of Results: Broad Crested Weir (Part 1)

The steady state results from the Broad Crested weir test for free (SS1) and drowned (SS2) flow conditions are presented in Tables 4.1 and 4.2 respectively. The unsteady results (transient conditions) are presented in Graphs 1 and 2, Appendix A.

Inspection of Tables 4.1 and 4.2 shows that both ISIS and HEC-RAS produce the same water level results downstream of the weir structure under both free and drowned flow conditions, however, MIKE 11 calculates a water level that is up to 0.03m lower. This difference can be attributed to the method by which MIKE 11 considers channel resistance in the calculation of conveyance (see results for Tests A and C and comments in Section 2.4).

Table 4.1: Part 1 (Broad Crested Weir) SS1: Free flow steady state results

	Stage at Weir (m)		
	Upstream	Downstream	Head loss (m)
ISIS	0.725	0.346	0.379
MIKE 11	0.738	0.326	0.412
HEC-RAS	0.735	0.346	0.389

Table 4.2: Part 1 (Broad Crested Weir) SS2: Drowned flow steady state results

	Stage at Weir (m)		
	Upstream	Downstream	Head loss (m)
ISIS	0.833	0.803	0.030
MIKE 11	0.813	0.801	0.012
HEC - RAS	0.813	0.804	0.009

In steady state flow conditions both MIKE 11 and HEC-RAS have produced the same upstream water level (to two decimal places) over the weir under both free and drowned flow conditions. Conversely, ISIS produces a slightly lower (0.01m) water level for free flow conditions and a higher (0.02m) water level for drowned flow conditions, which equates to a 2% and 4% difference in water depths respectively.

For free flow steady state conditions the head loss across the weir structure (to two decimal places) is 0.38m for ISIS and 0.39 for HEC-RAS whereas for MIKE 11 the head loss across the weir structure is 0.41m, approximately 9% greater than that observed for ISIS and HEC-RAS.

For drowned flow conditions the head loss across the weir structure (to two decimal places) is 0.03m for ISIS and 0.01m for both MIKE 11 and HEC-RAS. The difference between the two is equivalent to a 4% difference in water depth.

Graph 1, Appendix A, shows that the water level downstream of the weir during the unsteady simulation agrees with the findings of the steady state simulation for all three packages. Initially, MIKE 11 has a much lower water level result when compared to that produced by ISIS and HEC-RAS, which are very similar. As the downstream water level rises this discrepancy reduces. As previously stated this can be attributed to the method by which MIKE 11 considers channel resistance in the calculation of conveyance.

Graph 2, Appendix A, for upstream of the weir, shows that MIKE 11 has a higher water level and hence a notably higher head loss when compared to ISIS and HEC-RAS, both of which have very similar results.

The time at which the downstream water level influences the upstream water level is approximately 13hrs for both ISIS and HEC-RAS, whereas for MIKE 11 it is at 15hrs.

4.3 Analysis of Results: Crump Weir (Part 2)

The steady state results from the Crump weir test for free and drowned flow conditions are presented in Tables 4.3 and 4.4 respectively. The unsteady results (transient conditions) are presented in Graphs 3 and 4, Appendix A.

Inspection of Table 4.3 for the free flow condition shows that MIKE 11 calculates a water level that is 0.02m lower than that of ISIS downstream of the weir. For the drowned flow condition, which has an increased depth of water, this difference is reduced to less than 0.01m. This trend/difference can again be attributed to the method by which MIKE 11 considers channel resistance in the calculation of conveyance.

For steady state conditions both ISIS and MIKE 11 have produced the same upstream water level (to two decimal places) over the weir under both free and drowned flow conditions.

For free flow conditions the head loss across the weir structure (to two decimal places) is 0.34m for ISIS and 0.36m for MIKE 11 and for drowned flow conditions the head loss across the weir structure (to two decimal places) is 0.01m for ISIS and 0.02m for MIKE 11.

Table 4.3: Crump weir: Free flow steady state results

	Stage at Weir (m)		
	Upstream	Downstream	Head loss (m)
ISIS	0.688	0.346	0.342
MIKE 11	0.684	0.326	0.358
HEC-RAS	No Result	No Result	No Result

Table 4.4: Crump weir: Drowned flow steady state results

	Stage at Weir (m)		
	Upstream	Downstream	Head loss (m)
ISIS	0.809	0.803	0.006
MIKE 11	0.816	0.801	0.015
HEC-RAS	No Result	No Result	No Result

Inspection of Graph 3, Appendix A, for the unsteady simulation shows that the water level downstream of the weir agrees with the findings of the steady state simulation. Initially, MIKE 11 has a lower water level result than that produced by ISIS. As the downstream water level rises this difference reduces. Again, this can be attributed to the method by which MIKE 11 considers channel resistance in the calculation of conveyance.

Graph 4, Appendix A, shows that upstream from the weir MIKE 11 has only a marginally higher water level than that of ISIS and downstream from the weir a marginally lower water level and hence a slightly higher head loss.

The time at which the downstream water level influences the upstream water level is approximately 13hrs for ISIS and 10hrs for MIKE 11. The transition at these times, which represents the change from free to drowned flow, is smooth for ISIS throughout; however, for MIKE 11 there is initially a slight variation in the water level during the transition period.

5 DISCUSSION AND CONCLUSIONS

All three of the software packages have been capable of modelling the Broad Crested weir; however, only ISIS and MIKE 11 have been able to model the Crump weir. In both instances there have been several minor nuances in the set-up of the test.

The trial and error methods of modelling a Crump weir (i.e. adjusting the weir coefficient to suite the weir shape), as suggested by the developers of HEC-RAS, has not been tested as it is considered to be outside the scope of this study. Furthermore, in modelling terms, this approach may not be practicable.

A notable difference in results between the software packages is the water level that is calculated downstream of the weir structure for both parts of the test. The test has shown that both ISIS and HEC-RAS produce very similar water levels during free flow conditions; however, MIKE 11 produces a water level that is 0.02m lower. This difference can be attributed to the method by which MIKE 11 calculates channel conveyance (i.e. Resitance Radius and Hydraulic Radius), as discussed in detail in the Test A report for this study.

For the Broad Crested weir, in steady state conditions, both MIKE 11 and HEC-RAS have produced the same upstream water level (to two decimal places) over the weir under both free and drowned flow conditions. Conversely, ISIS produces a slightly lower (0.01m) water level for free flow conditions and higher (0.02m) water level for drowned flow conditions, which equates to a 2% and 4% difference in water depths respectively. The unsteady calculations are consistent with the steady calculations and show a notable difference to the MIKE 11 and HEC-RAS results during the transition between free flow and drowned flow.

For the Crump weir, in steady state conditions, both ISIS and MIKE 11 have produced the same results (to two decimal places) over the weir under both free and drowned flow conditions. For unsteady calculations there is a small but noticeable deviance in the results during the transition between free and drowned flow which is likely to be due to differences in the modular limit (point at which flow changes from free to drowned flow) that each software package uses.

The developers of HEC-RAS may wish to consider improvements to the user manual with respect to hydraulic details on weir flow especially for unsteady flow and when working in SI units.

The test has also shown that the point at which the upstream water level is influenced by the downstream water level (point of drowning out) is slightly different for each of the software packages.

Although MIKE 11 does not have a specific Crump weir unit it has been able to undertake the test by incorporating a defined q/h relationship at the location of the structure.

The incorporation of the q/h relationship for the Crump weir was developed from an MS Excel spreadsheet that is freely available from the DHI website. The spreadsheet incorporates the same Crump weir equations as used by ISIS. This approach has produced water level results upstream of the structure that are very similar to those produced by ISIS. The deviance observed during the transition between free and drowned flow are likely to be due to differences in the modular limit. Investigations in altering the default values within the spreadsheet obtained from DHI has been beyond the scope of this investigation.

The ability to obtain direct support from DHI, the developers of MIKE 11, has been of significant benefit to this study, as it provided the MS Excel spreadsheet download. Similar support can be obtained from Wallingford Software, the joint developers of ISIS. However, a similar equivalent is not available for HEC-RAS. Support for HEC-RAS can, however, be obtained through third party vendors/agents, which may not be as extensive as support obtained direct from the developer.

6 RECOMMENDATIONS

The novice and even expert modeller often needs the use of a good and well documented reference manual when using the software packages. From undertaking this test it is believed, by the testers, that the following improvements to the software packages would benefit the modeller:

- improved details within the MIKE 11 manual and on-line help on the method of calculating the q/h relationship over the weir;
- improved details within the HEC-RAS manual and on-line help on the method of calculating the flow over the weir and hence head loss;
- within HEC-RAS, improved guidance on selection of the coefficient of discharge in SI units, especially with regard to the tool tips, which currently provide assistance in imperial units; and
- details within the ISIS manual and on-line help on the method of calculating C_v, the coefficient of velocity.

Both HEC-RAS and MIKE 11 would benefit from the inclusion of specific units to model the Crump weir, which can be commonly found on many UK rivers.

Investigation of a real river, which has weir calibration data over a large range of flows and weir types, would provide a greater insight to the importance, appropriateness and variability of the weir coefficient values used in each of the software packages.

To model the Crump weir in MIKE 11 the “special weir unit” has had to be used so that a user defined q-h relation could be used to represent the Crump weir. A similar/analogous approach could have been adopted for both ISIS and HEC-RAS; however, the testing of this was considered beyond the scope of this study. It is recommended that this be investigated in any future testing.

The test has not considered flows that may ‘spill’ around the structure. Hence, it is recommended that the test specifications be refined so that this common flood flow feature can be tested and assessed for each of the software packages.

7 REFERENCES

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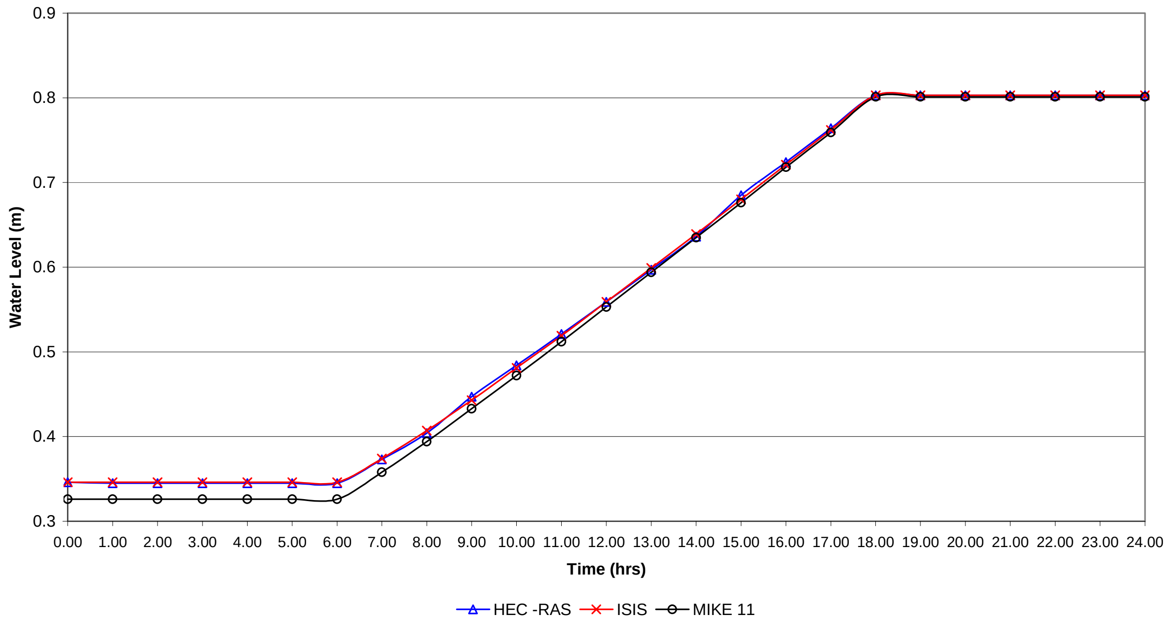
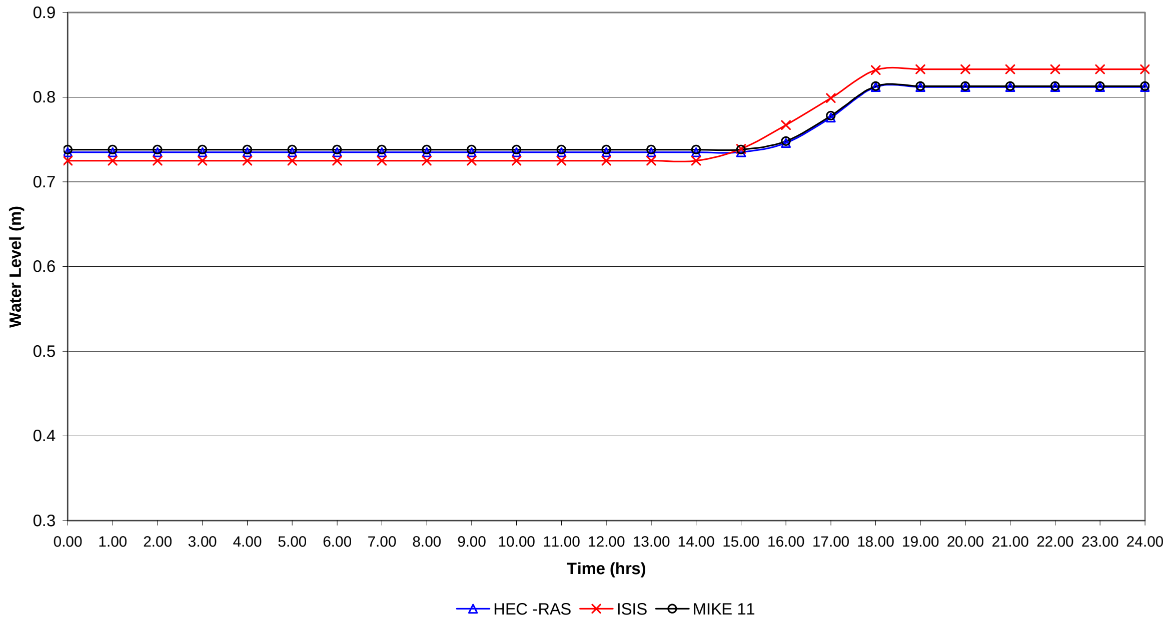
APPENDIX A RESULTS

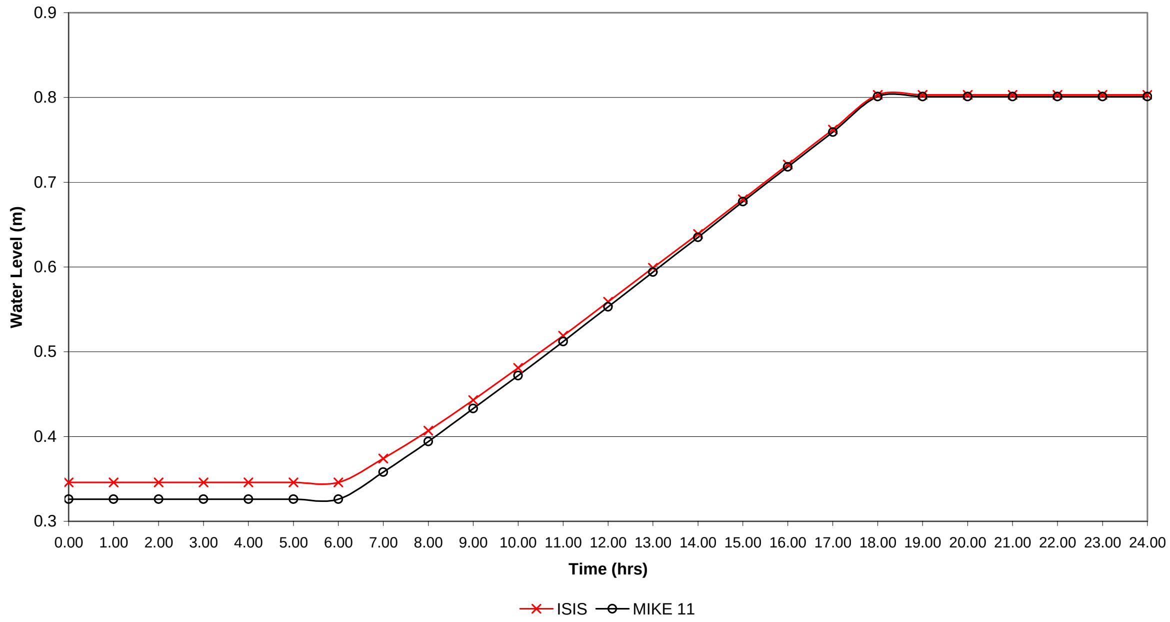
Graph 1 - Test D Part 2 (Unsteady): Water Levels Downstream of Broad Crested Weir
Comparison of ISIS, HEC-RAS and MIKE 11 Results



Graph 2 - Test D Part 2 (Unsteady): Water Levels Upstream of Broad Crested Weir
Comparison of ISIS, HEC-RAS and MIKE 11 Results



Graph 3 - Test D Part 2 (Unsteady): Water Levels Downstream of Crump Weir
Comparison of ISIS and MIKE 11 Results



Graph 4 - Test D Part 2 (Unsteady): Water Levels Upstream of Crump Weir
Comparison of ISIS and MIKE 11 Results