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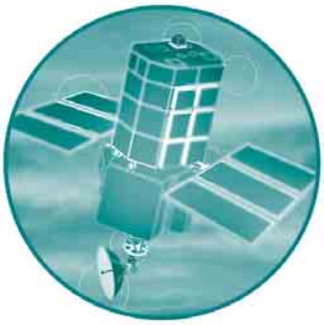

Benchmarking Hydraulic River Modelling Software Packages

Results – Test I (Embsakments)

R&D Technical Report: W5-105/TR2 I

Department for Environment Food and Rural Affairs

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BENCHMARKING HYDRAULIC RIVER MODELLING SOFTWARE PACKAGES

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R&D Technical Report: W5-105/TR2 I

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Statement of use
This document provides the results and findings from undertaking the Environment Agency's Benchmarking Test I (Embankments) 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, Embankments, Floodplain Flow, Weir Flow

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EXECUTIVE SUMMARY

The undertaking of this test has proven to be possible with all software packages. However, in some cases careful consideration had to be given to using different approaches that were appropriate to each package. In particular MIKE 11 does not have an explicit embankment or spillway unit and some ingenuity was necessary (link channel used) to represent the test case in MIKE 11.

HEC-RAS was the only software package that had the functionality to use its standard steady state solver for undertaking the test; however, it did require the split flow optimiser option be selected. Both ISIS and MIKE 11 have standard procedures to overcome this; in ISIS the "pseudo-timestepping" steady state solver and in MIKE 11 the quasi-steady solver.

It is a recommendation of this study that the three software packages tested be used in unsteady mode for such test cases. This is likely to be the case as most practical models with lateral flows over embankments occur with unsteady boundary conditions. Use of the steady solvers/methods may lead to misleading/not fully converged results.

The results for ISIS and HEC-RAS are generally similar, with those for MIKE 11 being somewhat different. The approach adopted by MIKE 11 for this test gives rise to notably higher flows over the embankment and, as such, should be used with care.

The HEC-RAS results for Part 2 of the test calculate a flow rate into the reservoir that is the same as that calculated by ISIS. However, there appears to be error in the results tables as at time t=0hrs the reservoir records a volume higher than the initial condition value. The MIKE 11 results for Part 2 of the test show a notably higher rate of flow over the embankment when compared to ISIS and HEC-RAS and is considered to be a consequence of the modelling approach (i.e. link channel) required for this test.

It should be noted that in this test case there was no analytic or experimental results available. Therefore, conclusions can only be drawn by using engineering judgement to compare the packages amongst themselves which could be unreliable.

It is a recommendation of this study that a test specification be developed that considers real life modelling of flows over embankments and into storage areas, which has calibration data so as to enable true benchmarking of the software packages.

CONTENTS

Appendices

List of Tables

List of Figures

1 INTRODUCTION

1.1 Background

This report presents the results and findings from Test I (Embankments) 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 I (Embankments), (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
Dr Mohammad Dastorani	Tester/Reporter	University of Nottingham

1.2 Aim of Test

The aim of the test is to:

- assess the ability of each software package to model a) flow between two channels over an embankment (Part 1), and b) flow from a single channel into a reservoir over an embankment (Part 2); and

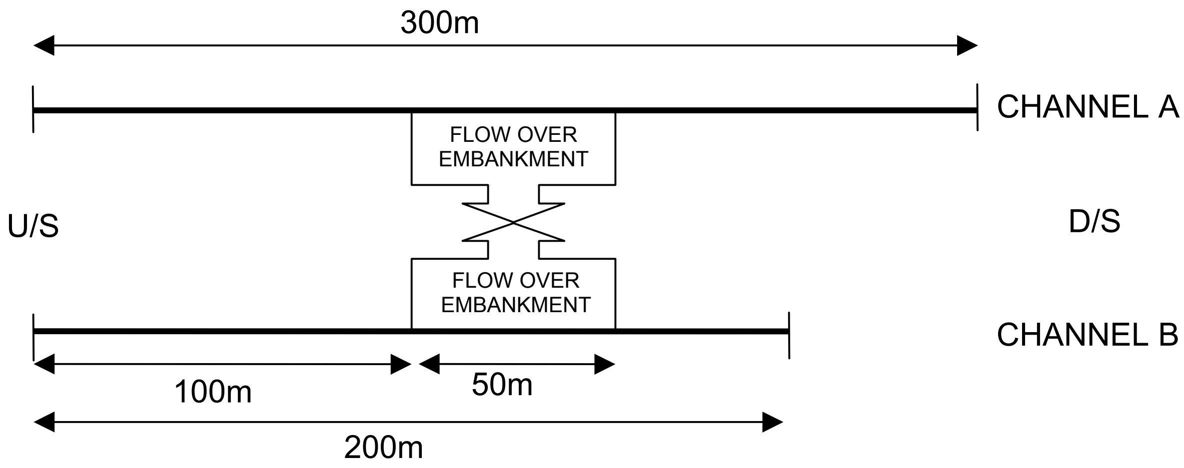
- present the particulars for developing and undertaking the tests (Model Build) with each of the software packages and the associated results so that others can repeat the test with their own software.

2 MODEL BUILD

2.1 Test Configuration – Part 1

In this part there are two trapezoidal channels designated Channel A and Channel B of length 300m and 200m respectively (Figure 2.1). The channels are hydraulically connected such that flow between the two channels can occur between 100m and 150m from the upstream boundary.

Figure 2.1: Part 1 - Schematic Illustration of Test Configuration



Cross-sections are specified at 50m intervals in each of the channels with a Manning's n value of 0.025 used to define channel roughness. The cross-section is trapezoidal with a side slope of 45^o and a bottom width of 2m.

The width of the embankment is set at 5m and by definition its length is 50m. The elevation of the embankment along its length is defined in Table 2.1.

Table 2.1: Part 1 - Embankment Dimensions

Distance from Upstream Boundary	Embankment Elevation	
	CHANNEL A	CHANNEL B
100m	1.90m	1.90m
150m	1.85m	1.85m

As specified in the test specification, a weir coefficient of 1.7 was used.

The software packages were tested with four separate steady state flow boundary conditions (SS1, SS2, SS3 and SS4) as defined in Table 2.2. They were also tested under the equivalent quasi-steady boundary conditions: QS1, QS2, QS3 and QS4. The conditions for the quasi-steady simulations were set by taking the steady state conditions and extending them for 24 hours to give quasi-steady conditions.

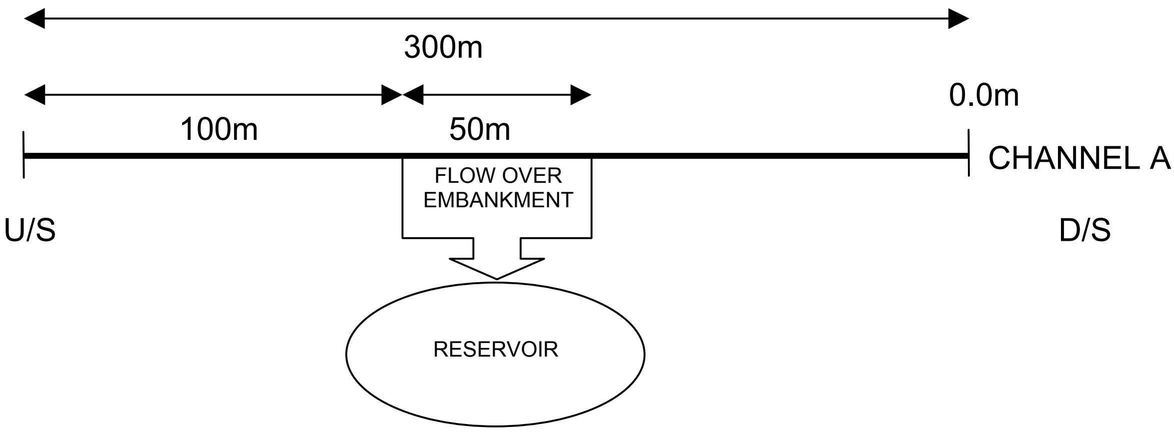
Table 2.2: Steady State Boundary Conditions

Boundary Case		CHANNEL A Upstream Flow (m^3/s)	CHANNEL A Downstream Water Level (m)	CHANNEL B Upstream Flow (m^3/s)	CHANNEL B Downstream Water Level (m)
SS1	Free Flow A → B	10.00	1.547	5.00	1.850
SS2	Drowned Flow A → B	10.00	1.547	7.00	1.835
SS3	Free Flow B → A	5.00	1.550	7.00	1.900
SS4	Drowned Flow B → A	3.50	1.900	7.00	1.900

2.2 Test Configuration – Part 2

A single trapezoidal channel designated Channel A of length 300m, which is hydraulically connected to a reservoir, such that flow can occur between the channel and reservoir between 100m and 150m from the upstream boundary (Figure 2.2). The flow from the channel to the reservoir is via an embankment that has a width of 5m and by definition a length of 50m. The elevation of the embankment is the same as that defined in Part 1 of the test.

Figure 2.2: Part 2 - Schematic Illustration of Test Configuration



Channel A is defined as in Part 1. The reservoir is defined so that it has a constant plan area of 1,000m^2 between -100m and 0.0m (i.e. a total volume of 100,000m^3 below 0.0m). The reservoir is initially be empty i.e. the water level set at -100m.

The software packages were tested with the SS1 steady state flow boundary conditions used for Part 1 and the QS1 quasi-steady boundary conditions used for Part 1.

2.3 Building the Model in ISIS

For Part 1 of the test, the two channels are connected by an ISIS SPILL unit.

The spill unit calculates the flow over a jagged or irregular weir. The unit can be used to model in-line flows over irregular weirs, as well as lateral flows, such as those over embankments between two open channels or between an open channel and a flooded area

(ISIS Manual). The unit requires the user to specify a set of offset/elevation pairs describing the crest of the weir or bank.

In this test, the unit was connected to the cross-sections 100m from the upstream boundary. The spill height was defined at 1.9m at 0m and 1.85m at 50m.

For Part 2 of the test, the channel is connected to the reservoir by a SPILL unit defined as in Part 1. Flow can occur between the channel and the reservoir.

The ISIS RESERVOIR option was used to define the reservoir. This requires the elevation and plan area of the reservoir to be defined.

As the model was stable no interpolated cross-sections were used. Simulations were completed in steady state and quasi-steady state.

ISIS calculates flow over a spill for different conditions using different equations. Four important modes are described below along with the equations employed. Further detail can be found in the ISIS Manual and in "A mathematical model of overbank spilling and urban flooding" by EP Evans and PH von Lany (1983).

Mode 0 - Zero Flow

Condition: The upstream (highest) water level is below the bank level defined in the spill unit, or the water levels are above the bank level but almost exactly equal.

where: $q_s = 0$

q_s = flow over the segments of the weir

Mode 1 - Free Flow (Positive Sense)

Condition:

$$\frac{y_{21} + y_{22}}{y_{11} + y_{12}} \le m$$

$$q_s = \frac{2C_d b\left(y_{12}^2\sqrt{y_{12}} - y_{11}^2\sqrt{y_{11}}\right)}{5\left(y_{12} - y_{11}\right)}$$

where:

y_{11} = upstream water depth in channel 1
y_{12} = downstream water depth in channel 1
y_{21} = upstream water depth in channel 2
y_{22} = downstream water depth in channel 2
m = modular limit
b = width of spill section

ISIS treats the following as a special case if the water surface is nearly parallel to bank:

$$y_{12} \approx y_{11}, \qquad \text{then} \qquad q_s = C_d b y_{11}\sqrt{y_{11}}$$

Mode 2 - Drowned Flow (Positive Sense)

Condition: $\frac{y_{21} + y_{22}}{y_{11} + y_{12}} < m$

$$q_s = Ab\{(2/3)y_k D - (4/15 y_i (dy_{22} - dy_{12})\}$$

where:
$D = y_{12}\, dy_{21} - y_{11}\, dy_{11}$
$A = -C_d / yk_2 \sqrt{1-m}$
$y_k = y_{12} - y_{11} - y_{22} + y_{21}$
$y_i = y_{12} - y_{11}$
$dy_{21} = (y_{12} - y_{22})3/2$
$dy_{22} = (y_{12} - y_{22})5/2$
$dy_{11} = (y_{11} - y_{21})3/2$
$dy_{12} = (y_{11} - y_{21})5/2$

Special Cases:

The following special cases may occur:

$y_{12} - y_{11} = y_{22} - y_{21}$
$q_s = -½\, A\, b\, yk_2\, (y_{11} + y_{12})\sqrt{(y_{11} - y_{21})}$

$y_{11} - y_{21} << y_{12} - y_{11} - y_{22} + y_{21}$
$q_s = - 2\, A\, b\, yk^{5/2}\, \{y_{11}/3 + (y_{12} - y_{11})/5\}$

$y_{12} - y_{21} << y_{12} - y_{11} - y_{22} + y_{21}$
$q_s = -½\, A\, yk^2\, (2y_{11} + y_i + y_k\, y_{11}/y_m)Ö(y_{11} - y_{21})$

where:
$y_k = y_{12} - y_{11} - y_{22} + y_{21}$
$y_m = y_{12} - y_{21}$

Mode 3 - Free Flow (Negative Sense)

The same formulae apply as for mode 1 but with y_{21} interchanged with y_{11}, and y_{12} interchanged with y_{22}.

Mode 4 - Drowned Flow (Negative Sense)

The same formulae apply as for mode 2 but with y_{21} interchanged with y_{11}, and y_{12} interchanged with y_{22}.

The basic weir equation for free flow used in the spill unit is:

$$Q = C_d b h^{1.5}$$

Thus, typical C_d values are 1.85 for sharp crested weirs and 1.7 for round nosed horizontal-crested weir.

In this test a value of 1.7 was used for C_d.

2.4 Building the Model in MIKE 11

MIKE 11 does not have a specific spill or embankment unit so the following set-up was used to approximate the specified situation.

For Part 1 in MIKE 11 the channels are hydraulically connected to each other by a link channel (a specific unit within MIKE 11) to allow flow between them. In order to replicate the spill set-up in other models an inflow head loss coefficient of 0.0 was set for both positive and negative flow. This set-up was chosen on the advice of the MIKE 11 support team.

The link channel was inserted 125m below the upstream boundary of each channel and given an upstream (at connection to channel A) and downstream (at connection to channel B) level of 1.85m. Clearly at chainage 125m the height of the embankment is 1.875, but the value of 1.85m was input in order to reflect the lowest position of the spillway cross-section specified in the test. The depth/width values were set to represent/replicate the cross-section specified in the test specification. Alternative formulations are possible, but it must be recognised that due to the differences between what is implemented in MIKE 11 and what is required by this test, the set-up will only be an approximation. After consultation with the vendors and discussions within the project team, the set-up used here was viewed as the best approximation possible.

MIKE 11 calculates a Q/H relation for the link channel from the channel geometry and its definition. This relationship is used to calculate the flow in the channel.

As the model was stable, and no error warnings were produced, no interpolated cross-sections were used.

For Part 2 in MIKE 11 the channel is connected to the reservoir by a link channel in a similar manner to Part 1.

In order to define a reservoir, and connect it to the channel in MIKE 11, the following steps were adopted on the advice of the MIKE 11 support team:

1. Definition of a link channel from channel A and the point specified for diversion of water to the reservoir.
2. Definition of a cross section at the end of this link channel.
3. Definition of the reservoir as a storage area at the end of the link channel (which is the cross section defined in stage (2)) by entering the reservoir geometry in the "Processed data" mode of the cross section.

The reservoir surface area vs. elevation data was entered in columns 1 and 5 of the processed data table. The storage width was set to zero to avoid duplicating the total storage. This data is "protected" to avoid it being overwritten by the actual computed raw data (which is usually synchronized with the processed data table).

Since initial water levels in the reservoir can not be determined by a steady state start, the initial water level in the reservoir needs to be specified. Hence, the .HD11 file, which contains the initial WL, was set at -100.0m. Elsewhere, the global default values of zero water level and zero discharge were specified, although it is recognized that these could be refined to so as reflect the actual initial conditions if necessary.

As the model was stable, and no error warnings were produced, no interpolated cross-sections were used.

It should be noted that the hydraulic radius in the conveyance calculation was used on this occasion rather than its default option of the resistance radius.

2.5 Building the Model in HEC-RAS

For Part 1 the channels (A and B) were hydraulically connected with a lateral weir embankment using the Lateral Structure option. This allows flow to occur between the two channels.

As the model was stable, and no error warnings were produced, no interpolated cross-sections were used.

For Part 2 the channel was connected to the reservoir with a lateral weir embankment using the Lateral Structure option.

The reservoir was defined using the Storage Area option which requires the surface area and level of the storage area. To connect the reservoir to the channel, the HEC-RAS option "Storage area connection" was used. With this option, a lateral weir embankment transfers flow from the channel to the reservoir.

Flow through the lateral structure is calculated using a weir embankment with appropriate data. HEC-RAS calculates the flow using the same standard weir equation that is used to model weir flow over an in-line structure:

$$Q = CLH^{3/2}$$

where:
- Q = Total flow over the weir
- C = Coefficient of discharge for weir flow (a value of 1.7 was used here)
- L = Effective length of the weir
- H = Difference between energy line and the weir bed level

To account for free and drowned flow states the weir coefficient is automatically adjusted when the upstream energy head is higher or lower than a user specified design head. Details of this adjustment are provided in the HEC-RAS Manual.

By default HEC-RAS uses the water surfaces to balance flows over the embankment, however, there is an option to use the energy gradeline for the upstream head reference. This can be selected from the side spillway editor.

3 RUNNING THE MODEL

3.1 Introduction

Each package was run for the cases as outlined in Section 2. Apart from HEC-RAS, Part 2 with SS1, no errors or warnings were observed for any of the packages. Default settings were used unless indicated otherwise below.

For Part 1 steady state simulations were carried out for each package using the four different boundary conditions designated SS1, SS2, SS3 and SS4. The flow data, as used for steady state simulations, were extended through to 24hr to give cases designated QS1, QS2, QS3 and QS4.

For Part 2 steady state simulations were carried out using the SS1 boundary conditions from Part 1. Quasi-steady simulations were also carried out using the QS1 conditions from Part 1.

3.2 Running the Model in ISIS

A steady run was carried out with the direct solver to establish suitable initial conditions. However, the direct solver does not solve for flow along a spill and gives a flow of zero between the channels. In view of this, the results of this solver were used as initial conditions for the ISIS “pseudo-timestepping” steady state solver to give the results for the simulations. This feature uses a quasi-steady solver to obtain a steady state solution.

For quasi-steady simulations, the results of the “pseudo-timestepping” steady run were used as initial conditions. A timestep of 20s was used.

3.3 Running the Model in MIKE 11

MIKE 11 generates a set of initial conditions automatically by running what the manual calls a quasi-steady solver. These values were extracted from the MIKE 11 results by extracting the values at time t=0s and these were taken as the steady state results.

The quasi-steady simulation was carried out up to 24 hours with a timestep of 30s and the final values were taken as the quasi-steady values required for this test.

To ensure the model starts with the initial conditions specified in the HD11 file, the initial condition were set to “parameter file” in the .sim11 file.

3.4 Running the Model in HEC-RAS

When completing the steady state solution with HEC-RAS the ‘split flow optimisation’ option was selected so as to enable the calculation of flows over the embankment. Not selecting this option results in zero flow over the embankment. For all but Part 1 with SS2 boundary conditions, a flow calculation was successfully completed without any errors or warnings. For Part 1, SS2 the following warning message was given "Flow Optimization failed to converge", which resulted in a zero flow over the embankment.

For quasi-steady simulations, initial conditions were set as a flow along the channel equal to the upstream discharge boundary.

For Part 2 the initial level in the reservoir was set to -100m. Again the 'split flow optimisation' option was selected. No errors or warning were produced for any of the quasi-steady simulations.

As an investigative measure for Part 2 of the test, HEC-RAS was also run with the mixed flow option selected for the QS1 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.

4.2 Analysis of Results – Part 1

Table 4.1 provides a summary of the split flow over the spill as calculated by each of the software packages for Part 1, and Table 1, Appendix A, provides the discharge at each defined cross-section. It can be seen that in all cases the packages predict flow in the same direction, but with varying magnitudes. For all software packages (with a converged solution) the discharge along the spill is higher for the free flow than for the drowned cases, as should be expected.

Table 4.1: Part 1 – Summary of Split Flows

	Free Flow		**Drowned Flow**		**Free Flow**		**Drowned Flow**	
	SS1	QS1	SS2	QS2	SS3	QS3	SS4	QS4
ISIS	0.706	0.706	0.470	0.477	-1.044	-1.044	-0.544	-0.544
MIKE 11	1.188	1.090	0.766	0.964	-3.276	-1.635	-1.000	-1.038
HEC-RAS	0.604	0.497	0.000	0.455	-0.702	-0.573	-0.682	-0.502

*Positive flows are defined as being from channel A to channel B
** HEC-RAS flow optimiser failed to converge for SS2

In comparing Part 1 steady state and quasi-steady state simulations it can be seen that ISIS gives negligible differences if any. This is to be expected as the pseudo-timestepping mode in ISIS is a quasi-unsteady procedure. However, for both HEC-RAS and MIKE 11 there is a notable difference between the steady state and quasi-steady results.

Table 2, Appendix A, shows the water levels at the cross-sections that are connected to the embankment in order to ascertain what head is available to create flow across the embankment. At first the head difference in MIKE 11 may seem anomalous as the flow has a direction counter to the head. However, due to the limitations of the set-up in MIKE 11 these levels do not govern the embankment flow directly. The MIKE 11 link channel is connected to a position 125m below the upstream boundary for each channel. MIKE 11 creates points at these positions and the water levels at these points give a value of head difference that is appropriate to the flow direction.

4.3 Analysis of Results – Part 2

Table 3, Appendix A, shows the flow through each cross-section and the spill for each condition tested in Part 2 and Table 4 shows the water levels in Channel A at the connection to the spill channel (125m from the upstream end). It can be seen that ISIS and HEC-RAS predict almost the same levels and flows for both SS1 and QS1; however, MIKE 11 produces somewhat different results.

Graph 1, Appendix A, shows the volume in the reservoir between t=0hrs and t=24hrs for the quasi-steady solution for each package. The results for HEC-RAS and ISIS show the same rate of reservoir filling (0.723 m^3/s), although HEC-RAS calculates an initial volume in the reservoir at t=0hrs even though the initial conditions set this at zero. The MIKE 11 results clearly show that the reservoir is filling at a much higher rate (1.090m^3/s) and that at the end of the 24hr simulation the difference in required storage is in excess of 35,000m^3 when compared to ISIS.

Using the mixed flow option in HEC-RAS for the QS1 simulation produced results in slightly different results, as shown in Table 3, Appendix A. The results are exactly the same as those produced by the SS1 solution.

4.4 Comparison of the Results

In Part 1 the differences between the ISIS quasi-steady and HEC-RAS quasi-steady embankment flows are more significant for the free flow (difference for QS1=0.209m^3/s and QS3=0.471m^3/s) than for the drowned flow cases (difference for QS2=0.022m^3/s and QS4=0.042m^3/s).

In each case MIKE 11 gives a greater magnitude of flow than HEC-RAS or ISIS. For example, in Part 1 the QS2 embankment flows for ISIS, HEC-RAS and MIKE 11 are 0.477m^3/s, 0.455m^3/s and 0.964 m^3/s respectively.

For Part 2 both ISIS and HEC-RAS give identical results for QS flow over the embankment (0.723m^3/s), however, MIKE 11 calculates a much higher flow rate (1.090m^3/s).

5 DISCUSSION AND CONCLUSIONS

All three packages were able to attempt this test, although different set-ups with different hydraulic units were required. In ISIS there is a specific unit called SPILL, and it was used to connect the two channels (Part 1) and the channel to the reservoir (Part 2). In HEC-RAS the "lateral structure editor" was used and then an embankment was defined to connect the channels to each other and also the channel to the reservoir. However, in MIKE 11 there is no specific unit for this purpose and so the "Link channel" option was used. The difference in the results from each package is due, in part, to these different model builds.

ISIS was unable to provide a steady state solution using the steady state solvers; however, using the pseudo-timestepping mode a solution could be obtained. HEC-RAS has a split flow optimiser, which must be used when undertaking steady state calculations than involve flow over an embankment. MIKE 11 does not have a specific steady state run function, however, the quasi-steady solver was used to calculate the initial conditions at t=0hrs and the results from t=0hrs taken as the steady state result.

The fact that MIKE 11 produces results that differ from the other packages is most likely due to the different (convoluted) way in which the embankment has to be represented in this package. It is clear that the MIKE 11 approach may not be the most appropriate and that alternative approaches to modelling this problem may produce more appropriate/realistic results to problems of this nature.

The pseudo-timestepping method available in ISIS could be considered as not being a direct comparison to the steady state solutions presented by HEC-RAS; however, it did provide a mechanism of producing a solution without undertaking a full unsteady simulation.

The differences between steady state and quasi-steady state results for MIKE 11 cause some concern; however, in practical terms the quasi-steady result is the one which is most likely to be used in most modelling situations for all software packages. Inspection of the results data files show that the MIKE 11 steady state result generally converges to the quasi-steady result with two or three time steps.

The MIKE 11 results for the flow into the reservoir in Part 2 cause some concern, but, as in Part 1, may well be due to the different way in which the embankment is represented.

A more representative assessment of overbank flows and the filling of a reservoir (over an embankment) could be achieved if the test specification was improved so as to consider a real life modelling problem of flows over embankments.

6 RECOMMENDATIONS

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

- The developers of MIKE 11 should consider the inclusion of an explicit embankment and reservoir unit in order to improve results for these situations with flow between channels and into storage units. This might change the results and make model building more straightforward.

- It is recommended that the developers of HEC-RAS provide similar functionality as is provided in both ISIS and MIKE 11 for providing a steady state solution for problems of this type i.e. an in-built quasi-steady or "pseudo-timestepping" steady state solver.

- In MIKE 11 the reservoir surface area vs. elevation data has to entered in columns 1 and 5 of the processed data table and the storage width set to zero to avoid duplicating the total storage. This data is then "protected" to avoid it being overwritten by the actual computed raw data (which is usually synchronized with the processed data table). This is considered to be a cumbersome procedure on one which could lead to modelling errors. It is recommended that the developers of MIKE 11 improve on this procedure.

Further consideration could be given to investigation of the performance of these software packages under a range of time varying boundary conditions i.e. flood hydrographs.

If the recommended changes to MIKE 11 are not made then modellers could consider modelling an embankment as a series of link channels i.e. 10 flat link channels of 5m width to represent a sloping channel of 50m width.

It is recommended that all of the software packages be used in unsteady mode for cases involving spills. This is likely to be the case as most practical models with spills occur with unsteady boundary conditions.

Without suitable calibration data the modelling approach adopted by this study for MIKE 11 may be inappropriate and hence, it is recommended that careful consideration be given to how to represent embankments or spillways when using MIKE 11.

Investigation in the failure of HEC-RAS to converge with the split flow optimiser for SS2 Part 1 should be investigated further along with the volume of storage in the reservoir at t=0hrs for Part 2.

The test should be repeated in MIKE 11 using the resistance radius option and results compared with those presented herein.

It is a recommendation of this study that a test specification be developed that considers real life modelling of flows over embankments and into storage areas which has calibration data so as to enable true benchmarking of the software packages.

7 REFERENCES

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EP Evans and PH von Lany (1983), A mathematical model of overbank spilling and urban flooding, Hydraulic aspects of floods and flood control, London, UK, 1983.

APPENDIX A RESULTS

		CHANNEL A							Embankment	CHANNEL B				
	Chainage	300m	250m	200m	150m	100m	50m	0m		200m	150m	100m	50m	0m
SS1	ISIS	10.000	10.000	10.000	9.294	9.294	9.294	9.294	0.706	5.000	5.000	5.000	5.706	5.706
	MIKE 11	10.000	10.000	10.000	8.805	8.805	8.805	8.805	1.188	5.000	5.000	5.000	6.188	6.188
	HEC-RAS	10.000	10.000	10.000	9.396	9.396	9.396	9.396	0.604	5.000	5.000	5.000	5.604	5.604
SS2	ISIS	10.000	10.000	10.000	9.530	9.530	9.530	9.530	0.470	7.000	7.000	7.000	7.470	7.470
	MIKE 11	10.000	10.000	10.000	9.227	9.228	9.228	9.227	0.766	6.999	6.999	7.004	7.966	7.962
	HEC-RAS	10.000	10.000	10.000	10.000	10.000	10.000	10.000	0.000	7.000	7.000	7.000	7.000	7.000
SS3	ISIS	5.000	5.000	5.000	6.044	6.044	6.044	6.044	-1.044	7.000	7.000	7.000	5.956	5.956
	MIKE 11	5.000	5.000	5.000	8.263	8.266	8.266	8.263	-3.276	7.000	7.000	7.000	3.733	3.733
	HEC-RAS	5.000	5.000	5.000	5.702	5.702	5.702	5.702	-0.702	7.000	7.000	7.000	6.298	6.298
SS4	ISIS	3.500	3.500	3.500	4.044	4.044	4.044	4.044	-0.544	7.000	7.000	7.000	6.456	6.456
	MIKE 11	3.500	3.500	3.500	4.505	4.503	4.503	4.505	-1.000	7.000	7.000	7.000	5.987	5.987
	HEC-RAS	3.500	3.500	3.500	4.182	4.182	4.182	4.182	-0.682	7.000	7.000	7.000	6.318	6.318
QS1	ISIS	10.000	10.000	10.000	9.294	9.294	9.294	9.294	0.706	5.000	5.000	5.000	5.706	5.706
	MIKE 11	10.000	10.000	10.000	8.910	8.910	8.910	8.910	1.090	5.000	5.000	5.000	6.090	6.090
	HEC-RAS	10.000	10.000	10.000	9.503	9.503	9.503	9.503	0.497	5.000	5.000	5.000	5.497	5.497
QS2	ISIS	10.000	10.000	10.000	9.523	9.523	9.523	9.523	0.477	7.000	7.000	7.000	7.477	7.477
	MIKE 11	10.000	10.000	10.000	9.036	9.036	9.036	9.036	0.964	7.000	7.000	7.000	7.964	7.964
	HEC-RAS	10.000	10.000	10.000	9.545	9.545	9.545	9.545	0.455	7.000	7.000	7.000	7.455	7.455
QS3	ISIS	5.000	5.000	5.000	6.044	6.044	6.044	6.044	-1.044	7.000	7.000	7.000	5.956	5.956
	MIKE 11	5.000	5.000	5.000	6.635	6.635	6.635	6.635	-1.635	7.000	7.000	7.000	5.365	5.365
	HEC-RAS	5.000	5.000	5.000	5.573	5.573	5.573	5.573	-0.573	7.000	7.000	7.000	6.427	6.427
QS4	ISIS	3.500	3.500	3.500	4.044	4.044	4.044	4.044	-0.544	7.000	7.000	7.000	6.456	6.456
	MIKE 11	3.500	3.500	3.500	4.538	4.538	4.538	4.538	-1.038	7.000	7.000	7.000	5.962	5.962
	HEC-RAS	3.500	3.500	3.500	4.002	4.002	4.002	4.002	-0.502	7.000	7.000	7.000	6.498	6.498

*Positive flows are defined as being from channel A to channel B
**ISIS QS results are for pseudo-timestepping

Table 1: Discharge in m^3/s at each cross-section for Part 1

[illegible]

Table 2: Water Levels (mAD) at the cross-sections adjacent to the embankment for Part 1.

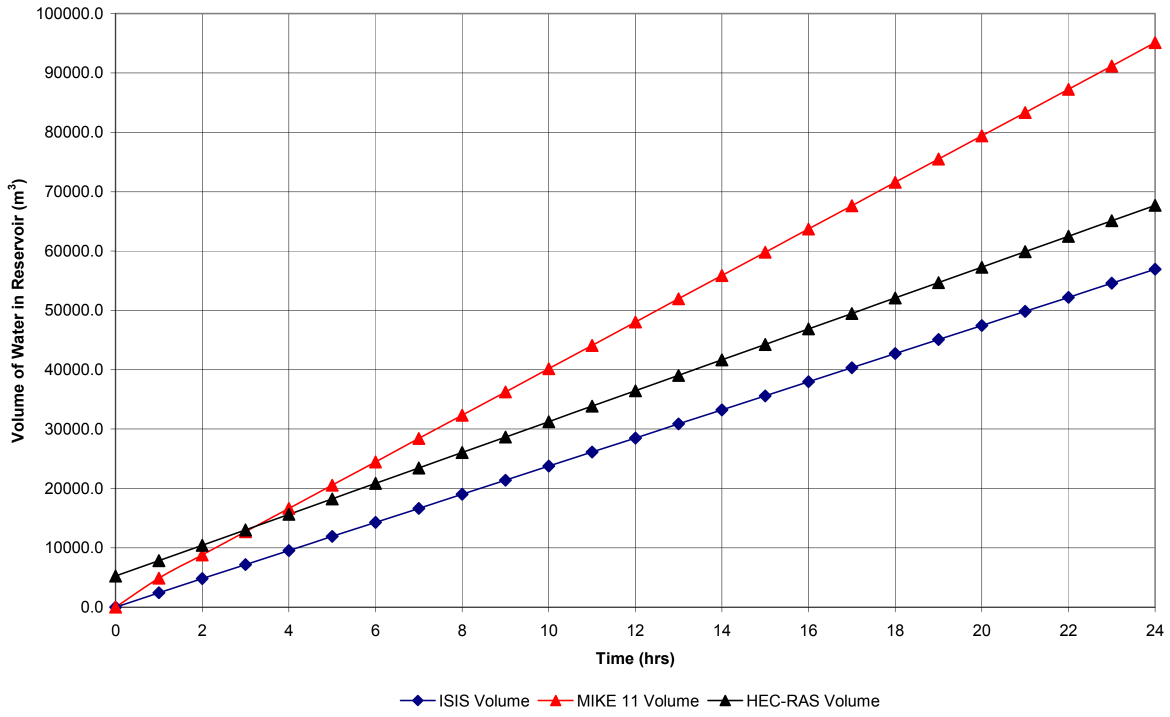
Head is calculated as the difference between the average water level at 200m and 150m for each channel

*Positive flows are defined as being from channel A to the reservoir
**ISIS QS results are for pseudo-timestepping

Table 3: Discharge in m^3/s at each cross-section for Part 2

	QS1	
	Chainage	
	200m	150m
ISIS	1.951	1.882
MIKE 11	1.999	1.867
HEC-RAS	1.951	1.882
Embankment Level	1.900	1.850

Table 4: Water Levels (mAD) at the cross-sections adjacent to the embankment for Part 2



Graph 1: Comparison of Volume in Reservoir against Time for Part 2