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

## Benchmarking Hydraulic River Modelling Software Packages

### Results – Test H (Pumps)

### R&D Technical Report: W5-105/TR2H

Department for Environment Food and Rural Affairs

Environment Agency

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# BENCHMARKING HYDRAULIC RIVER MODELLING SOFTWARE PACKAGES

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RA Crowder, AT Pepper, C Whitlow, A Sleigh, N Wright, C Tomlin

Research Contractor: Bullen Consultants

**Publishing organisation**
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: +44 (0)1454 624400 Fax: +44 (0)1454 624409 Web: www.environment-agency.gov.uk

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## Statement of use

This document provides the results and findings from undertaking the Environment Agency's Benchmarking Test H (Pumps) 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, Pumps, Water Level Control, Sluice Gate

## Research Contractor

This document was produced under R&D Project W5-105 by:
Bullen Consultants Ltd, 11/12 Eldon Place, Bradford, West Yorkshire, BD1 3AZ
Tel: +44 (0)1274 370410 Fax: +44 (0)1274 734447 Web: www.bullen.co.uk.

Contractor's Project Manager: Dr Richard Crowder
Halcrow Group Ltd, Arndale House, Headingly, Leeds, West Yorkshire LS6 2UL
Tel: +44 (0)113 220 8220 Fax: +44 (0)113 274 2924 Web: www.halcrow.com

## Environment Agency's Project Manager

The Environment Agency's Project Manager: Mr Andrew Pepper, ATPEC Ltd,
External Advisor to Engineering Theme

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## EXECUTIVE SUMMARY

The undertaking of this test has proven to be possible with both the ISIS and MIKE 11 software packages. However, the HEC-RAS package has been unable to solve this test case.

The failure of HEC-RAS to solve this test case is due to the inability of the software package to consider sluice gates that are operated by water level rules. This has now been addressed in a subsequent release of the software and should be benchmarked in due course. It should be noted that HEC-RAS has the functionality to operate pumps based on rules, although this could not be tested.

The test has highlighted the differences between software packages and the difficulties that can arise when defining suitable initial conditions for use in unsteady modelling. ISIS has required modelling judgement and workarounds to be employed in deriving suitable initial conditions, whereas MIKE 11 has been able to use the standard steady state initial condition option within the software.

The version of MIKE 11 being tested was restricted by the absence of a pump unit. However, as a workaround the control structure option was used. As a consequence, the full performance characteristics of a pump could not be modelled. It should be noted that the latest (subsequent) release of the software has a specific pump unit, which may be more appropriate for this test.

MIKE 11 does not have a specific reservoir unit. The solution employed to workaround this was to add a link channel with dimensions that appropriately represented the volume of storage required. This is a simple procedure, but one that is not necessarily intuitive and one that may cause some inconvenience.

There were differences between the packages particularly in water levels when the pumps are operating, and the discharge with respect to time. However, the overall discharge through the pumps is comparable suggesting that ISIS and MIKE 11 could be successfully used in modelling these scenarios. In the absence of measured data, or an analytic solution, it is not possible to say which performs better.

On the basis of this test the modeller may find that both ISIS and MIKE 11 are suitable for modelling problems of this nature.

# CONTENTS



**Appendices**



**List of Tables**



**List of Figures**

# 1 INTRODUCTION

## 1.1 Background

This report presents the results and findings from Test H (Pumps) 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 H (Pumps), (Crowder *et al,* 2004):

| | Role | Affiliation |
|---|---|---|
| Mr Andrew Pepper | EA Project Manager | ATPEC River Engineering |
| Dr Richard Crowder | Study Project Manager/Reporter | 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 implement a rule-based methodology to simulate the operation of hydraulic structures, namely a pump and a sluice gate; and

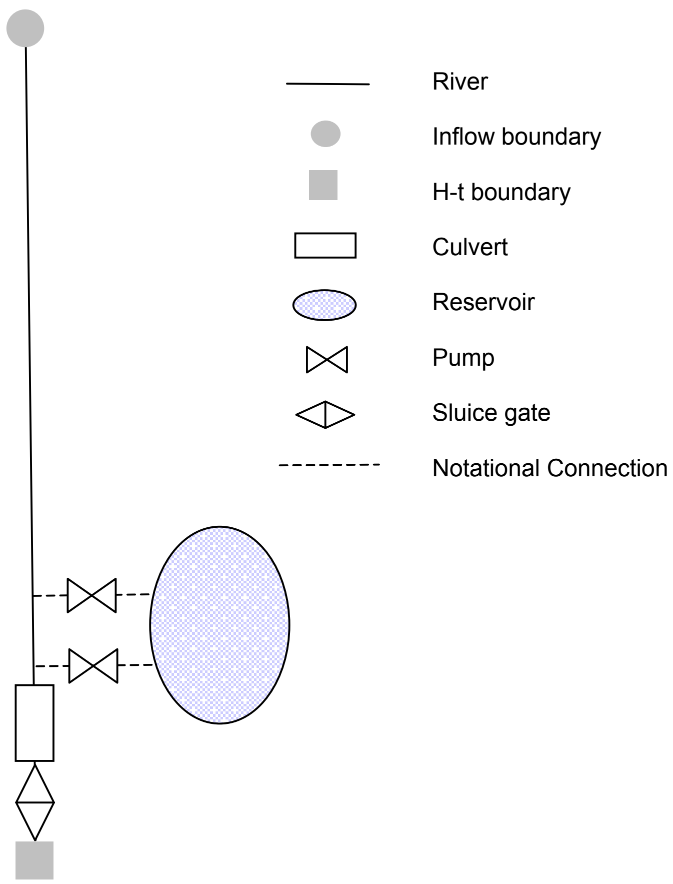
- present the particulars for developing and undertaking the tests (Model Build) with each of the software packages and the associated results so that others can repeat the test with their own software.

# 2 MODEL BUILD

## 2.1 Test Configuration

The test configuration for the pump test represents a generic case where a tributary discharges into a defended watercourse.

**Figure 2.1: Schematic Illustration of Test Configuration**




The model comprises cross-sections and interpolated sections along with a culvert, reservoir and a downstream tidal exclusion structure. Additional interpolated sections have been used as specified below for each software package.

The reservoir is connected to the watercourse via two pumps, which operate at different water levels. Both pump units are connected to the watercourse just upstream of the culvert and exclusion structure. Pump 1 is switched on when the water level in the river rises to 2.75m and then turns off when the water level has fallen to 2.25m. Pump 2 is switched on when the water level in the river rises to 3.25m and then turns off when the water level has fallen to 2.5m.

The pump rating details, which were the same for both pumps, is given in Table 2.1. The optimal point data for the pump rating was defined as 3.75m for head, 0.95m$^3$/s for flow and 0.80 for efficiency.

**Table 2.1: Pump Rating Details**

| Pumping Head (m) | Flow (m3/s) | Efficiency |
|---|---|---|
| 5.250 | 0.725 | 0.700 |
| 5.100 | 0.750 | 0.700 |
| 5.000 | 0.800 | 0.700 |
| 4.600 | 0.850 | 0.740 |
| 4.500 | 0.875 | 0.760 |
| 4.250 | 0.900 | 0.780 |
| 4.000 | 0.925 | 0.800 |
| 3.750 | 0.950 | 0.800 |
| 3.600 | 0.970 | 0.800 |
| 3.500 | 0.980 | 0.780 |
| 3.300 | 1.000 | 0.780 |
| 2.750 | 1.025 | 0.760 |

Between the pumps and the downstream boundary is a culvert with length 33m, diameter 1.7m and Manning's *n* of 0.030.

The downstream boundary is modelled as a single tide curve (H-t boundary). Just upstream of this boundary there is a tidal exclusion structure (sluice gate) with operating rules. These rules state that the structure is closed if the downstream depth is greater than the upstream depth. The dimensions used are as follows:

| | |
|---|---|
| Elevation of crest | 1.711m |
| Length of crest | 0.100m |
| Breadth of crest | 2.100m |
| Height of crest above bed upstream | 0.100m |
| Height of crest above bed downstream | 0.100m |
| Number of gates | 1 |
| Height of gate | 5.000m |

Overtopping of the structure is not permitted.

The upstream boundary of the model is an unsteady flow hydrograph.

## 2.2 Building the Model in ISIS

After an initial run produced warning messages, the ISIS interface was used to manually insert a total of fourteen cross-sections to improve model stability.

The culvert was implemented using the SYMMETRICAL CONDUIT option. Further details about this unit are given in the report on Test K – Culverts.

The ISIS PUMP unit was used to define the pump structures. In order to incorporate the pumps, a JUNCTION unit was defined between the river and the pump.

The PUMP unit has switching facilities that allow it to be operated with time or level dependency. There are two possible modes of operation – OFF (speed zero) and RUNNING (speed greater than zero). When the pump is OFF the unit simply equates the heads and flows at the two nodes. When in RUNNING mode the pump is assumed to be operating at the given speed and the output heads and flows are calculated using the Q-h relationship derived from Suter's method (Fluid Transients, Wylie and Streeter, 1978). Further details are available in the ISIS manual.

When the flow falls outside the range specified in the head-flow-efficiency dataset, the maximum speed is used to determine the pump characteristic curves.

The reservoir takes water from the river reach via the pumps located between the junction and the reservoir. The reservoir is represented by defining the plan area with respect to elevation. For this test the definition of the reservoir was arbitrary as it was merely present to receive water from the pumps, therefore its definition is not specified. When the water level in the reservoir exceeds the maximum elevation, as defined by the data, then ISIS automatically assumes a vertical wall around the reservoir and increases the reservoir volume accordingly.

A vertical sluice gate, located at the downstream end of the modelled reach, was defined using the VERTICAL SLUICE option.

The VERTICAL SLUICE structure in ISIS allows the sluice gate to be controlled according to model time, water levels, logical rules or by an attached control unit. In this test it was controlled by a logical rule i.e. gate is closed when the downstream depth exceeds the upstream depth. Flow beneath the sluice gate where the gate does not interfere with the flow is described by the round nosed horizontal broad crested weir equations. Drowned or free orifice flow equations are used when the gate does interfere with the flow. Further details are available in the ISIS manual.

## 2.3 Building the Model in MIKE 11

The culvert was defined using the CULVERT option within the software package. Further details about culverts in MIKE 11 are given in the report on Test K – Culverts. A requirement of the model network was the need for a cross section between the upstream junction and the culvert and the between the culvert and the downstream control structure. These were defined through the manual interpolation through the MIKE 11 interface.

MIKE 11 does not have a specific reservoir unit; however, the test was undertaken by modelling the reservoir as a separate branch of length 100.0m. This was set up using a LINK channel with additional storage specified at the downstream end so as to represent the reservoir. To ensure that no water could come over the top of the link, the crest level of the link was set to a value of 100.0m. The upstream end of the link is connected to the main river reach at chainage 437.5m. Further details on this method are available in the MIKE 11 manual.

MIKE 11 does not have a specific structure for pumps. However, it is acknowledged that a subsequent release of MIKE 11 has this functionality. Therefore, the CONTROL STRUCTURE option was used. This required three control definitions as follows:

1) Pump running - Conditioned by water level above start level.
2) Pump running - Conditioned by water level above stop level and pump already running.
3) Pump stopped - Default value.

Both pumps were located in the link channel at chainage 50.0m. Three control rules were used to operate the pump, which for Pump 1 were as follows:

[ if (PUMP1(Q) = 0) AND (WL(Branch1 437.5) > 3.25] then [PUMP1(Q) = 0.50 ]
(turn Pump ON)
ELSE
[ if (PUMP1(Q) > 0) AND (WL(Branch1 437.5) < 2.50] then [PUMP1(Q) = 0.0]
(turn Pump OFF)
ELSE
"Do nothing" (if pump is ON, it stays ON, if OFF, it stays OFF).

The control rule menus are used to enter the rules for each pump. The text for each of the first two rules can be seen by pressing "Details" and then "Logical Operands". The actual rule to be implemented in case the logical statement returns TRUE can be seen on the "Control and Target Point" and "Control Strategy" tabs. The last rule is always executed in case the previous rules all return FALSE. To implement "Do nothing", a rule is set up to ensure that whatever the discharge in the pump is it will remain the same.

In order to have MIKE 11 produce extra information about the pump discharges in the results file, it is necessary to specifically request this information before the simulation is run.

To model a tidal exclusion structure in MIKE 11 the CONTROL STRUCTURE option was used. For this test the "Under Flow" option for the gate type was used as this corresponds to a vertical sluice gate. Implementing the gate operation required in this test was achieved by using the following two control definitions:

1) The gate is closed if the difference between upstream and downstream depth (dH) is less than zero.
2) Otherwise the gate is open.

Care needs to be taken when specifying the control points. If these do not correspond at actual computational grid points, MIKE 11 will relocate them to the closest available. The user can view the location of all computational points prior to a model run via the Gridpoint page in the network editor. In this test case MIKE 11 used the point immediately downstream of the structure and this lead to incorrect behaviour. Therefore, the control point was set explicitly to be the next h-point upstream from the structure.

It should be noted that the test specification intended for the exclusion structure to be attached to the downstream face of the culvert. However, this cannot be represented in MIKE 11. The principle adopted by MIKE 11 is to have a Q/H relationship imposed at upstream face of the culvert. As a consequence, additional cross-sections have been needed as described above.

As with the ISIS model, the upstream boundary was an unsteady flow hydrograph (Q-t) and a stage hydrograph (H-t) was used as downstream boundary.

The developers of MIKE 11 have suggested that a more sophisticated approach could be adopted for modelling the pumps than that described above. This was not adopted by this study as it was considered to be beyond the scope of the test specifications.

The developers of MIKE 11 have suggested that the outfall structure may be modelled using the valve facility for a culvert. This alternative/additional approach was not adopted by this study.

## 2.4 Building the Model in HEC-RAS

This test case could not be constructed in HEC-RAS. Although both pumps and sluice gates can be modelled in the test version, there is no option in the test version to use rules to control the operation of the sluice gate based on downstream water levels. It is however acknowledged that during the study a subsequent release of the software has added the capability to have elevation controlled gate operations which can consider any node within the river system for applying the rules.

The test version of HEC-RAS software does have the ability to control sluice gates with either a time series of gate openings, or an elevation controlled gate operation. The elevation controlled gate operation is a rules based controller; however, it only looks at the cross section immediately upstream of the gate for applying the rules.

Through discussions with the developers of HEC-RAS it was suggested that a model of this system could have been put together so as to test the pump feature within HEC-RAS. This could have been achieved by modelling the downstream sluice gate with a time series of gate opening option. The time series would initially have had to have been set to fully open and then once an initial run was made, the output could have been reviewed to see at what time the downstream water surface exceeded the upstream water surface at the sluice gate. The time series of gate openings could then have been modified to close the gate at this time. Then rerunning the software, the gate operations would represent the test and thus the HEC-RAS pump station capability tested. This approach was considered to be out with the test specification (i.e. logical control of sluice) and hence, it has not been tested.

# 3 RUNNING THE MODEL

## 3.1 Running the Model in ISIS

It was found that the steady solver within ISIS could not produce a result and hence, initial conditions for the unsteady simulation.

Two methods for developing the initial conditions have been investigated and have been proven to work for this test, as follows:

Option 1:
Remove the pump and reservoir units from the data file and undertake a steady state calculation.
Reinstate the pump and reservoir units and use the steady state result from the previous simulation as the initial conditions for the unsteady simulation.

Option 2:
Create a temporary data file with inflow boundary set at $0.2m^3/s$ at time zero which then reduces to 0.08 $m^3/s$ at 12 hours (the required initial boundary condition) and similarly for the downstream water level boundary set to 3.0m reducing to 1.5m. Beyond 12 hours the boundary conditions were linearly extended.

Operation of the pumps was adjusted so as to have linearly extended operation parameters. Set all initial flows and water levels within the data file at all nodes to 0.2 $m^3/s$ and 3.0m respectively.

Undertake time-stepping simulation (20s time-step) using data file initial conditions to produce a stable and convergent result for subsequent use as initial conditions to an unsteady simulation. The ISIS parameters for the minimum and maximum number of iterations of the matrix solver were set to 5 and 40 respectively.

Undertake an unsteady simulation using the above initial conditions for a period of 24 hours, and then - extract the results at 24 hours for use as the test initial conditions.

The adaptive time-stepping option was used to achieve a balance between accuracy and fast run times. The initial time-step was set to 37.5s. When adopting Option 2 above for the development of initial conditions, the ISIS parameters for the minimum and maximum number of iterations of the matrix solver were set to 5 and 40 respectively so as to provide a solution. This was not required for Option 1. All other default options for the solution parameters were used.

## 3.2 Running the Model in MIKE 11

The model created in MIKE 11 was run with initial conditions generated by the default steady state option. A timestep of 15s was used and it was found necessary to increase the delta value from the default of 0.55 to 0.7.

The following error and warning messages were observed.

| | |
|---|---|
| Error No. 25: | At the h-point: BRANCH1 km 0.425 the water depth is greater than 4 times maximum depth. |
| Warning No. 47: | At the h-point: BRANCH1 km 0.373 the water level has fallen below the bottom of the slot 1 times. |
| Warning No. 62: | The water level boundary condition at river BRANCH1 chainage 470.800 was below the bed level 110 times during the simulation. The boundary condition was set equal to the bed level (i.e. dry out). |

Both Error No. 25 and Warning No. 47 were eliminated; however, it was not possible to eliminate Warning No. 62. This is not surprising given that the minimum water level from the boundary is 1.5m and minimum bed level at this location is 1.61m.

### 3.3 Running the Model in HEC-RAS

The HEC-RAS software package was not able to undertake this test.

# 4 RESULTS

## 4.1 Introduction

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

Before examining the results it should be noted that the test case has a number of aspects that can lead to variations in the results. For example, if the packages predict slightly different water levels at the control point for the pump, the pump operation will be different. This in turn leads to differences in water levels and the consequent changes in discharge can affect the downstream tidal exclusion structure. In view of this difference the results do not always have a ready explanation.

The first set of graphs (1 to 7) show the longitudinal water level profile at two hour intervals throughout the simulation. From these it can be seen that the level rises as the input discharge increases. The results of ISIS and MIKE 11 differ, but are broadly similar. The results and comparisons at the downstream end are affected by the different ways in which the packages represent the test and the different nodal arrangements (see Section 2.3). The differences that do occur are approximately in the period 6-8 hours. This is when the pumps are operating and the water levels are being affected by the pumping.

Graphs 8 to 14 show the discharge throughout the channel at two hour intervals. These demonstrate the increase in discharge as the simulation starts. Graphs 10 and 11 show the effect that the pumps are having on the discharge as they are activated.

The difference in discharge seen in Graph 13 (10hrs) can be explained by examining Graph 17. It can be seen that at 10hrs in MIKE 11 the gate is open, but in ISIS it has just closed. So the difference in discharge is due to a backwater effect from the tidal exclusion structure.

Graph 15 shows the discharge into the reservoir via the pumps. The effect of the switching on and off of the pumps as water levels increase and then decrease can be clearly seen. The differences between the packages are likely to be due to the different means of representing the pumps in the two packages. It should be recalled that MIKE 11 had no pump unit so a control structure had to be set up for this purpose. Comparison of Graphs 15 and 16 shows how the pumps are operating at the appropriate depths and how, in turn, the pump operation affects the water levels. MIKE 11's performance is less varied because the unit used does not have the complexity of the ISIS unit. The total volume extracted by the pumps is 37,545$m^3$/s and 35,910$m^3$/s for ISIS and MIKE 11 respectively which differs by less than 5%.

Graph 17 demonstrates the behaviour of the tidal exclusion structure. This is broadly similar, but there is a difference between the two packages around 9-10hrs, as previously commented on.

### 4.3 Evaluation of Mass Conservation

A mass conservation test was carried out. For each package the boundary conditions were extended beyond 12 hours by using the initial boundary values. This was done to ensure that the mass within the system at the end of the simulation was identical to that within the system at the start. The values of the discharge entering the system and leaving it at the downstream end and into the reservoir were compared. If mass is being correctly conserved this should result in a value of zero. A percentage error was calculated by dividing the error by the total inflow. ISIS had an error of 0.28% and MIKE 11 0.06%. Both of these lie well within the limits that are satisfactory for practical modelling.

The investigation of the mass error revealed an interesting result. When examining the cumulative mass error (i.e. mass error against time) ISIS gave a continually decreasing value after 12 hours. MIKE 11, however, gave a decreasing value until approximately 13 hours and then the value began to increase (Graph 18). Examination of the results showed that MIKE 11 had maintained a steady state solution at 13 hours and so this value was taken to assess mass conservation. However, after 13 hours the results subsequently became oscillatory which is not explicitly a steady state solution.

The error in mass conservation after 13 hours is a result of the quasi-steady solution becoming oscillatory. Therefore, the increase in mass error does not necessarily mean that mass conservation is being violated. However, the oscillatory solution means that the volume within the system differs from the volume in the system initially and it is this that gives the mass error.

# 5 DISCUSSION AND CONCLUSIONS

In this test ISIS, HEC-RAS and MIKE 11 packages were tested to model flow through pumps and a sluice gate.

The development of initial conditions for this test for ISIS was considered in two ways. Neither was straightforward. However, it should be noted that this is not uncommon in river modelling. In comparison, MIKE 11 was able to develop initial conditions automatically using the steady state initial condition option.

HEC-RAS was not able to model this test due the absence of the ability to control sluice gates by rules. This is a significant limitation, which has been addressed by the developers in a subsequent release of the software.

Both the packages were able to model the pumps, but MIKE 11 was restricted by the absence of a pump unit in this version. This meant that the unit in MIKE 11 did not reflect the full performance characteristics of a pump in the way that ISIS did.

The absence of a reservoir unit in MIKE 11 may cause some inconvenience. The solution to this is to add a link channel with dimensions that appropriately represent the volume of storage required. This is a simple procedure, but one that is not necessarily intuitive.

Care must be taken with the way in which MIKE 11 selects the control point for a structure as the modeller may inadvertently use an unsuitable point which may lead to serious inaccuracies in model results.

There were differences between the packages, particularly in water levels when the pumps are operating, and in the discharge with respect to time. However, the overall discharge through the pumps is comparable suggesting that ISIS and MIKE 11 could be successfully used in modelling these scenarios. In the absence of measured data or an analytic solution it is not possible to say which performs better.

# 6 RECOMMENDATIONS

Further to this study it is noted that the latest version of MIKE 11, which has not been tested as part of this study, has a specific pump unit. Hence, the modeller may wish to consider the use of this new unit as opposed to the approach adopted for this study.

The developers of MIKE 11 may wish to consider implementing a specific unit for modelling reservoir flow from a main channel to overcome the inconveniences found in Section 2.3.

The developers of ISIS may wish to consider changes to the software to make it easier to generate initial conditions for case with pumps through use of the direct steady state solver.

Further investigation of the results observed at the downstream end in Graphs 1 to 14 and Graph 16 may be of interest.

Further investigation of the results for discharge through the pumps (Graph 15 and 16) may be of interest, although this should be done with results from the latest version of MIKE 11 with a pump unit.

The developers of MIKE 11 may wish to consider improvements to the software such that a modeller is explicitly aware of the model node that is being used to control a structure.

In MIKE 11, to view any data other than discharge at Q-points or water levels at h-points, the user needs to use an additional results file. This may be considered to be cumbersome by some users. The software developers may wish to improve the functionality of the software so as to facilitate the interpretation and viewing of these results.

The absence of the ability to control sluice gates by water level rules in HEC-RAS has been addressed in a subsequent release of the software. Hence, it is recommended that this be now benchmarked.

Although HEC-RAS has the functionality to control pumps by rules this could not be tested due to the limitation of the sluice gate. Hence, it is recommended that a specific test specification be developed to assess the performance and ability of the pumps or alternatively this test is undertaken now water level rule operation is incorporated to the sluice gate.

The pump unit feature which has been added to the MIKE 11 software during a subsequent release of the software should be tested.

# 7 REFERENCES

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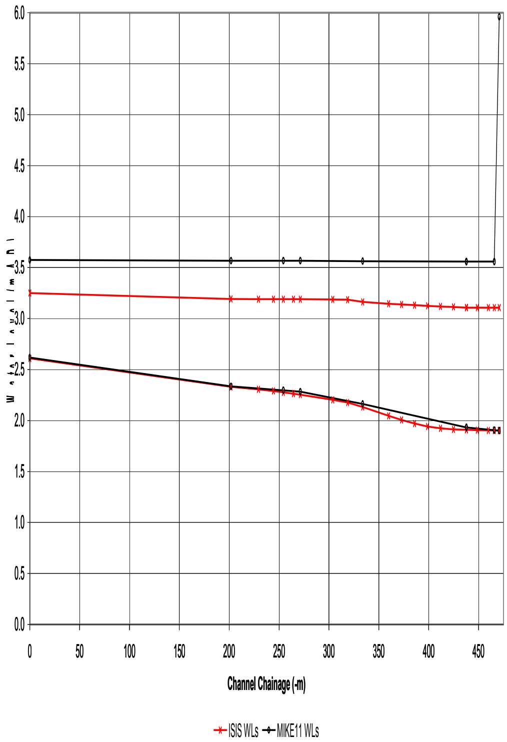
Crowder, R.A., Pepper, A.T., Whitlow, C., Wright, N., Sleigh, A., Tomlinson, C., (2004) Benchmarking and Scoping of 1D Hydraulic River Models, Environment Agency Research and Technical Report, W5-105/TR1

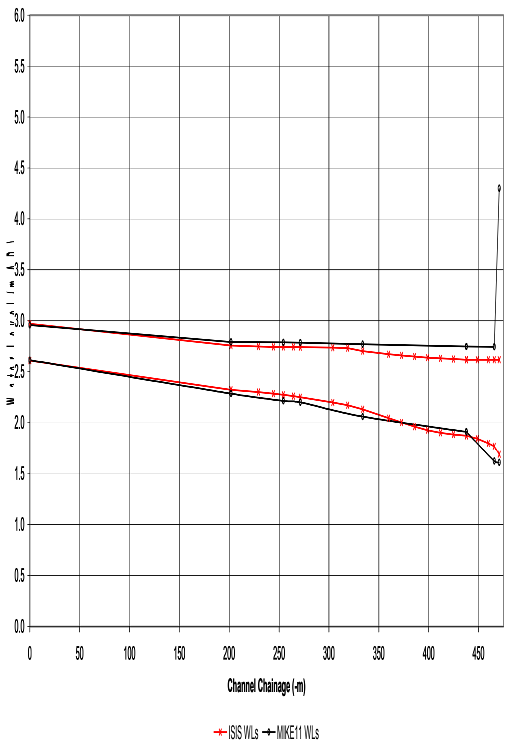
Fluid Transients (1978), McGraw-Hill, Inc., New York, 1978

# APPENDIX A RESULTS

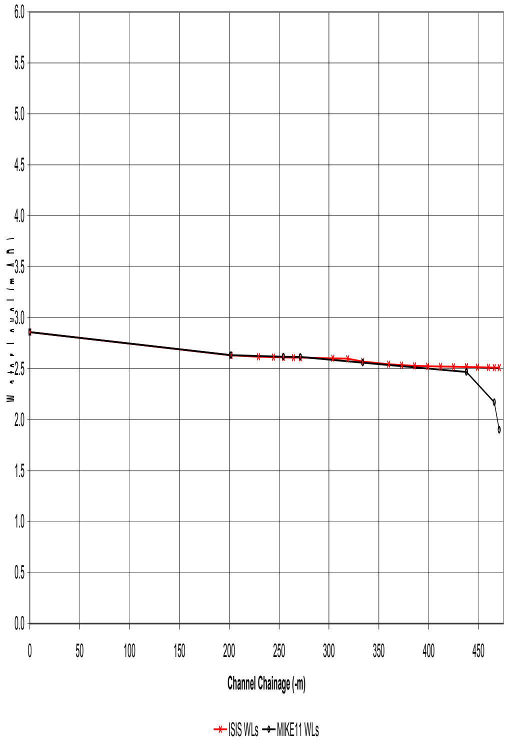
**Graph 2 - Test H: Comparison of Calculated Longitudinal Water Level Profiles at 2.0hrs**



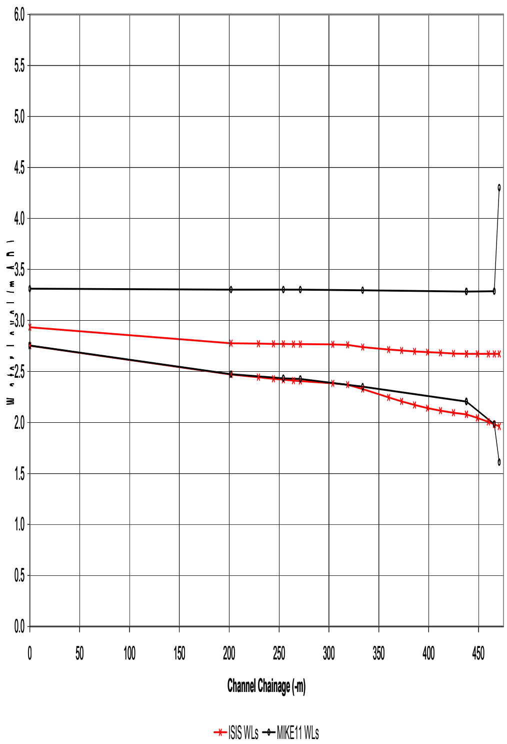

**Graph 3 - Test H: Comparison of Calculated Longitudinal Water Level Profiles at 4.0hrs**



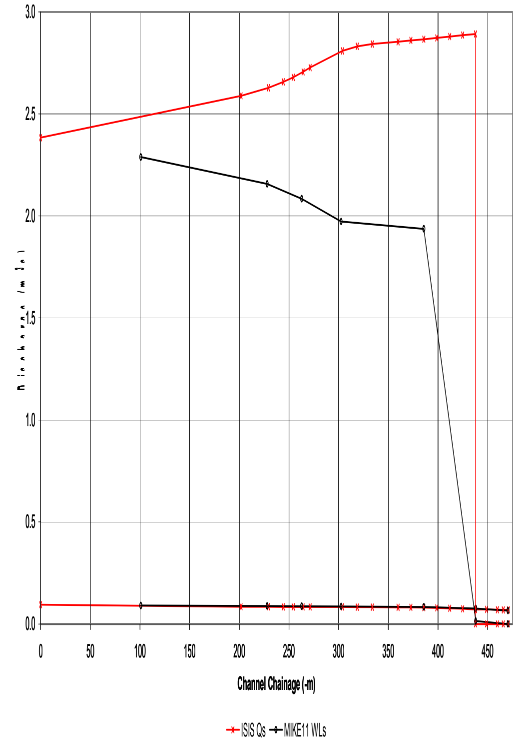
Graph 6 - Test H: Comparison of Calculated Longitudinal Water Level Profiles at 10.0hrs



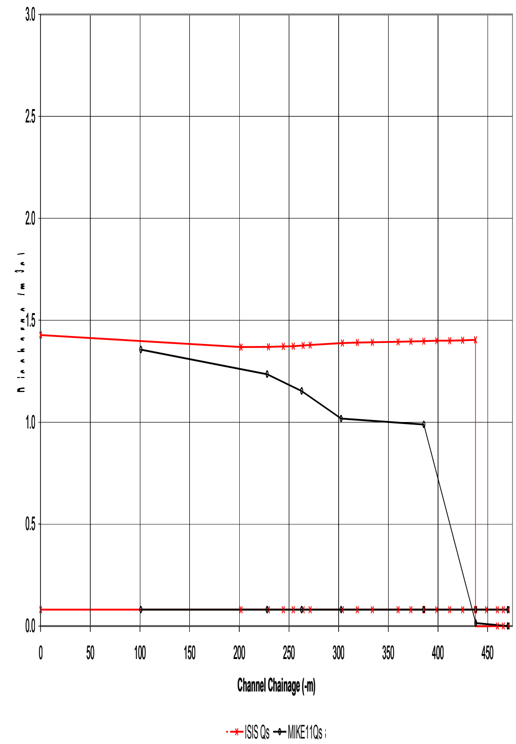

Graph 7 - Test H: Comparison of Calculated Longitudinal Water Level Profiles at 12.0hrs

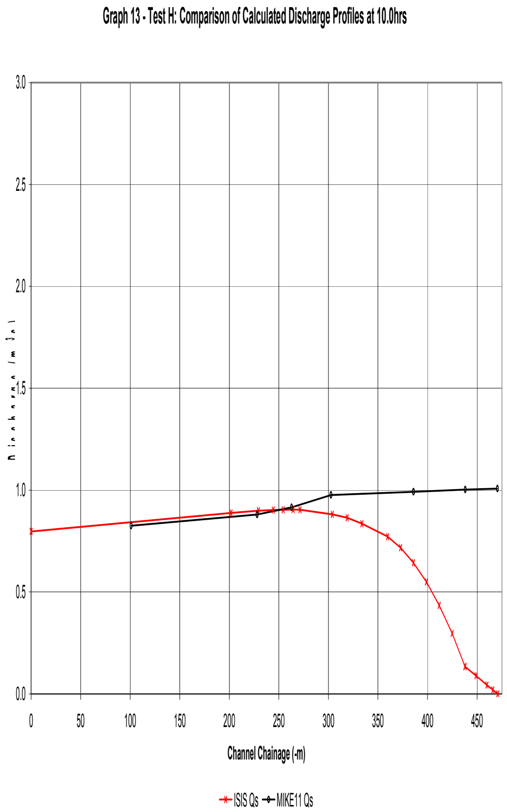


Graph 91 – Test H: Comparison of Calculated Discharge Profiles at 2.0hrs

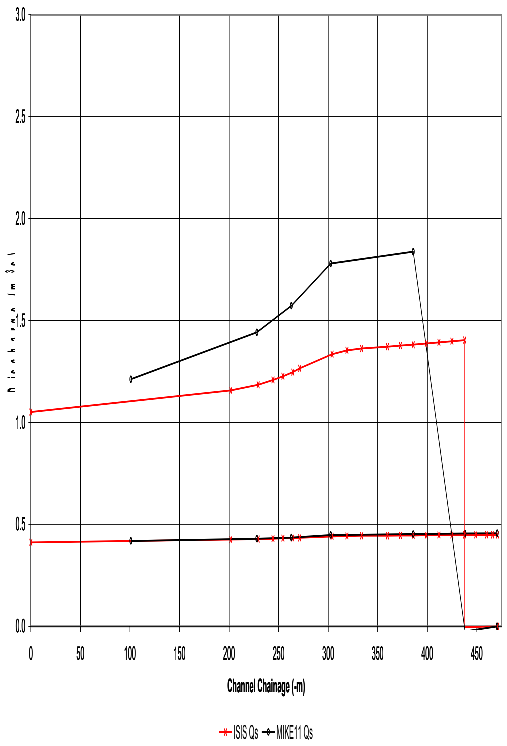



Graph 80- Test H: Comparison of Calculated Discharge Profiles at 0.0hrs

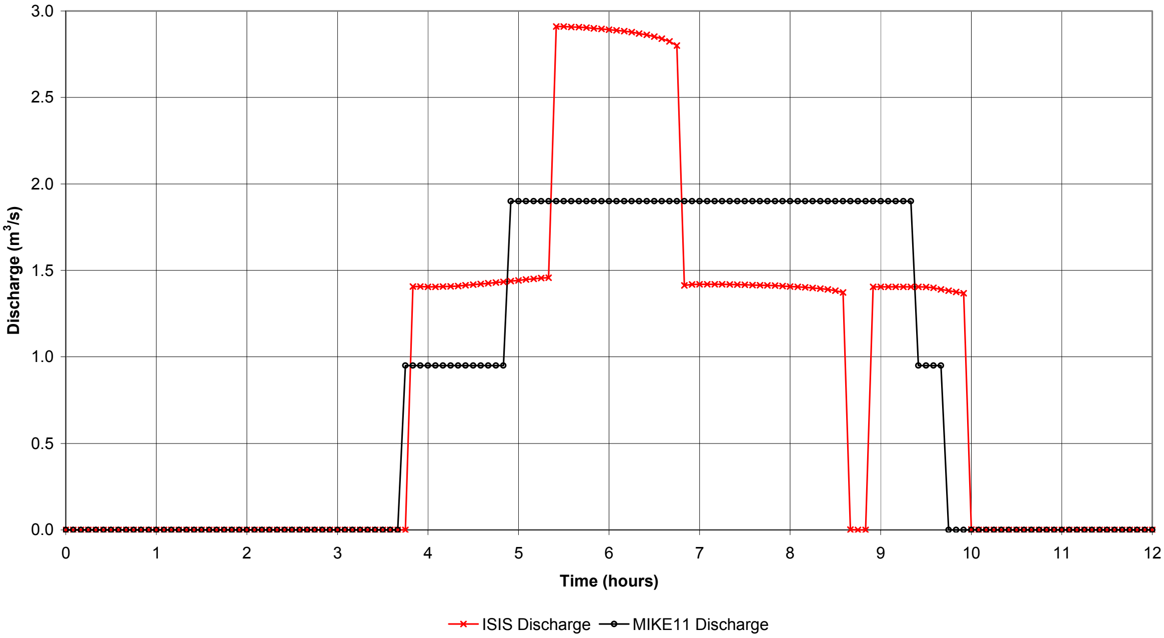



Graph 13 - Test H: Comparison of Calculated Discharge Profiles at 10.0hrs
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
350
400
450
Channel Chainage (-m)
ISIS Qs
MIKE11 Qs

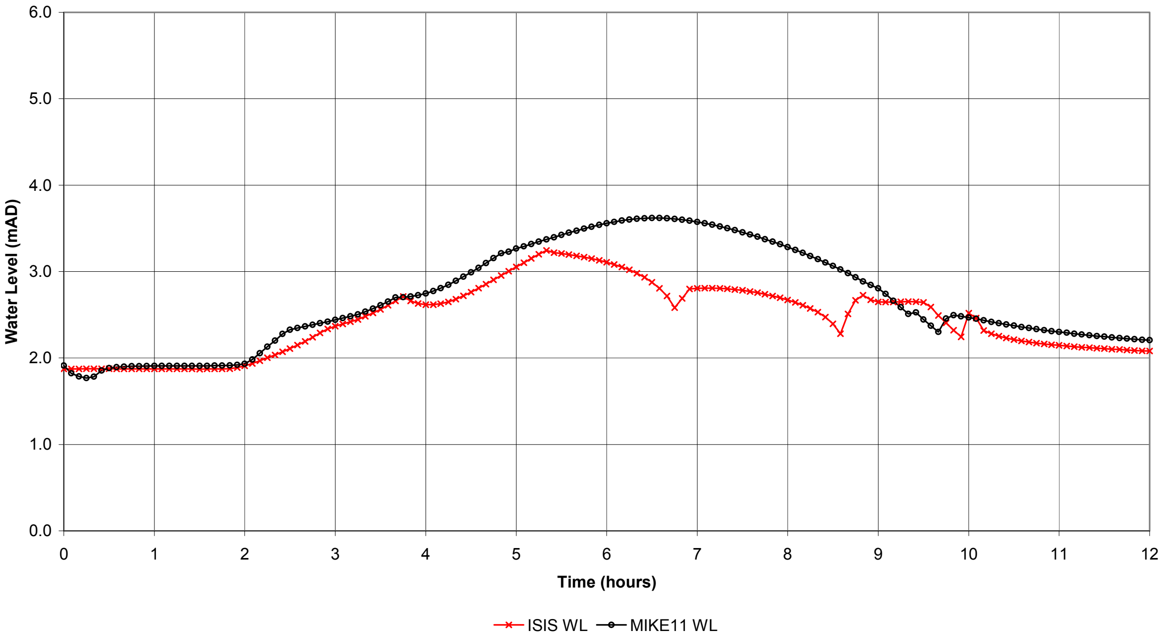
Graph 12 – Test H: Comparison of Calculated Discharge Profiles at 12.0hrs



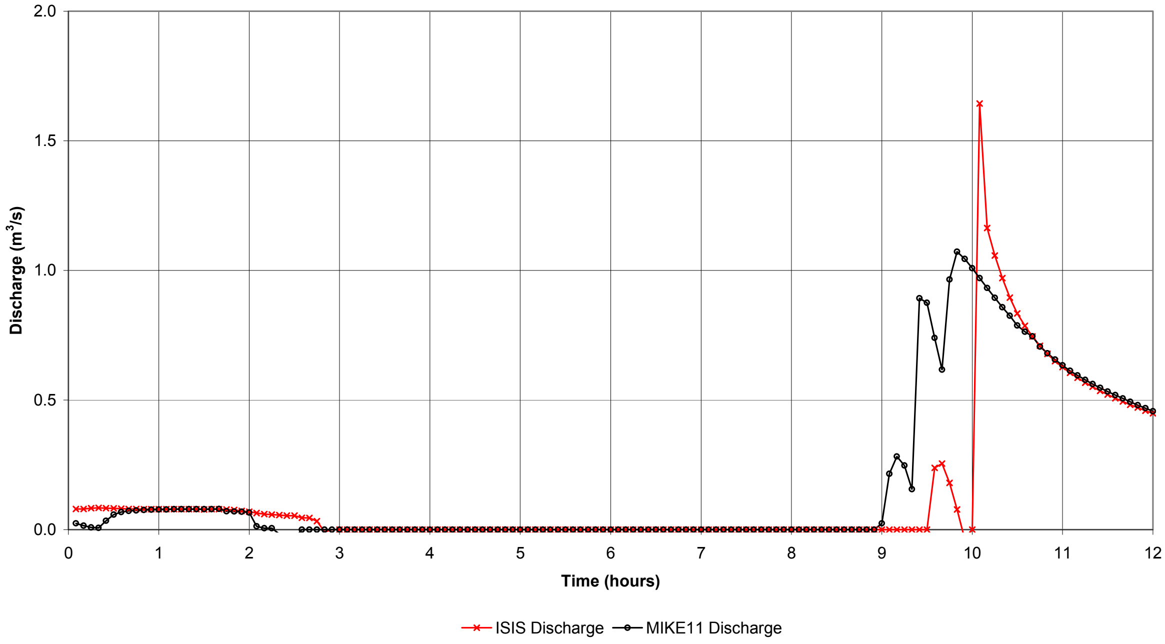
**Graph 15 - Test H: Comparison of Calculated Discharge into the Reservoir**




**Graph 16 - Test H: Comparison of Water Levels at Control Point for Pumps**



Graph 17 - Test H: Comparison of Calculated Discharge at the Downstream Structure




Graph 18 - Test H: Comparison of Mass Errors