Benchmark testing the Swift flood modelling solver: Version I

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Abstract

In this study the CSIRO flood modelling software ”Swift” (Shallow Water Integrated Flood Tool) was benchmarked and validated using a set of test cases published by the UK Environment Agency (UKEA) in two reports (Nelz and Pender [2010, 2013]). Input datasets were acquired directly from the UKEA, enabling identical scenarios to be simulated using Swift. The Swift results were plotted and overlaid on the figures provided in the UKEA reports - enabling a direct comparison of the results. Overall the Swift solver showed excellent agreement with the results provided in the UKEA reports.

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1 Introduction

In this study the CSIRO flood modelling software ”Swift” (Shallow Water Integrated Flood Tool) was benchmarked and validated using a set of test cases published by the UK Environment Agency (UKEA) in two reports (Nelz and Pender [2010, 2013]). Input datasets were acquired directly from the UKEA, enabling identical scenarios to be simulated using Swift. The Swift results were plotted and overlaid on the figures provided in the UKEA reports - providing a direct comparison of the results.

2 Method

The CSIRO Swift flood modelling solver uses a finite volume method to solver the shallow water equations. More details of this solver are available in Hilton et al. [2015], Prakash et al. [2015], Cohen et al. [2015]. Additional up to date information is available on the website https://research.csiro.au/swift/

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3 Results and discussion

In this section the sequence of benchmark test cases are outlined along with the Swift results and their comparison with the UKEA findings.

3.1 Test Case 1 - Flooding a Disconnected Water Body

3.1.1 Problem description

The domain for this test case consists of a 2-dimensional rectangular region which is 800 m long and 100 m wide (Fig. 3.1). From the left hand side ($x = -100$) there is a gentle upwards slope, followed by a trough and another gentle upwards slope. The left hand boundary has a prescribed water height which changes with time. Water flows into the initially empty domain from the left hand boundary, up the hill and into the trough. Full details of this test case are available in Nelz and Pender [2013].

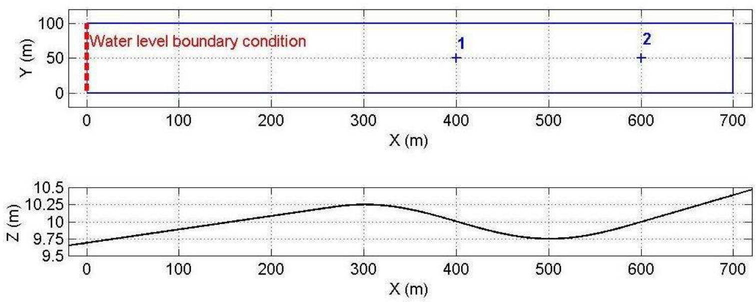

Figure 3.1: Test Case 1: Domain and elevation. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

The objective of this test case is stated as:

> *The objective of the test is to assess basic package capabilities such as handling disconnected water bodies, and the wetting and drying of floodplains.*

3.1.2 Results

Gauge points located to the left and right of the trough (Fig. 3.1) were used to compare the solver performance. The heights of the water at each of these gauge points (Fig. 3.2) are observed to have good agreement with the results from the other solvers at both gauge points.

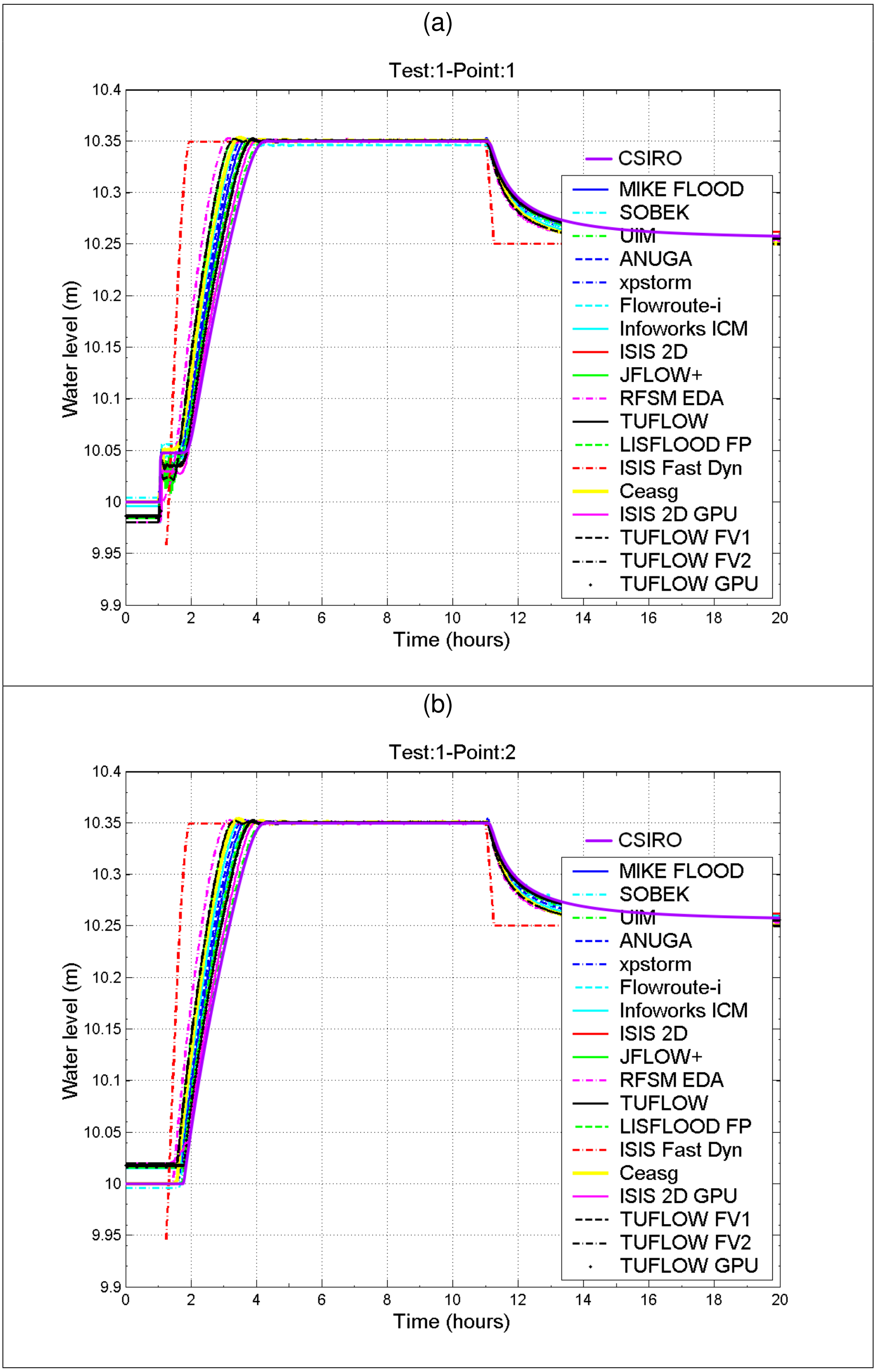

Figure 3.2: Test Case 1: Water heights at (a) Point 1, and (b) Point 2. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

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3.2 Test Case 2 - Filling of floodplain depressions

3.2.1 Problem description

The domain for this problem consists 16 dams with a volume inflow in the top left hand corner (Fig. 3.3). The volume inflow rate (in m^3/s) is specified over time. Since the primitive variables are height and flow speed in the solver, the inflow rate could be obtained from different combinations of these variables and potentially lead to very different solutions. Since the test case is ambiguous, here (and in subsequent test cases) it was chosen to use the critical Froude number of 1 to control the volume flow rate.

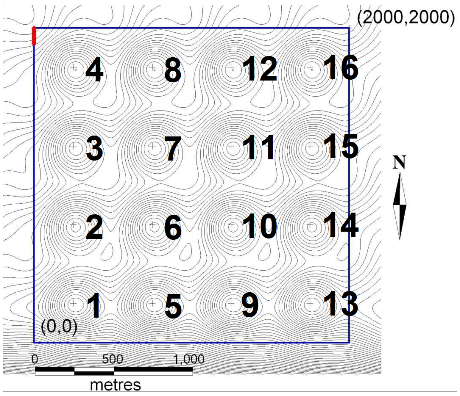

Figure 3.3: Test Case 2: Domain with each of the gauge points numbered. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

The objective of this test case is stated as:

> *The test has been designed to evaluate the capability of a package to determine inundation extent and final flood depth, in a case involving low momentum flow over a complex topography.*

3.2.2 Results

From the simulation results the volume flow rate closely matches the specified volume flow rate (Fig. 3.4) except at the sharp transitions between volume flow rate values. The final water height contours (Fig. 3.5) also closely matches the published image. Finally the heights of the water at each of the 12 gauge points (Fig. 3.6 and Fig. 3.7) are in good agreement with the majority of results from the other solvers.

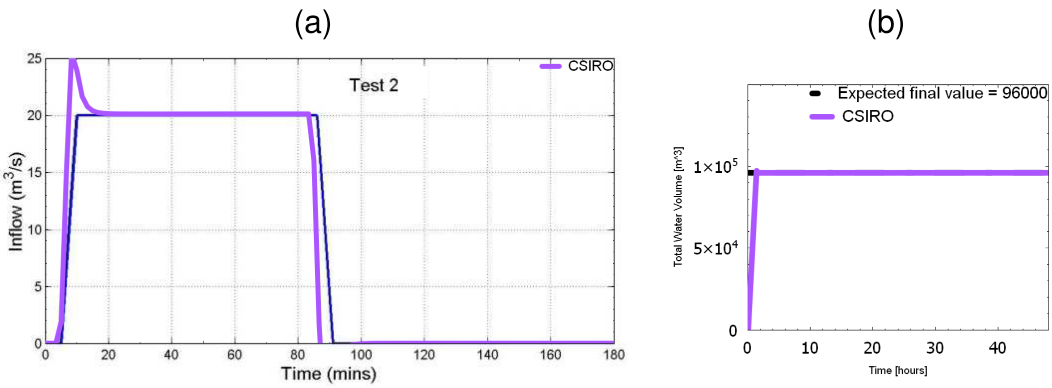

Figure 3.4: Test Case 2: (a) Volume flow rate into the domain as specified by the test case and measured in the present simulation, and (b) total volume of fluid in the domain. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

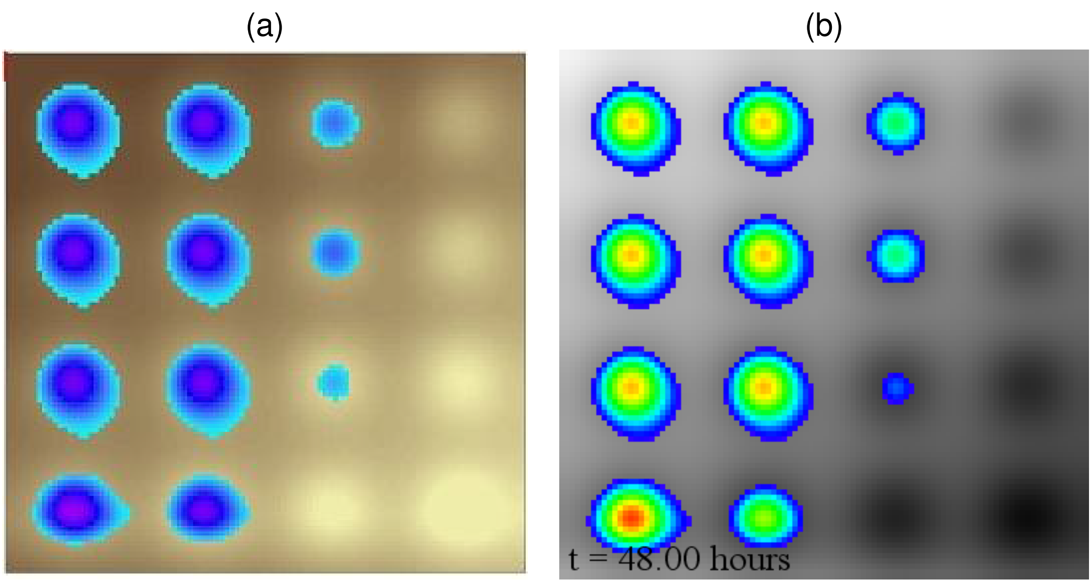

Figure 3.5: Test Case 2: Height contour plots (a) published by UKEA (b) present simulation. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

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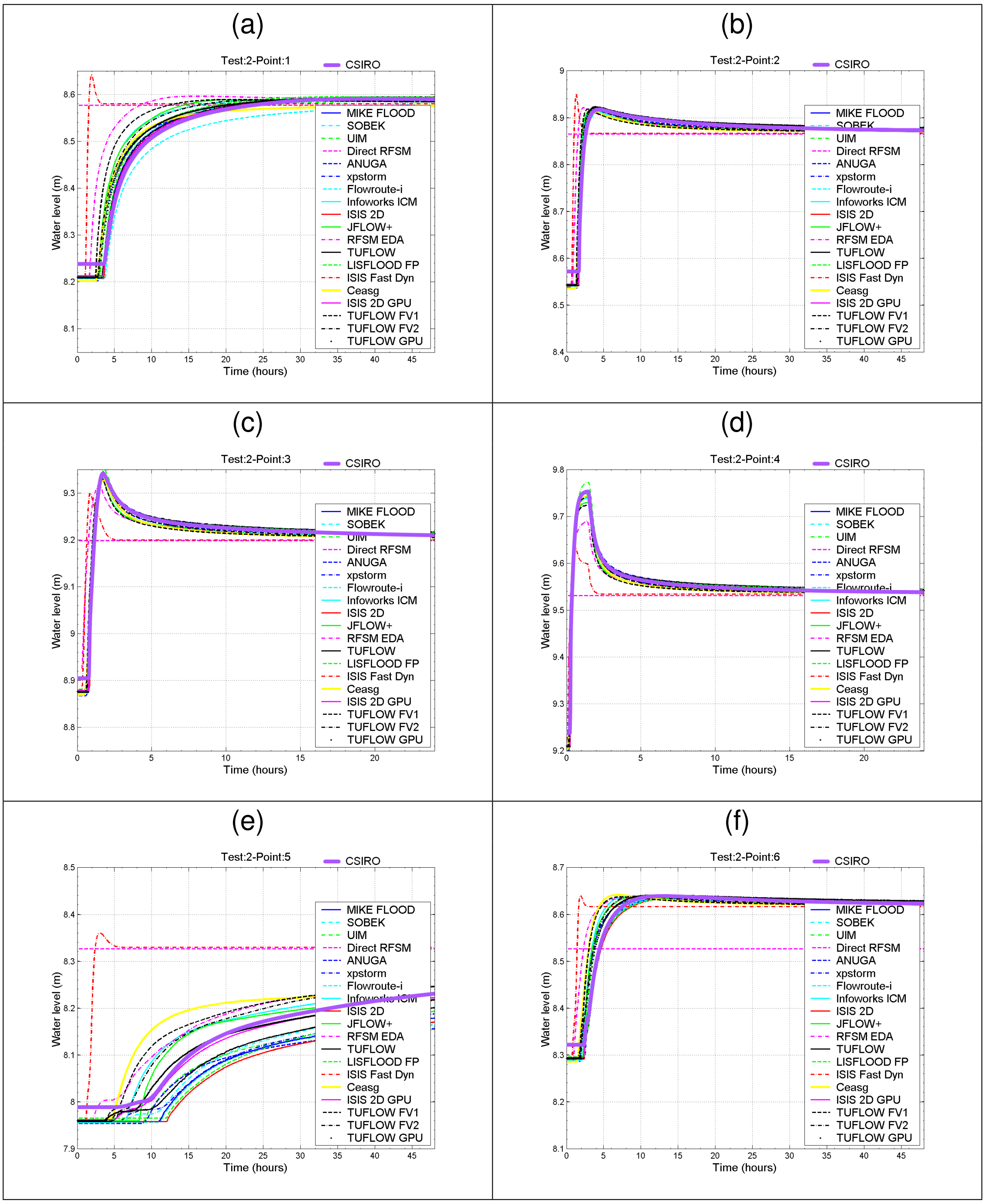

Figure 3.6: Test Case 2: Water heights at: (a) Point 1, (b) Point 2, (c) Point 3, (d) Point 4, (e) Point 5 and (f) Point 6. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

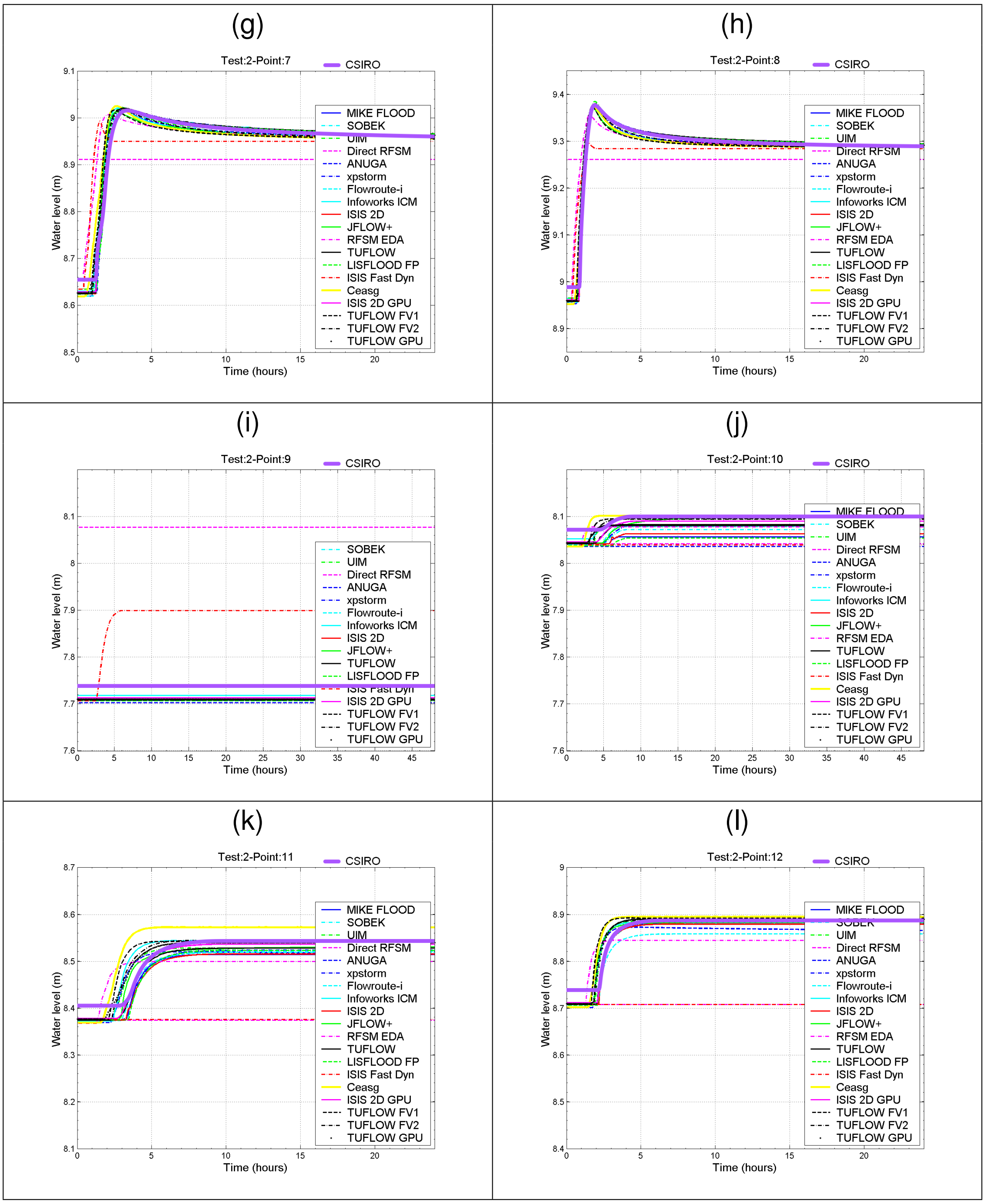

Figure 3.7: Test Case 2: Water heights at: (g) Point 7, (h) Point 8, (i) Point 9, (j) Point 10, (k) Point 11, and (l) Point 12. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

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3.3 Test Case 3 - Momentum conservation over a small obstruction

3.3.1 Problem description

The domain for this test case is shown in Fig. 3.8. This consists of a rectangular region with two troughs at the bottom of a valley. A volume inflow rate (in m/s^3) is specified along the left boundary. Like test case 2, this incomplete specification meant that an arbitrary choice of Froude number of 1 was chosen to be used.

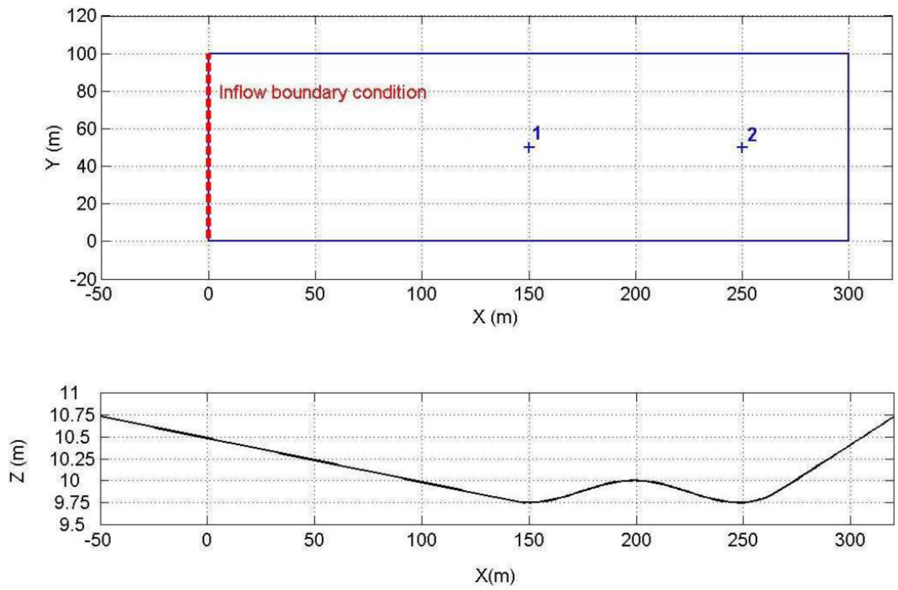

Figure 3.8: Test Case 3: Domain. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

The objective of this test case is stated as:

> *The objective of the test is to assess the packages ability to conserve momentum over an obstruction in the topography. This capability is important when simulating sewer or pluvial flooding in urbanised floodplains. The barrier to flow in the channel is designed to differentiate the performance of packages without inertia terms and 2D hydrodynamic packages with inertia terms. With inertia terms some of the flood water will pass over the obstruction.*

3.3.2 Results

The volume flow rate and total volume and for this test case is shown in Fig. 3.9. The simulation volume inflow rate does not perfectly match the inflow rate rate from the specification, although the final fluid volume (1353 L) is only slightly higher than the specification is (1310 L). The heights of the water at gauge point 1 (Fig. 3.10a) has good agreement with the results from the other solvers. The water height at gauge point 2 (Fig. 3.10b) is higher than for all other solvers except ISIS 2D. Finally, the water speed at point 1 (Fig. 3.11) is similar to most other solvers except ”ISIS 2D” and ”Flowroute-i”. These differences in values at the gauge points can be partly attributed to the ambiguity in the specification of the inflow conditions.

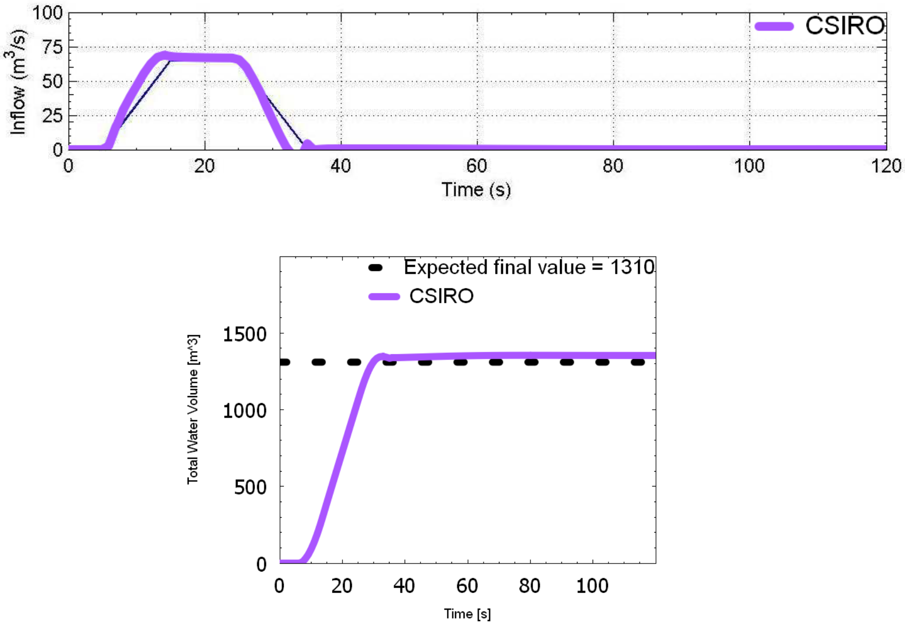

Figure 3.9: Test Case 3: (a) Volume flow rate into the domain as specified by the test case and measured in the present simulation, and (b) total volume of fluid in the domain. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

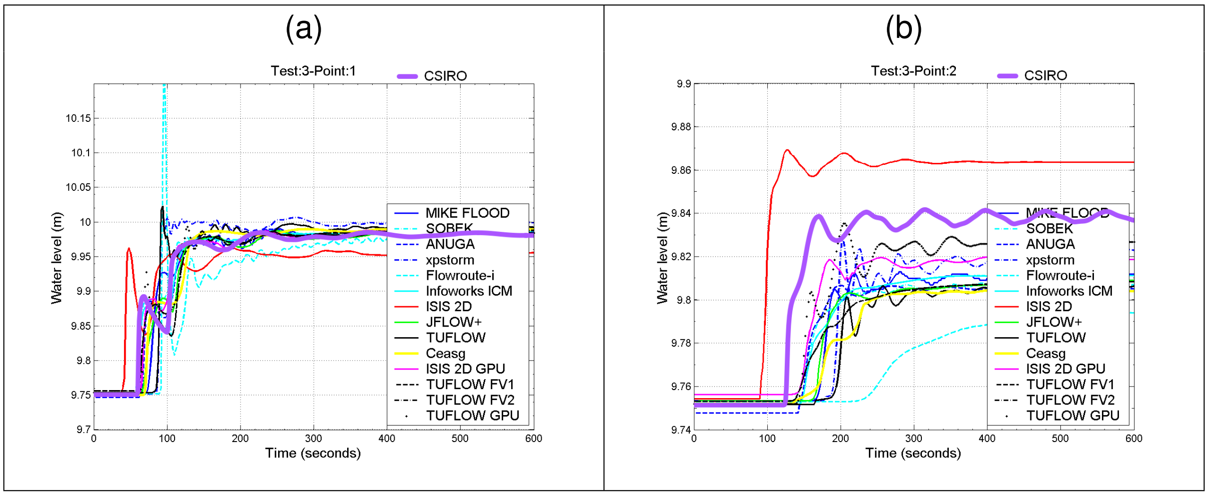

Figure 3.10: Test Case 3: Water heights at: (a) Point 1 and (b) Point 2. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

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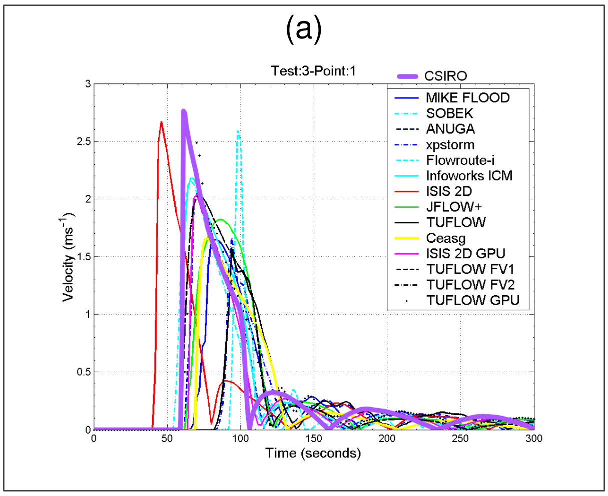

Figure 3.11: Test Case 3: Water velocities at: (a) Point 1. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

3.4 Test Case 4 - Speed of flood propagation over an extended floodplain

3.4.1 Problem description

The domain for this test case (Fig. 3.12) consists of a flat rectangular domain with a solid wall boundary conditions along the four sides. There is a source with a specified volume inflow rate in the middle of the left boundary. Six gauge points are shown on the domain.

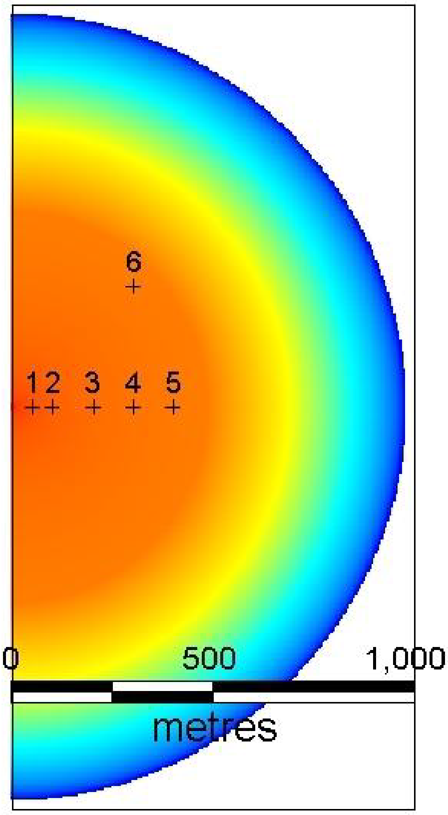

Figure 3.12: Test Case 4: Domain. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

The objective of this test case is stated as:

> *The objective of the test is to assess the packages ability to simulate the celerity of propagation of a flood wave and predict transient velocities and depths at the leading edge of the advancing flood front. It is relevant to fluvial and coastal inundation resulting from breached embankments.*

3.4.2 Results

The measured volume inflow for this test case (Fig. 3.13) shows slight differences to the problem description. The heights of the water at each of these gauge points (Fig. 3.14 and Fig. 3.15) compare very well to the other simulation results. Finally, contours of water heights and profiles of water heights and speed (Fig. 3.16) also compare well to the other solver results.

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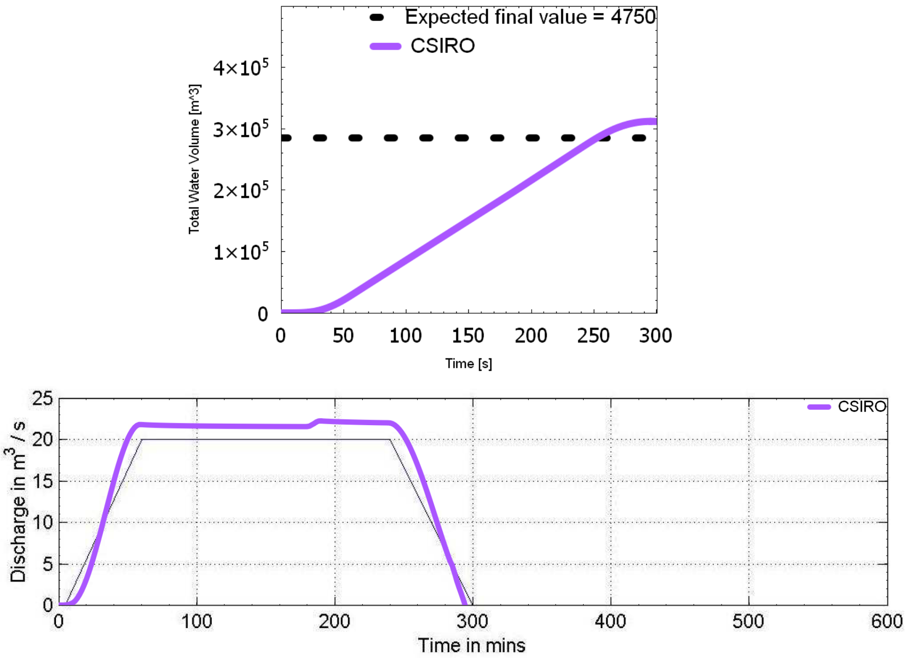

Figure 3.13: Test Case 4: Volume and volume change in the domain. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

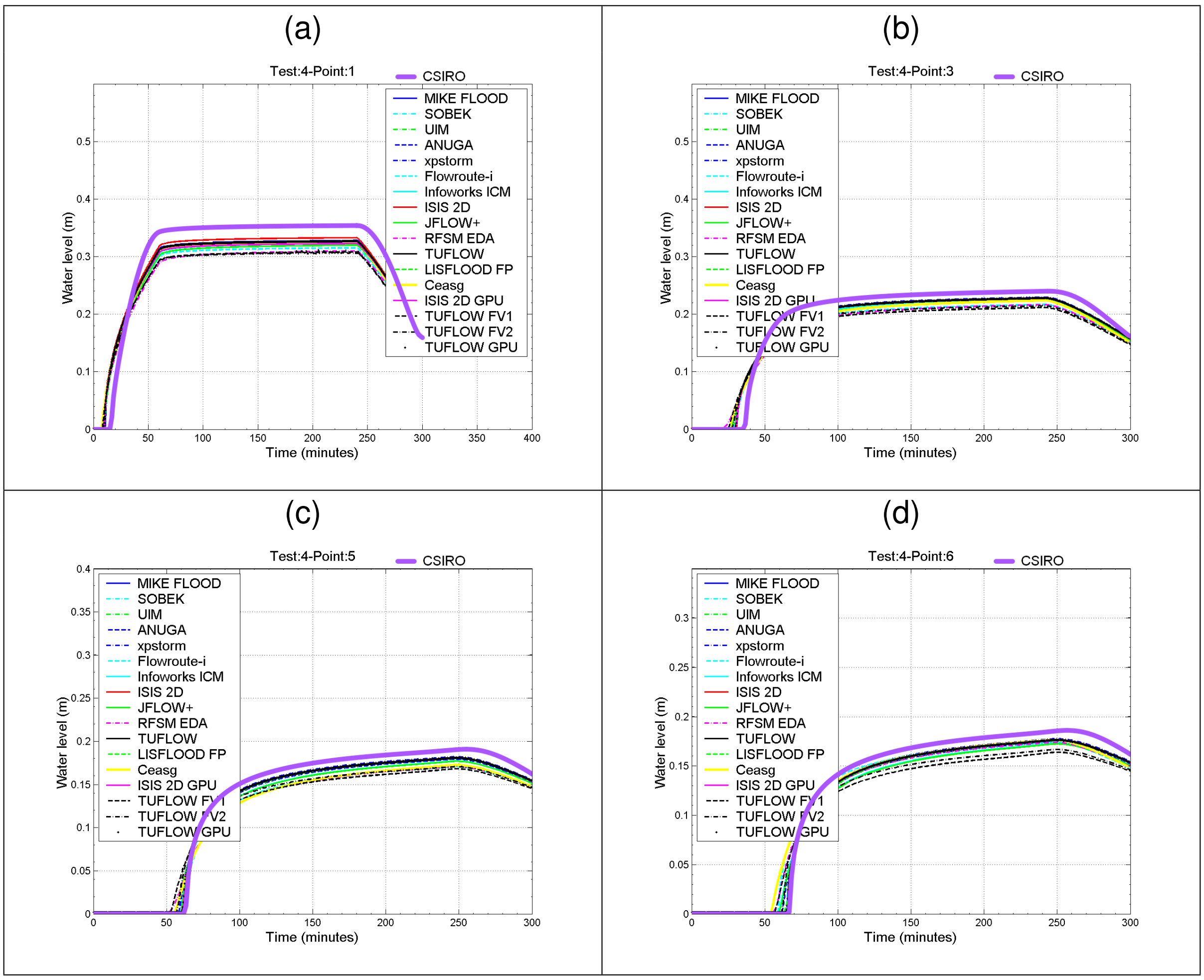

Figure 3.14: Test Case 4: Water heights at: (a) Point 1, (b) Point 3, (c) Point 5 and (d) Point 6. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

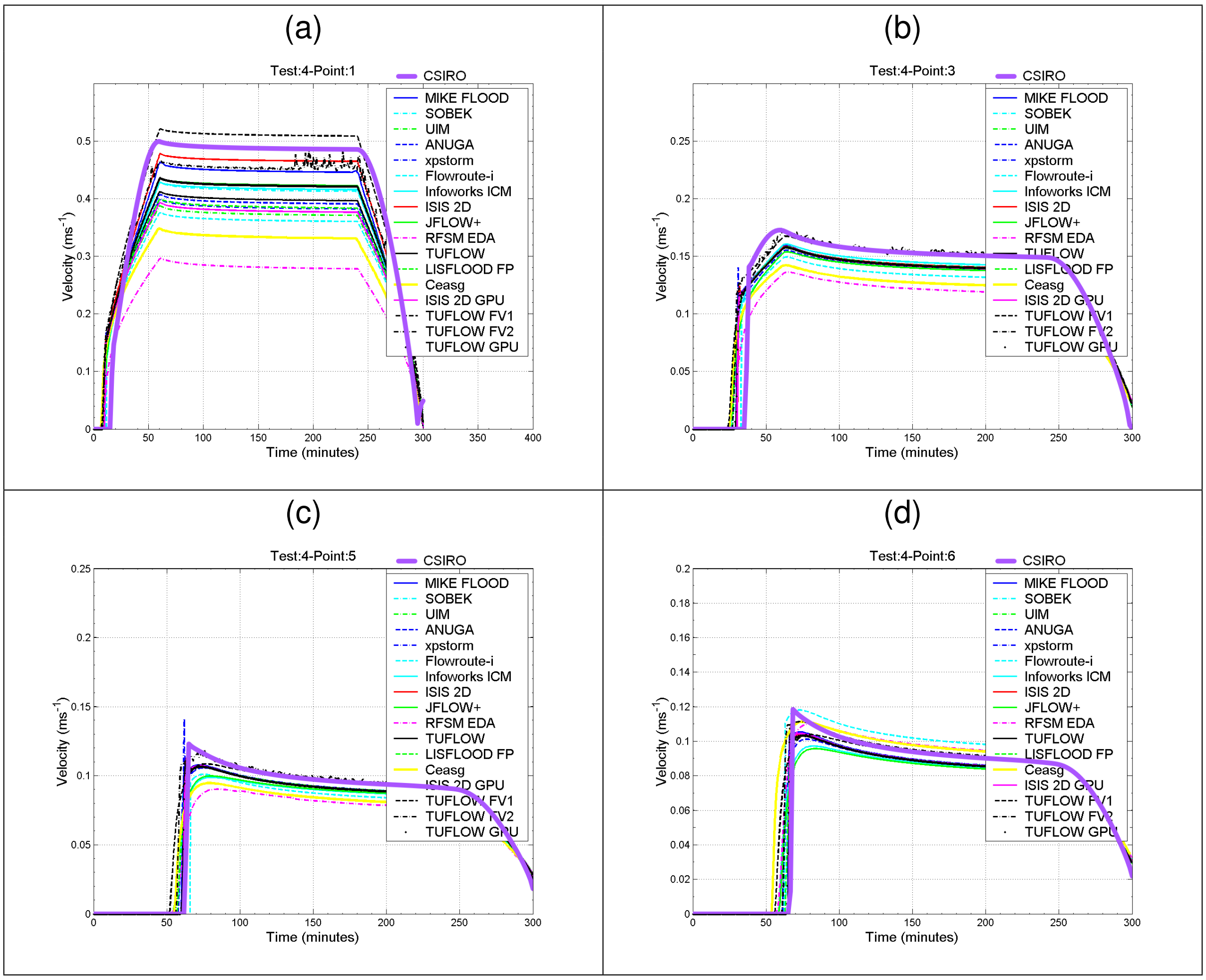

Figure 3.15: Test Case 4: Water velocities at: (a) Point 1, (b) Point 3, (c) Point 5 and (d) Point 6. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

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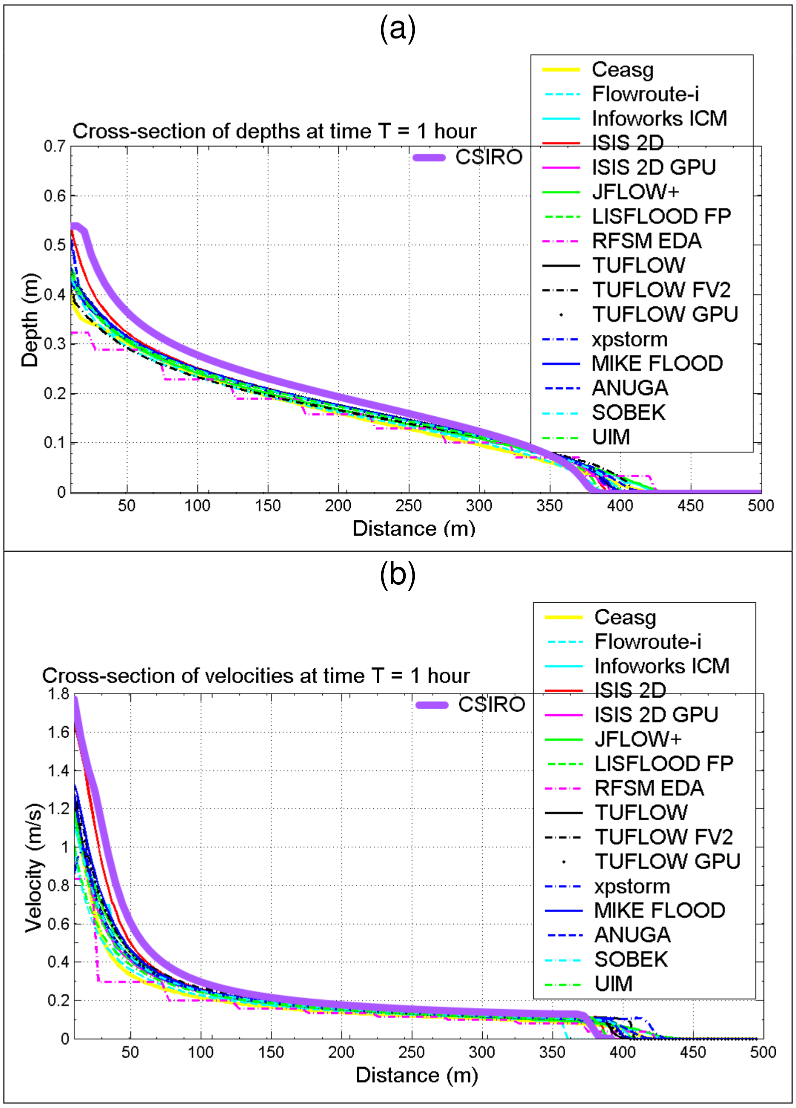

Figure 3.16: Test Case 4: (a) Profile of water height at time of 1 hour; and (b) Profile of water speed at time of 1 hour. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

3.5 Test Case 5 - Valley flooding

3.5.1 Problem description

The domain for this test case (Fig. 3.17) consists of an empty river bed with a volume inflow in the lower left hand corner. Also shown is the river bed height profile.

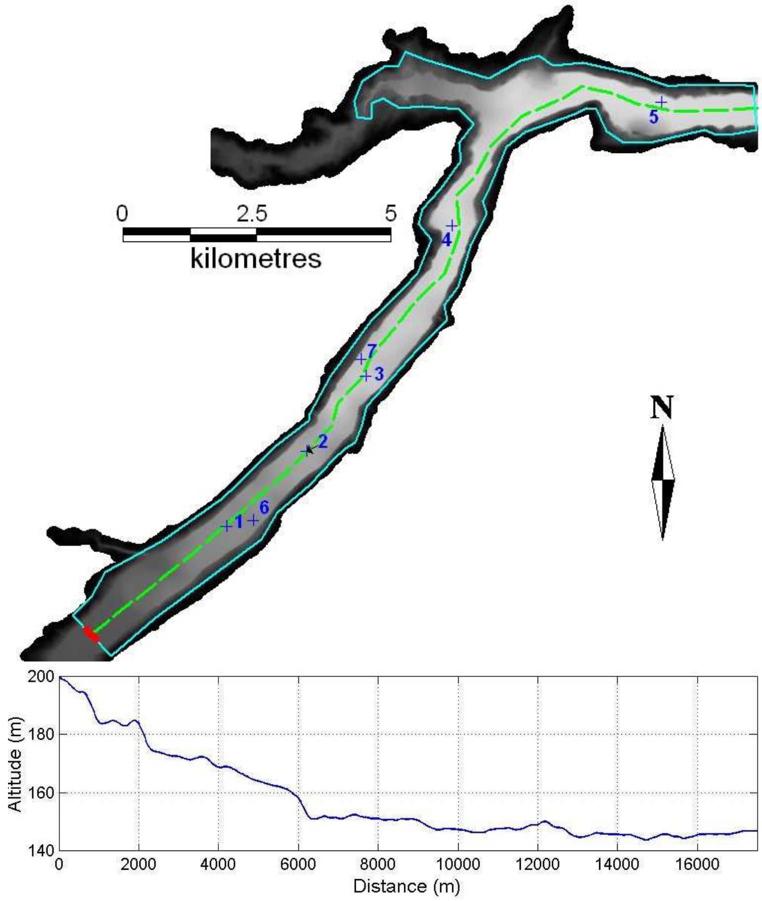

Figure 3.17: Test Case 5: Domain and elevation profile

The objective of this test case is stated as:

> *This tests a packages capability to simulate major flood inundation and predict flood hazard arising from dam failure (peak levels, velocities and travel times).*

3.5.2 Results

The volume flow rate (Fig. 3.18) is close to the test case specifications. Time histories of gauge point water levels and speeds (Fig. 3.19) are in close agreement with the other solvers. Finally, profiles of peak water heights and peak water speeds (Fig. 3.20) are in good agreement with the other solvers. Note that this simulation was run at the finer 10 metre resolution rather than the specified resolution of 50 m.

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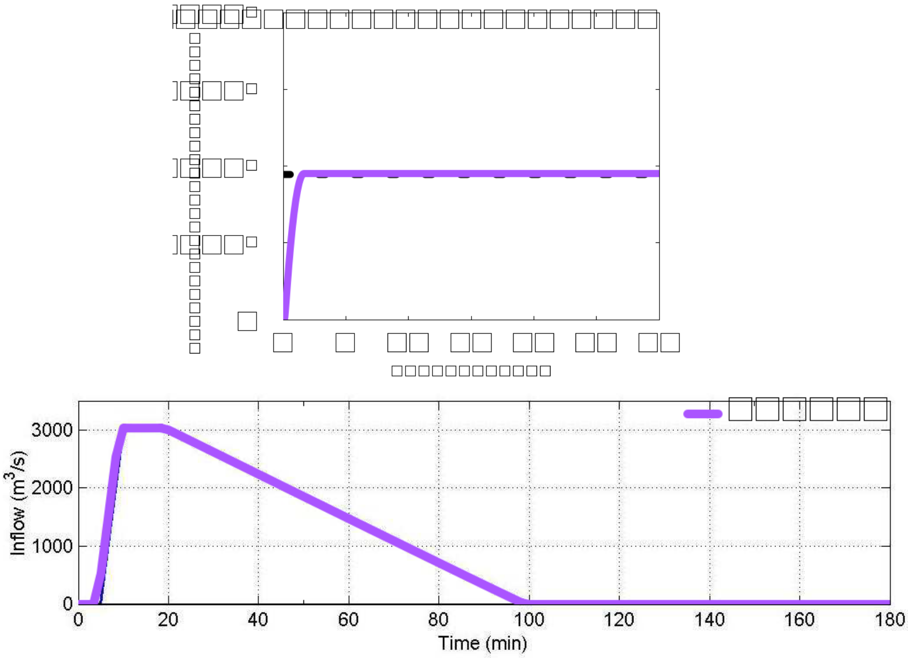

Figure 3.18: Test Case 5: Volume and volume change in the domain.

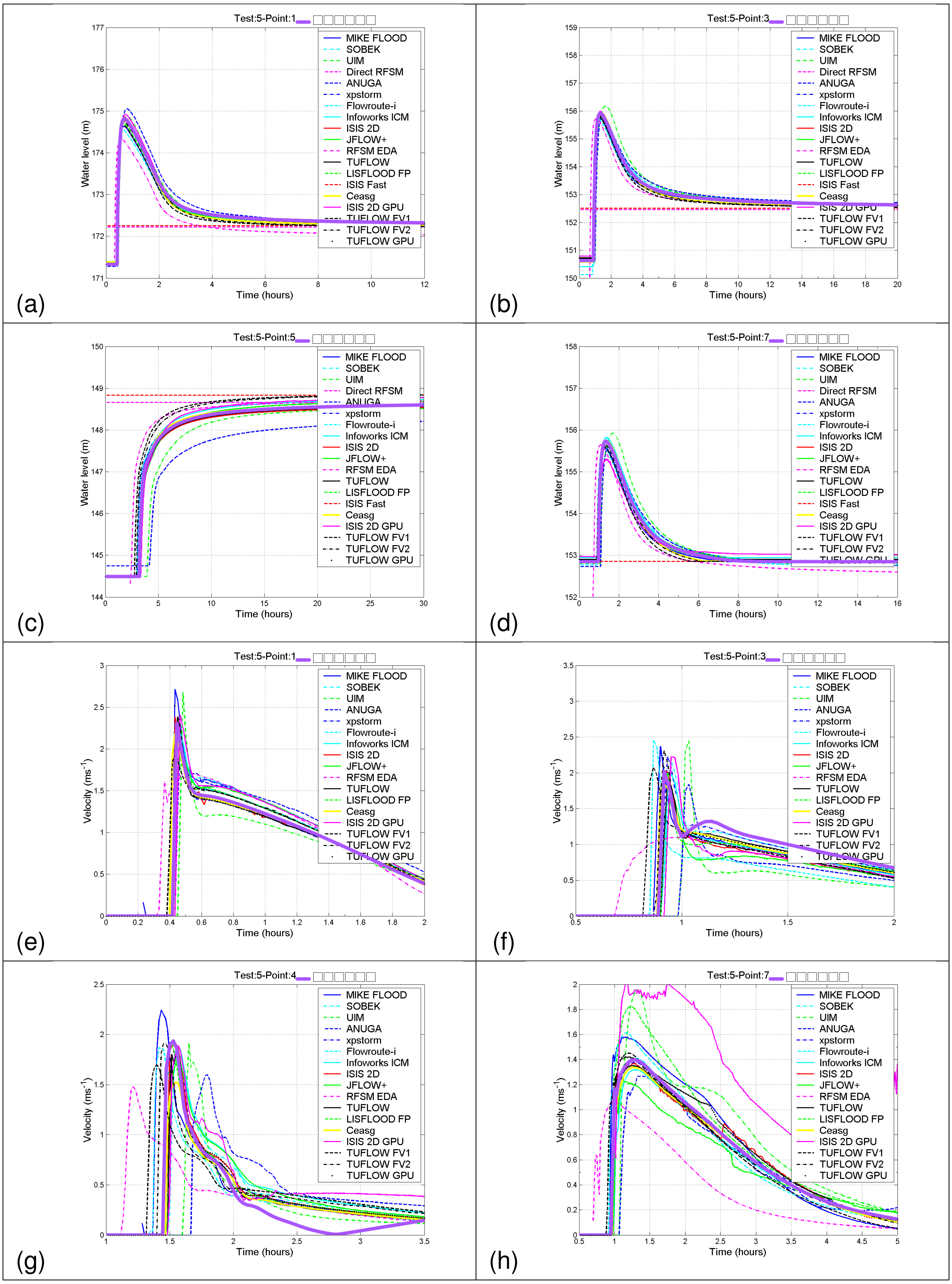

Figure 3.19: Test Case 5: Water heights at (a) Point 1, (b) Point 3, (c) Point 5, and (d) Point 7. Water velocities at (e) Point 1, (f) Point 3, (g) Point 4, and (h) Point 7.

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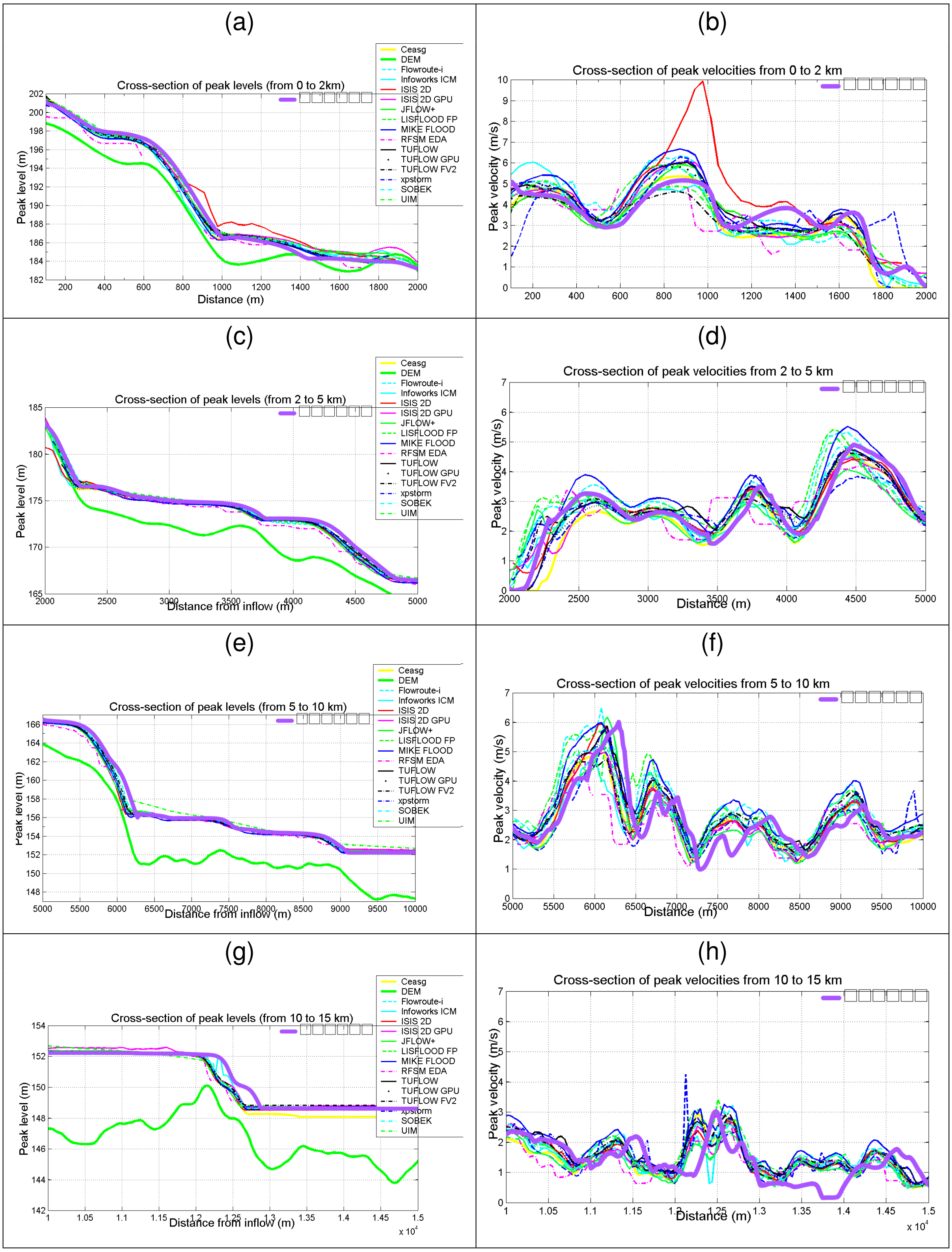

Figure 3.20: Test Case 5: Maximum water height and maximum water speed along the centre of the valley.

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3.6 Test Case 6 - Dam Break

3.6.1 Problem description

This problem involves a dam break from a reservoir on the left side of the domain (Fig. 3.21) which flows on to hit an oblique rectangular object. The test points used to compare against other solvers are:

- Points 1 and 2: In front of the rectangular object.
- Points 3, 4 and 5: To the sides and behind the rectangular object.
- Point 6: Inside the reservoir.

The domain for both test cases are identical except that test case 6B is scaled to be twenty times larger.

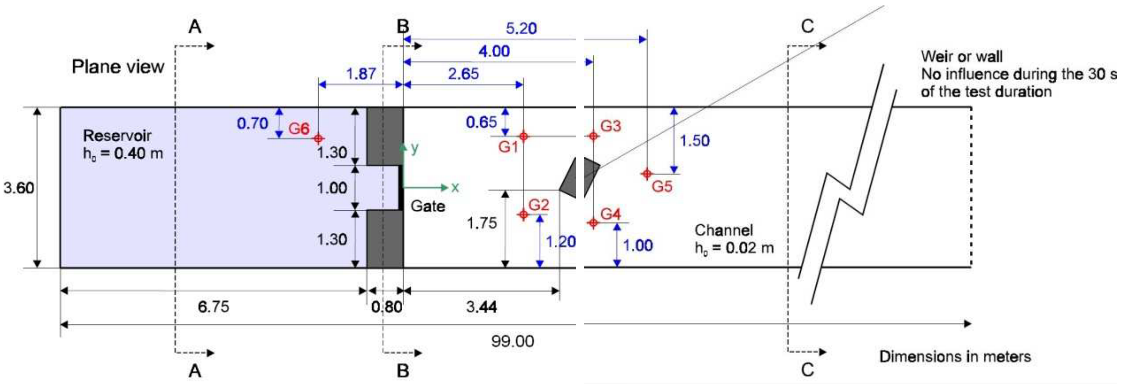

Figure 3.21: Test Case 6A: Domain. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

The objective of this test is stated to be:

> *This tests the capability of each package to correctly simulate hydraulic jumps and wake zones behind buildings using high-resolution modelling.*

3.6.2 Results - Test A - Laboratory scale

Gauge heights at the test points (Fig. 3.22) are in good agreement with the other solvers.

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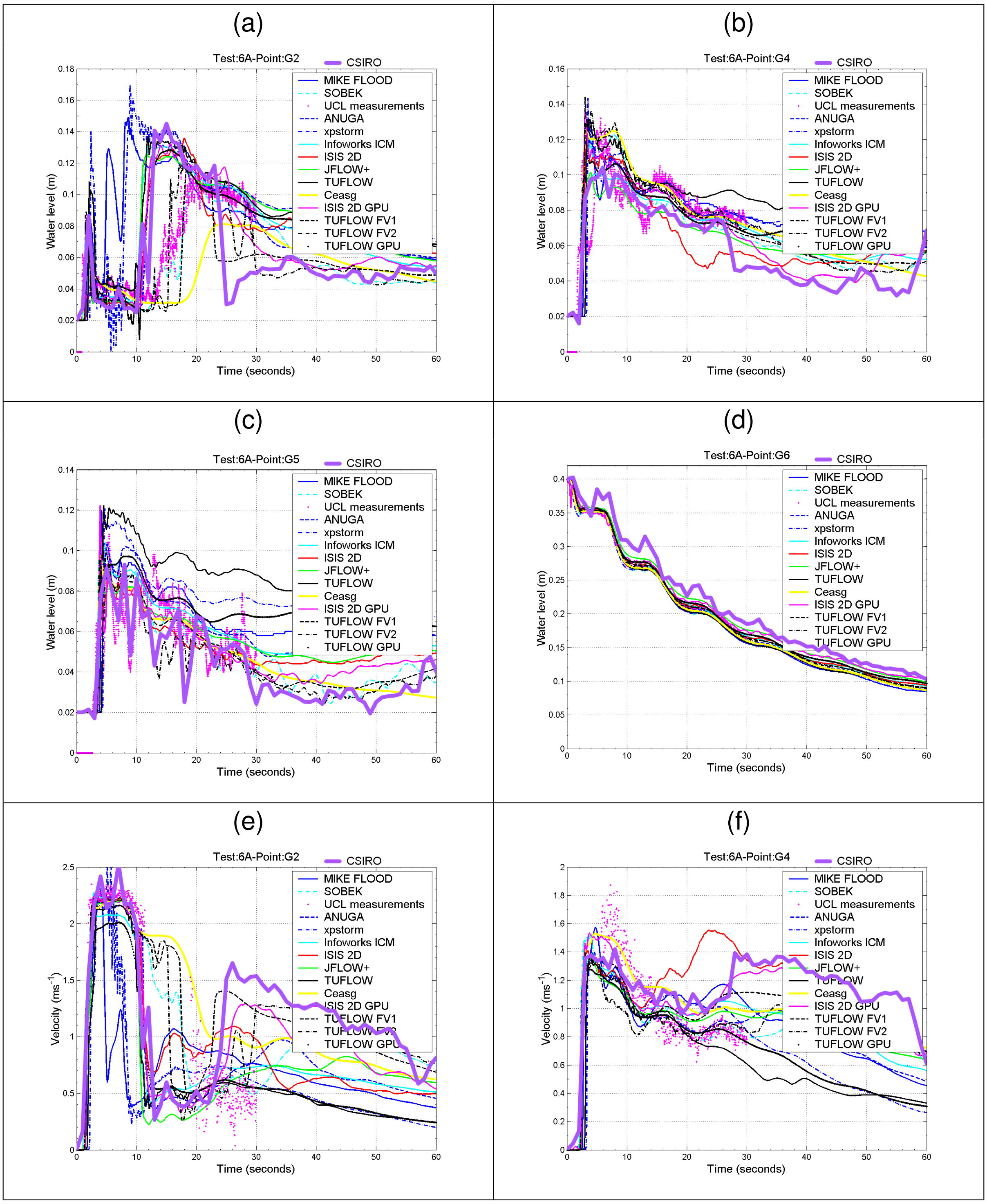

Figure 3.22: Test Case 6A: Water heights at (a) Point 2, (b) Point 4, (c) Point 5, and (d) Point 6. Water velocities at (e) Point 2, and (f) Point 4. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

3.6.3 Results - Test B - Field scale

Gauge heights at and velocities some of the test points (Fig. 3.23) are in good agreement with the other solvers. Peak heights and peak speeds along two profiles (Fig. 3.24) are also in good agreement with the other solvers.

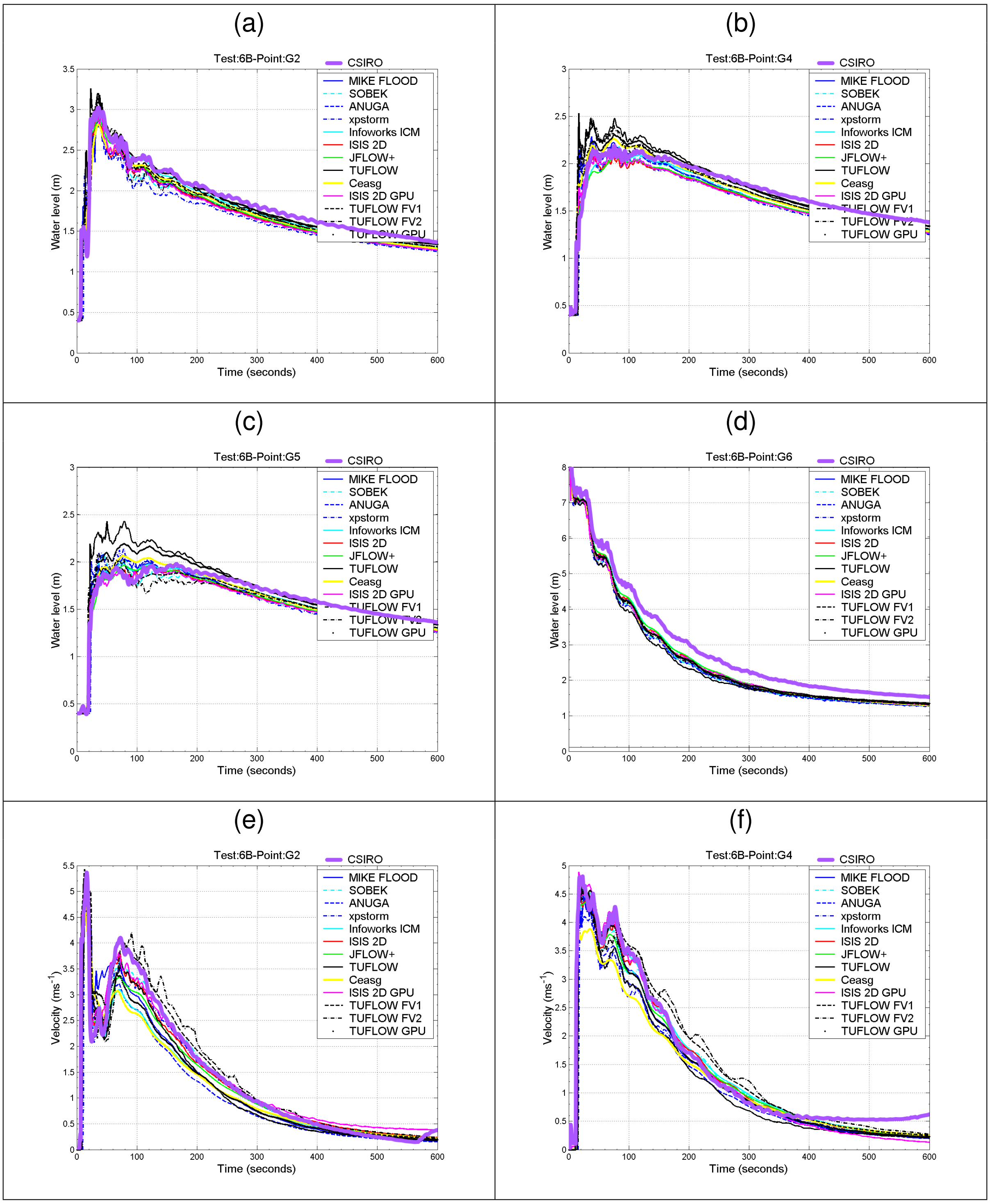

Figure 3.23: Test Case 6B: Water heights at (a) Point 2, (b) Point 4, (c) Point 5, and (d) Point 6. Water velocities at (e) Point 2, and (f) Point 4. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

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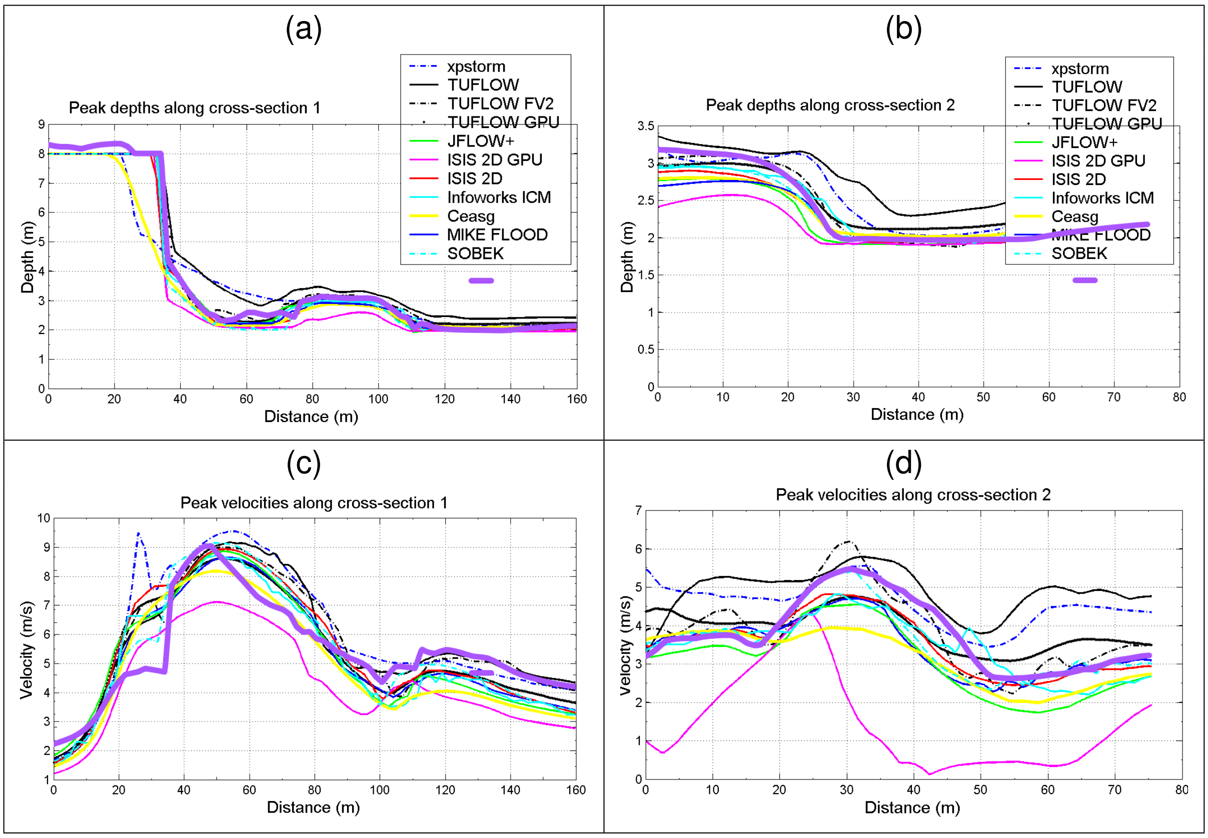

Figure 3.24: Test Case 6B: Maximum water heights along (a) Profile 1, and (b) Profile 2; and maximum water speed along (c) Profile 1, and (d) Profile 2. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

3.7 Test Case 8A - Rainfall and point source surface flow in urban areas

3.7.1 Problem description

The domain for this test case (Fig. 3.25) consists of a rectangular domain with road sections having different Mannings drag values to the rest of the domain. This domain is subjected to water inputs from both rainfall and from a point source.

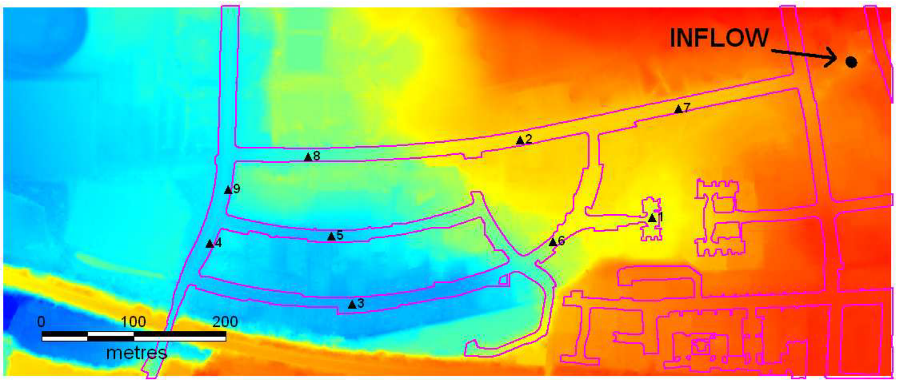

Figure 3.25: Test Case 8A: Domain. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

The objective of this test case is stated as:

> *This tests the packages capability to simulate shallow inundation originating from a point source and from rainfall applied directly to the model grid, at relatively high resolution.*

3.7.2 Results

The total fluid volume within the domain and the rate of change of fluid volume within the domain are shown in Fig. 3.26. Time histories of heights and speeds at several gauge points (Fig. 3.27) are in good agreement with the other solvers.

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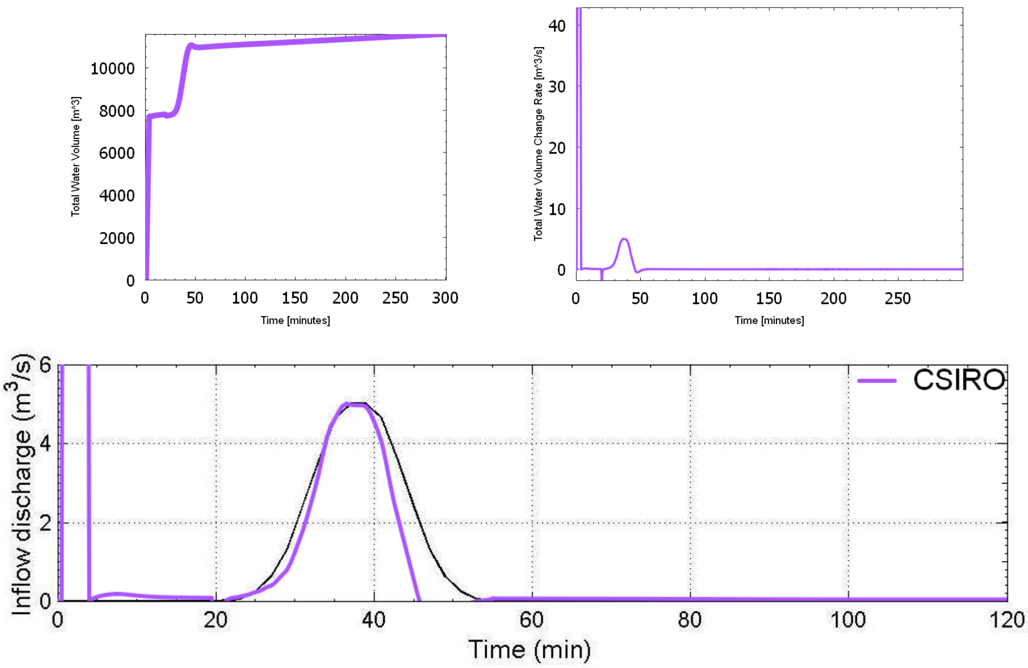

Figure 3.26: Test Case 8A: Volume and volume change in the domain. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

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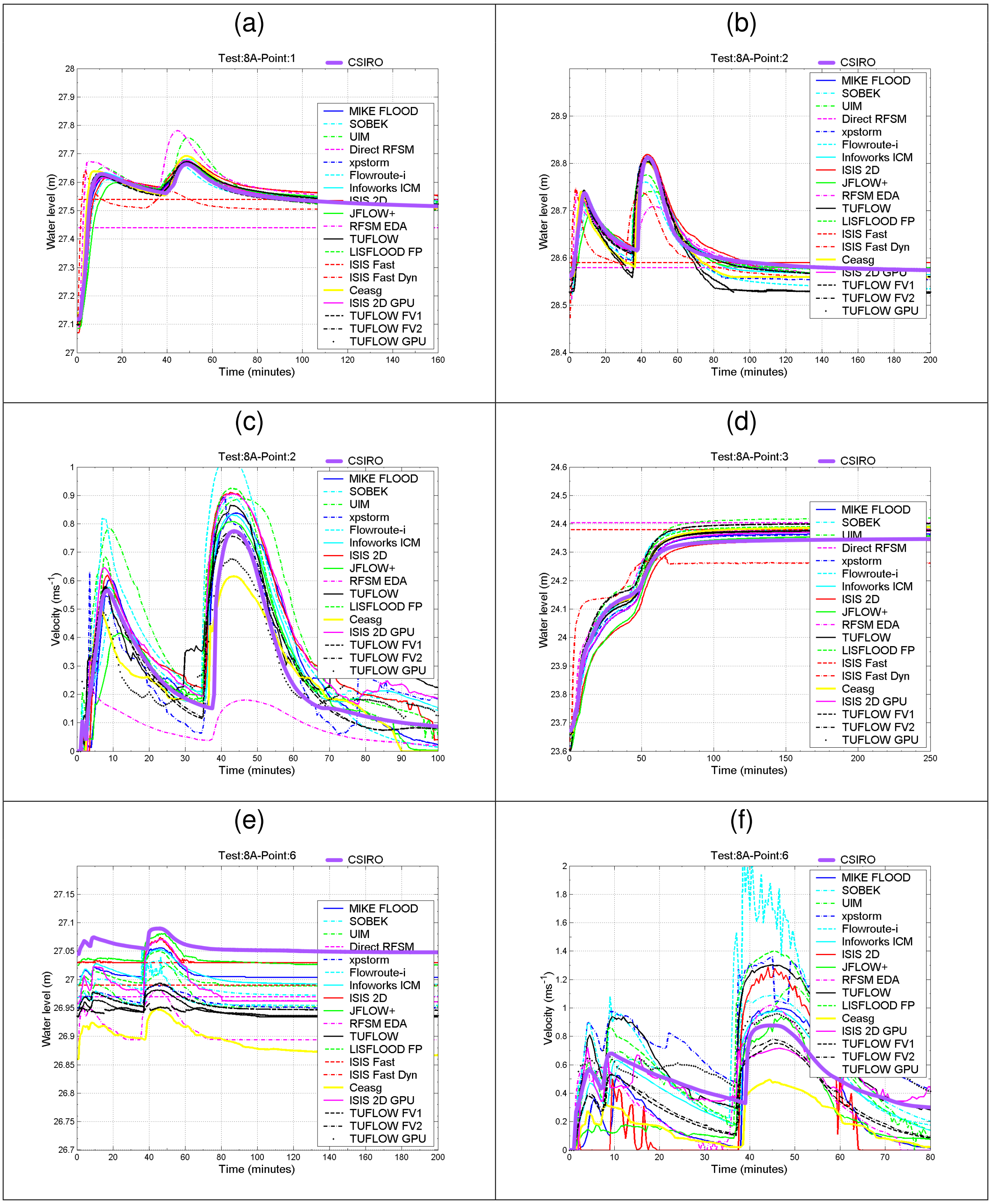

Figure 3.27: Test Case 8A: Water heights and speeds. Image(s) courtesy of UKEA Benchmark Report (Nelz and Pender [2013]).

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4 Conclusions

The CSIRO Swift flood modelling tool does an excellent job of modelling many critical aspects of flooding that are tested by the UKEA Benchmark test cases. This provides confidence in the future use of the Swift software for industrial modelling problems.

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