Opanuku Stream Benchmark Validation

1. Introduction

The model accuracy benchmark published by the Flood Risk Management Committee of the IAHR in http://members.iahr.org/iMIS/CommunityManagement/CommunityLayouts/Flood_Risk_Management.aspx?iUniformKey=172dbcf0-3138-42fe-8a17-7ba5b7f72e99 had requirements stated for Validation.

Also the following statement was included in the instructions: "Note this benchmark has been validated by a published demonstration of compliance using the Chézy formula as the base resistance model. Hydrological computations used a simple kinematic wave rainfall/runoff model."

The specified successful validation was performed on the *AULOS* Package developed by HYDRA Software Ltd, and this document now presents an updated collation of the various literature covering that validation over the last ten years.

2. The Opanuku Stream Model

The benchmark dataset derived from one of the most intensively monitored river reaches in the urban territory of the Auckland Council, New Zealand. At the upstream section, the Border Road bridge, the water level is monitored continuously by a recorder. At the downstream section, the Vintage Reserve footbridge, the water level is also monitored continuously. In addition, the discharge has been gauged there repeatedly over almost 20 years under a range of conditions, including steady flow and rising and falling flood flows.

The model files listed in Appendix A specify cross-sections from distance 3.429 km at the Border Road bridge to 4.798 km at the Vintage Reserve footbridge, and thereafter a short distance downstream to the last measured section at distance 4.839 km. As a precaution, a further extension downstream from distance 4.839 km to 5.100 km was extrapolated to ensure that backwater effects of any downstream boundary error would not intrude into the study reach upstream of the Vintage Reserve footbridge. Although no surveyed cross-section data was available in this extrapolation zone, Lidar information was considered sufficient to support the lesser accuracy required for extrapolation of the channel bed.

Figure 1 indicates the layout of the *AULOS* cross-sections. Note the background aerial photograph has been blanked out below the 10m contour, providing clear space for superimposing a plot of channel depth contours at various stages of the flood. An initial low flow stage is shown.

The schematised channel axis is shown in dark blue, with nodes shown as diamond shapes, also dark blue. Most of the nodes simply signal the position of the surveyed cross-sections as supplied with the benchmark dataset. Outside the low flow channel, sections were extracted from the Lidar terrain model using the *AULOS* editor. The cross-section survey was preferred for the low flow channel, as Lidar readings have problems where water was covering the bed during the Lidar measurements. As seen in Figure 1, the initial low flow channel appears as a series of disconnected pools because for this plot the channel bed terrain surface was derived from Lidar, picking up the water surface rather than the underlying channel thalweg at the time of survey.

To improve accuracy of the scalar 3D numerical volume integration where significant longitudinal curvature of the water surface profile might be anticipated at times, low flow sections were interpolated where necessary using AULOS hydraulic interpolation routines.

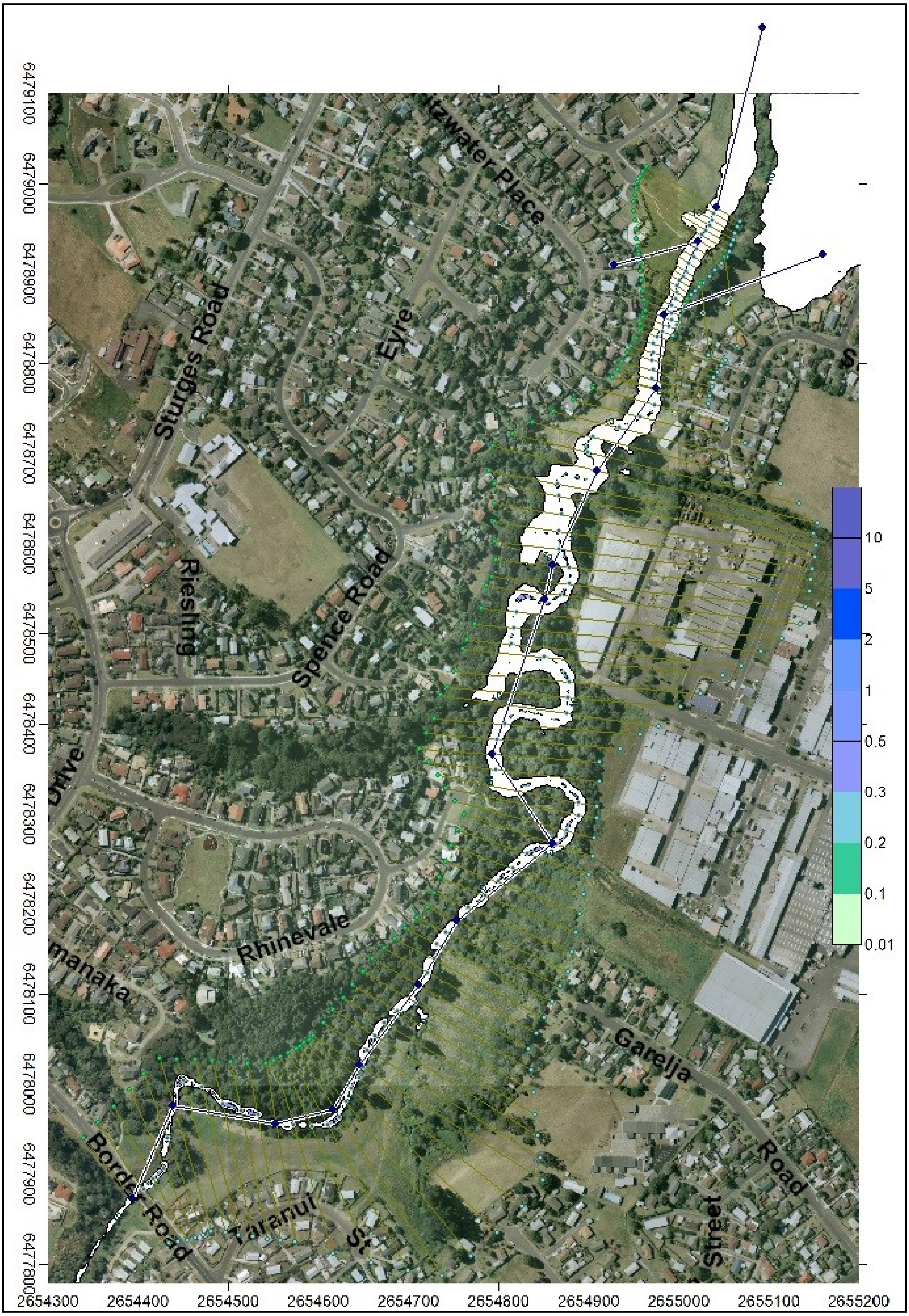

Figure 1. AULOS Model Cross-Sections along the Test Reach

Use of the standard channel chainages (distances) supplied with the benchmark could not be continued, as these apparently relate to measurements along the low flow channel, which takes several sharp turns within a more gradually curved floodplain. For modelling purposes, the distance between cross-sections must be measured perpendicular to the cross-sections if accurate volume balances are to be maintained. This distance is significantly less than the surveyed chainage differences where the low flow channel is oblique to the cross-sections, which required to be set up to represent the floodplain to cover high flow events as well as low flows.

As a result, it was necessary to modify the river chainages in the lower half of the pictured area, where the low flow channel was not approximately straight. The standard and revised chainages are given in Table 1.

Table 1

Standard chainages vs Revised model chainages

Standard Chainage (km)	Revised chainage (km)
3.114	3.429
3.233	3.529
3.375	3.645
3.446	3.711
3.503	3.776
3.615	3.886
3.699	3.968
3.841	4.081
4.033	4.174
4.318	4.356
4.357	4.395
4.506	4.511
4.624	4.624

Downstream from chainage 4.624km the chainages are as in the original benchmark dataset. Note this reduces the length of the reach from Border Road to Vintage Reserve (chainage 4.798km) by 315m to 1.369 km, and the slope between ends accordingly increases.

An overland flow branch leaves the right of the main channel from the node at chainage 4.706km where there is a low point on the right bank. However after some model experimentation, minimal flow was found over this low point during the highest floods in the period of record, and as no significant overflows had been noticed in the field either, this branch was disabled.

More important was the short stub tributary joining the node at chainage 4.798km (Vintage Reserve) from the left of the channel. This insertion was required to allow the level boundary condition to be applied at the position of the downstream level recorder. Under the rules applying to external boundary nodes, specification of the level here meant that the discharge hydrograph through this nominal tributary had to be computed as part of the model solution.

3. Accuracy Benchmark Compliance

To establish compliance with the published IAHR Flood Risk Management Committee accuracy benchmark, applicants were required to provide for at least one of the two specified floods (2006 and 2008) the following plotted evidence of successful model results:

1. A match within measurement accuracy between modelled and observed level hydrographs at the upstream and downstream ends of the test reach.
2. A match within measurement accuracy between the model stage/discharge curve at the downstream cross-section and the observed gauging points there. Note the model discharge hydrograph must finally be derived by calibration of the resistance model.
3. A match within hydrological modelling accuracy between the model lateral channel inflow and the runoff hydrograph derived by rainfall/runoff modelling from observed rainfall records. (Note the "lateral channel inflow" is that deduced as the residual hydrograph obtained throughout the flood by adding downstream discharge to rate of change in reach volume, then subtracting the upstream inflow. This upstream inflow is the discharge through the upstream section, again derived from the calibrated resistance model).

This evidence is provided for the *AULOS* validation in both the 2006 and 2008 floods in the following sections.

3.1 Modelled and Observed Level Hydrographs Upstream and Downstream

The match between modelled (x and + markers) and observed (continuous lines) is plotted for the 2006 flood in Figure 2 and for the 2008 flood in Figure 3. The upstream (Border Road) results are plotted in red and the downstream (Vintage Reserve) results in blue.

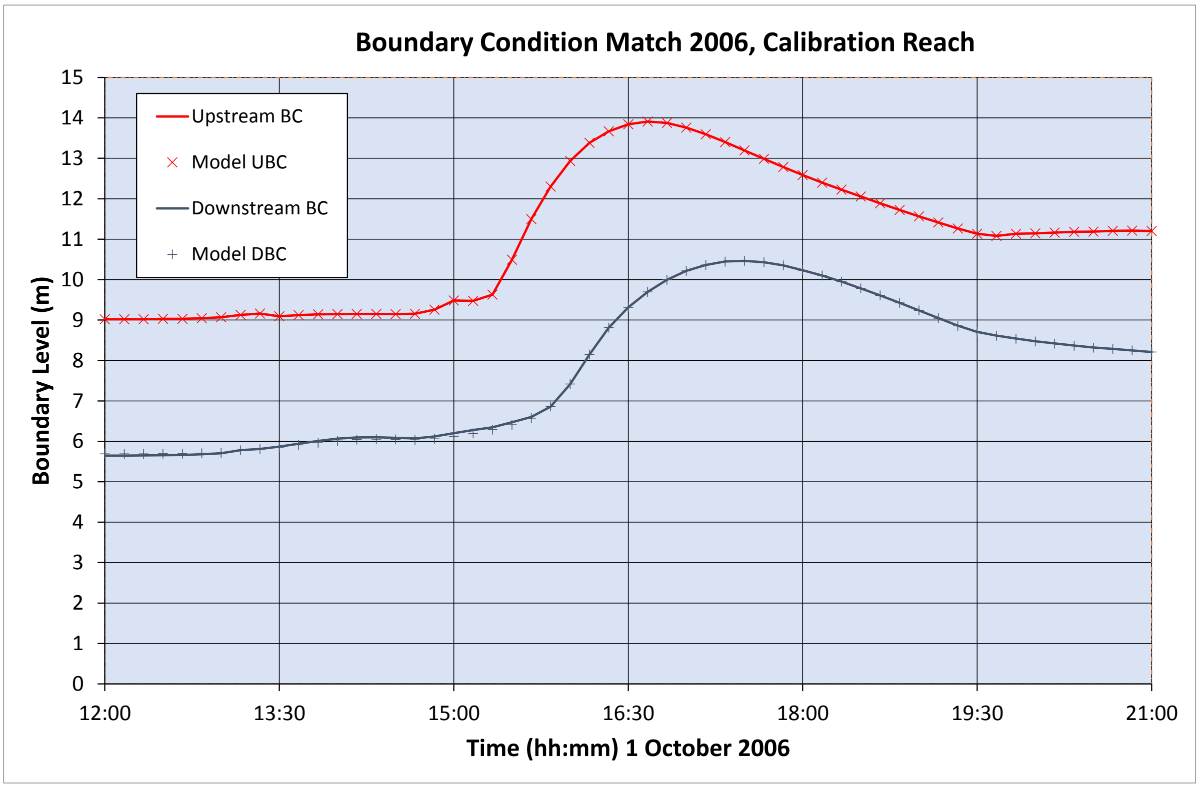

Figure 2. Boundary Condition Match for Recorded and Modelled 2006 Flood Level Hydrographs

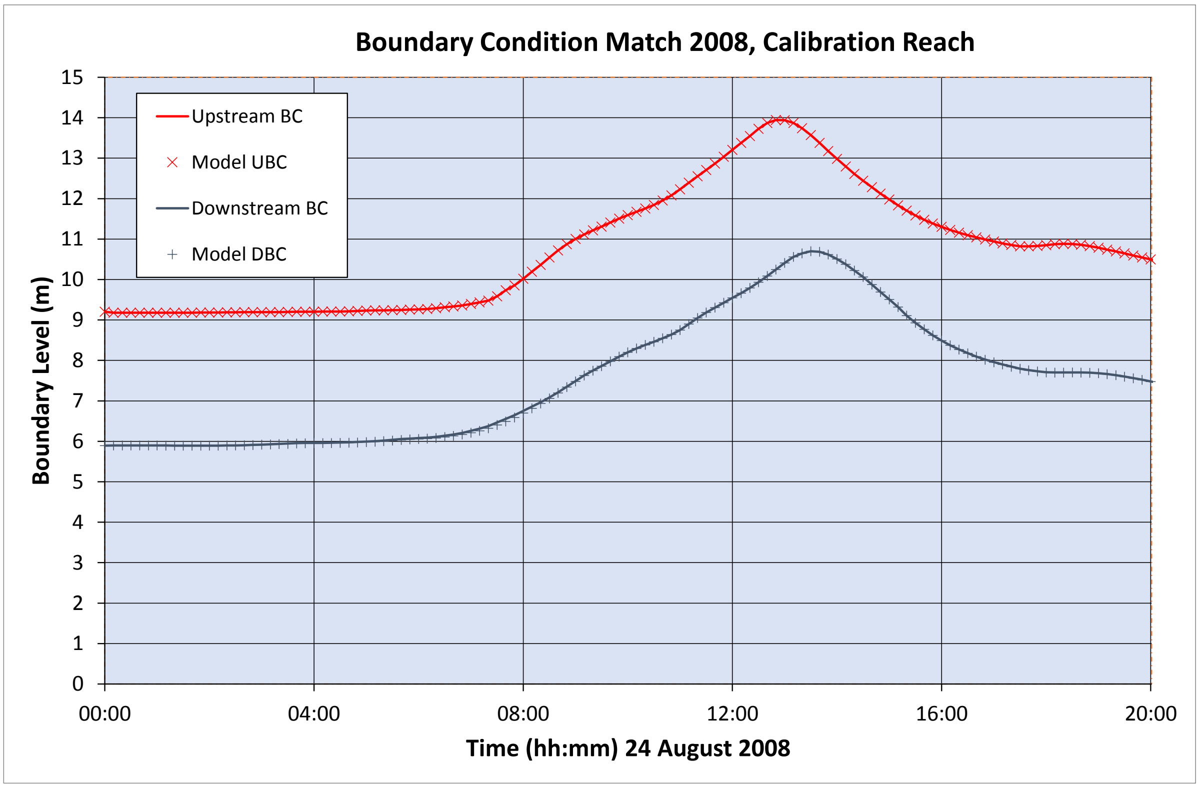

Figure 3. Boundary Condition Match for Recorded and Modelled 2008 Flood Level Hydrographs

For both floods the upstream results are indistinguishable, simply because the observed level hydrographs were applied directly as the model upstream boundary condition. No attempt at applying an upstream flow hydrograph can be expected to result in a comparable match.

However small departures of the order of a few millimetres can be seen at the downstream boundary, where the model + markers fall below the continuous line, particularly at the beginning of the rising flood waves. This is because the observed boundary level hydrograph was applied at the open end of the stub tributary while the model results are plotted on the main channel where the inflow from the stub tributary joins the main flow. The small head loss along this tributary flow could be further reduced by enlarging the cross-section of the nominal tributary, but the match is already considered good enough to satisfy the first compliance criterion.

3.2 Match between Model Stage/Discharge Curve and Observed Gauging Points

The model stage/discharge results are plotted against the observed gauging points in Figure 4. The gauging points are identified by a range of markers according to date of observation, as indicated in the legend, while the model stage/discharge results are plotted as curves: a continuous green line for the 2006 flood results (Run Opa06Y) and a dotted brown line for the 2008 results (Run Opa08Y).

Note the rising limbs of the floods plot below the falling limbs, giving a loop rating in accordance with standard hydraulic theory, and also consistent with the gauged evidence in which the gaugings on a rising limb (marked with a red + sign) fall generally below and to the right of those measured during steady or falling flows. Only a single rising limb gauging was recorded for floods above the 9m level, and this is below and to the right of all the other results at these higher levels. However it is possible that this gauging coincided with an extremely rapidly rising flood, making the corresponding loop wider than for the 2006 and 2008 floods.

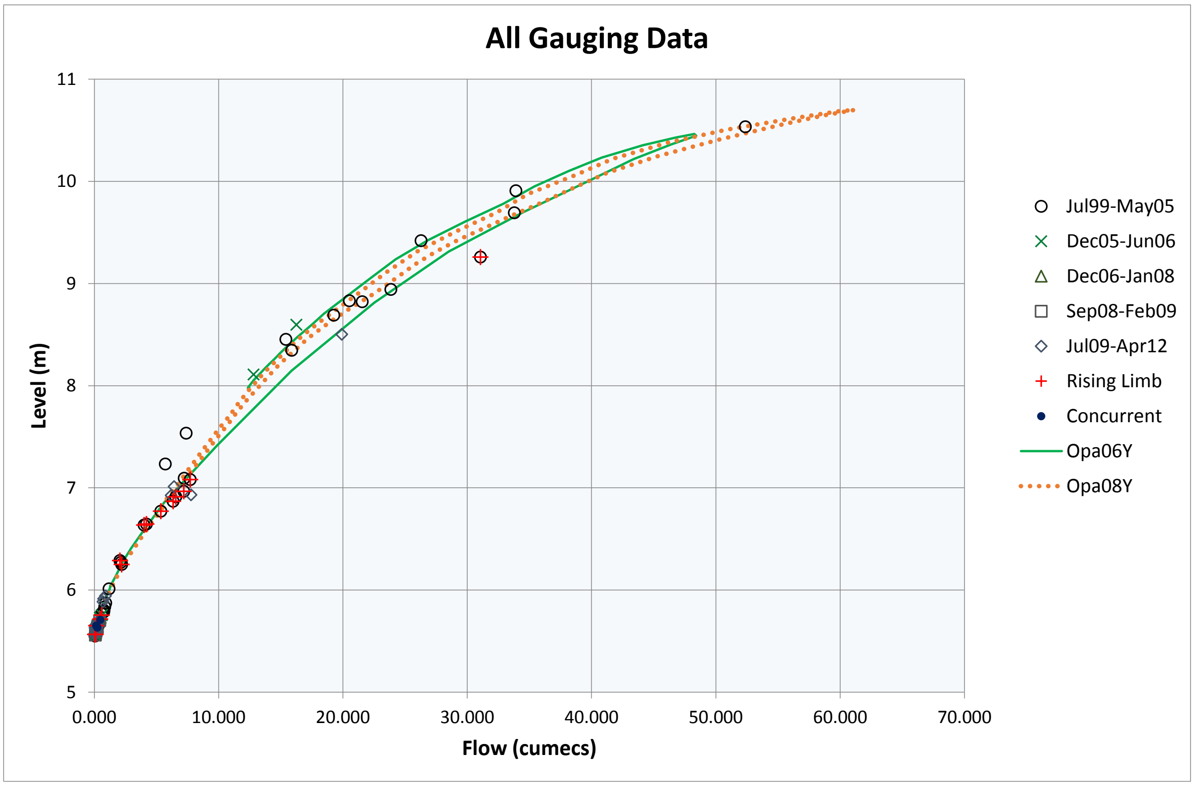

Figure 4. Match between Model Stage/Discharge Curves and Observed Gaugings

The falling limb curve for the 2006 flood lies slightly above and to the left of that for the 2008 flood. This is caused by the use of a base Manning n=0.045 for the model 2006 flood, while that calibrated for the model 2008 flood was n=0.040. This difference is discussed further in the next section.

3.3 Match between Model Lateral Channel Inflow and Rainfall/Runoff Calculations

The match between the lateral channel inflows deduced by hydraulic and hydrological methods is plotted in Figure 5 (2006 flood) and Figure 6 (2008 flood).

The two inflow hydrographs are strictly comparable only to a first order, that is where the total lateral inflows are always significantly smaller than the main stream flow. This is because the hydraulic method computes the difference between flows *arriving* at the gauging station originating from flows entering the upstream end, and flows *leaving* the gauging station which must comply with the observed rating curves. In contrast, rainfall/runoff models estimate inflow hydrographs arriving at the banks on both sides of the river along the full length of the study reach. Depending on the level of detail attempted, the contributing catchment may be divided into several subcatchments, each of which contributes flows arriving at different places at different times. Summation of these flows then becomes difficult, because each will have a different transit time from the point of discharge at the river bank to the gauging station where the hydraulic method counts the inflow.

For these reasons the comparison of hydrographs is best made on the basis of cumulative inflow hydrographs as plotted in Figures 5 and 6. The cumulative rain volumes, plotted as continuous lines, then indicate the total precipitation on the 271 ha catchment based on the rain gauges at the Power NZ and Candia Road sites identified in the published benchmark documentation. These should provide an upper limit to the expected runoff, together with an indication of the uncertainty associated with the selection of rain gauge records.

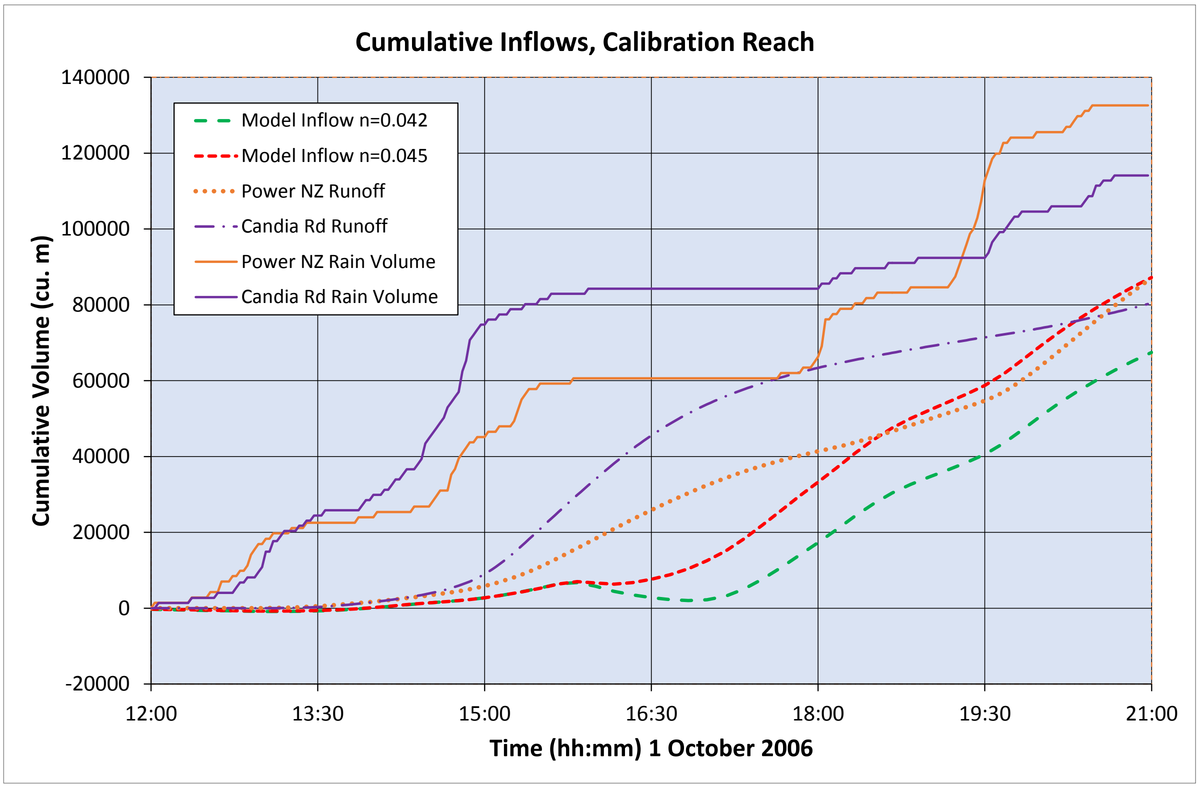

Figure 5. Match between Model Lateral Flows and Rainfall/Runoff Calculations: 2006 Flood

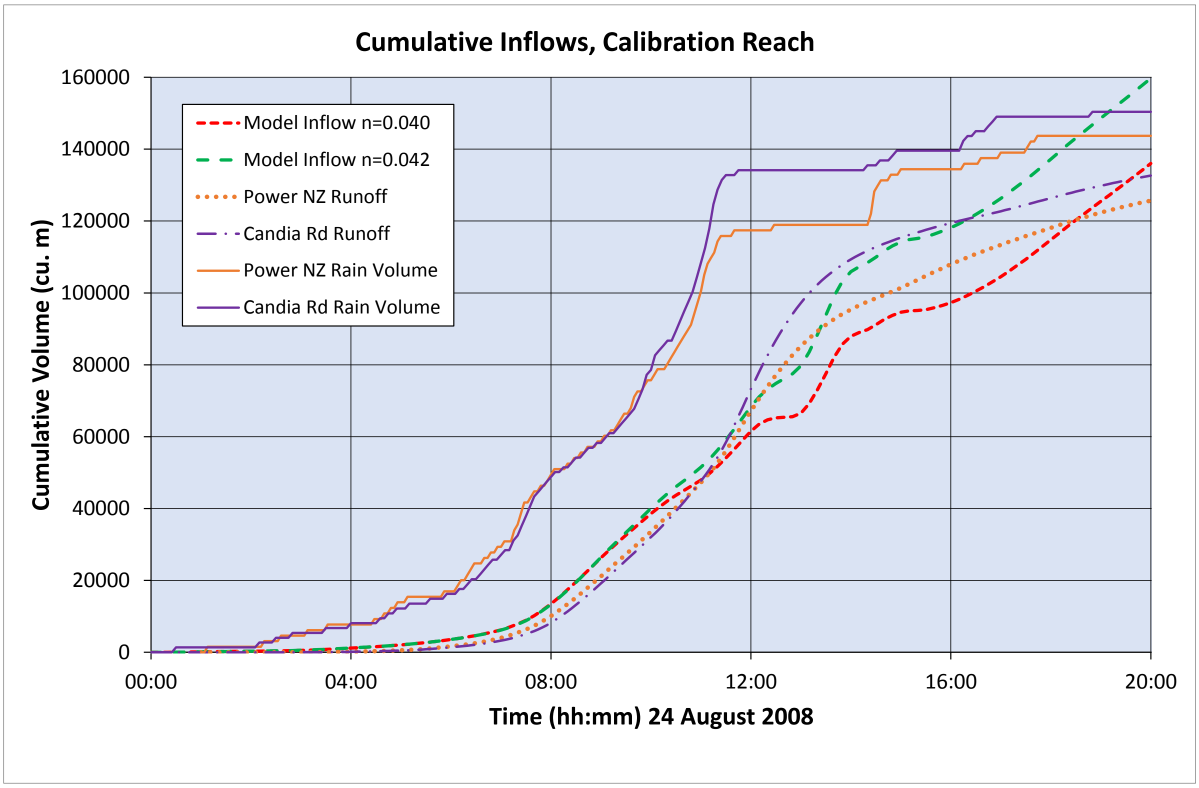

Figure 6. Match between Model Lateral Flows and Rainfall/Runoff Calculations: 2008 Flood

The corresponding rainfall/runoff estimates are plotted as a brown dotted line for the Power NZ site and as a purple chain dotted line for the Candia Road site.

These were computed using the HYCEMOS-U hydrological package, which uses kinematic wave analysis based on a single catchment open book model, incorporating two sloping planes contributing to a central sloping channel. The best fits (shown plotted) were obtained with one plane contributing a fast response and the other contributing a slow response into a relatively short nominal channel.

Two hydraulic model results are shown in each plot, corresponding with a base Manning n=0.042 and n=0.045 in Figure 5 and with a base Manning n= 0.040 and n=0.042 in Figure 6. In both Figures the curves for n=0.042 are plotted with long green dashes, while the curves for the other Manning n values are plotted with short red dashes. It turns out that the hydraulic inflow predictions are highly sensitive to the choice of base Manning n, as a variation of only 1% in this roughness parameter will produce a significant difference to the lateral inflows produced by the model.

As a result, the best fit for the 2006 flood gave a Manning n=0.045 for the 2006 flood and a Manning n=0.040 for the 2008 flood. A seasonal explanation for this difference can be suggested, as illustrated in Figure 7.

Figure 7. View of Opanuku Stream Upstream from Vintage Reserve Footbridge

This photograph was taken on 30 August 2007, less than a year after the 2006 flood and almost exactly a year before the 2008 flood. Vegetation obviously contributes strongly to the resistance to flow as soon as levels exceed the low flow channel, but at the end of winter regrowth has barely commenced. If this corresponds to a Manning n=0.040 as fitted, then it is not difficult to accept that a Manning n=0.045 could be expected after a further month of spring growth.

Therefore a match between model lateral channel inflows and runoff hydrographs derived by rainfall/runoff modelling has been established within hydrological modelling accuracy, taking into account the differences in location of the assumed inflow points.

3.4 Note on Downstream Boundary Conditions

The actual model downstream boundary is at the top of Figure 1, as the model must be continued downstream of the Vintage Reserve gauging station to allow the difference between flows arriving at the gauging station and leaving the gauging station to be computed. As shown in Figure 4, a good fit was obtained by computing the backwater from a drawdown to an overfall at Chainage 5.000km, near the downstream boundary at Chainage 5.100km. This overfall effectively disconnected the downstream boundary from the rest of the model, as any arbitrary downstream level can be specified without changing the solution, as long as that level is not high enough to cause drowning of the overfall.

Accordingly an arbitrary downstream boundary level was specified as a constant 4.000m at Chainage 5.100km. This is similar to the common laboratory model practice of establishing an overfall into a discharge pit downstream of the area of interest. Considerable variations in discharge pit level then have no effect on model results.

4. Summary

Three compliance criteria were stated for validation of the published IAHR Flood Risk Management Committee accuracy benchmark. All three criteria have been met for both the 2006 and 2008 floods by the *AULOS* hydraulic modelling package developed by HYDRA Software Ltd.

Appendix A. Computer Files

Files provided for download as Validation for Accuracy Benchmark A_2 (October 2016):

File Type	Name	Format	Contents
Document	Accuracy Validation A_2	pdf	Report on the validation by *AULOS,* plus working model file structures.
Zipped Folder	Benchmark	zip	
	Hycemos	Subdirectory	ASCII Text files containing input to and output from the HYCEMOS-U rainfall/runoff modelling package.
	Report	Subdirectory	*AULOS* Report (.rpt) files, in particular Opa06Y.rpt for the 2006 flood and Opa08Y.rpt for the 2008 flood. Also miscellaneous ASCII Text auxiliary files used for the preparation of the validation Excel files (see below).
	Validation	Subdirectory	Files used for the preparation of the validation report figures. GaugingValidation.xls provides all the workings for preparation of Figure 4. Opamap.jpg is the basis of Figure 1. ResidualValidation.xls provides all the workings for preparation of Figures 2, 3, 5 and 6.
	AULOS key files	.aky (ASCII Text)	Key (aky) files contain all information necessary to run a model. In particular Opa06Y.aky will run the 2006 flood and Opa08Y.aky will run the 2008 flood.
	AULOS brn files	.brn (ASCII Text)	Branch-Reach-Node (brn) files contain all model data, which may be inspected and edited. In particular, Opa06Y.brn contains the 2006 flood model and Opa08Y.brn contains the 2008 flood model.
	AULOS arw file	.arw (ASCII Text)	AULOS Raw data files stores the raw cross-section database managed by the brn editor. OpanukuW.arw holds several versions of the sections.
	AULOS boundary files	.txt	Boundary Condition databases for the 2006 and 2008 floods.