Port Curtis hydrodynamic model evaluation

John Andrewartha
Michael Herzfeld

December 2005
Port Curtis hydrodynamic model evaluation

John Andrewartha and Michael Herzfeld

December 2005
Port Curtis hydrodynamic model evaluation

Contents

1. Background................................................................................................................................iii
2. Field program design.................................................................................................................. 3
3. Field program implementation............................................................................................... 4
4. The hydrodynamic model........................................................................................................ 10
5. Model domain ...................................................................................................................... 10
6. Model forcing ........................................................................................................................ 13
   Surface elevation................................................................................................................ 15
   Wind ................................................................................................................................... 15
   Rainfall and river flow...................................................................................................... 16
   Temperature and salinity ................................................................................................. 18
7. Model trials ............................................................................................................................ 19
   Sea level ............................................................................................................................. 19
   Minimum water depth...................................................................................................... 21
   Dilution .............................................................................................................................. 21
   Initial conditions ............................................................................................................. 23
   Boundary conditions ...................................................................................................... 24
   Calliope River representation ........................................................................................ 24
   River flow......................................................................................................................... 25
8. Evaluation results .................................................................................................................. 26
9. Conclusions ........................................................................................................................... 41
10. Recommendations............................................................................................................... 43
11. References .......................................................................................................................... 44
Port Curtis hydrodynamic model evaluation

List of figures

Figure 1. Original curvilinear grid used for Port Curtis hydrodynamic modelling ......................2
Figure 2. Salinity sections from a model simulation of a flood event in March, 1999
   Distance in right-hand figure is measured from northern end of transect .........................3
Figure 3. Field program design ..............................................................................................4
Figure 4. Field program sampling sites ..................................................................................5
Figure 5. Field program transect sampling sites .....................................................................6
Figure 6. Salinity and temperature data as returned from the three fixed loggers at
   sites T3, C5 and A4 .........................................................................................................7
Figure 7. ‘Pre-flood’ surface salinities measured on 27 and 29 January, 2005 .........................8
Figure 8. Calliope River flow during January–February 2003 ...............................................9
Figure 9. Measurements of salinity and temperature from Clinton Wharf (blue) and
   Boyne Wharf (red) during a flood event in February 2003 ...............................................9
Figure 10. Model bathymetry for Port Curtis Estuary ..............................................................12
Figure 11. Smoothed model bathymetry ..............................................................................13
Figure 12. Map showing the nesting of the Port Curtis model domain within the regional grid 14
Figure 13. Wind measurements from Gladstone for the 3-month modelling period .............16
Figure 14. Overlay of Gladstone rainfall and Calliope River flow from 1 December 2004
to 28 February 2005 ......................................................................................................18
Figure 15. Fitzroy River flow ..................................................................................................18
Figure 16. Measured sea level (blue line) compared with modelled sea level (red line)
   for a site near South Trees for the 3-month modelling period ..........................................20
Figure 17. Measured sea level (blue line) compared with modelled sea level (red dots)
   for a site near South Trees during one spring-neap tidal cycle .......................................20
Figure 18. Low-pass sea level from measurement (blue line) compared with that from
   the model (red line) for the full 3-month modelling period .............................................21
Figure 19. Area (red) that would be reduced from 35psu to 31psu by dilution with
   7x10^6 m^3 of fresh water ..................................................................................................22
Figure 20. Area (red) that would be reduced from 35psu to 32psu by dilution with
   7x10^6 m^3 of fresh water ..................................................................................................22
Figure 21. Modelled salinity near the surface at site C5 for model runs initialised
   from the regional grid (blue) and from field data (red) ...................................................23
Figure 22. Modelled surface salinity at site C5 for the full length river (blue) and
   the ‘short’ river (red). Measurements from the logger are also shown (black) .................25
Port Curtis hydrodynamic model evaluation

Figure 23. Modelled salinity near the surface at site C5 for a run with the unverified Calliope flow data (blue), and with the same data multiplied by a factor of four (red) ........ 26

Figure 24. Modelled surface salinity for the ‘short’ river at 2-hour intervals for 26 January 2005 .................................................................................................................... 27

Figure 25. Modelled surface salinity for the ‘short’ river at 2-hour intervals for 27 January 2005 .................................................................................................................... 28

Figure 26. Time-series comparisons of salinity from the transect measurements (blue) and the model (red) for the ‘half-length’ river ........................................................................ 29

Figure 27. Time-series comparisons of salinity from the transect measurements (blue) and the model (red) for the ‘short’ river ............................................................................. 30

Figure 28. Salinity sections along Transect #1, interpolated from measurement profiles taken during the period 27 January to 3 February 2005 ....................................................... 32

Figure 29. Salinity sections along Transect #1, from the model run with the ‘short river’, for the period 27 January to 3 February 2005 ........................................................................ 33

Figure 30. Salinity sections along Transect #1, interpolated from measurement profiles taken during the period 5 February to 24 February 2005 ....................................................... 34

Figure 31. Salinity sections along Transect #1, from the model run with the ‘short’ river, for the period 5 February to 24 February 2005 ................................................................. 35

Figure 32. Salinity sections along Transect #2, interpolated from measurement profiles taken during the period 27 January to 3 February 2005 ....................................................... 36

Figure 33. Salinity sections along Transect #2, from the model run with the ‘short’ river, for the period 27 January to 3 February 2005 ........................................................................ 37

Figure 34. Salinity sections along Transect #2, interpolated from measurement profiles taken during the period 5 February to 24 February 2005 ....................................................... 38

Figure 35. Salinity sections along Transect #2, from the model run with the ‘short’ river, for the period 5 February to 24 February 2005 ................................................................. 39
1. Background

This report describes the evaluation of a numerical hydrodynamic model established previously in 2003 to describe the circulation and transport of conservative tracers (e.g. heat and salt) within the waters of Port Curtis, the estuary adjoining Gladstone, Queensland.

In the earlier phase of the project (CM2), a pilot 3D hydrodynamic model was developed by CSIRO Marine Research (now CSIRO Marine & Atmospheric Research, CMAR) for Port Curtis and the local region (Herzfeld et al. 2003). The model domain, which spans the coastline from Port Curtis southeast to Rodds Bay, is shown in Figure 1.

The pilot model was subjected to limited calibration only, that is, with respect to sea level but not with respect to current flow, salinity or temperature. In its current form the model does not include atmospheric exchanges of heat and salt. As such, it is thought the pilot model should provide realistic, but not necessarily accurate, predictions of water-column mixing and advection.

In the current phase of the Coastal CRC project (IC4.1 to IC6.1), CMAR has committed to providing limited modelling effort in order to provide scenario runs of the pilot model, with no further calibration. However, the stakeholders for the project have expressed a desire for further calibration.

The resources allocated in the IC project were not sufficient to carry out a full model calibration. We estimate this would take about a fourfold increase in personnel resources plus a comprehensive field program. However, CMAR were keen to meet stakeholder needs so, as a compromise, it was suggested that with the support of a limited field program, a less rigorous model evaluation could be carried out with existing IC project resources.

The idea was accepted and a model evaluation was proposed (Herzfeld et al. 2004) which would assess the existing model’s performance, and make recommendations as to what model tuning and data might be necessary to perform a full calibration. The model evaluation was not to include alteration of the model parameters or processes to improve predictions.
The pilot model was designed to address environmental impacts (rather than engineering design) and, for these purposes, tracer transport over multiple tidal cycles is the key output. Evaluation of transport prediction is best addressed by comparing predicted and observed distributions of a conservative tracer. Comparing modelled and measured velocity is often problematic, since velocity is usually influenced by small temporal and spatial scale processes (e.g. high-frequency wind variations, bathymetry gradients and small-scale turbulent mixing) that cannot be captured by the model. The larger-scale fields of temperature and salinity, whose distributions are controlled more by large-scale transport processes, constitute a more robust comparison measure. The most readily available tracer to deal with is salinity, especially given the rapid changes it can undertake in Port Curtis following a significant flow down the Calliope River. Thus an evaluation was based around a wet-season flood event.
Port Curtis hydrodynamic model evaluation

To aid in the evaluation, a limited field program was designed. This report describes the design, implementation and results of the field program, followed by a comparison of salinities between the field measurements and the model predictions.

2. Field program design

To prepare for the evaluation, model output from the existing pilot model was used to aid in the design of a field program and sampling strategy. An example of this output, derived from the modelling of an actual 140 cumec ($\text{m}^3\text{s}^{-1}$) flood event in March 1999, is shown in Figure 2. This figure contains both a horizontal and vertical snapshot through the 3D salinity field. (The jagged blue line in Figure 2a is the model representation of the Calliope River, folded back on itself to minimise the horizontal extent of the model grid. Since this river is represented in laterally averaged form, the geography of the river need not be represented exactly.)

![Figure 2. Salinity sections from a model simulation of a flood event in March, 1999](image)

Distance in right-hand figure is measured from northern end of transect.

The results depicted in Figure 2 were used in conjunction with a separate series of scenario model runs which simulated the results of varying wind and tide forcings being applied to a 150 cumec flow event. The combined results were used to
Port Curtis hydrodynamic model evaluation
determine the best salinity sampling positions for an evaluation field program. These results are summarised in Figure 3 which displays:

- Twelve sites to be sampled prior to an anticipated flood event, for the purpose of initialising the model salinity field
- Three sites to obtain continuous salinity measurements throughout the flood event from moored loggers
- Two transects along which salinity profiles could be taken at regular intervals throughout and after the flood event.

![Figure 3. Field program design](image)
Sites 1 to 12 represent the proposed pre-flood sampling positions, sites ‘m’ represent logger mooring positions, and the solid black lines represent proposed transect sampling lines.

3. Field program implementation

Preparation for the above field program was put in place in mid 2004, in anticipation of a suitable flood event occurring within the 2004–05 wet season. On 5 November 2004, three loggers (type Yeo-Kal Y611) were fixed in place, one metre below low-water level to channel pylons at sites T3, C5 and A4 (see Figure 4).
Port Curtis hydrodynamic model evaluation

The first significant rains occurred in early December 2004. However, it was thought this event would not produce significant river flow and so the remainder of the field program was not instigated. The next significant rain event began on 22 January 2005 and continued until 27 January, with a peak rainfall of 70 mm in Gladstone on 23 January. It was not until 27 January that field work began when ‘pre-flood’ sites 1 to 9 were sampled (Figure 4). The estuary transects (Figure 5) were also commenced on the same day.

A further transect sampling was carried out on 28 January 2005, and then again on 29 January when the remainder of the offshore ‘pre-flood’ sites 10 to 12 were completed. From there on, transects were taken on 30 and 31 January and 1, 2, 3, 5, 7, 9, 11, 16, 17, 18 and 24 February 2005, making a total of 16 sample events. Throughout this time there was some rainfall on 2 February and 10 February.

Figure 4. Field program sampling sites

The red dots represent the fixed logger locations, while the blue dots represent pre-flood sampling locations. Two further sites, S11 and S12, are not shown but lie further offshore east of Facing Island.
Figure 5. Field program transect sampling sites
Transect #1 is represented by sites T1 to T22, while transect #2 is represented by sites T24 to T29. There is no site T23, and T27 is co-located with T8.

The fixed data loggers experienced several problems, including marine growth and the batteries not lasting as long as expected. In hindsight it may have been better to keep the loggers away from the pylons, which were themselves encrusted with organisms, and to deploy them with a system which was more readily retrieved from the water for calibration and servicing. Also, a different type of logger such as SeaBird may have proved more reliable.

The data recovered from the loggers is shown in Figure 6. Unfortunately, very little of it appears useful for comparing with time-series output from the model.
The surface salinity measures at the ‘pre-flood’ sites on 27 and 29 January are plotted in Figure 7. Although these measurements were not taken as early as hoped for, the relatively high values within the estuary suggest that they are still appropriate for pre-flood conditions before the onset of freshwater discharges from the Calliope River.

It is interesting to note, however, the relatively low salinity values recorded in The Narrows at site S1 and offshore at sites S10, S11 and S12. One possible explanation is that this is a result of an earlier flood of the Fitzroy River, with low saline water moving south through The Narrows and also around the outside of Curtis Island. (There were flood peaks of 300, 360 and 800 cumecs down the Fitzroy on 13 December, 12 January and 1 February, respectively, see Figure 15).
The results of the sampling along transects #1 and #2 are summarised in Figures 26, 28, 30 and 32, where they are retained for easier comparison with model output.

At this stage it is of interest to compare the size and nature of the evaluation flood event with two previous events—the March event of 1999 which was used in designing the evaluation program and a February 2003 event for which data was made available.

The March 1999 event registered 140 cumecs and the modelled effects of this flow are shown in Figure 2. The February 2003 event was 1600 cumecs. The Calliope flow is plotted in Figure 8 and its effect on salinity and temperature within the estuary at the Clinton and Boyne wharves is shown in Figure 9 (data courtesy of the Gladstone Port Authority).

The event is marked by a significant depression in salinity to 10–20 practical salinity units ( PSU ).
Port Curtis hydrodynamic model evaluation

Figure 8. Calliope River flow during January–February 2003

Figure 9. Measurements of salinity and temperature from Clinton Wharf (blue) and Boyne Wharf (red) during a flood event in February 2003

Note that these salinity time-series alone are not sufficient to use in a model evaluation, and would need to be supplemented by pre-flood initial conditions and spatial distributions of salinity.
It was hoped that an event at least of the magnitude of the 1999 event would prevail for this evaluation. At the very least, the event needed to be sufficient to produce detectable gradients across the estuary, but not so large as to result in overtopping of the boundaries of the main channels.

4. The hydrodynamic model

The hydrodynamic model used in the earlier pilot study was termed MECO (Walker & Waring, 1998). The model had been developed by the Environmental Modelling group at CMR over the last decade. MECO is a general-purpose model applicable to scales ranging from estuaries to regional ocean domains, and has been successfully applied to a variety of applications encompassing these scales. Technical details describing MECO can be found in Herzfeld et al. 2003.

Recently, and since the conclusion of phase CM2 of the project, MECO has been upgraded and extensively modified and is now called SHOC (Sparse Hydrodynamic Ocean Code). This model utilises the same computational physics as MECO but is cast in an alternate coordinate system to allow distributed processing on supercomputer platforms, has an enhanced suite of diagnostics and contains some additional features.

5. Model domain

There are four major differences between the model domain used for the pilot study and that used here for the evaluation. The first difference relates to the inclusion of the full length of the Calliope River. In the earlier study, the river was only represented for several hundred metres into the hinterland, and in the absence of available data the boundary condition for salinity was set at a nominal 20 psu. When modelling the salinity distribution resulting from a flood event, a more accurate representation of the river is clearly required. In the absence of measured data, the only way to accurately represent the river was to extend its length to that where it is known to be fresh (i.e. where a boundary condition can be set at 0 psu). For the Calliope this length is approximately 20 km and in the field program design stage it was included by wrapping a line of cells around to nest within existing unused land cells (see Figure 2).
For the evaluation, the model grid has been extended on the southern side of the domain to allow the river to be included as a single ‘straight’ line of cells, albeit wider than the actual river. Since the river is represented in a two-dimensional, laterally averaged form, the exact course of the river has no influence on the model solutions, hence the course may be arbitrary.

The second difference relates to the minimum water depth used in the model. It is a requirement of this type of model that the water depth exceed a minimum value, otherwise the models become unstable. For the pilot model based on MECO the minimum water depth applied was 4 m. This meant that large areas of water of 1 m or 2 m depth—for example, the region between the Calliope mouth and Fishermans Wharf—were slightly misrepresented. This could have important ramifications for the dilution rate of the output flow from the Calliope mouth. The new model SHOC is capable of handling shallower water and for the evaluation the minimum water depth was able to be set at 0.5 m.

The third major difference between the models also relates to the bathymetry and is linked to the second difference. In order to keep the model stable throughout all scenarios, with the 0.5 m minimum water depth in place, the bathymetry was smoothed using five passes of a filter which averaged the depth of each water cell with the depths of neighbouring cells. The overall bathymetry of the domain contains the same features, but bathymetric changes are not as abrupt.

Finally, stability of the model was found to improve with the creation of a slightly deepened channel from the mouth of the Calliope out to the main shipping channel. This channel probably exists in reality but bathymetry data was not sufficient to resolve it for the pilot model.

The model grid showing the main estuary and the representation of the Calliope River is given in Figure 10, while the smoothed bathymetry for the entire model domain is shown in Figure 11.
Figure 10. Model bathymetry for Port Curtis Estuary

The two gaps in the Calliope River representation indicate the half and 1/6 lengths that were trialled.
6. **Model forcing**

The model was forced with sea-surface elevation, wind, rainfall and river flow, and temperature and salinity. The model simulation period chosen was the three months of December 2004 to February 2005 inclusive. All data were collected to span this period. The sources of the forcing data are detailed further below.

In order to maximise accuracy of the surface elevation forcing (and temperature and salinity forcing where field data was not used) the model domain was nested inside a larger rectangular grid model domain as shown in Figure 12. Further details on the forcing of this larger regional grid may be found in Herzfeld *et al.* 2003.
Port Curtis hydrodynamic model evaluation

The regional grid was used to provide surface elevation, temperature and salinity on the offshore boundary and The Narrows boundary of the Port Curtis model domain. Currents were also provided for The Narrows boundary. Wind, river flow and rainfall were provided independently for the Port Curtis model.

Figure 12. Map showing the nesting of the Port Curtis model domain within the regional grid
Port Curtis hydrodynamic model evaluation

Surface elevation

The time series of surface elevation used for forcing the open boundaries of the Port Curtis domain were supplied as output from the regional model. The elevations used for forcing the regional model consisted of a high frequency tidal component (periods <1 day) and a low frequency component with periods of days to weeks, for example, for coastally-trapped waves and storm surges. The tidal component was derived from global model constituents, while the low-frequency component was derived from low-pass filtering of hourly tide measurements supplied for Burnett Heads by the Queensland Department of Transport. See Herzfeld et al. 2003 for complete details of how the forcing was applied to each of the regional grid boundaries.

Hourly tide records were also obtained for stations at South Trees near Gladstone, Port Alma near the Fitzroy mouth, and at Rosslyn Bay (courtesy of the National Tidal Centre).

Although not used in forcing the models, these measured data were useful for calibrating the tide and low-frequency signals within the model domains.

Wind

Wind speed and direction data at 3-hourly intervals were obtained from the Bureau of Meteorology at several sites surrounding the Port Curtis–Fitzroy region. This data was interpolated onto a regular grid for input to both the regional and Port Curtis models to provide a temporally and spatially varying wind field.

A sample of the wind data from Gladstone is shown in Figure 13. These data indicate that winds were predominantly from the southeast with a typical speed of about 5 m/s, and tended to blow into the estuary.
Rainfall and river flow

Rainfall is now available as an input parameter to the SHOC model and so rainfall records were obtained for Gladstone (see Figure 14). Rainfall was input as a surface boundary condition (i.e. freshwater fluxes existed through the surface) to the Port Curtis model only.

River flow records were obtained for the Calliope River at Castlehope (Figure 14) and Fitzroy River at The Gap (Figure 15). The Calliope flow was input to the Port Curtis model and regional models and the latter input into the regional model only. The Fitzroy River maintains an influence on the Port Curtis region via flow through The Narrows, and output from the regional grid at The Narrows was used as an open boundary condition in the Port Curtis model. Due to resolution restrictions, the representation of The Narrows in the regional grid was wider than in reality; however the depth was adjusted to maintain correct cross-sectional area. The modelled salinity of water entering The Narrows should be subject to validation if future calibration to temperature/salinity is undertaken.
The Boyne River was omitted due to the presence of the Awoonga Dam reducing flows to negligible levels.

Daily flows for the Calliope River for the three months of the modelling period are shown in Figure 14. The volume of flow into the Calliope River does affect the barotropic circulation within the estuary, and since barotropic flow is a major driving force in the estuary, this input should be accurately specified. There are numerous other small rivers and creeks that flow into Port Curtis, especially at times of heavy rain, but no data was available for these.

Two comments can be made from an analysis of Figure 14, which overlays rainfall at Gladstone with flow for the Calliope River. First, there appears to be a 2–3 day lag between the peak rainfall and the peak flow (at Castlehope which is approximately 20 km upstream of the Calliope mouth). Thus, although the 27 January 'pre-flood' sampling was carried out later than hoped for, it may still have captured the background state of the estuary, especially given that there would also be a delay between flow at Castlehope and its ingress to the estuary. Second, the flood event of early December and the evaluation event of late January appear dissimilar in that the December event produced a relatively higher flow from less rainfall than the January event.

The January event was only a 30 cumec flow event which is relatively small for the Calliope River in summer. In fact the earlier December 2004 event produced a larger river flow of 75 cumec. A possible explanation for this would be that the (higher) January rainfall may have been more confined to the coastal fringe than the catchment, and hence produced a lower river flow. This is in part borne out by the fact that Rockhampton rainfall for the time of the January event is much lower than that for Gladstone. Unfortunately, no other rainfall figures for the region, in particular for the catchment, could be found to confirm the above assertion.
Port Curtis hydrodynamic model evaluation

Figure 14. Overlay of Gladstone rainfall and Calliope River flow from 1 December 2004 to 28 February 2005

Rainfall (mm/day) is shown in blue, while river flow (cumec, measured from Castlehope), is shown in red.

Figure 15. Fitzroy River flow

Temperature and salinity

The temperature and salinity data used to force the open boundaries of the regional domain were obtained from the CARS atlas (Climatological Atlas of Regional Seas, Ridgway et al. 2002). In previous use of the pilot model, these data were available from global model output ACOM3; however, the latter terminated in 1999 and so an alternative source was required. The resolution of the CARS climatology is 1/8 x 1/8° which is sufficient for the regional grid but consists of only 10-day averaged data. It does, however, constitute the best three-dimensional time-series distributions available.
Port Curtis hydrodynamic model evaluation

The CARS data sets were used to initialise the regional model which was also relaxed to CARS on a time scale of 10 days.

The Port Curtis temperature and salinity initial conditions and boundary forcing were provided from output of the regional model for some of the trial runs while other runs were performed using an interpolation of the pre-flood field data depicted in Figure 7.

Unfortunately the Gladstone Port Authority instrumentation at Boyne and Clinton wharves was not in operation throughout the modelling period, and so data akin to those presented in Figure 9 were not available.

Water temperature data were obtained for the Calliope River but these data were not continuous and contained many gaps, hence were deemed unreliable and so the temperature of the Calliope River input was taken to be equal to the low-pass filtered air temperature from Gladstone.

Due to the lengthening of the Calliope River in the evaluation model relative to that used in the pilot model, the headwaters could be assumed to be above the reach of the tide and hence the salinity of the input water was assumed to be zero.

No surface heat fluxes have been included in the model at this stage.

7. Model trials

The scope of work for this project did not include a calibration of the model. However, with the advent of the newer model with its enhanced capabilities, there was a need to conduct some preliminary trial runs to test sea-level prediction, the minimum water depth that could be used, initial and boundary conditions, and the best representation for the Calliope River which had not been fully included in the pilot model.

Sea level

Although the pilot model was shown to accurately reproduce sea level within the Port Curtis region, it was prudent to first check that the newer model was similarly capable. Modelled sea levels are compared to those measured at South Trees in Figures 16 and 17, from which it is observed that there is close agreement.
Port Curtis hydrodynamic model evaluation

Figure 16. Measured sea level (blue line) compared with modelled sea level (red line) for a site near South Trees for the 3-month modelling period

Figure 17. Measured sea level (blue line) compared with modelled sea level (red dots) for a site near South Trees during one spring-neap tidal cycle

The measured and modelled sea-level data for the 3-month period were low-pass filtered and the results are compared in Figure 18. Agreement is good in that the model reproduces all the low-frequency features, although there are some offsets. These are not considered significant for the evaluation given that it is the higher frequency tides which are dominating circulation within the region.

All results were found to be independent of boundary conditions and minimum water depth used.
Minimum water depth

As stated earlier, the pilot model employed a minimum water depth of 4 m. However, the actual depths within Port Curtis become much shallower in several areas, and this could have a bearing on the total modelled volume of the estuary and hence the salinity concentrations. Trial runs were therefore performed to determine the minimum depth that could be set while maintaining model stability. The results of these tests indicated that the minimum water depth could be set at 0.5 m provided the bathymetry was also smoothed. As reported above, the smoothing was carried out five times with the application of a spatial averaging filter. Salinity comparisons between model and measurements, as described in the following section, were markedly improved with this reduction in minimum water depth.

Dilution

Before any modelling is attempted, it is useful to employ a simple mass balance calculation to investigate the effect of the flood event on salinity distribution. The event lasted approximately eight days, with a maximum flow of 30 m³s⁻¹ and a mean of ~10 m³s⁻¹. These are quite small events. Integrating the whole flood event in time yields a total volume of ~7x10^6 m³ that entered the estuary. Assuming this volume of water entered with a salinity of 0 psu (an underestimation since the water is likely to be brackish due to mixing with existing water in the river channel), then an inverse calculation provides the area of the estuary which would result in a dilution comparable to that observed. The minimum salinity observed during the flood in the estuary is >31 psu (see Section 8) and the initial salinity pre-flood is assumed to be 35 psu (slightly underestimated, see Figure 7). The maximum areas of estuary that would have
Port Curtis hydrodynamic model evaluation

their salinity reduced from 35 psu to 31 psu and 32 psu, as a result of directly inputting and mixing $7 \times 10^6$ m$^3$ of fresh water, are displayed as Figures 19 and 20, respectively. These areas are likely to be smaller in reality due to the assumptions made.

Figure 19. Area (red) that would be reduced from 35psu to 31psu by dilution with $7 \times 10^6$ m$^3$ of fresh water

Figure 20. Area (red) that would be reduced from 35psu to 32psu by dilution with $7 \times 10^6$ m$^3$ of fresh water
Figures 28 and 30 contain an interpolated cross-sectional transect derived from the field measurements. This shows that the fresh plume is indeed well mixed vertically, and covers much of the lateral extent of the estuary (e.g. Figure 30, 18 February shows salinity is less than ~32 psu throughout the estuary). The areas shown in Figures 19 and 20 are significantly less than that observed during the flood, suggesting that other sources of freshwater (besides the Calliope discharge) must also be diluting the estuary.

Initial conditions

Trial runs were carried out to ascertain the best initial conditions to employ for the Port Curtis model. Options existed to initialise the salinity and temperature fields throughout the model domain, either with output from the regional grid or by using interpolated fields from the pre-flood measured data (Figure 7).

One result from these trials is shown in Figure 21 which indicates there is very little difference in salinity behaviour within the estuary, with simply an offset of approximately +0.4 psu for the case where the field data was used. Because the regional grid was in turn forced with climatology and therefore likely to be less accurate, it was decided to maintain use of the interpolated field data for the initialisation in subsequent trials and in the evaluation runs.

![Figure 21. Modelled salinity near the surface at site C5 for model runs initialised from the regional grid (blue) and from field data (red)](image-url)
Port Curtis hydrodynamic model evaluation

Boundary conditions

Trial runs were carried out to ascertain the appropriate boundary conditions to employ for the Port Curtis model. Boundary conditions for the regional model were left as for the pilot study.

The surface elevation forcing of the offshore boundary was always performed with output from the regional model. Additionally, a condition to allow the passage of gravity waves through this boundary was implemented to increase model stability. The Narrows open boundary could either be forced with surface elevation or directly with velocity profiles output from the regional model. Trial simulations revealed little difference between these two methods in terms of salinity observed in the estuary. The current-forcing condition was chosen for the evaluation as it was deemed more accurate in setting up the correct flow within The Narrows region. Temperature and salinity at the offshore and The Narrows boundary could be specified using either the regional grid output or the pre-flood field data. The latter was chosen, to remain consistent with the initial condition for temperature and salinity.

Calliope River representation

Trial runs were conducted to assess the most appropriate length to use for the model representation of the Calliope River. While the actual length of 20 km from the mouth to Castlehope may seem the most appropriate, this length had the disadvantage of containing too great a volume because the model resolution does not allow the width to be realistically represented. This problem could be addressed to some extent by decreasing the river depth, but this increases bottom friction and consequently reduces flow rate. Also, the representation of the river was made harder by an absence of river depth and width data required to accurately specify cross-sectional area.

Therefore, three river lengths were tested: the full length (~20 km), a half-length and a short (~1/6) length. In each case the river depth was maintained at a constant 4 m. Results are presented in Figure 22 where it is shown that the short river produces markedly lower salinities in the estuary, more in keeping with the field measurements.
River flow

Early comparisons showed that the modelled estuary salinities during the flood events did not decrease as far as the field measurements. Since this modelling was carried out with unverified Calliope flow data, it was suspected that the flow values may have been too low. To gauge the effect of increasing the flow, a simulation was conducted (using the full river length) with the river flow values a factor of four larger than the given values. The results are presented in Figure 23 where it is found that the use of higher flow values produces quite lower salinities which are more in line with measurements. Verification of the flow data indicated it was accurate; hence arbitrarily increasing flow is unjustified. However, the exercise has proved useful in illustrating sensitivity of salinity in the estuary to flow rate.
8. Evaluation results

This section presents the results from two model runs (using the ‘short’ river and the ‘half-length’ river) which were implemented using the best configuration and forcing methods as prescribed by the trials outlined in the previous section. The results are compared with the field measurements described in Section 3.

Plots showing surface salinity gradients predicted by the ‘short river’ model at 2-hour intervals for a 24-hour period in the middle stages of the flood are shown in Figures 24 and 25. These figures clearly show the dominant effect of the tide in moving the plume backwards and forwards along the estuary.
Figure 24. Modelled surface salinity for the ‘short’ river at 2-hour intervals for 26 January 2005
The surface signature of the salinity plume in Figures 24 and 25 is broadly consistent with the spatial extent expected from results of the mass balance calculation (Figures 19 and 20). This indicates the model is performing in a conservative manner.
Port Curtis hydrodynamic model evaluation

Time-series comparisons of modelled and measured salinity are shown in Figure 26 for the half-length river and in Figure 27 for the short river. The modelled salinity values were obtained each hour from the surface cell of the model at the three logger sites T3, C5 and A4. Since the fixed logger output was deemed too inaccurate to use for the comparison, the measured surface salinities were extracted from the transect data for the three closest sites (T8, T12 and T19) on each of the days that profiles were taken.

Figure 26. Time-series comparisons of salinity from the transect measurements (blue) and the model (red) for the 'half-length' river
The transect data, having a minimum time separation of 1 day, do not have sufficient temporal resolution for detailed comparisons to be made. The lack of the continuous logger data has compromised the evaluation of the model’s performance in the time domain. However, the comparisons in Figures 26 and 27 do present two definite discrepancies between model and measurement.
First, the model flood peak occurs too early, and for the half-length river does not reduce salinity by as much as the measured data suggests. Although a judgment is difficult, the short river is probably performing the better of the two simulations.

The second discrepancy concerns salinity recovery in the days following the Calliope flood. While the transect measurements show salinity to remain depressed throughout most of February at levels of about 32 to 33 psu, the model predicts salinity to gradually recover to pre-flood levels during that time. So, either the model has overestimated flushing rates or, as is more likely, there has been additional input of fresh water from sources unaccounted for by the model. These could be other creeks and streams entering the estuary, or input through The Narrows and offshore regions. The plots in Figures 14 and 15 suggest the latter may be the case in that there was no local large freshwater event, but there was a reasonably large Fitzroy runoff event occurring on 2 February. It seems plausible that after a small delay, floodwaters from the Fitzroy could penetrate the estuary both via The Narrows and from around the outside of Curtis Island.

A final and encouraging result to come from the comparison is that the model does pick up fairly well the two salinity depressions, shown about two weeks apart in the measurements. This is best seen in the plots for station C5.

The second comparison is for salinity section ‘snapshots’ taken along the two transects shown in Figure 5. They are not true snapshots since the measured profiles were recorded over a period of a few hours on the days they were recorded. As such, the model output was interpolated to the same stations at the same times as the measurements to enable a direct comparison.

Transects were recorded on 16 separate days spanning the period 27 January to 24 February. These were split into two groups of eight days each and salinity sections comparing measurements with ‘short river’ model results for Transect #1 are contained in Figures 28 to 31. Similar sections for Transect #2 are contained in Figures 32 to 35.
Figure 28. Salinity sections along Transect #1, interpolated from measurement profiles taken during the period 27 January to 3 February 2005
Figure 29. Salinity sections along Transect #1, from the model run with the ‘short river’, for the period 27 January to 3 February 2005
Figure 30. Salinity sections along Transect #1, interpolated from measurement profiles taken during the period 5 February to 24 February 2005
Figure 31. Salinity sections along Transect #1, from the model run with the ‘short’ river, for the period 5 February to 24 February 2005
Figure 32. Salinity sections along Transect #2, interpolated from measurement profiles taken during the period 27 January to 3 February 2005
Figure 33. Salinity sections along Transect #2, from the model run with the ‘short’ river, for the period 27 January to 3 February 2005
Figure 34. Salinity sections along Transect #2, interpolated from measurement profiles taken during the period 5 February to 24 February 2005
Figure 35. Salinity sections along Transect #2, from the model run with the ‘short’ river, for the period 5 February to 24 February 2005
Port Curtis hydrodynamic model evaluation

The measured data of Figures 28 and 32 show that the main flood reached the estuary on 29 January when salinities of 32–34 psu are evident; in particular the river plume can be seen near the centre of the 29 January transect of Figure 28. Thereafter the measurements show the waters to decrease in salinity only marginally, with a minimum of approximately 31 psu showing up late in February and the 18 February transects showing the lowest overall salinities.

The measurements for Transect #1 (Figure 30 in particular) indicate a slight salinity gradient from lower values in the upper estuary to higher values in the lower estuary. This observation is in accord with the suggestion made earlier that there could have been significant freshwater input through The Narrows. From 2 to 24 February, the observations show salinities at T1—near The Narrows—to be of the order of 31–32 psu, while the model maintains values above 34. At T22, the site furthest offshore, the observations show salinity to be about 32–33 psu, while again the model is higher at 34–35 psu. So, in agreement with the earlier time-series comparisons, it appears there could have been freshwater influences through The Narrows, and perhaps to a lesser extent from offshore, which were not accounted for by the model.

In a further comparison, the modelled salinities in Figure 29 show that the flood has begun earlier than shown by the measured salinities of Figure 28. In fact, the model is showing the flood to be already established on 27 January. Overall magnitudes, however, are in near agreement over the period up to about 2 February; thereafter the modelled salinities begin a recovery back to pre-flood values while the measured values remain depressed. The comparison is also not particularly good with regard to the position of the plume, with the model results tending to show it stronger near the centre of Transect #1 whilst the measurements show it further toward the upper estuary.

All figures show that the model and measurements are in agreement regarding the vertical structure which is well mixed in both cases.
9. Conclusions

The objective of this evaluation was to ascertain if further work was required to calibrate the pilot model developed earlier in CM2. This was to be achieved by comparing model output with measurements obtained during a period when the Calliope River was in flood. The results of the evaluation have proved inconclusive in this regard due to a number of factors:

1. The flood event was not ideal. The objective of evaluating the model response to an input of passive tracer (i.e. freshwater flood) relied on several factors. Firstly the initial state of the system had to be well captured. Although the first survey took place after the rainfall event, the lag between rain and maximum flow of the Calliope River meant that the timing of this survey was satisfactory for use as initial conditions.

Secondly, the magnitude of the event needed to be sufficient to create adequate salinity gradients suitable for model/measurement comparison. The actual maximum flow of the evaluation event (~30 m$^3$s$^{-1}$) was well below the 150 m$^3$s$^{-1}$ considered necessary for this purpose. However, resulting salinity gradients in the estuary appeared useful for some comparisons to be made, which relates to the third factor, which is the accurate quantification of all sources of fresh water.

It is clear from the simple analysis presented in Figures 19 and 20 that the flood event alone was not capable of lowering salinity to that observed, and therefore freshwater input from other drainage systems into the estuary—probably combined with direct rainfall over the estuary surface—must also have contributed to lowering salinity. This is a result of the nature of the rainfall event responsible for the flood; rainfall was spread over the lower catchment and estuary itself. There also existed contributions of fresh water through The Narrows and offshore boundary, attributed to a flood of the nearby Fitzroy River. All of these other sources of fresh water into the estuary were required to be well quantified as inputs if the model was to respond realistically.

Ideally, a flood event was required resulting from rainfall confined to the upper catchment, so as to create an isolated singular pulse of fresh water down the river which could be easily quantified with no confounding influences from other creek systems, rainfall or fresh water entering through
Port Curtis hydrodynamic model evaluation

open boundaries. This ideal event did not eventuate. Salinity measurements from a fixed logger within The Narrows would have proved invaluable, and should be incorporated in any future calibration exercise.

2. The data retrieved from the field program was not optimum, due to failure of the continuous loggers. Continuous time-series of salinity were required from at least one location in the freshwater plume so that the behaviour of salinity over small time scales could be evaluated. This is particularly important in an estuary such as Port Curtis where tides are strong and tidal excursion is large, resulting in dramatic changes in salinity over a tidal cycle. These time series were required to be augmented by transects to evaluate the spatial scale of the plume. The construction of a time series from the transect data is far from optimum due to the coarse temporal resolution of the samples, making model data comparisons difficult.

3. The representation of the Calliope River was not optimum. The trials conducted indicated that salinity distribution in the estuary was sensitive to the volume of water contained in the river (i.e. river length, width and depth). Without data to prescribe the river’s cross-sectional area this volume can only be approximated. Furthermore, the resolution of the model grid is not sufficiently fine to accurately represent the river width. The resolution constraints resulted in the average width of the modelled river being ~250 m, widening to ~450 m at the upstream end. Clearly the river must be made shallower to preserve cross-sectional area and total volume, which in turn impacts on the velocity. The river was lengthened in the first place so as to accurately prescribe the boundary condition for salinity (i.e. 0 psu). In retrospect, due to the above difficulties, it would probably have been better to place a salinity logger closer to the mouth and prescribe the salinity boundary condition from measured data, thus circumventing the need to resolve the entire river length.

Figures 26 and 27 indicate that the modelled salinity drop due to the flood occurs before the measured data and recovers more rapidly. The former phenomenon is no doubt due to the treatment of the river in the model, particularly the river length and velocity profile established in the channel in response to the depth. Dilution of fresh water with the channel volume also impacts the magnitude of the salinity drop. The rapid recovery suggests that fresh water not accounted for in the model continues to input to the system to lower salinity after the flood peak. Alternatively, but less likely, the flushing time of the estuary in the model is underestimated (note that the flushing
Port Curtis hydrodynamic model evaluation

of the whole estuary was estimated as ~19 days; a slower salinity recovery due to underestimated flushing would imply a rate significantly longer than this).

The evaluation exercise described here has not allowed a rigorous assessment of the performance of the model with respect to transport of salinity. The key problem is an inability to quantify the inputs of fresh water into the model domain with sufficient accuracy during the selected event. In particular, it appears highly likely that fresh water from a major flow event in the Fitzroy has entered via The Narrows and has dominated local inputs from the Calliope. It was not possible to capture that effect without a continuous salinity record from The Narrows.

Despite these flaws associated with prescribing boundary conditions in the model calibration exercise, there are grounds to be optimistic that the model represents tracer transport reasonably well. The transport regime in the estuary is predominantly tidally driven, and the distribution of passive tracer will reflect this dominant forcing. The model reproduces tidal elevation well. A full calibration exercise incorporating a comprehensive field program carried out for a similar model implemented for the Fitzroy River–Keppel Bay region showed that model to reproduce salinity distributions well (Atkinson et al. 2004).

10. Recommendations

The Port Curtis Estuary and surrounds is clearly a complex region in terms of its shallow topography and high tidal regime, and the many rivers and creeks which impact during the wet season. Ideally, a hydrodynamic model of such a region should be fully calibrated. Our recommendations in doing this would include an improved physical characterisation of the estuary with quantification of all freshwater sources and sinks. The Calliope River and The Narrows boundaries could be dealt with more effectively with appropriate sampling. Dedicated field programs to retrieve calibration data using moored instruments, sampling transects and profiles in both the wet and dry seasons would also be recommended.
11. References


