International Congress on Environmental Modelling and Software

7th International Congress on Environmental Modelling and Software - San Diego, California, USA - June 2014

Jun 18th, 2:00 PM - 3:20 PM

Varying the temporal resolution of river nutrient boundary conditions to a coupled hydrodynamic-biogeochemical model of a coastal system has surprisingly little impact on model results

Barbara J. Robson
CSIRO Land and Water, barbara.robson@csiro.au

Jenny Skerratt
CSIRO Marine and Atmospheric Research

Mathieu Mongin
CSIRO Marine and Atmospheric Research

Karen Wild-Allen
CSIRO Marine and Atmospheric Research

Mark Baird
CSIRO Marine and Atmospheric Research

Robson, Barbara J.; Skerratt, Jenny; Mongin, Mathieu; Wild-Allen, Karen; and Baird, Mark, "Varying the temporal resolution of river nutrient boundary conditions to a coupled hydrodynamic-biogeochemical model of a coastal system has surprisingly little impact on model results" (2014). *International Congress on Environmental Modelling and Software*. 21.
https://scholarsarchive.byu.edu/iemssconference/2014/Stream-B/21

International Environmental Modelling and Software Society (iEMSs)
7th Intl. Congress on Env. Modelling and Software, San Diego, CA, USA
Daniel P. Ames, Nigel W.T. Quinn and Andrea E. Rizzoli (Eds.)
http://www.iemss.org/society/index.php/iemss-2014-proceedings

Varying the temporal resolution of river nutrient boundary conditions to a coupled hydrodynamic-biogeochemical model of a coastal system has surprisingly little impact on model results

Barbara J. Robson[a], **Jenny Skerratt**[b], **Mathieu Mongin**[b], **Karen Wild-Allen**[b] **and Mark Baird**[b]
[a] barbara.robson@csiro.au, CSIRO Land and Water, GPO Box 1666, Canberra, ACT 2601, Australia
[b] CSIRO Marine and Atmospheric Research, GPO Box 1538, Castray Esplanade, Hobart, TAS 7001, Australia

Abstract: Differences in the temporal resolution of catchment models and receiving water models often represent a problem for coupling of these models. Many catchment models are optimised for prediction of event-mean, monthly, or average annual sediment and nutrient loads, while coupled biogeochemical-hydrodynamic models typically run on time-steps measured in seconds, and often aim to predict patterns on a day-to-day or even sub-daily time-scale. Though previous work has shown that low temporal resolution of river boundary conditions set from *in situ* measurements can compromise the accuracy of a receiving water model, this is in large part because total river loads derived from such data are likely to be inaccurate. The case of a catchment model that accurately calculates total river loads, but at low temporal resolution, is different. To test the effect of varying catchment model temporal resolution, we ran a coupled, three-dimensional hydrodynamic-biogeochemical model of the Fitzroy Estuary and Keppel Bay, Queensland, Australia, using (a) daily varying river concentrations, (b) monthly mean river concentrations, and (c) event mean concentrations (EMCs) of nitrogen and phosphorus species for the river boundary condition. All three cases used the same, daily-varying river flow and delivered the same total nutrient loads over the simulation period. The model was run for a three-month period during a very dynamic wet season, with two major flood events in different parts of the catchment. The results were compared in terms of simulated water-column water quality, total system primary productivity, and net exports of nitrogen and phosphorus mass to the Great Barrier Reef Lagoon. The results did not support the hypothesis that daily river constituent boundary conditions produce significantly different results than monthly or event-mean concentrations.

***Keywords**:* integrated modelling; time-scales; river loads; coastal water quality; biogeochemistry

1 INTRODUCTION

A common issue in integration of models from catchment to coast or catchment to lake is the question of how to combine models designed to operate at different time-scales. Catchment models are often designed to answer questions about where sediment and nutrient loads to rivers come from within the landscape and how much changes in land use or land management are likely to affect overall loads. As such, they are typically designed to deliver load predictions that are accurate at annual, monthly, or, at best, flood-event-integrated time-scales. Lake models and marine models, by contrast, are typically designed to operate at sub-daily time-steps and may aim to predict brief algal bloom events or tidal variations in water quality (Robson, 2014). Integration of these models becomes a challenge: should we force catchment models to deliver predictions on a time-step shorter than the time-step for which they have been optimised, should we use empirical approaches to disaggregate monthly predictions from catchment models, or should we feed marine models with river nutrient concentrations that are updated much less frequently than the time-step on which the marine models operate?

The eReefs project (Chen et al., 2011; Schiller et al., 2013) is developing a large-scale, integrated suite of catchment, estuary and marine models and linked data and information products to facilitate management of the Great Barrier Reef Lagoon, a World Heritage conservation site and the largest reef system in the world. For purposes of scenario modelling, the eReefs marine models, which operate at near real-time with time-steps measured in seconds (for the underlying hydrodynamic model) to hours (for biogeochemical and ecological processes) will rely on inputs from Source Catchment models that have been evaluated on event-mean and annual average timescales (Dougall and Carroll, 2013). To devise a path forward for integration of these models, it was necessary to assess the degree to which the time-step of river load specification affected marine modelling results. This paper discussion shows how this evaluation was performed using a test estuary (rather than the whole of the Great Barrier Reef Lagoon) as a case study.

2 METHODS

2.1 Study Site

Figure 1 The Fitzroy Estuary and Keppel Bay, on the East coast of Australia

The Fitzroy Estuary (Figure 1) is a macrotidal estuary (7 m spring tides) located just north of the tropic of Capricorn, and flowing into Keppel Bay and the Great Barrier Reef Lagoon (GBRL). It accounts for a substantial proportion of total catchment nitrogen, phosphorus and sediment loads reaching the GBRL (Brodie et al., 2012) and this is a concern as there is evidence that the pelagic productivity driven by enhanced catchment nutrient loads to the GBRL (Furnas et al., 2005) drives the spread of the invasive Crown of Thorns starfish, which has caused enormous damage to the Great Barrier Reef over the past 30 years (De'ath et al., 2012).

Previous work in the Fitzroy Estuary has included quantification of sediment and nutrient budgets for the estuary (Webster et al., 2005), examination of the biogeochemistry and drivers of production in the system (Ford et al., 2005; Radke et al., 2010), both statistical and semi-distributed modelling of nutrient and sediment loads from the river (McKergow et al., 2005; Robson and Dourdet, 2013), and implementation and validation of detailed hydrodynamic, sediment dynamic and biogeochemical models for both dry-season and flood conditions (Margvelashvili et al., 2013; Robson et al., 2008). Previous biogeochemical models have been driven by river loads estimated on a daily time-step, though this has required both interpolation of monitoring observations, and disaggregation of catchment model outputs provided at longer time-steps.

For the present study, the model domain includes highly simplified grid, very approximately representing the mouth of Fitzroy Estuary and Keppel Bay on a resolution of approximately one kilometre horizontally, with 20 vertical layers to a maximum depth of 20 m at mean tide.

2.2 Model

We applied the CSIRO EMS modelling suite, a three-dimensional baroclinic hydrodynamic, biogeochemical and sediment dynamic model which has been fully described by previous authors (Skerratt et al., 2013; Wild-Allen et al., 2013) and has been previously calibrated and validated for the study site (Robson et al., 2008). Processes simulated include benthic and pelagic primary production, nitrogen and phosphorus biogeochemistry in both water column and sediment layers, and the transport, physical and chemical dynamics of particulate as well as dissolved materials.

For the present study, the model was run in transport mode (as discussed by Margvelashvili et al., 2013), allowing faster, decoupled implementation of the sediment and biogeochemical modules after completion of a hydrodynamic model run.

2.3 Simulation period and river boundary conditions

The 2008 wet season and its immediate aftermath (i.e. the period from Jan to May 2008) was selected as an ideal simulation period for this study, as this period included a major flood event with two flow peaks that resulted from rainfall events in different parts of the catchment and showed different characteristics in terms of the relationship between flow and concentrations of dissolved and particulate nutrients and sediments, with the first event carrying a much higher load of particulate material in particular than the second. The 2008 wet season was also one of the largest and best monitored flow events in the region in recent decades, and has been linked with increased chlorophyll production in Great Barrier Reef waters (Alvarez-Romero et al., 2013).

Water quality data included measured total suspended solids, nitrate+nitrite, ammonium, total nitrogen, total dissolved nitrogen, total phosphorus, total Kjeldale phosphorus and total dissolved measured in the river on seventeen occasions during the January-February flow period, and at monthly intervals subsequently. Daily flow estimates were obtained from previously established rating curves combined with stage height measured at the furthest downstream gauge, approximately 20 km upstream of the mouth of the estuary. A load estimation tool was used to convert calculated loads of key sediment and nutrient constituents in the river on a daily time-step (Packett et al., 2011).

Three simulations were conducted:

1) With concentrations of river nitrogen and phosphorus constituents (i.e. nitrate, ammonium, dissolved organic nitrogen, particulate organic nitrogen, dissolved inorganic phosphorus, dissolved organic phosphorus, particulate organic phosphorus and adsorbed phosphorus) calculated on a daily time-step.
2) With concentrations of river nitrogen and phosphorus constituents calculated on a monthly time-step, to give the same total load in each month as in simulation 1 – i.e. flow-weighted monthly mean concentrations.
3) With concentrations of river nitrogen and phosphorus constituents calculated on an “event mean” basis, treating the first and second major flow events as separate events and delivering the same total load for each flow event as simulation 1 – i.e. flow-weighted event mean concentrations (EMCs). Time series of flow and nitrogen boundary conditions for each of the three simulations are illustrated in Figure 2 to Figure 5.

For all simulations, the same estimated daily flow and sediment concentrations were applied, while constant upstream-advection boundary conditions were applied at the ocean boundary.

The three simulations were then repeated with a shallower test estuary (1/3 the depth of the simplified Fitzroy estuary grid), as a first step towards assessing the generalisability of the results.

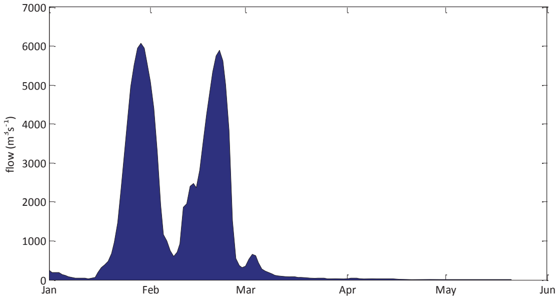

Figure 2. River flow (m^{3}s^{-1}) applied as an inflow boundary condition for all three simulations

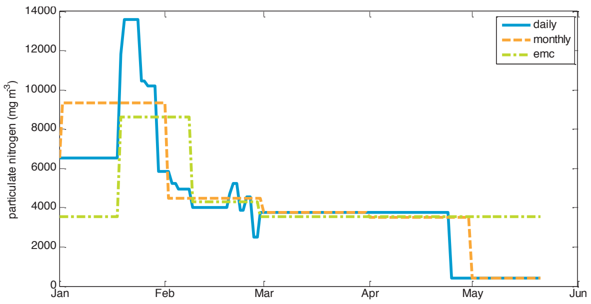

Figure 3. Particulate organic nitrogen concentrations applied at the inflow boundary.

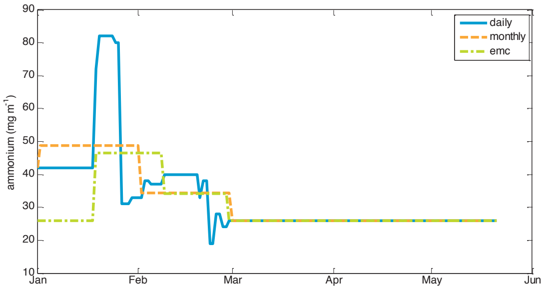

Figure 4. Ammonium river inflow boundary conditions for the three simulations.

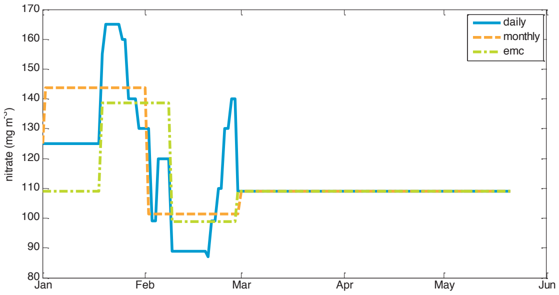

Figure 5. Nitrate river inflow boundary conditions for the three simulations: daily (solid blue line), monthly (dashed orange) and event mean concentrations (dot-dashed green lines).

3 RESULTS AND DISCUSSION

Figures 6 and 7 and Figures 8 and 9 show snapshots and time-series of surface ammonium, dissolved inorganic nitrogen, and chlorophyll concentrations in each of the three simulations using the deeper (up to 20 m) and shallower (6 m) test estuary embayment bathymetries, respectively. Nitrogen rather than phosphorus results are shown, since nitrogen was the key nutrient limiting pelagic production during these simulations. Altering the depth of the embayment substantially alters the hydrodynamics of the system, with a clear surface plume developing in the deeper embayment (Figure 6), while fresh water mixed to the bottom and spread laterally in the shallower test system (Figure 8).

In both cases, however, the differences in water quality time-series outside the river channel were minimal (Figure 7 and Figure 9). Although the river load time-series were significantly different amongst the three simulations (Figure 3 to Figure 5), by the time the plume reached the middle of the embayment, only the brief peak dissolved inorganic nitrogen and chlorophyll *a* concentrations were significantly different. In a few cases, such as a peak value that exceeds a reference value to trigger regulatory action, this peak may be important, and in some cases, an incorrect peak concentration will contribute to miscalibration of the marine model. In these test cases, however, the implications of these differences for simulated ecosystem function are minimal.

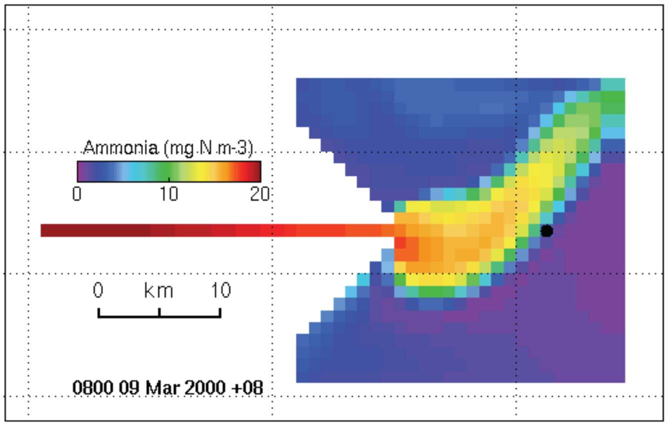

Figure 6. Surface ammonium concentrations in the fully-developed flood plume, forced with daily varying river nutrient concentrations.

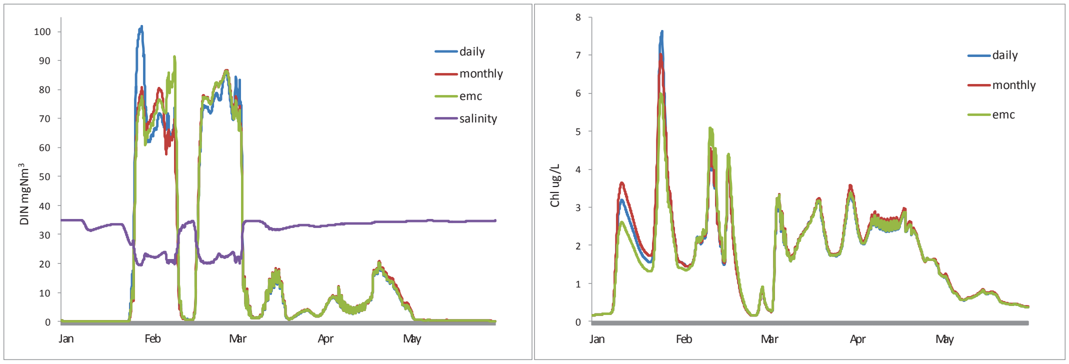

Figure 7. Salinity, dissolved inorganic nitrogen (left) and chlorophyll *a* (right) in each of the three simulations (blue: daily, red: monthly; green EMC varying river nutrient concentrations) at the surface of the deeper test estuary, at the location shown as a black dot in **Figure 6**.

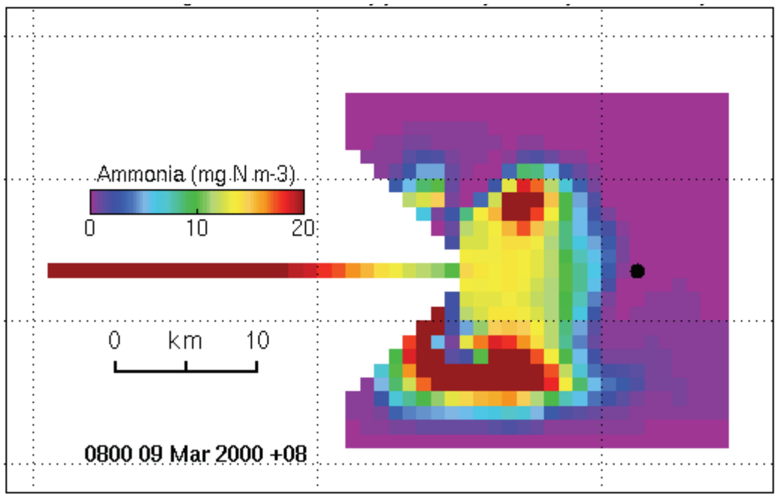

Figure 8. Surface ammonium concentrations in the fully-developed flood plume in the shallower test estuary, forced with daily varying river nutrient concentrations.

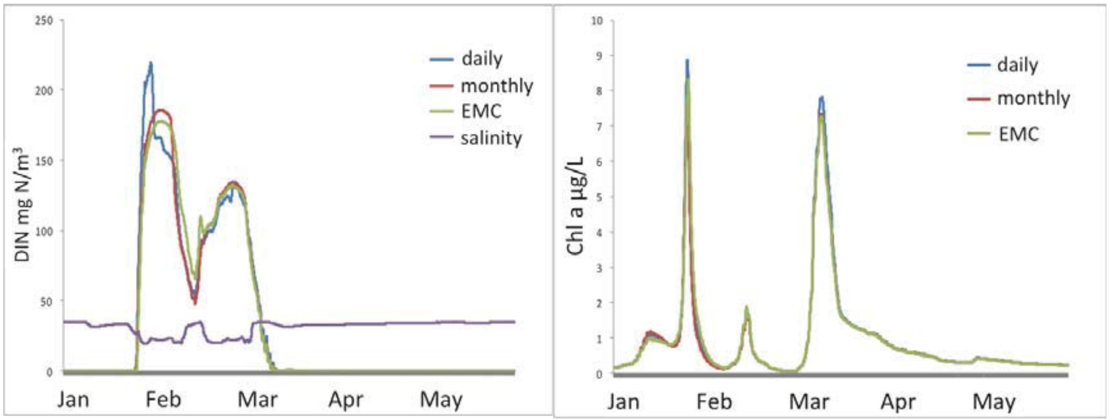

Figure 9. Salinity, dissolved inorganic nitrogen (left) and chlorophyll *a* (right) in each of the three simulations (blue: daily, red: monthly; green EMC varying river nutrient concentrations) at the surface of the shallower test estuary, at the location shown as a black dot in Figure 8.

Results of the simulations were also analysed to evaluate total primary production within the system and total fluxes of nitrogen and phosphorus exported across the open ocean boundary to the Great Barrier Reef Lagoon. These metrics (given in Table 1 and Table 2) provide a good indication of the likely mid-term implications of the simulated flood event for reef health, beyond the immediate effects of exposure of reef and seagrass habitats to low salinity, high turbidity flood plume water. For both the shallow and deep embayment test cases, the differences in these overall metrics between simulations forced on daily, monthly or event mean time-scales are well within the error of the marine model itself and the error introduced by calculating fluxes across a macrotidal open boundary.

Table 1. Summary results for the three simulations. Deep embayment (approximately representing the mouth of the Fitzroy Estuary). “Daily”, “monthly” and “EMC” refer to the time-step of variation of river nutrient concentrations. Results shown are temporal means over the duration of the simulation. Negative values indicate a net import.

Net export to the ocean	daily	monthly	EMC
Dissolved N (t N d^{-1})	-3414	-4343	-4279
Particulate N (t N d^{-1})	8941	6445	5122
Dissolved P (t P d^{-1})	19685	18289	17524
Particulate P (t P d^{-1})	4096	4091	4094
Pelagic primary production (kg d^{-1})	36.90	37.76	36.84

Table 2. Summary results for the three simulations: shallow embayment. Results shown are temporal means over the duration of the simulation.

Net export to the ocean	daily	monthly	EMC
Dissolved N (t N d^{-1})	33606	34531	32131
Particulate N (t N d^{-1})	22470	22637	21555
Dissolved P (t P d^{-1})	47214	46338	44916
Particulate P (t P d^{-1})	16883	16883	16882

4 CONCLUSIONS AND RECOMMENDATIONS

In many cases, catchment models that provide accurate river nutrient loads on a monthly or event mean timescale may be sufficient to drive a marine model that operates on a subdaily time-step.

We acknowledge that these early results are somewhat limited in scope, but present them here because they surprised us and have important implications for integration of catchment and marine models. Further work is needed to explore the generalisability of our conclusions, and to determine in what circumstances more frequent river boundary nutrient concentration data may be required.

Note that this result does not necessarily carry over to models forced with observed river nutrient concentrations rather than by catchment models. In the case of observed river nutrient concentrations, it is important to verify that the observations are of sufficient frequency to produce a correct total river nutrient load, and that the method used to interpolate between observations is adequate for this purpose.

ACKNOWLEDGMENTS

This work was conducted as part of eReefs, a collaboration between the Great Barrier Reef Foundation, the CSIRO Wealth from Oceans National Research Flagship, the Australian Institute of Marine Research, the Government of Queensland and the Australian Bureau of Meteorology. eReefs is supported by funding from the Science Industry Endowment Fund, the Government of Australia, BHP Billiton, BMA and in-kind contributions from the participating organisations. Thanks are due to Dr Robert Packett (Government of Queensland) for providing estimated daily river nutrient loads to Fitzroy Estuary during the January-February 2008 flood event, and to Farhan Rizwi and Mike Herzfeld (both CSIRO Marine and Atmospheric Research) for their substantial roles in development of the EMS modelling suite.

REFERENCES

Alvarez-Romero, J.G., Devlin, M., da Silva, E.T., Petus, C., Ban, N.C., Pressey, R.L., Kool, J., Roberts, J.J., Cerdeira-Estrada, S., Wenger, A.S., Brodie, J., 2013. A novel approach to model exposure of coastal-marine ecosystems to riverine flood plumes based on remote sensing techniques. Journal of Environmental Management 119 194-207.

Brodie, J.E., Kroon, F.J., Schaffelke, B., Wolanski, E.C., Lewis, S.E., Devlin, M.J., Bohnet, I.C., Bainbridge, Z.T., Waterhouse, J., Davis, A.M., 2012. Terrestrial pollutant runoff to the Great Barrier Reef: An update of issues, priorities and management responses. Marine Pollution Bulletin 65(4-9) 81-100.

Chen, Y., Minchin, S., Seaton, S., Joehnk, K., Robson, B., Bai, Q., 2011. eReefs–a new perspective on the Great Barrier Reef, Proceedings of the 19th International Congress on Modelling and Simulation, Perth, Australia, pp. 12-16.

De'ath, G., Fabricius, K.E., Sweatman, H., Puotinen, M., 2012. The 27-year decline of coral cover on the Great Barrier Reef and its causes. Proceedings of the National Academy of Sciences of the United States of America 109(44) 17995-17999.

Dougall, C., Carroll, C., 2013. Great Barrier Reef Source Catchment's modelling: Enhanced simulation and water quality targeting through event based assessment, In: Piantadosi, J., Anderssen, R.S., J., B. (Eds.), MODSIM2013, 20th International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand. MSSANZ: Adelaide, Australia.

Ford, P., Tillman, P., Robson, B., Webster, I.T., 2005. Organic carbon deliveries and their flow related dynamics in the Fitzroy estuary. Marine Pollution Bulletin 51(1-4) 119-127.

Furnas, M., Mitchell, A., Skuza, M., Brodie, J., 2005. In the other 90%: phytoplankton responses to enhanced nutrient availability in the Great Barrier Reef Lagoon. Marine Pollution Bulletin 51(1-4) 253-265.

Margvelashvili, N., Andrewartha, J., Herzfeld, M., Robson, B.J., Brando, V.E., 2013. Satellite data assimilation and estimation of a 3D coastal sediment transport model using error-subspace emulators. Environmental Modelling & Software 40 191-201.

McKergow, L.A., Prosser, I.P., Hughes, A.O., Brodie, J., 2005. Sources of sediment to the Great Barrier Reef World Heritage Area. Marine Pollution Bulletin 51(1-4) 200-211.

Packett, R., Waters, D., McCloskey, G., 2011. Increasing confidence in model prediction: A case study on water quality data collation for model validation in the Great Barrier Reef catchments. 19th International Congress on Modelling and Simulation (Modsim2011) 4134-4140.

Radke, L.C., Ford, P.W., Webster, I.T., Atkinson, I., Douglas, G., Oubelkheir, K., Li, J., Robson, B., Brooke, B., 2010. Biogeochemical Zones Within a Macrotidal, Dry-Tropical Fluvial-Marine Transition Area: A Dry-Season Perspective. Aquatic Geochemistry 16(1) 1-29.

Robson, B.J., 2014. State of the art in modelling of phosphorus in aquatic systems: Review, criticisms and commentary. Environmental Modelling & Software. (In press, available online)

Robson, B.J., Dourdet, V., 2013. Incorporating a generalised additive model of river nutrient concentrations into a mechanistic receiving water model, In: Piantadosi, J., Anderssen, R.S., J., B. (Eds.), MODSIM2013, 20th International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand. MSSANZ: Adelaide, Australia, pp. 373-379.

Robson, B.J., Hamilton, D.P., Webster, I.T., Chan, T., 2008. Ten steps applied to development and evaluation of process-based biogeochemical models of estuaries. Environmental Modelling & Software 23(4) 369-384.

Schiller, A., Herzfeld, M., Brinkman, R., Stuart, G., 2013. Monitoring, Predicting and Managing one of the Seven Natural Wonders of the World. Bulletin of the American Meteorological Society. Jan 2013. 23-30.

Skerratt, J., Wild-Allen, K., Rizwi, F., Whitehead, J., Coughanowr, C., 2013. Use of a high resolution 3D fully coupled hydrodynamic, sediment and biogeochemical model to understand estuarine nutrient dynamics under various water quality scenarios. Ocean & Coastal Management 83 52-66.

Webster, I.T., Ford, P.W., Tillman, P., 2005. Estimating nutrient budgets in tropical estuaries subject to episodic flows. Marine Pollution Bulletin 51(1-4) 165-173.

Wild-Allen, K., Skerratt, J., Whitehead, J., Rizwi, F., Parslow, J., 2013. Mechanisms driving estuarine water quality: A 3D biogeochemical model for informed management. Estuarine Coastal and Shelf Science 135 33-45.