Hydro-ecological modeling in coastal catchments: Connectivity and hydro-ecological function

Report from the MTSRF Projects 3.7.3 and 3.7.4 Workshop held at CSIRO Davies Laboratory, Townsville, 19-20 April 2007

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Project 3.7.3 – Freshwater indicators and thresholds of concern.
Project 3.7.4 – Wetlands and floodplains: connectivity and hydro-ecological function

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Acronyms Used In This Report

ACTFR .... Australian Centre for Tropical Freshwater Research
AIMS .... Australian Institute of Marine Science
CRC............... Cooperative Research Centre
CSIRO .... Commonwealth Scientific and Industrial Research Organisation
GU .... Griffith University
JCU .... James Cook University
MTSRF .... Marine and Tropical Sciences Research Facility
RRRC .... Reef and Rainforest Research Centre Limited

Abbreviations Used In This Report

ANCOVA .... Analysis of covariance
DIN .... Dissolved inorganic nitrogen
DON .... Dissolved organic nitrogen
ERM .... Ecological response modeling framework
GBR .... Great Barrier Reef
LiDAR .... Light detection and ranging
MCB .... Marine Catchment Basin
MFAT .... Murrya Flow Assessment Tool
NRM .... Natural Resource Manager
PhD .... Doctor of Philosophy
RiM-FIM .... River Murray Flood Innundation Model
RRC............... River continuum concept
UNESCO .... United Nations Education Science and Cultural Organisation
WINDS .... Weighted index of salinisation

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Summary

This report summarises the presentations, discussion and recommendations made at a Hydro-ecological modeling Workshop held as part of the Marine and Tropical Science Research Facility (MTSRF) Water Quality Program. The main aim of the Workshop was to initiate the development of an integrated package of conceptual and quantitative models, supported by field-based research, to predict the key hydro-ecological functions in Wet Tropics rivers, wetlands and floodplains. Particular attention was given to connectivity issues that need to be understood and managed at a range of spatial scales.

The Workshop was held under the auspices of two MTSRF projects; Project 3.7.3 which is designed to develop conceptual biophysical models to identify: (i) appropriate indicators of waterway ecosystem health, and (ii) probable thresholds of concern and their effects on biodiversity and ecological processes. In parallel, and closely linked with this project, is Project 3.7.4, which focuses on the development of a core floodplain hydrological model to quantify two important aspects of hydro-ecological functioning: (i) sources, sinks and transport of sediments and nutrients across floodplains, and (ii) connectivity of wetland systems within floodplains. The twin development of conceptual models of the ecological dynamics of these systems and how these interact with the hydrological processes is strategically designed to improve our capability to predict the impacts of changes in land use, land and water management and climate on the flow and water quality regimes and ecological dynamics in the wetlands and floodplains of catchments adjacent to the Great Barrier Reef.

The Workshop involved 30 leading hydrological and ecological experts and was held on 19 and 20 April 2007 at the CSIRO Davies laboratory. During the first day a series of 13 hydrological and ecological presentations relevant to tropical floodplains were made. The second day focussed on the development of disciplinary and integrated hydrological and ecological models using a breakout group approach. The hydrological presentations highlighted recent studies of floodplain hydrology using contrasting static and hydro-dynamic approaches. The former combined state of the art remote sensing techniques with peak river flow data to identify inundated areas in the Murray-Darling basin. The hydro-dynamic floodplain modeling showed how inundation extent, material transport and wetland connectivity could be simulated dynamically during individual flood events. The differences between the flow and water quality regimes in the Wet and Dry Tropics were also highlighted along with the potential role of wetlands to filter sediment and nutrients. The connection of the floodplain system to the marine environment was made via two presentations, one on estuarine bio-geochemistry and the other on freshwater-marine water quality interactions.

Links with the ecological domain were made by a scene setting paper on water and ecosystem health, which was followed and illustrated by recent studies in the Wet Tropics. These two papers demonstrated the complexity of ecological interactions in tropical waterways, but also how statistically rigorous approaches could help the monitoring programs of natural resources managers. The interaction of the hydrological regimes with freshwater ecosystems was elaborated by looking at the influence of various characteristics of a river’s flow regime on habitat structure, fish diversity, fish migration, reproduction and recruitment processes, and other ecological processes (migration, spawning) associated with lateral and longitudinal patterns of connectivity. New PhD research on the influence of flow seasonality on the recruitment ecology of riverine fishes from lowland Wet Tropics rivers was also presented. This project will identify the location of recruitment under the influence of seasonal (wet and dry) flow regimes and document shifts in habitat use and migratory patterns. Fish migration was also addressed in the context of man made structures, where conceptual models of fish passage were used to aid their design. The final paper described a software tool, the “ecological response modeling framework” (ERM) for compiling the existing

knowledge of ecological responses to time series of habitat drivers such as flow, water quality, and physical habitat drivers such as woody debris or substrate. Ecological response models, such as habitat suitability and rule based models, are also captured in the ERM framework as is a measure of the confidence of each model component.

Much of the discussion on the second day revolved around the Marine Catchment Basin concept proposed by Gehrke and Sheaves (2006); see Figure 1. This links the 6 key domains of the upper and lower catchment with the open ocean waters. Land, wetland and river interactions are represented in the upper catchment, floodplain and estuary and these connect with the marine environment via the freshwater plume that mixes with the deeper ocean waters. Lateral interactions occur in each domain, but with differing hydrological and ecological characteristics. Longitudinal interactions between the domains mix waters of different chemistry and acts as a conduit for materials and freshwater and marine biota. The Marine Catchment Basin concept was used as a construct for discussion and led to an initial ‘typology’ of the hydrological and ecological regime in each of the model domains. It was recognised that details of the Marine Catchment Basin concept would be different in Wet and Dry tropical systems and that hydrological and ecological sub-models would need to be specified for each domain and system. Candidate hydrological and ecological models for each domain were proposed along with suggestions on how the goals of the two MTSRF Projects could be both clarified and better integrated.

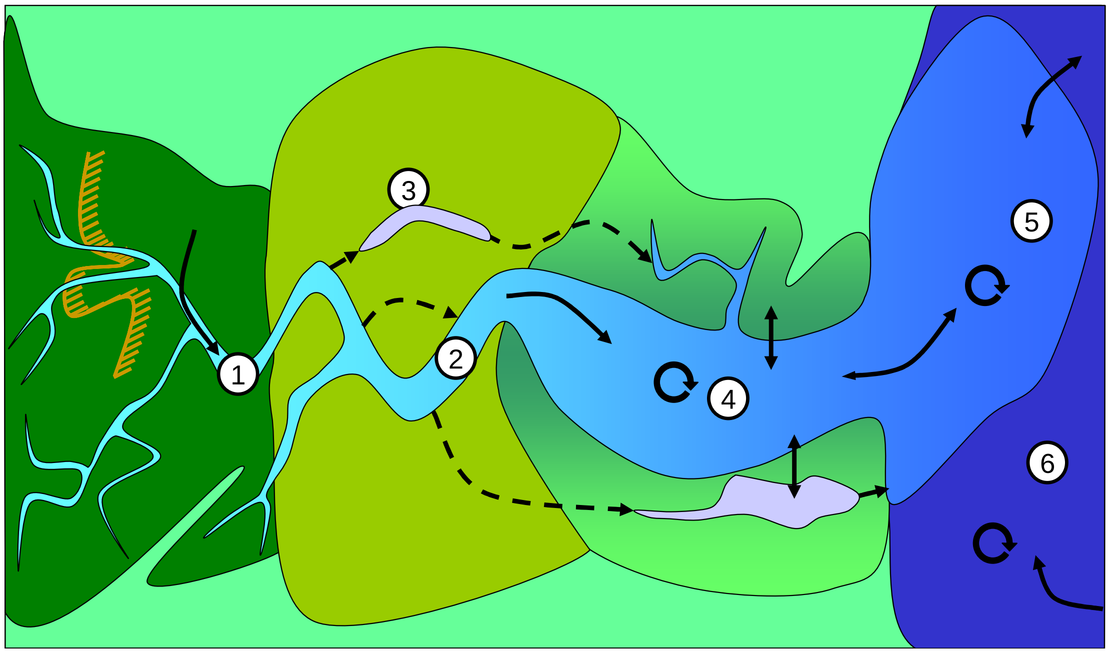

Figure 1. The Marine Catchment Basin concept showing the major sub-components of the catchment, floodplain, estuary and marine continuum. 1. River reaches upstream of the lowland floodplain; 2. Lowland river reaches adjacent to; 3. Well-developed floodplain with freshwater wetlands; 4. Estuarine reaches with salt-tolerant riparian vegetation and brackish wetlands; 5. River plume extending seaward and 6. Coastal waters outside the river plume. Arrows indicate direction of major material transport within numbered zones. Circular arrows show major zones of material recycling. Modified from Gehrke and Sheaves (2006) who adapted the original concept of Caddy (2000).

The Workshop participants made 12 primary recommendations centred around the use and modification of the Marine Catchment Basin concept as an overarching framework to build and link component hydrological and ecological models. Within this framework the number and type of models to be developed should be clarified. Separate models would be required for the hydro-ecological links during the dry (ambient flow) season and the wet (flood flow) season. Natural and modified flow regimes need to be modeled and the role of groundwater needs to be better understood. Comparative approaches to floodplain inundation modeling should be considered, especially where this might provide a means of extrapolating inundation modeling to a range of other catchments along the GBR coast. There was a recommendation to include measurement and modeling of carbon and detritus in the floodplain hydro-dynamic model and wetland filtering model. This would open up links to food web analysis and ecological models as well as providing a vital link with estuarine models. The capacity to deal with estuarine connectivity should be further explored, for example, by linking the proposed floodplain hydro-dynamic model to an estuarine eco-hydrology model. Linking with the UNESCO Ecohydrology program would help to develop this aspect of the projects. Further recommendations referred to the need to liaise closely with MTSRF marine water quality projects to ensure maximum synergy of data and models that run from the upper catchment, via river channel, floodplain, estuary and out into the marine environment. Finally, further field trips to Tully to refine experimental designs were recommended along with presentation of the projects to local stakeholders and NRM managers.

Introduction

Floodplains and wetlands are important physical and biological components and links in the aquatic continuum, providing unique and essential habitat and connectivity for specialist and wide-ranging biota. Yet very little is known about the hydrological dynamics of these systems, and how hydrological dynamics and physical connectivity influence aquatic habitats, water quality, biological diversity and ecosystem processes. These systems provide access and vital habitat for iconic species such as barramundi, but they are typically badly managed, highly impacted and, in the case of freshwater wetlands, severely depleted (~75% of such wetlands in GBR catchments having been lost to agricultural and other development). Proper management will depend on understanding the biophysical relationships and connectivity in these systems. It is particularly important to develop a better and more predictive capacity to quantitatively link changes in land use, land management, water management or climate change to freshwater and marine ecosystem health. Conceptually this is mediated through the hydrological regime, Figure 2, where both the flow and quality of water can affect habitat and the biogeochemical and ecological processes in rivers, wetlands and estuaries.

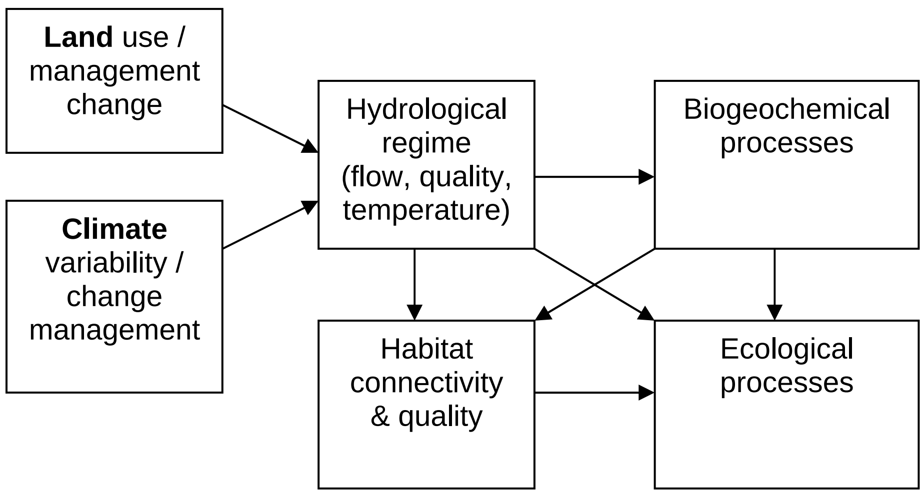

Figure 2. A simple conceptual model of the way in which changes on the land or in climate can affect habitat, biogeochemical and ecological processes via the hydrological regime. Note that not all possible interactions are shown (e.g., ecological processes can affect habitats, water quality and biogeochemical processes)

A particular challenge lies in the quantification of ecological processes that relate to ecosystem health, so one of the water quality projects within the MTSRF water quality program (Project 3.7.3, see Appendix I) will develop conceptual biophysical models to identify: (i) appropriate indicators of waterway ecosystem health, and (ii) probable thresholds of concern, in terms of stressors (such as contaminant concentrations, instream habitat, riparian zone condition, hydrological change) and their effects on biodiversity and ecological processes. In parallel, and closely linked with this project, is one which focuses on the floodplain hydrological regime. This project (Project 3.7.4 – see Appendix I) will develop a core floodplain hydrological model to quantify two important aspects of hydro-ecological functioning: (i) sources, sinks and transport of sediments and nutrients across floodplains, and (ii) connectivity of wetland systems within floodplains. The twin development of conceptual models of the ecological dynamics of these systems and how these interact with the hydrological processes is strategically designed to improve our capability to predict the impacts of changes in land use, land and water management and climate on the flow and water quality regimes and ecological dynamics in the wetlands and floodplains of catchments adjacent to the GBR.

Given these challenges, project leaders of the MTSRF project 3.7.3 and 3.7.4 held a joint Workshop on hydro-ecological modeling within their first year of activity (see Appendix II for details). The Workshop took place at the CSIRO Davies laboratory on 19 and 20 April 2007, with about 30 hydrological and ecological experts attending, Figure 3 (see also Appendix III). This report summarizes contributions and conclusions as to how the two MTSRF Projects could refine, integrate and achieve their goals.

Figure 3. Participants of the Hydro-ecological Modeling Workshop held at the CSIRO Davies Laboratory in Townsville, 19-20 April 2007.

Background to Workshop

The Overall MTSRF Program

The two projects that are associated with the Hydro-ecological Workshop are both part of the MTSRF. Figure 4 shows the location of Projects 3.7.3 and 3.7.4 within the Catchments sub-section of the Water Quality Program (7). Both of the catchments projects will link strongly with the Marine and Estuarine water quality Projects led by Katharina Fabricius from AIMS. Initial discussions have been held with this group and representatives were invited to the Hydro-ecological Workshop. Projects 3.7.3 and 3.7.4 will also link to the social and economic studies being carried out in the Ecosystems and Social Frameworks sub-program led by Professor Iain Gordon from CSIRO. In particular, Projects 3.7.3 and 3.7.4 will contribute to the Integrated Report Card framework being developed within this sub-program, largely by providing robust wetland connectivity indices and other appropriate indicators of waterway health. To this end, representatives from the Ecosystems and Social Frameworks sub-program and Integrated Report Card framework projects were invited to the Hydro-ecological Workshop

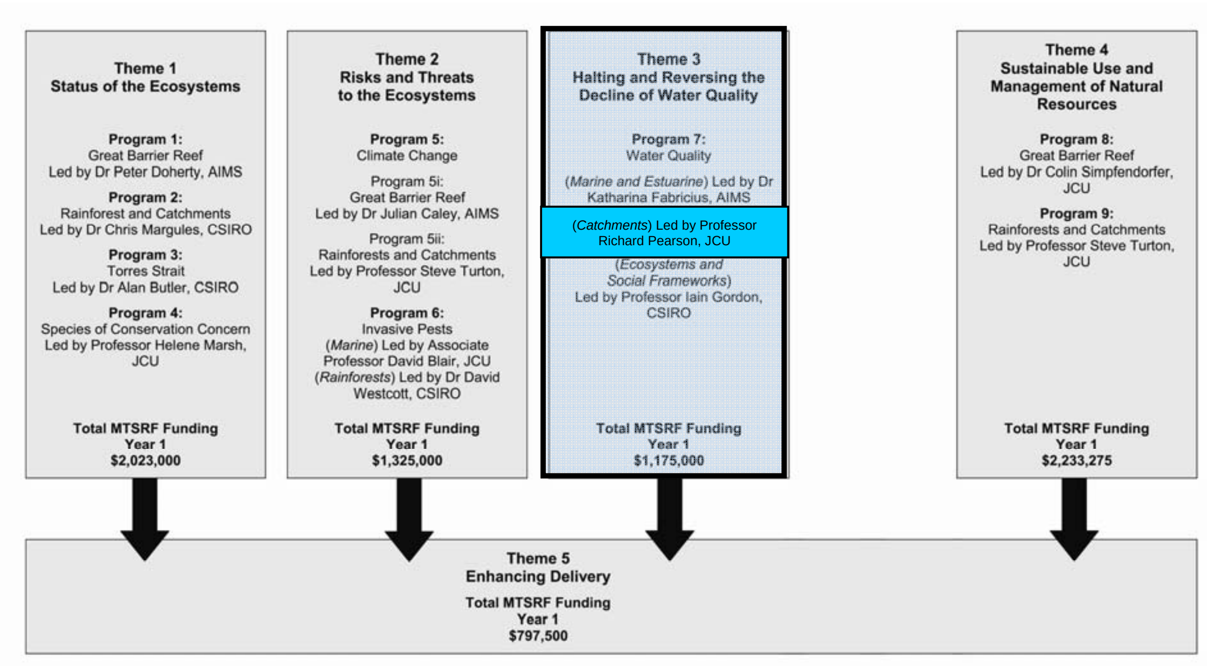

Figure 4 The complete MTSRF Research Programme showing the location of the Water Quality Program (7) and its component Projects 3.7.3 and 3.7.4.

Project Objectives

The key objectives of the two projects are as follows:

Project 3.7.3: Freshwater indicators and thresholds of concern

Key Objectives:

(a) Conduct field, laboratory and desk-top research to develop physical, chemical and ecological indicators of freshwater ecosystem health in the Wet and Dry Tropics as part of an Integrated Water Quality Report Card that meets end-user needs and objectives.
(b) Identify thresholds of potential concern relating to land use, water quality, riparian condition, habitat and food web structure in freshwater ecosystems of the Wet and Dry Tropics.
(c) Develop an interactive Web database documenting the distribution and ecological requirements of freshwater biota in the Wet and Dry Tropics, to assist river health assessments and inform a range of end users.
(d) Train new researchers via PhD programs that will be integral to the identification and testing of efficient and effective freshwater condition indicators in the Wet and Dry Tropics.
(e) Provide monitoring methods, manuals and guidelines of relevance to a range of skills and end users.

Project 3.7.4: Wetlands and floodplains: connectivity and hydro-ecological function

The overall objective of this project is to develop the capability to predict the impacts of changes in land use, management and climate on the flow and water quality regimes and ecological dynamics in the wetlands and floodplains of catchments adjacent to the GBR. This will be achieved via the following key objectives:

(a) Quantify how the flood regime affects the main sinks and sources of sediment and nutrient and their transport across floodplains.
(b) Develop a model to predict how the hydrological response and connectivity of tropical floodplains are affected by land use, land and water management and climate.
(c) Develop models that link ecological structure (e.g. biodiversity, community patterns) and processes to the core floodplain hydrology model to quantify the consequences of changes in water body connectivity between freshwater and saline waterways for biodiversity, biological connectivity and healthy ecological function.

The first two of the above objectives will form the core work of sub-project 3.7.4 while the last objective will largely be delivered in conjunction with ecological models developed in Project 3.7.3.

Purpose of the Workshop, Format and Program

The main purpose of the Workshop was to initiate the development of an integrated package of conceptual and quantitative models, supported by field-based research, to predict the key hydro-ecological functions in Wet Tropics rivers, wetlands and floodplains. Particular attention was given to connectivity issues that are central to ecosystem health and that need to be understood and managed at a range of spatial scales. Further details of the aims of the Workshop are given in Appendix II, where the specific objectives were to identify a range of hydrological, biochemical and ecological models best suited to quantifying the connectivity of water bodies on the floodplain, and t

he impacts of this on habitat and ecological response. Through this exercise it was also hoped to be able to identify key knowledge gaps that limit our ability to link hydrological and ecological models.

The Workshop was held over two days, the first day being a series of hydrological and ecological presentations relevant to tropical floodplains (see Appendix IV). The second day focussed on the development of disciplinary and integrated hydrological models using a breakout group approach. Brief summaries of the individual presentations are given in the following section.

Summary of Presentations

Floodplain hydro-dynamic modeling of water quality and wetland connectivity... Jim Wallace

This paper presented a novel approach to modeling of material transport across a floodplain using a hydro-dynamic model. The floodplain model is fed by number of sub-catchment rainfall-runoff models and as water ponds on the floodplain and breaks the banks of the Tully and Murray Rivers, the hydro-dynamic model moves water across the surface according to elevation and surface roughness. The current model (Mike 21; Connell Wagner 2005) only deals with fluxes of water, but this hydro-dynamic scheme has sub models that can represent the movement of sediments and dissolved nutrients. A second application of the hydro-dynamic model illustrated how the connectivity of wetlands could be quantified by combing the model dynamics with maps of the floodplain wetlands.

Eco-Hydrology modeling on the Murray Floodplain.. Ian Overton

The Flood Inundation Modeling (RiM-FIM, Overton 2005) approach was used to calculate inundation extend on the Murray (NSW) floodplain. The model uses satellite images of inundation extent and relates these to measured flows in the Murray River. LiDAR data were also used to improve the identification of inundated areas and to allow flood depths and volumes to be estimated. Time series of flood periods were then used to determine flood habitats, where areas are coded according to multiples of flood returns compared to the 'natural' flood regime. For example, significant environmental impacts appear when the natural flood return periods are extended by a factor of ~ 3. Temporal impacts of flooding were estimated using rating curves taken from the MFAT model (Young *et al*. 2003. Vegetation health was also estimated using the WINDS (Overton *et al*. 2006) model, which combines flood frequency with a vegetation water balance and salinity model. The resultant combination of models can then provide Floodplain Risk maps of the entire Lower Murray basin.

Hydrology and water quality relationships in northern Australian catchments... Jon Brodie

This paper compared the key factors that influence water quality in Dry and Wet tropical catchments. Water quality is highly dependent on the flow regime and the timing of flow events. Wet tropical rivers tend to flow all year around, with very high flows (and flooding) occurring frequently during the rainy season. In contrast, Dry tropical rivers spend much of the time with little or no flow, interspersed with very large high flow events. Sediments are primarily moved in large events, with the highest sediment concentrations occurring in the 'first flush', i.e. following the first substantial rains of the wet season. However, an early, small event can give rise to very high sediment/contaminant concentrations in water that can sit in pools until a subsequent larger flooding event occurs. The source and hence quality of water throughout a flow sequence may also change. For example, early river flow is likely to represent run-off from the lower (more polluted) sub-catchments and later (cleaner) flow is likely to be from the upper catchment. There are also important groundwater inputs to rivers and this may contain nitrate. Overall, there is a substantial body of data that demonstrate that river water quality reflects land use, in particular the amount of fertilised land-use. In high flow conditions water quality is generally determined by the upper catchment as local factors have little time to have an effect. Conversely, under low or no flow conditions local factors dominate and the wider catchment signal is minimal. These behaviours are very impotent when trying to set water quality targets.

Modeling of wetland filtering processes......Dave McJannet

The potential role of wetlands to reduce sediments and nutrient loads moving across the floodplain was presented in this paper. Conceptual models of wetland water and nutrient balances outlined the scope of the important wetland processes. Several different wetland modeling approaches were presented ranging from catchment or floodplain wide models which contained wetlands, to models that specifically dealt with within wetland hydrological, bio-chemical and ecological processes. The type and scale of wetland model used depends on the questions to be addressed. The paper finished by outlining the hydrological measurements being made in Kyambul lagoon in the Tully catchment. This emphasised two key points; (i) wetland models are of little use without locally appropriate data and (ii) in the Wet Tropics wetlands have two distinct phases, an ambient condition where (low to moderate) flows into and out of the wetland are channelised and another where they become inundated as part of much larger flood events.

Estuarine bio-geochemical modeling................Ian Webster

An estuarine bio-geochemical systems model was described in this paper and illustrated with examples from The Coorong and lower lakes of the mouth of the Murray River. The system model had three main components that dealt with (i) hydro-dynamics, (ii) bio-geochemical process and (iii) ecological function. The ecological function model was based on the links between primary production (as affected by water level and quality), food web structure, and, for example, food supply for birds or fish. The bio-geochemical model component included dissolved inorganic (DIN) and organic nitrogen (DON) cycling within and between the water column and the sediment substrate beneath it. DIN and DON in the sediment and water column interacted with detritus to affect levels of phytoplankton and zooplankton. The illustrations from the Gippsland lakes showed that when the system model was run using inputs of nutrient and sediment loads, tidal mixing and solar radiation it could reproduce chlorophyll dynamics reasonably well. It is then assumed that the model may also successfully predict nutrient dynamics (of N, P, C and O_2) and primary production (phytoplankton, microalgae and seagrass).

Freshwater/marine water quality interactions..Eric Wolanski

This paper focussed on a description of a process based estuarine ecohydrology model. The conceptual model used had three interacting components, (i) hydrology, (ii) biota/biology and (iii) ecosystem health. The physical sub-model takes freshwater, sediment, nutrient and plankton from the river and adjacent wetlands feeding the estuary. These elements are then mixed and transformed within the tidal limit and then transported towards the ocean. The biology sub-model uses the sediment and nutrients concentrations determined in the physical model to affect the interactions between phytoplankton, zooplankton, bivalve biota and fish. Key components of this model are the carbon and detritus fluxes within the estuary, as these ultimately determine the biomass of the different trophic levels in the food web and hence the overall ecosystem health. Successful applications of this estuarine modeling system were given for the Guadiana estuary in Portugal as well as the Great Barrier Reef in Australia. This suggests that in both temperate and tropical wetland fringed estuaries, the main drivers and key processes are correctly incorporated in the model. These were summarised as: (i) river inflow of nutrient, (ii) residence time (which is driven by both the river and the ocean), (iii) wetland sediment trapping, outwelling of particulate matter and juvenile refuge, (iv) ocean physical (tidal stirring) and biological (larval supply) influences and (v) the role of sediment in the estuarine food web.

The author recommended that the current MTSRF projects be linked with the UNESCO Ecohydrology program, of which he is a founder member.

Mapping water quality dynamics in the Leichhardt catchment.........Leo Lymburner (presented by George Lukacs)

A very brief description was given of some recent work by ACTFR where (Landsat) remote sensing was used to estimate water clarity in wetlands and rivers within the Leichhardt catchment in North West Queensland. Three broad water clarity classes were identified (very clear, clear and turbid) and multi-temporal analysis looked at how consistently given water bodies fell into each class. From this preliminary analysis it appears that very clear water bodies only occur in bedrock dominated areas, whereas all water bodies on areas of poorly consolidated sediment were always turbid. The analysis illustrates the utility of remote sensing for estimating catchment wide water clarity and also the need to recognise the geomorphological setting when considering water quality.

Water and ecosystem health .... Richard Pearson

The complexities of ecological interactions in tropical waterways were illustrated along with a basic understanding of patterns and processes that could be used to develop indicators of ecosystem health and thresholds of concern. From a simple model of the major components of tropical freshwater ecosystems, a diagram that captured many of the important driving factors and processes was developed and discussed, to demonstrate the need to understand interactions before developing any sort of monitoring system. In particular, it was shown that great care was needed in choosing indicators (for example, the platypus is a good indicator of conditions being suitable for platypus, but this does not necessarily equate with ecosystem health). Similarly, in determining thresholds it is important to recognise the different patterns of response by ecosystem components – in some cases there are very clear step-like thresholds, while in others changes in levels of responses are more gradual. Geographical scale was shown to be important, for example, while the catchment view helps understand broad-scale processes such as water movement and overall connectivity, it is at the habitat scale that the biota may have the strongest interactions. Various examples of the effects of scale, flow and biotic interactions, including food webs, were discussed, and a preliminary list of indictors for Wet Tropics streams was presented. It was stressed that it was important to understand within-catchment processes for the successful management of the catchment as well as for determining downstream impacts on estuaries and the GBR lagoon.

Land use influences and river health in the Wet Tropics: Russell-Mulgrave case study........................... Niall Connolly

This presentation described the development of indicators of ecosystem health in Wet Tropics streams as part of the joint Rainforest and Reef CRCs' Catchment to Reef program, which is being completed as part of project 3.7.3 in the MTSRF. Component projects examined the utility of various river health indicators, including metrics based on habitat integrity, water quality, aquatic macrophytes, macroinvertebrates and fish assemblages. Water quality variables and macroinvertebrate biodiversity examined in paired subcatchments of the Russell and Mulgrave rivers showed clear contrasts that correlated with land management practice. The approach was to examine natural longitudinal variation in the streams so that this could be excluded from the sub-catchment comparisons. It was demonstrated that water quality measures (especially nitrate + nitrite) strongly related to the proportion of agricultural land in the catchment upstream of each site. Macroinvertebrate diversity provided a strong indication of ecosystem health, relating particularly to the integrity of the riparian zone. Different measures of aquatic diversity were compared, with some current approaches being questioned. The detailed longitudinal approach in the current paper provided substantial statistical power (through ANCOVA models) in making contrasts between river systems. This statistical rigour is rarely available in comparable studies and suggested ways in which monitoring programs might be developed in conjunction with land managers, community groups, etc.

Hydro-ecological interactions ....Angela Arthington

Hydro-ecological interactions in freshwater ecosystems were illustrated with reference to the conceptual hydro-ecological model of Bunn and Arthington (2002). The influence of various characteristics of a river's flow regime on habitat structure, fish diversity, fish migration, reproduction and recruitment processes, and other ecological processes (migration, spawning) associated with lateral and longitudinal patterns of connectivity, were outlined. Drawing upon research in Cooper Creek in the Lake Eyre Basin, the presentation outlined features of aquatic habitat structure of importance to fish during dry periods when floodplain water bodies progressively dry down, yet may still sustain fish populations. The importance of flow-habitat interactions at three spatial scales (floodplain, whole water hole and within water hole) was discussed, with the Cooper Creek study presented as a possible approach of relevance to planned MTSRF research on connectivity and floodplain water body health. It was noted that significant new work will be needed to map the life history patterns and processes of fish onto the particular river-floodplain landscape of a system such as the Tully-Murray. A conceptual model of fish history processes and potential movement patterns was also discussed. This presentation also touched on how the two MTSRF projects (3.7.3 and 3.7.4) could be developed as a single, integrated program of work that could meet the main objectives of both projects. The hydro-ecological components of project 3.7.4 could inform understanding of the ecological implications of altered flow regime and loss of lateral connectivity between the river channel and its floodplain water bodies. Ecological response variables sensitive to hydrological alteration and loss of connectivity could serve as ecological indicators of the heath of floodplain wetlands exposed to these particular disturbances and should also inform climate change scenarios.

Hydrology, connectivity and larval fish...........Paul Godfrey

New PhD research on the influence of flow seasonality on the recruitment ecology of riverine fishes from lowland Wet Tropics rivers was presented. It was noted that Australia's freshwater fishes are well represented in the lower Wet Tropics rivers yet fundamental knowledge about the spatial and temporal dynamics of their recruitment and the factors that impinge on the survival and growth of their young, are poorly understood. This is probably due to a combination of limited sampling effort and larvae developing in habitats (e.g. marine waters) removed from those occupied as adults (i.e. freshwater). This project aims to identify the location of recruitment under the influence of seasonal (wet and dry) flow regimes and to document ontogenetic shifts in habitat use, including diadromous migratory patterns. Fish have been sampled fortnightly over a single dry season from the estuary and freshwater reach of the lower Mulgrave river, north-eastern Australia. Preliminary results have identified several members of the freshwater fish assemblage occurring within salt water during their early stages of development. A similar life history strategy is anticipated among those species that recruit during the wet season, although the position of this nursery habitat may shift downstream as a result of increases in river discharge. This observation and future predictions will be compared in four additional wet tropics rivers that incorporate gradients of flow and habitat variability. These results and their importance for maintenance of natural flow regimes and biodiversity in lowland riverine habitats were discussed.

Fish passage..Ross Kapitzke

This presentation took the view that conceptual models of river-floodplain connectivity and ecological response should include the effects of man-made barriers to fish migration. Research on the planning, design and implementation of structures and devices intended to facilitate fish movement past barriers, and through obstacle courses such as culverts, were described. This includes road corridor scale planning for fish passage provisions across the new Bruce Highway road crossing of the Tully Murray floodplain, where classification and conceptualisation of fish movement characteristics for design of fish passage facilities for the road-waterway crossings include: waterway character and fish habitat assessment; fish movement corridors across the floodplain; fish species and fish movement behaviour; critical fish movement directions and species. Design and testing of fishway devices is undertaken using prototype fishways on University Creek on the James Cook University campus in Townsville, where full size facilities provide for hydraulic and biological monitoring and adaptation of various fishway designs for pipe and box culverts and other waterway structures. Conceptual models that are used to predict hydro-ecological functions of floodplains and to manage habitat impacts and ecological responses, can conceivably be extended to include impact mitigation practices and techniques, and provisions for infrastructure planning and design. This will assist in determining design objectives, design parameters, and design criteria for fish passage and other facilities at these floodplain waterway structures, which must meet multipurpose requirements for drainage, transportation and amenity as well as provisions for fish passage.

Ecological Response Modeling.......................... Nick Marsh

A fundamental objective of river management is the ability to compare the relative merits of different stream management strategies. Predictions of ecological responses for natural resource management planning are often made with limited scientific underpinning and a poor representation of the likely uncertainty in the predicted response. This presentation described a software tool, the “ecological response modeling framework” (ERM) for compiling the existing knowledge of ecological responses to time series of habitat drivers such as flow, water quality, and physical habitat drivers such as woody debris or substrate. Ecological response models are captured in the framework for reuse and review. A measure of the confidence of each model is also captured so that the output predictions can be qualified by the confidence level of the model components. The ecological response modeling framework creates an expandable knowledge base representing our current understanding of ecosystem response, and also highlights the deficiencies in our knowledge by identifying areas of poor model confidence. The framework allows several commonly used model types such as habitat suitability and habitat preference curves, multiple linear regression, hydraulic habitat requirements and rule based models. Future versions of the framework will allow for incorporation of additional modeling approaches and will also be able to accommodate spatial variables. The current version of the ecological response modeling framework is a stand alone application but can be used as an add-in to catchment modeling tools such as E2 (Argent *et al*., 2005), to allow whole of catchment planning scenarios to be presented in terms of predicted improvements in habitat.

Summary of Breakout Groups and Associated Discussion

There were two breakout groups in the first session on day 2, one consisting mainly of hydrologists and biogeochemists, the other consisting mainly of ecologists. Each group was briefed to suggest and discuss the relative merits of disciplinary based models (conceptual and process). It was suggested that they do this within the framework shown below (Table 1). This framework is a modification of the Marine Catchment Basin concept proposed by Gehrke and Sheaves (2006). The key modifications are to separate the floodplain domain in the original model into two distinct components, the river channel and the floodplain and its wetlands. The main reason for this is that very distinctive and different hydrological and ecological regimes exist in these two domains. River channels represent the 'ambient' conditions that exist for most of the year. The floodplains and wetlands are partly a reflection of the more ephemeral flooding events that occasionally connect the river channel and the floodplain (although they too come to reflect local ambient processes and conditions as connectivity is lost). Another modification is to reduce the ocean representation to one component, the flood plume in the original model. However, it is recognised that this flood plume will have an outer boundary that is affected by the deeper ocean conditions. Further, it was pointed out that much of the drainage from the floodplain reaches the coastal wetlands and the sea via distributary waterways, and does not return to the main river. The modified conceptual diagram is shown in the next section and it retains the name 'Marine Catchment Basin' in recognition of the author of the original concept (Caddy 2000). It was also felt helpful to consider the behaviour and characteristics of each of five domains of the Marine Catchment Basin in both the Wet and Dry Tropics. A preliminary characterisation of this type is shown below. This was not intended to be either exclusive or exhaustive, but simply as a starting point for the breakout group discussions. The final version of this Table is presented in Section 6 after the breakout group discussion summary.

Table 1. The key domains in the Marine Catchment Basin concept with possible examples of the hydro-ecological characteristics of each domain (working draft).

	Wet Tropics	**Dry Tropics**
1. Upstream slopes and river reaches.	Largely pristine – not a source of pollutants. No management options.	Highly disturbed – major source of pollution. Area for management.
2. River channel.	Never / rarely / no flow. Low flows don'g dominate ecology. Less seasonal flows – more predictabled ecology.	No / low flows frequent. Low flows dominate ecology. More seasona flows – less predictable ecology.
3. Floodplain and freshwater wetlands.	Frequent inundation. Wetland ecology dominated by flood connectivity. Antecedent flood conditions less important.	Infrequent inundation. Wetland ecology less dominated by flood connectivity. Antecedent flood conditions very important.
4. Estuary and brackish wetlands.	More minor modification of water quality flux to ocean. Signfiicant biological processes feed back upstream.	Significant / major modification of water quality flux to ocean. Significant biological processes feed back upstream.
5. and 6. Near coastal ocean.	Physical 'stirring' of estuary (via tides). Biological larval supply. Hydraulic influence of tide on flood height / flow.	Physical 'stirring' of estuary (via tides). Biological larval supply. Hydraulic influence of tide on flood height / flow.

Feedback from the 'hydrology and water quality' breakout group

Members:
Keith Bristow, Jim Wallace, Jon Brodie, Ian Overton, Eric Wolanski, Dave McJannet, Ian Webster, Darren Baldwin, Lachlan Stewart, Jane Waterhouse.

This group structured their discussion around three areas: (i) conceptual models, (ii) predictive models and (iii) the Marine Catchment Basin Table.

Conceptual models:
The Marine Catchment Basin model (Figure 1) was endorsed as a useful high level schematic that provided a structure to enter more details into. The group reaffirmed the need to clarify the key questions that are being addressed, as these affect the choice of detailed models that would populate the overall Marine Catchment Basin concept. Clarification was also sought over the main objectives, for example, in addition to the stated aims of (i) providing a model to predict material transport across floodplains during floods and (ii) quantifying the connectivity of wetlands on the floodplain are we trying to combine water quality and hydrology to understand what drives water quality and what influences concentrations? How much of our modeling effort will deal with how land use change alters the hydrological regime (flow and water quality)?

Key issues that affect the hydrological regime were discussed and the group recommended that these were considered in the choice and design of the final hydrological modeling scheme. The issues included the recognition that tropical floodplain systems were largely event driven, with high inter-annual variability. This variability contains long-term cycles of hydrological behaviour that can leave a historical pattern within the floodplain geomorphology and ecology. It is therefore important for the project to recognise this longer-term hydro-geological context and consider ways of assessing this (e.g. by using sediment cores, etc). The highly variable nature of the flow and flood regimes means that it is not sufficient to consider behaviour in terms of annual means, but rather to explicitly recognise variability. This can be done by characterising (statistically or otherwise) wet and dry periods, flow maxima and minima and their durations as a means of classifying different river and flood regimes. This will set the range of conditions that can occur naturally, so that modeling can then predict the effects of future perturbation (natural or anthropogenic). When making links to wetlands the capacitance of these systems and the residence time of water within them are important factors that determine their water quality and the ecological systems they support.

It is important to clarify what time scales the projects will address, as all of the key processes are time-scale dependent. It may be necessary to consider nesting of time-dependent processes, so that model predictions can be made for the longer time periods associated with hydro-ecological responses to land-use changes. Clearly, different species within ecosystems may have different time scales of response to a hydrologically mediated perturbation.

Returning to the discussion on the Marine Catchment Basin conceptual model the group made the following observations:

- It currently recognises the key zones of where water is.
- Needs a sequence of images – at least wet season and dry season (where freshwater and saltwater inundations may dominate), preferably more detailed depiction of key interactions depending on the particular system being represented.

- It would be useful to include transects, both from the coast to uplands and orthogonally across the river channel and floodplain to demonstrate interactions, especially between groundwater and surface water.
- Need to show the potential for water distribution across floodplain and flow paths to the ocean other than the main river channel.
- May be useful to have a series of versions for wet and dry, typical and modified river and floodplain conditions.
- Will the model capture water extracted off stream (i.e. from groundwater) for agricultural application and its subsequent return to smaller streams?
- Should the model attempt to include management modifications?

Predictive models:
There was good potential to quantitatively link the floodplain hydrodynamic model described by Wallace with the estuarine eco-hydrological model presented by Wolanski. In doing this it would be important to incorporate carbon and detritus fluxes in the floodplain hydro-dynamic model as these are a necessary input to the estuarine model. The reason for including carbon fluxes is that primary production driven by carbon and the overall ecological system is more limited by carbon than by nutrition. It is also important to know the bio-availablity of the different forms of carbon (and nitrogen). The move towards combined carbon and nutrient dynamics (along with other key drivers such as shade, turbidity, macrophyte growth, etc) might open up the possibility of predicting dissolved oxygen concentrations, which are known to be vital to the survival of a range of aquatic biota including fish.

It was suggested that we could consider the application of Overton's area of inundation versus flow model (RiM-FIM; Overton, 2005) as an alternative predictive tool (in parallel to the hydro-dynamic modeling). This could be compared with the hydro-dynamic model and may be a means of extrapolating river flow / area of inundation modeling to a range of other catchments along the GBR coast.

The group also suggested clarification of the number and type of models to be developed. At present it looks like there will be one model for material transport across the floodplain, another for wetland connectivity. The former model will allow the quantification of how the floodplain modifies the sediment load to the estuary / ocean. However, will there be a model for predicting how water quality changes over the floodplain during flood events? Will there be a model of water quality and ecological impacts in wetlands? Will these models include pesticides and their potential ecological impacts? Other points that may need to be considered by the various component hydrological models are:

- Wetland models should recognise the role of groundwater (quantity and quality).
- How over bank flow modifies delivery of materials to the coast.
- The influence of nitrate in groundwater as a nutrient load to the GBR lagoon.
- The need for a different approach where floodplain agriculture actively accesses groundwater for irrigation.
- The role of acid drainage.

Feedback from the 'ecological' breakout group.

Members:
Pat Dale, Niall Connolly, Brad Pusey, Peter Gehrke, Marcus Sheaves, Ross Kapitzke, Richard Pearson, Rod Oliver, Clayton Sharp, Paul Godfrey, Angela Arthington, Frederieke Kroon.

This group structured their discussion around three areas: (i) the Marine Catchment Basin model (Table 1), (ii) populating the five boxes in Table 1 with information on the similarities and differences in 5 catchment zones of rivers in the Wet and Dry Tropics, and (3) general discussion of key issues, concepts to be further developed and ways forward for Projects 3.7.3 and 3.7.4.

1. Marine Catchment Basin model

There was general agreement that this conceptual model, which is based on that described by Gehrke and Sheaves (2006), is a useful starting point for discussion and research planning but needs to be modified in several ways to reflect our understanding of spatial relationships, connectivity and processes in coastal catchments of the Wet and Dry Tropics. Peter Gehrke explained that the conceptual model is based on a paper by Caddy (2000), and is intended to reflect the fact that marine ecology is strongly determined by catchment influences. However, the ecology group felt that to be useful to MTSRF research, the model must reflect the freshwater components of the catchment in a more realistic manner, especially with respect to spatial scale and connectivity patterns. The upland catchment is under-represented in the model and should be redrawn to represent its scale and the many small tributaries flowing into the main river channel. It was also felt that the lower catchment (estuary) is over-represented with respect to scale. In addition, flow pathways and patterns of hydrological connectivity need to be represented in the model by adding more arrows within the floodplain zone in particular. The Tully-Murray floodplain model described by Wallace indicates that over bank flows probably achieve connectivity from river to floodplain, but not necessarily back to the river when floods recede (i.e. water flows outwards but does not necessarily flow back to the river channel). This needs to be checked for different floods and places in the landscape. For the Tully-Murray, for example, there will be different flow patterns depending on rainfall distributions in the catchment, presence of levee banks, groundwater influences, movement of water from floodplain wetlands towards the coast via small tributaries, and from their into groundwater and even into wonky holes. More specific catchment representation of these flow paths will need to be considered as the MTSRF Projects develop. Flow pathways could be represented in the model by adding more arrows linking the channel and floodplain wetlands.

It was agreed that the model is only a starting point for conceptualisation of flow-ecological connectivity and responses in marine catchment basins. It will be necessary to examine the specifics of hydrological regimes, flood dynamics, flood flows and inundation sequences, as well as areas inundated during specific flow events for each catchment. It was proposed that the model could be elaborated by developing transect sub-models (as presented by Arthington) for selected locations from source to sea of a Wet and a Dry Tropics river system. Such models should show contrasts in the spatial array of habitat structure and connectivity pathways between wet and dry periods. This type of conceptual model would immediately inform Projects 3.7.3 and 3.7.4 and assist the conceptualisation of flow-ecological connectivity and ecological responses.

2. Populating the key domains of the Marine Catchment Basin

The ecology group worked systematically through the key zones represented in the marine catchment basin model, comparing and contrasting wet and dry tropical river systems.

Zone 1: Upstream slopes and river reaches

Wet Tropics:
Small, upland streams of the Wet Tropics have a perennial and predictable seasonal flow regime with occasional high flows during predominantly low flow periods. However, exactly when the flood flows will occur during the Wet season is unpredictable. The ecology of upland streams in the Wet Tropics is fairly well documented and understood. Several conceptual models of ecosystem structure and functioning are relevant and have been tested in streams such as Yuccabine Creek by Richard Pearson and his students. These models include the River Continuum Concept (Vannote *et al*. 1980) and the Nutrient Spiraling Concept (Webster and Patten 1979). The former presents a model of carbon sources and mechanisms of organic matter processing along the 'continuum' from upland streams to the mid-reaches and lowlands of a typical river system. This model identifies ecological assemblages along the continuum with a focus on invertebrate tophic structure and the roles of invertebrates in processing organic matter. The Nutrient Spiraling Concept describes nutrient movement in riverine ecosystems. As nutrients enter a stream, they are cycled through biotic and abiotic compartments while being transported downstream. The combination of these uptake and longitudinal transport processes thus resemble a spiral. The distance nutrients travel while completing a cycle through the biotic and abiotic compartments is called the 'spiralling length'. Streams with short spiralling lengths retain more nutrient with less transported downstream.

The impacts of nutrients, sediments and low dissolved oxygen concentrations on macroinvertebrates and fish have been studied in the field and in laboratory experiments (Pearson and Connolly, 2000; Connolly *et al*., 2004; Connolly and Pearson, 2007). Spatial and temporal patterns of fish assemblage composition and relative abundance have been documented and related to flow regimes and habitat characteristics of upland and mid-reach streams of the Russell-Mulgrave and north-south Johnstone rivers; the dietary ecology and reproductive biology of some species have also been documented (see Hortle and Pearson, 1990; Pusey and Arthington 2003; Pusey *et al*. 1995a,b; Pusey *et al*. 2000, Pusey and Kennard 1996; Pusey et al. 2004a.b; 2005, 2007). The Catchment to Reef project of the former Rainforest and Reef CRCs has explored the effects of land use, water quality and riparian degradation on aquatic plants, invertebrates and fish, and from this work proposed a suite of indicators of stream ecosystem health (Arthington and Pearson 2007).

Dry Tropics:
Upstream conditions depend on the location of the tributaries: for example, the Burdekin River receives substantial inputs from Wet Tropics streams (as described above), which has a major bearing on the water quality in riverine waterholes as flows diminish in the dry season. Upstream tributaries in the Dry Tropics, however, are very different: they are typically intermittent and are substantially affected by grazing pressure. Problems derive from overgrazing and erosion of the landscape (with consequent sediment deposition in streams), damage to stream banks as cattle access water holes in the dry season, concomitant fouling of remnant water holes with likely impacts on the biota, and smothering of native riparian vegetation with weeds such as rubber vine, with probable adverse consequences in the aquatic ecosystem.

Zone 2: River Channel

Wet Tropics:

The channel zones of Wet Tropics rivers have been studied to some extent but not as fully as upland streams. In this zone there is still a definitive effect of the perennial and predictable seasonal flow regime and sustained base flows. Hence there is good longitudinal connectivity in the river channel, even during low flow periods. Low flow/no flow ecology (e.g. recruitment, food web dynamics) has important implications for the functioning of the river channel and its influences on river-floodplain connectivity and associated processes could have huge impacts. However, low flow/no flow processes may be far more important in rivers of the Dry Tropics than in the Wet Tropics rivers as the latter have perennial base flow unless modified or regulated.

Floods have a major impact as they reset the river ecosystem quite frequently (at least once a year in many Wet Tropical rivers and more often in the Tully-Murray). The flood-pulse concept (Junk *et al*., 1989; Junk and Wantzen 2004; Sedell *et al*., 1989) may not be applicable in Wet Tropics rivers if over-bank flows do not return to the river channel, but are dissipated on the floodplain. Hydrological connectivity between the channel and floodplain waterbodies, and the associated transport of constituents, organisms and propagules, would be achieved by the overbank flows. However, the return of constituents, organisms and propagules from the floodplain to the river would be much reduced, if occurring at all, where flood waters do not return to the river channel at any point along the lower river continuum, or if there is only a weak return flow off the floodplain. Various aspects of channel and floodplain configuration/morphology need to be explored. For example, what are the effects on floodplain flow distribution of natural levee banks and slopes away from the river channel? It was noted that although floods may link the river channel to floodplain wetlands, there are few backwaters in Wet Tropics river channels and therefore little lateral habitat within the river channel itself. This has implications for species that require this type of habitat at some stage of the life history. In addition, it was also noted that we need to understand the role of ground water in maintaining low flow habitats.

In discussing the roles of the flow regime and floodplain connectivity, we need to be aware of the effects of Koombooloomba Dam and the diversion of river flows to the Tully hydroelectric plant on the downstream flow regime and associated ecosystem. The effects of the Tully-Millstream Hydro scheme on the ecology of plants, invertebrates and fish, and more recent work on fish life histories and recruitment patterns are relevant here (Hogan and Graham 1994; Hogan and Nicholson 1987).

The group discussed drivers of primary productivity and trophic structure in the channel zone of Wet Tropics rivers. Does the river follow available ecological models with respect to productivity (i.e. RCC, Flood Pulse Concept, see above) and the Riverine Productivity Model (Thorp and Delong 1994)? This may depend on upstream and in-stream sources of organic matter (carbon). For example, what is the role of terrestrial organic matter (leaves and fruits of riparian vegetation) and other terrestrial inputs (insects, spiders from riparian vegetation)? Several studies provide relevant data and food web analyses - Tom Rayner's PhD in the Mulgrave River (Rayner 2007), Perrin Cook's research in Tully River, Frederieke Kroon's work in the Douglas River and Richard Pearson's work in the region (e.g., Cheshire et al., 2005). In the river channel zone of the Tully-Murray system there is no river plankton and few aquatic macrophytes, although this may not be true in disturbed areas (e.g. those infested with para grass and other alien species).

The connectivity of the river channel zone to the estuary is important, as this can influence river water quality, salinity, carbon sources and the fish and invertebrate assemblages far up into the river channel.

Dry Tropics:

Rivers are characterised by occasional high flows, with long dry spells in between. There can be a strong seasonal flood signal reflected in ecosystem dynamics, but this depends on the relatively unpredictable magnitude and timing of events. For example, floods can reset habitats and ecosystems as demonstrated by Pusey and Arthington (1996) and Pusey *et al*. (1998) where different hydrological regimes affected fish assemblages, but such floods may not occur for years at a time. The behaviour of over-bank flows varies with location, so for example, upstream, flood water may return to the river as levees recede, but downstream on the floodplain, floodwaters tend not to return to the main channel, but reach the sea via distributaries. This has implication for ecological connectivity. Within river channels, floods create a moving littoral zone; they also provide substantial connectivity, both between previously remnant water holes, and also cross barriers such at cascades and small falls.

After floods, and through much of the dry season, these rivers rend to be shallow and meander across sandy beds, with much of the wetted area unshaded by riparian or in-channel vegetation. Primary productivity (mostly algae) is high, with associated high secondary production reflected in abundant invertebrate and fish populations. Flow becomes increasingly groundwater-dependent during dry periods.

While some changes along the river system conform to the River Continuum Concept (Vannote *et al*. 1980), at least for some periods of the cycle of flood and drought, it is not a very useful model of ecosystem processes because of the over-riding influence of the unpredictability of the flow regime.

<u>Zone 3: Floodplain and freshwater wetlands</u>

The group defined three different freshwater habitats that occur in (i) remnant lagoons, (ii) distributaries, and (iii) flooded areas. These parts of the freshwater ecosystem, in particular, are by no means in a natural state (due to clearing, drainage, irrigation, fertilizer and other chemical inputs). There are flow-on effects on water quantity and quality, and associated ecology. How are these going to be taken into account in Project 3.7.4?

Wet Tropics:

In the floodplain and freshwater wetland zone, over bank floods move out onto the floodplain or back to the channel, or they may flow out to the ocean via distributary channels, or groundwater flow may connect to and feed wonky holes. After some discussion it was suggested that off-stream habitats do not necessarily link back into the river via connectivity pathways; instead, water may flow towards the coast via distributaries after it overtops river banks, depending on bank elevation, slopes and levees, etc. During these processes of water movement, physical and water quality barriers to the movements of biota may be created.

Isolated pools on the floodplain may or may not flood when the river overtops, depending on flood discharge and the spatial scale of flood. Wetland pools are left after floods, and these may be sustained by rainfall, inflow from small catchments and groundwater. Distributaries may be fed also by small local catchments. The retention time of water in these floodplain areas has changed significantly due to changes in connectivity, related to land use/land cover change and construction on the flood plain, and this must have flow-on effects on water quality, habitat suitability, ecological patterns and processes.

As discussed above for the river channel zone, the drivers of primary productivity and trophic structure in floodplain water bodies are important to their capacity to sustain aquatic biota during non-flood periods. These processes are expected to differ between wet and dry periods. What are the roles of terrestrial organic matter and carbon sources in floodplain water bodies? Are they sustained by local productivity from algae (e.g. benthic algae, phytoplankton) and/or aquatic plants? A key question for both MTSRF projects is the role of floodplain wetlands as habitat for aquatic biota. Are these water bodies the main nursery areas for fish, prawns, etc. in the Wet Tropics? Such areas are important in Northern Territory and Gulf rivers. Are they 'sinks' in many cases – particularly when adverse conditions lead to fish kills or when lagoons dry out? This may not be so common in the Wet Tropics but remains a possibility depending upon patterns and pathways of water movement, retention times and groundwater influences.

Turning to life history and recruitment processes, the group discussed how the timing of spawning and/or recruitment relate to flood timing and extent and hence the availability of floodplain habitats. It was suggested that at present we really have little or no idea what is happening in these habitats, including the effect of surrounding land uses and land management on their ecology. It was reported that the Tully River may experience 3-4 over bank flood events per year. Is this more frequent than in other Wet Tropical rivers? If so, what are the ecological consequences of several flood events that may or may not inundate and connect the river and the full array of floodplain wetlands? Some may receive one flood event, some all flood events, yet others, no flood events in some years. In the Tully it is thought that groundwater sustains floodplain wetlands during the dry season, with overland flow 'topping up' in the wet season – we need to confirm this and other aspects of water regimes and their influence on the river channel and floodplain wetlands.

Dry Tropics:

Floods (and so over-bank flows) do not happen every year in the Dry Tropics, so replenishment of floodplain wetlands and connectivity between them is unpredictable. Wetlands therefore may be either intermittent, or permanent if they receive sufficient groundwater input. Flood waters typically move through a series of lagoons and distributary channels, reaching the coastal environment via distributaries that discharge through saline wetlands (e.g. Barratta Creek on the Burdekin floodplain). However, in some floodplains, wetlands connect in both directions – filling from and emptying back into the main river system (e.g. in the Queensland Fitzroy River)

Antecedent flood conditions therefore have important influences on productivity, connectivity and ecosystem dynamics. In the floodplains, which have been extensively developed for agriculture, loss of wetlands has led to a reduction of water retention, with likely flow-on effects on ecological patterns and processes. Development of floodplains has led to new barriers to connectivity, such as drop boards that control water levees, weed infestations, and patches of poor water quality

When well connected, wetlands provide important fish habitat – for example, for juvenile barramundi. It is unclear whether fish actively seek out these habitats, or whether they use them opportunistically. It is also unclear to what extent wetlands act as sinks for organic matter, including fish.

Dry Tropics systems have different rates of change in processes from those in the Wet Tropics: for example, the length of time between wet and dry periods varies enormously – in the Dry Tropics the interval may be up to 5 years. Productivity in riverine lagoons is strongly influenced by local features such as size and bathymetry of the water body, and landscape processes immediately contiguous with the water hole.

Sources of productivity include algae in the shallows, extensive macrophyte beds in deeper water and phytoplankton in open waters. Inputs from the riparian vegetation can be important in smaller water holes, although litter from the most abundant riparian trees (e.g.

Melaleuca species) breaks down very slowly. Many fish take advantage of terrestrial fruit and insects, derived from the riparian vegetation (Pusey *et al*. 2004a,b).

Various studies are available on invertebrates and fishes of rivers of the floodplains of the drier zones, such as Pusey *et al*. (1998) on Burdekin River fish and Pearson and Connolly (2000) on the invertebrates and fish of the Burdekin floodplain.

Zone 4: Estuary and brackish wetlands

The group discussed how to define habitat in this zone. What is an estuary? Do Wet Tropics rivers have "real" estuaries?

Wet Tropics:

With workshop time running out only a few points were discussed, one being the spatial scale and extent of the physical estuary in terms of water quality during low and high flow periods. The estuary can be offshore during higher flows (perhaps in general), whereas physical estuarine habitat is near shore (e.g. mangroves). An estuary experiences marine and freshwater inputs, and thus forms a large mixing zone supporting resident species and species that move between freshwater and tidal zones and *vice versa*. The role of floods is important, for instance, in the Tully, the first flood pulse brings down organic matter, sediment, nutrients and perhaps also pesticides. The effects of these constituents may be felt at all levels of the food web, and may ultimately influence estuarine productivity. Physical and water quality barriers may influence the movement patterns of aquatic biota, but little is known about such processes. Estuarine ecology in general is poorly documented/understood in tropical estuaries, a rather surprising fact give the importance of estuaries to fishery and ecosystem values in the tropics. This could therefore form the basis of a small sub-project to review and collate literature on estuarine ecology.

Dry Tropics:

In low flows, the estuary is typically a marine inlet, which may become hypersaline because of a lack of flushing. Biotic communities include marine visitors, freshwater visitors and estuarine residents. There is an extensive mixing zone. During floods the effective estuary is shifted to the coastal waters, outside the river channel.

Zones 5 and 6: Near coastal ocean

These components of the Marine Catchment Basin was not discussed.

3. General discussion of key issues, concepts to be further developed

The Marine Catchment Basin model is useful but needs to be modified to include the freshwater uplands zone and to better represent river-wetland interactions, connectivity and processes once water leaves the river channel and flows onto floodplains. Flow regimes (natural and modified) need to be modelled so that we can extract ecologically meaningful descriptions of flow regime change in each river chosen for study. The location and residence time of groundwater needs to be understood during wet and dry periods in Wet Tropics and Dry Tropics systems.

It was noted that there was little discussion about 'water quality' (from either group); how does water quality differ in different spatial domains in relation to hydrology, and what are the flow-on effects on ecological processes? The complex relationships between hydrology, water quality and ecology, as depicted in Figure 5 (after Pearson, - Brodie *et al*. 2007), must be explored. Water quality is partly/largely driven by ecological processes, so we need feed back loops in our primary conceptual model of ecosystem health especially with regard to the development of indicators of ecosystem health and thresholds of concern. We also need to model effects of land use management on (floodplain) ecosystem health in order to meet the goals of Project 3.7.3.

Wet Tropics rivers are relatively short, with ecological processes relatively constrained in short channels. Dry Tropics rivers are much longer and their ecology is very 'busy'.

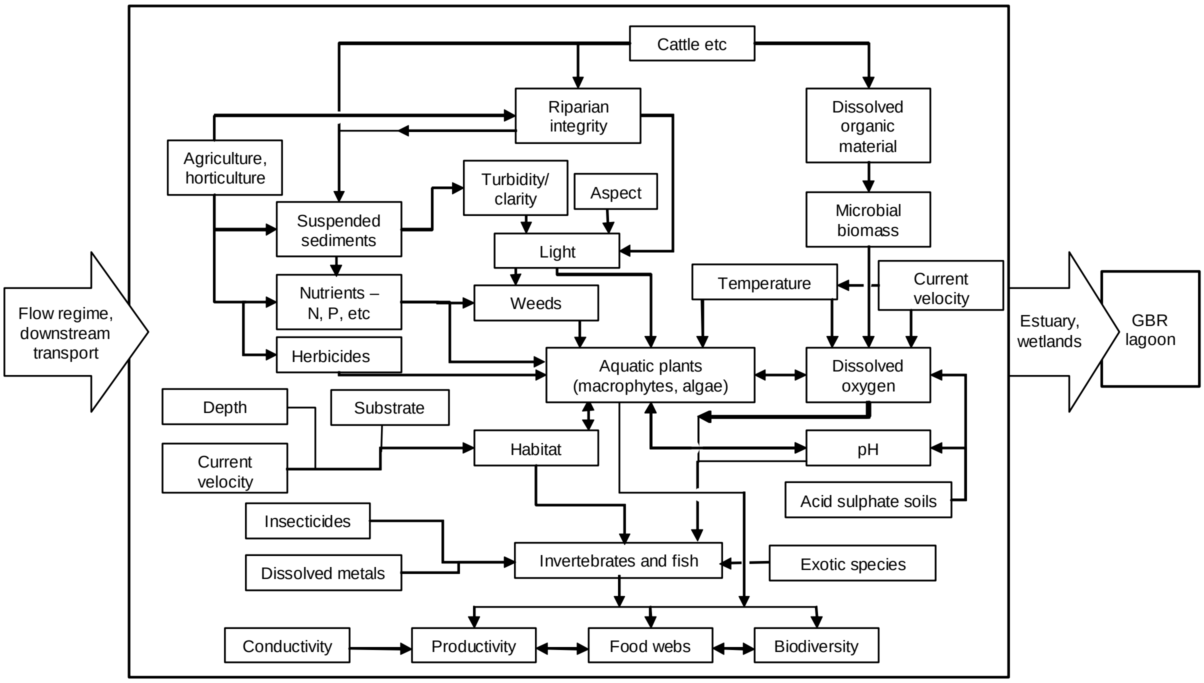

Figure 5. Biophysical interactions affecting ambient water quality in the tropics. The large box represents typical processes and interactions in a stream reach, a discrete water hole or a habitat within them. The large arrows represent flow-related connectivity. Connectivity with the terrestrial landscape is implicit in some of the smaller boxes. Note that not all factors or interactions can be shown. (after Brodie *et al.* 2007).

Marine Catchment Basin Concept

Hydrological and Ecological Characteristics of Wet and Dry Tropics

Table 2. The key domains in the Marine Catchment Basin concept with the main hydro-ecological characteristics of each domain (updated following breakout group discussions).

	Wet Tropics	Dry Tropics
1. Upstream slopes and river reaches.	Perennial, predictable seasonal flow regime with high summer flows, never/rarely no flow, high longitudinal connectivity within streams. Many catchments are largely pristine, not a source of pollutants. Others are cultivated and deliver pollutants downstream to rivers and floodplain wetlands. Management options include BMP land use, flow management, protection of riparian buffer zones, habitat restoration, control of alien weeds. Ecology of invertebrates, fish, food webs in upland streams well-understood. Indicators of ecosystem health already available.	Highly disturbed – major source of pollution Area for management
2. River channel	Perennial, predictable seasonal flow regime with annual high summer flows, sustained base flows, and good longitudinal connectivity in channel. Low flows have important roles, but do not dominate ecology. High flows reset ecosystem at least annually, or more often. Management options as above, but also need to understand the effects of dams and water diversions in upper Tully River. Sources of organic carbon and flood web structure, biotic assemblage structure and recruitment processes less well-known. Indicators of ecosystem health available but need further testing.	No/low flows frequent Low flows dominate ecology More seasonal flows – less predictable ecology
3. Floodplain and freshwater wetlands	Annual or more frequent flood inundation, some wetting by local in-flows, or wetlands may be sustained by groundwater during dry periods. If over bank flows do not return to the river channel, no return flows of constituents, organisms or propagules, or they return some distance downstream. Few backwaters in Wet Tropics river channels, little lateral channel habitat. This may affect species present and recruitment processes. Management options as above, but also need to understand the effects of dams and water diversions, levees, roads, bridges, on flood flow pathways and connectivity. Sources of organic carbon and flood web structure, biotic assemblage structure and recruitment processes not known. Indicators of ecosystem health not yet available.	Infrequent inundation Wetland ecology less dominated by flood connectivity Antecedent flood conditions very important

	Wet Tropics	**Dry Tropics**
4. Estuary and brackish wetlands	Modification of water quality flux to ocean, which is minor for large floods and large for small floods and for dry season flows. Major recycling of the detritus (carbon) that supports the food chain; detritus originates from the land and from the sea. Wet season input drives the dry season estuarine ecology. Effect of tidal systems: tide levels range and patterns. Connectivity issues significant for extent and duration of connection	More modification of the water quality flux to ocean, which is minor for large floods and large for small floods. Major recycling of the detritus (carbon) that supports the food chain; detritus originates from the land and from the sea. Wet season input drives the dry season estuarine ecology. Connectivity and disconnection important and significantly different from Wet Tropics.
5. and 6. Near coastal ocean	Physical 'stirring' of estuary (via tides) Biological larval supply Tidal pumping of sediment landward, some returning in the estuary from wet season outflow. Tidal stirring makes particulate nutrients available for productivity Hydraulic influence of tide on flood height/flow Major impact of land-derived mud, detritus and nutrients on WQ and ecosystem health throughout the dry season.	Physical 'stirring' of estuary (via tides) Biological larval supply Tidal pumping of sediment landward, some returning in the estuary from wet season outflow. Tidal stirring makes particulate nutrients available for productivity Hydraulic influence of tide on flood height/flow Major impact of land-derived mud, detritus and nutrients on water quality and ecosystem health throughout the dry season.

Summary of Research Strengths and Weaknesses

Although not meant to be exhaustive, the Workshop presentations and discussion has provided a good initial picture of where the main research strengths and weaknesses are in relation to hydro-ecological modeling capability in tropical systems. A number of strengths and weaknesses were identified as listed below:

Strengths:

1. The Marine Catchment Basin (MCB) concept in an amended from is an excellent framework for developing more specific hydrological and ecological models for each of the MCB domains. Moreover, it also provides a framework for the integration of the various sub-component hydrological and ecological models. The capacity to link upper catchment, floodplain, estuary and marine environment therefore exists.
2. Several alternatives are available to specify upper catchments runoff and some of these have already been calibrated in the Tully-Murray catchments. Catchment sediment and nutrient delivery can also be modelled for upper catchments, although uncertainty (especially in nutrients) is still quite high. There is also some doubt about the ability of these models to correctly specify sediment and nutrient fluxes from forested areas, which are the largest proportion (~ 72%) of the Tully-Murray catchments.
3. The ecology of Wet Tropics upland streams is fairly well understood. This includes ecosystem structure (food webs) and function, dietary ecology, disturbance ecology and reproductive biology. Ecosystem health indicators are also already available from the extensive work carried out by the Rainforest CRC. However, only some of this knowledge has currently been used to develop quantitative models of the response of aquatic biota to key drivers, including the hydrologic regime.
4. Sophisticated mechanistically based estuarine bio-geo chemical models have been developed and applied in the Dry Tropics (e.g. Fitzroy). These models now form the cornerstone of modeling of the response of marine ‘receiving waters’ to fluxes of sediment and nutrient from the land. However, these models need to be applied in Wet Tropics and this will require new estuarine data to customise and test these models in this environment.
5. Similar to the estuaries, biophysically based marine sediment and nutrient mixing and transport models have been developed for the entire GBR lagoon. These models are being constantly refined to improve their ability to predict ecosystem impacts in the marine environment. The models use land based models of water, sediment and nutrient fluxes and these need to be updated to deal with the weaknesses listed below.

Weaknesses:

1. Current catchment models do not represent the behaviour of the floodplain very well. This is particularly important in the Wet Tropics where over bank flooding occurs quite frequently and where the marine pollutant load is strongly influenced by large events. To improve floodplain modeling it will be necessary to treat (and model) floodplains separately from rivers, since the transport processes are different during flood events. There is therefore a need to build a new floodplain modeling capability using both static and dynamic modeling approaches. These new floodplain models need to be able to quantify the connectivity of rivers and wetlands during floods as well as the flow pathways to and from rivers during floods. They also need to be event driven and to operate at spatial scales commensurate with the scales of potential land use or management change.

2. While flow regimes are relatively easy to predict, how water quality varies with flow regime is much more difficult to specify. This is because of the heterogeneity of point and especially diffuse sources of pollution as well as the chemical, depositional and entrainment transformations that can occur during transport. More effort is needed to develop ways of predicting water quality both in rivers and floodplains.
3. A major gap exists in our ability to quantify flow regime and water quality impacts on ecological processes. Some empirical approaches exist to relate flow regimes to freshwater ecology (e.g. habitat simulation models), however, these presently take no account of water quality. A major effort is therefore needed to explore the effects of acute and chronic expose of important freshwater biota to key pollutants.
4. Within the floodplain, river channel ecology is less well understood than it is in upper catchment streams. Some of the concepts developed in upper catchment streams therefore need tested on the floodplain. This testing will inevitably involve the collection of new freshwater ecological data in floodplain river channels. For example, the life history of fish, their recruitment processes and floodplain habitats and how these relate to the timing, size and duration of floods will need to be explored.
5. The role of terrestrial organic matter in freshwater productivity is currently poorly understood. It will therefore be necessary to include studies of carbon and detritus fluxes in rivers and floodplains as well as the bioavailability of the various carbon and nutrient forms.
6. Much more information on the role of wetlands is needed to clarify their potential role as pollutant filters and freshwater habitats. For example, to predict the sediment and nutrient filtering capacity of wetlands, their capacity and the residence time of water in them needs to be known. More data is required on the filtering capacity of rehabilitated and artificial wetlands as these are seen as potential ways of cleaning up polluted water before it enters the marine environment. The biological role of wetlands also needs further study, for example, are they a sink or source of organic matter?; do they provide juvenile habitats for fish?
7. Much of the above study would focus on the collection and interpretation of contemporary hydrological and ecological data. There is however, a need to also look at the longer term hydro-geological background, in order to separate anthropogenically induced change from natural change. Progress in this area could be made by characterising historical wet and dry periods using long term river flow records and proxy data such as sediment cores and coral growth rings.
8. The role of groundwater in riverine and wetland hydrology needs to be taken into account as does its role in sustaining low flow habitats.
9. Compared to Dry Tropics systems, estuarine ecology is poorly understood in tropical systems. It would be useful to establish a sub-project to review what literature there is as a means of focussing future studies in this area. It will also be necessary to connect estuarine models with floodplain models, so that the final fluxes of water and contaminants to the ocean can be specified.

Recommendations for MTSRF Projects 3.7.3 and 3.7.4

1. Clarify Project 3.7.3 and Project 3.7.4 goals (especially the scientific and management objectives of each).
2. Develop and use a modified version of the Marine Catchment Basin concept as an overarching framework to build and link component hydrological and ecological models. The Marine Catchment Basin model is useful, but needs to be modified to better represent the freshwater uplands zone, river-wetland interactions, connectivity pathways and surface-groundwater processes once water leaves the river channel and flows onto floodplains. Temporal patterns, sequences and duration of flooding, and well as water residence time and related processes during the dry season need to be understood to underpin ecological studies and models.
3. Clarify the number and type of models to be developed in addition to the (i) material transport across the floodplain model and (ii) the river-wetland connectivity model. For example, will there be a model for predicting how water quality changes over the floodplain during flood events?, or a model of water quality and ecological impacts in wetlands? Will these models include pesticides and their potential ecological impacts?
4. Consider separately the hydro-ecological links during the dry (ambient flow) season and the wet (flood flow) season.
5. Flow regimes (natural and modified) need to be modelled so that we can extract ecologically meaningful descriptions of flow regime change in each river system chosen for study. The location and residence time of groundwater needs to be understood during wet and dry periods in Wet Tropical and Dry Tropical systems.
6. Consider the application of the RiM-FIM (Overton 2005) approach as an alternative way of predicting inundation and connectivity. This could be compared with the hydro-dynamic model and may be a means of extrapolating river flow / area of inundation modeling to a range of other catchments along the GBR coast.
7. Include measurement and modeling of carbon and detritus in floodplain hydro-dynamic model and wetland filtering model. This would open up links to food web analysis and ecological models as well as providing a vital link with estuarine models.
8. Develop some capacity to deal with estuarine connectivity, for example, by linking the proposed floodplain hydro-dynamic model to an estuarine eco-hydrology model (such as the ones described by Webster and Wolanski)
9. Liaise closely with MTSRF marine water quality projects (and other relevant projects in the Tully-Murray) to ensure maximum synergy of data and models that run from the upper catchment, via river channel, floodplain, estuary and out into the marine environment.
10. Arrange a field trip to Tully for the MTSRF Projects leaders and key staff to decide site selection, develop and refine the data collection and experimental programs. (Will need careful site selection process if Projects 3.7.4 and 4.7.4 are to be integrated).
11. Consider a workshop/presentation to Tully stakeholders to input local knowledge of system (e.g. via Cardwell Shire Floodplain Program Steering Committee or its Biodiversity Action Team). Organize through Frederieke Kroon and/or Damon Sydes. If/when projects become active in Dry Tropics consider equivalent stakeholder consultation process there.
12. Link the current MTSRF projects with the UNESCO Ecohydrology program. Eric Wolanski can help us to achieve this.

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Appendix 1

MTSRF Program 7: Halting and Reversing the Decline of Water Quality

Project 3.7.3: Freshwater indicators and thresholds of concern

Project Leaders and Host Organisations

Professor Richard Pearson, James Cook University (JCU)
Professor Angela Arthington, Griffith University (GU)

Project Team

Title	Organisation	Role	FTE
Richard Pearson	JCU	Joint project leader; aquatic ecologist	0.35
Niall Connolly	JCU	Invertebrate ecologist and link to Report Card Framework	0.75
Jon Brodie	JCU	Water quality input and link to Project 3.7.2	0.10
Barry Butler	JCU	Water quality input and link to other JCU projects	0.10
Damien Burrows	JCU	Link to wetlands research program and other JCU projects	0.05
Angela Arthington	GU	Joint project leader; aquatic ecologist	0.30
Stuart Bunn	GU	Aquatic ecologist; link to other related research programs	0.05
Brad Pusey	GU	Fish ecologist	0.10
Mark Kennard	GU	Fish ecologist	0.20
Steve Mackay	GU	Aquatic plant ecologist	0.60
Jim Wallace	CSIRO	Hydrologist, link to Project 3.7.4	0.10
Lachlan Stewart	CSIRO	Hydrological modeler, link to Project 3.7.4	0.05
Frederieke Kroon	CSIRO	Aquatic ecologist, link to other CSIRO projects	0.10

Project Duration

Start Date: 1 July 2006 End Date: 30 June 2010

Project / Task Objectives

This project will develop conceptual biophysical models based on our previous work to identify (i) appropriate indicators of waterway health and (ii) probable thresholds of concern, in terms of contaminant concentrations, ecological processes and biodiversity. We will test those indicators in waterways in the Wet and the Dry Tropics, so that they can be implemented in fully functional monitoring systems as part of the Integrated Report Card (Project 3.7.7). We will build on the Catchment to Reef program, which has concentrated on sampling protocols and design, and has produced understanding of the requirements of an indicator system. In this project we will fully develop that indicator system. We will provide methods for monitoring for a range of people and organisations (including government agencies, industry, community groups and land owners), and will feed the essential scientific methodology into the Integrated Report Card (Project 3.7.7).

The generality of the results of this project will depend on the level of co-investment attracted, which will govern the number of systems in which model and indicator testing can be undertaken, and will determine the scope of laboratory testing of indicators.

Key Objectives:

(a) Conduct field, laboratory and desk-top research to develop physical, chemical and ecological indicators of freshwater ecosystem health in the Wet and Dry Tropics as part of an Integrated Water Quality Report Card that meets end-user needs and objectives.

(b) Identify thresholds of potential concern relating to land use, water quality, riparian condition, habitat and food web structure in freshwater ecosystems of the Wet and Dry Tropics.

(c) Develop an interactive Web database documenting the distribution and ecological requirements of freshwater biota in the Wet and Dry Tropics, to assist river health assessments and inform a range of end users.

(d) Train new researchers via PhD programs that will be integral to the identification and testing of efficient and effective freshwater condition indicators in the Wet and Dry Tropics.

(e) Provide monitoring methods, manuals and guidelines of relevance to a range of skills and end users.

Project / Task Methodology

The research outlined below on mature and new biophysical indicators will progress in stages that will link to the steps of the Integrated Water Quality Report Card framework.

Objective (a): Conduct field and laboratory research to develop physical, chemical and ecological indicators of freshwater ecosystem health in the Wet and Dry Tropics as part of an Integrated Water Quality Report Card that meets end-user needs and objectives.

We will work with Project 3.7.7 (Integrated Report Card) to define end-user needs for water quality and freshwater ecosystem health monitoring using biophysical indicators and protocols. We will undertake a review of knowledge of spatial/temporal scales of indicator response to disturbance along the whole river continuum, and identify possible spatial and temporal thresholds of potential concern in Wet Tropics rivers (e.g. Russell-Mulgrave, Tully), using published results and results from our CRC Catchment to Reef program, in relation to disturbances of land use, water quality, channel, habitat and food web structure and riparian condition. From this we will develop summary conceptual models and identify knowledge gaps concerning the sensitivity of existing indicators and potential new indicators for subsequent testing. We will workshop these conceptual models and freshwater indicators with end users to ensure that they can provide the means for various user groups to monitor and interpret pressures of particular relevance to their interests and concerns in tropical waterways. These pressures are likely to include patterns and types of land use, general water quality and contaminants, hydrological regime, channel and habitat structure, and riparian vegetation condition.

In new field and/or laboratory studies, a range of promising indicators will be quantified and correlated with physico-chemical indicators of water quality, riparian influences on light and shade (linking to Project 4.9.4), stream channel condition, hydraulic habitat structure and food web structure along gradients of disturbance. Potential indicators will include:

- Community analysis of fish and invertebrates, including analysis at functional group level, number of species that are alien (e.g. tilapia, poeciliids), accounting for different habitats;
- Condition, growth and breeding metrics on key species;
- Community analysis of aquatic plants and measures of biomass and cover including metrics to represent plant alien species; and
- Food web structure and sources of energy driving aquatic food webs.

We will test both spatial and temporal variability of Catchment to Reef freshwater indicators in Wet Tropics rivers (e.g. Russell-Mulgrave, Tully) to refine our spatial/temporal understanding and conceptual /predictive models of responses to gradients of disturbances. This will provide early information on thresholds of potential concern.

We plan to develop new PhD projects to test freshwater indicators and thresholds of concern in Wet Tropics (Russell-Mulgrave, Tully) and Dry Tropics (Burdekin). PhD research will run over years 2 to 4, alongside team research to test organism-level indicators of fish, invertebrate and plant health, as well as ecological processes, by testing response levels, rates and times, and examine the efficacy of measurement using surveys and laboratory and field experiments. Research on refined indicators will be linked to the broad scale field trials of indicators to be conducted under the Integrated Report Card framework.

Objective (b): Identify thresholds of potential concern relating to land use, water quality, riparian condition, habitat and food web structure in freshwater ecosystems of the Wet and Dry Tropics.

To provide theoretical and practical support to the research on thresholds outlined under Objective (b), we will review historical and existing approaches to determining and representing thresholds of potential concern, such as water quality guidelines (e.g. ANZECC Guidelines), benchmarking methods such as those applied in Queensland Water Resource Plans, and other approaches used globally (e.g. in South Africa). We may invite external experts to give advice on threshold methodologies, linking this task to Project 3.7.7. A collaborative end-user Workshop will allow us to present the review of the most useful and robust approaches to threshold identification, reporting and visualisation, also linked to Project 3.7.7

Objective (c): Provide an interactive Web database documenting the distribution and ecological requirements of freshwater biota in the Wet and Dry Tropics to assist river health assessments.

By the end of the Catchment to Reef program in 2006 we will have developed a prototype interactive platform that will provide a Web database of the distributions and ecological requirements of freshwater invertebrates, plants and fish in streams, rivers and wetlands.

New data collected during MTSRF research will be entered into this database during the program. Where to house this Web database and how to support its ongoing development and delivery of useful information is an issue for discussion with a range of end-user agencies and MTSRF.

Objective (d): To train new young researchers via PhD programs

Part of our research strategy is to engage with existing and new PhDs and link their work into this Project. We will share the supervision between JCU and GU, as we do now with two Catchment to Reef PhDs, to great effect. Both will be able to contribute to improving the scientific basis for selection of indicators beyond those already well established from previous Catchment to Reef and other monitoring programs. We expect that at least three new PhDs will be recruited, and supervised collaboratively across universities. We propose these projects for co-investment, but we will also seek candidates with Commonwealth or University Scholarships and top them up using MTSRF funds as a cost-effective approach.

Objective (e): To provide monitoring methods, manuals and guidelines of relevance to a range of end users.

Our biophysical models, indicator development and threshold identification will provide the underpinning science for the development of monitoring manuals and guidelines that will be useable by a variety of parties, including government agencies, industry bodies, community groups and landholders. We will build on the Catchment to Reef protocols by including the models and specified indicators, and by channelling different products to different end-users. This part of the project will link to the Integrated Report Card framework which will be developing a report card system for GBR catchments.

The Catchment to Reef Communication Strategy revised in April 2006 offers a range of communication products and activities. By June 2006 we will produce a Technical Report on the catchment and freshwater indicators trailed in the Russel-Mulgrave system in 2005. MTSRF research will allow us to test the spatial and temporal variability of this suite of physical, water quality and ecological indicators, and new indicators of ecological processes, in Wet and Dry tropical rivers. A final Manual and Guidelines will be produced from this Project. This will provide scientific background to river health monitoring, conceptual models of stressor-response relationships along the river continuum, a process for indicator selection, field techniques and monitoring methods, data analysis and modeling requirements, and guidelines on the establishment of monitoring programs of relevance to a range of people, skills and end users.

Project Outputs / Milestones

Objective	Targeted Activity	Completion Date
(a)	Contribute to the integration workshop to define end-user needs for reporting on issues related to freshwater water quality and ecosystem health.	December 2006
(a), (b)	Synthesise knowledge of biophysical models of the ecological consequences of changes in landscape stressors in the tropics, and propose a suite of biophysical indicators of freshwater ecosystem health, building on Catchment to Reef research, ANZECC Water Quality Monitoring Guidelines, EPA Water Quality Guidelines and SEQ Healthy Waterways Program.	March 2007
(a), (c)	Workshop biophysical models and indicators for Wet Tropics waterways with end users. Develop summary conceptual models and identify knowledge gaps. Define final scope of project research and where to house Web-based atlases.	May 2007
(a)	Test spatial and temporal variability of Catchment to Reef freshwater indicators in selected Wet Tropics rivers, refine summary conceptual models and identify key research issues to support development of new or refined indicators.	June 2007
(b)	Synthesise knowledge of spatial/temporal scales of indicator response to disturbance along the river continuum, and identify possible spatial and temporal thresholds of potential concern in Wet Tropics rivers in relation to disturbances of land use, riparian condition and instream biophysical parameters and/or processes.	June 2007
(d)	Develop postgraduate projects	
(e)	Develop end-users agreed products from the program	

Project 3.7.3 Milestone Payments 2006/2007

<table>
<tr><th>For 2006/2007 outputs only</th><th rowspan="2">Date</th></tr>
<tr><th>Milestones</th></tr>
<tr><td>Signing of contract</td><td></td></tr>
<tr><td>Report 1 submission:
• Input into progress update for activities listed against objectives a-e (above) [GU]
• Input into progress update for activities listed against objectives a-e (above) [CSIRO].
• Progress update for activities listed against objectives a-e (above). [JCU]
• Input into collation of Catchment to Reef products related to the activities listed in objectives a-e available for uploading to website [GU]
• Collation of Catchment to Reef products related to the activities listed in objectives a-e available for uploading to website. [JCU]
• Plan of communication outputs and products for Year 1 and summary of any liaison activities undertaken to date, including minutes of meetings/workshops if applicable. [JCU]</td><td>8 Dec 2006</td></tr>
<tr><td>Report 2 submission:
• Input into report defining status and trends of freshwater water quality and ecosystem health of freshwater environments in the Wet Tropics World Heritage Area [GU]
• Input into report defining status and trends of freshwater water quality and ecosystem health of freshwater environments in the Wet Tropics World Heritage Area [CSIRO]
• Report defining status and trends of freshwater water quality and ecosystem health of freshwater environments in the Wet Tropics World Heritage Area. [JCU]
• Input into report on the review of biophysical models of the ecological consequences of changes in landscape stressors and proposed suite of biophysical indicators of freshwater ecosystem health [GU]
• Input into report on the review of biophysical models of the ecological consequences of changes in landscape stressors and proposed suite of biophysical indicators of freshwater ecosystem health [CSIRO]
• Report on the review of biophysical models of the ecological consequences of changes in landscape stressors and proposed suite of biophysical indicators of freshwater ecosystem health. [JCU]
• Summary of any liaison activities undertaken to date in collaboration with GU. [JCU]</td><td>18 Mar 2007</td></tr>
</table>

For 2006/2007 outputs only Milestones	Date
Report 3 submission: • Report on the review of spatial/temporal scales of indicator response to disturbance along the whole river continuum, and identification of possible spatial and temporal thresholds of potential concern in Wet Tropics rivers [JCU] • Report on the review of spatial/temporal scales of indicator response to disturbance along the whole river continuum, and identification of possible spatial and temporal thresholds of potential concern in Wet Tropics rivers. [GU] • Report on end-user workshop on biophysical models, indicators and thresholds, including provisional list of indicators – Wet Tropics. [JCU] • Progress report on field testing of indicators, model refinement and threshold determination – Wet Tropics in collaboration with CSIRO and GU. [JCU] • Input into progress report on development of web-based atlases [GU] • Progress report on development of web-based atlases [JCU] • Summary of liaison activities undertaken through course of Year 1 of project in collaboration with GU. [JCU]	8 June 2007
Information transfer between agencies: • Mutual transfer of information between JCU, GU and CSIRO to progress development of Integrated Report Card required.	8 June 2007

Project 3.7.4: Wetlands and floodplains: connectivity and hydro-ecological function

Project Leader and Host Organisation

Professor Jim Wallace, Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Project Team

Title	Organisation	Role	FTE
Jim Wallace	CSIRO	Project leader; hydrology expertise	0.35
Mohammed Karim	CSIRO	Hydrodynamic modeling	0.75
Lachlan Stewart	CSIRO	Hydrological analyses	0.2
Frederieke Kroon	CSIRO	Catchment management; links other CSIRO/NRM program	0.1
Richard Pearson	JCU	Aquatic ecology; links to Project 3.7.3 and to other relevant research	0.05
Niall Connolly	JCU	Aquatic ecology; links to project 3.7.3	0.05
Jon Brodie	JCU	Water quality; link to Project 3.7.2	0.1
Damien Burrows	JCU	Wetland rehabilitation; link to wetlands research programme	0.05
Marcus Sheaves	JCU	Estuarine ecology	0.05
Angela Arthington	GU	Aquatic ecology; links to project 3.7.3 and to other relevant research	0.05
Brad Pusey	GU	Freshwater fish ecology	0.05
Steve Mackay	GU	Freshwater plant ecology	0.05
Rod Connolly	GU	Estuarine ecology	0.05

Project Duration

Start Date: 1 July 2006 End Date: 30 June 2010

Project / Task Objectives

Floodplains and wetlands are important physical and biological links in the aquatic continuum, providing unique and essential habitat and connectivity for specialist and wide-ranging fauna. Yet very little is known about the hydrological dynamics of these systems, and about the dynamics of the physical and biological connectivity through them. These systems provide access and vital habitat for iconic species such as Barramundi, but they are typically badly managed, highly impacted and, in the case of freshwater wetlands, severely depleted (~75% of such wetlands in GBR catchments having been lost to agricultural and other development). Proper management will depend on understanding the biophysical relationships and connectivity in these systems. This project will develop a core floodplain hydrological model to quantify two important aspects of hydro-ecological functioning: (i) sources, sinks and transport of sediments and nutrients across floodplains and (ii) connectivity of wetland systems within floodplains. In parallel, we will develop conceptual models of the ecological dynamics of these systems and how these interact with the hydrological processes. Ecological work to test the models of ecological processes and dynamics and links to estuarine systems will depend on the level of co-investment in the project.

The overall objective of this project is to develop the capability to predict the impacts of changes in land use, management and climate on the flow and water quality regimes and ecological dynamics in the wetlands and floodplains of catchments adjacent to the GBR. This will be achieved via the following key objectives:

(a) Quantify how the flood regime affects the main sinks and sources of sediment and nutrient and their transport across floodplains.
(b) Develop a model to predict how the hydrological response and connectivity of tropical floodplains are affected by land use, land and water management and climate.
(c) Develop models that link ecological structure (e.g. biodiversity, community patterns) and processes to the core floodplain hydrology model to quantify the consequences of changes in water body connectivity between freshwater and saline waterways for biodiversity, biological connectivity and proper ecological function.

This project will make links with several other MTSRF and non-MTSRF Projects, particularly Project 3.7.2, and CSIRO and other wetland-orientated research. Our hydrological Workshop will involve representatives from all of the MTSRF water quality projects and there will be particularly strong links with Projects 3.7.1 and 3.7.2 as they will be working in the marine environment adjacent to the Tully-Murray catchments. The biophysical information generated by this project will be linked with appropriate socio-economic aspects of land use change via the economic case studies that Project 3.7.5 will carry out in the Wet Tropics. Socio-economic links will also be strengthened via the geographical co-location of Project 3.7.4 and social and economic studies funded by CSIRO WfHC in the Tully-Murray catchments. Our main contribution to the Integrated Report Card framework will be delivered via our wetland connectivity index Decision Support System. This DSS will then be used to clarify how the current Queensland Wetlands program assessment could be improved. Subject to co-investment to support additional components, this project will develop its ecological scope in close collaboration with Project 3.7.3.

Project / Task Methodology

Objective (a): Quantify how the flood regime affects the main sinks and sources of sediment and nutrient and their transport across floodplains.

We will use a novel approach that combines state-of-the-art remote sensing and ground based data with the development of a hydrodynamic model of floodplain inundation. It will build on hydrodynamic modeling work already carried out by Main Roads in the Tully-Murray catchments in support of the redesign of the road south of Tully. The Main roads model only deals with water quantity and so this project will focus on developing and testing the sediment and nutrient transport routines that will quantify the sinks, sources and movement of materials across the floodplain during flood events. These important processes are not dealt with in existing sediment and nutrient transport models (e.g. SedNet), yet the floodplain is the area where much of the pollutants arise and it is also the area where most management interventions can take place.

The high resolution topography needed for accurate hydraulic modeling on low relief floodplains will be acquired from remote sensing (e.g. airborne laser altimetry, stereoscopic aerial photography, etc.). These types of data will also give important information on the hydraulic roughness of the vegetation on the floodplain, an essential parameter in the hydrodynamic model of the floodplain. Historical and current flood extents can be obtained using SAR (Synthetic Aperture Radar) data. Ground based data on drainage channel networks and cross sections are also required.

The hydrodynamic model predictions of flood depth, flow velocity and direction and sediment and nutrient concentrations will be tested using a combination of manual and automatic sampling of these variables during flood events.

Objective (b): Develop a model to predict how the hydrological response and connectivity of tropical floodplains are affected by land use, land and water management and climate.

The hydrodynamic model developed above will also be used to calculate wetland connectivity and how this would vary under land use and climate change. By overlaying a map of the current wetlands (permanent and ephemeral) with dynamic simulations of the evolution of flood waters it will be possible to quantify the timing and duration of hydrological connections between wetlands. The model will also be able to quantify the degree of connectivity of different wetlands (e.g. how many other water bodies are they connected to, how far away are they and how long do they stay connected?).

Using historical flood frequency data it will also be possible to characterise the frequency with which different wetland bodies are flooded and how these frequencies change with climate, land use and management changes. For example, it should be possible to quantify how a range of wetland connectivity indices have changed since the introduction of flood levees and cane drains. The impacts of future options for the introduction and/or removal of drains, levees and artificial wetlands on the wetland connectivity of the entire floodplain should also be predictable. We will make explicit links to the socio-economic aspect of floodplain development and change through Project 3.7.5.

Objective (c): Develop models that link ecological structure (e.g. biodiversity, community patterns) and processes to the core floodplain hydrology model to quantify the consequences of changes in water body connectivity between freshwater and saline waterways for biodiversity, biological connectivity and proper ecological function.

The core hydrodynamic model developed above will provide a range of new opportunities to explore the interactions between flood regimes, water quality and aquatic productivity and biodiversity. In particular the model will allow fish passage during and after flood events to be studied. This will require links with biological processes that affect the migration of tropical fish between the floodplain wetlands, freshwater streams, estuaries and the ocean.

The mechanism adopted to identify the types of freshwater ecological model that are required will be via a Workshop involving the key aquatic scientists and natural resource managers in the region. The workshop will focus on developing a plan for implementing the aquatic ecology work identified. Some initial pump-priming of the core work identified will be funded through a small number of PhD student ‘top up’ grants. These PhD studies and other externally funded projects will be targeted at field sampling to test flow-habitat-ecology relationships and models for test locations in the Wet and Dry tropics.

Project Outputs / Milestones

Objective	Targeted Activity	Completion Date
(a)	Obtain hydrodynamic software and high resolution data for test location/s.	February 2007
(a)	Acquire hydraulic characteristics and water quality data for test location in the Wet Tropics; preliminary analysis of model predictive ability for sediment and nutrient transport.	June 2007*
(b)	Workshop to define scope and scale of inundation and connectivity model, explore links between the hydrodynamic model and aquatic ecology model/s, and methods to link flow-ecology models. Participants to include researchers and relevant stakeholders, including representatives of the Qld Wetlands program, to ensure appropriate linkages.	February 2007
(c)	Review of flood data, inundation models and existing wetland connectivity models.	June 2007
	Start initial linked hydrological and ecological PhD studies using top-up funds.	June 2007*

Project 3.7.4 Milestone Payments 2006/2007

For 2006/2007 outputs only	Date
Milestones	
Signing of contract	
Report 1 submission: • Input into progress update for activities listed against objectives (a)-(c) (above). [JCU] • Input into progress update for activities listed against objectives (a)-(c) (above). [GU] • Progress update for activities listed against objectives (a)-(c) (above). [CSIRO] • Evidence that hydrodynamic software and high resolution data for test location/s has been secured. [CSIRO] • Plan of communication outputs and products for Year 1 and summary of any liaison activities undertaken to date including minutes of meetings/workshops if applicable. [CSIRO]	28 Feb 2007
Report 2 submission: • Input into proceedings of the workshop on the development of the hydrological and ecological models and the links between them (objective b), including an implementation plan. [GU] • Input into proceedings of the workshop on the development of the hydrological and ecological models and the links between them (objective b), including an implementation plan. [JCU] • Proceedings of the workshop on the development of the hydrological and ecological models and the links between them (objective b), including an implementation plan. [CSIRO] • Draft synthesis report on the review of existing hydrological data, inundation models for use in floodplain sediment and nutrient transport and wetland connectivity models. [CSIRO]	30 Apr 2007

For 2006/2007 outputs only **Milestones**	**Date**
Report 3 submission: • Report on hydraulic characteristics and water quality data for test locations in the Wet Tropics and the preliminary analysis of model predictive ability for sediment and nutrient transport. [CSIRO] • Final synthesis report on the review of existing hydrological data, inundation models for use in floodplain sediment and nutrient transport and wetland connectivity models. [CSIRO] • Progress update on student activities associated with objectives (a)-(c) (above). [JCU] • Progress update on student activities associated with objectives (a)-(c) (above). [GU] • Final summary of liaison activities undertaken through course of Year 1 of project. [CSIRO]	8 Jun 2007
Information transfer between agencies: • Data collected in this project by CSIRO, JCU and GU will be made freely available amongst these parties on request. Responsible officers: J Wallace (CSIRO), R Pearson (JCU) and A Arthington (GU)	

Appendix 2

Key Aims of the Hydro-ecological Workshop

MTSRF Workshop on Hydro-ecological Modeling

Project 3.7.4 Wetlands and floodplain: connectivity and hydro-ecological function

Date: 19-20 April 2007
Location: CSIRO Davies Lab

This Marine and Tropical Sciences Research Facility (MTSRF) project is holding a Workshop to initiate the development of an integrated package of conceptual and quantitative models, supported by field-based research, to predict the key hydro-ecological functions in Wet Tropics rivers, wetlands and floodplains. Particular attention will be given to connectivity issues that need to be understood and managed at a range of spatial scales.

Broadly the aims of the workshop are to:

1. Articulate a shared understanding of key drivers, system components, connectivity and hydro-ecological processes operating at different scales and at different locations in floodplains.
2. Capture our discussions dynamically in a floodplain conceptual diagram, or hierarchy of diagrams.
3. Identify key knowledge gaps, prioritise research activities and promote project interactions and collaborative opportunities.

The Workshop will mainly involve hydrological and ecological experts, but we will also discuss how to communicate our conclusions to key stakeholders.

Specific objectives:

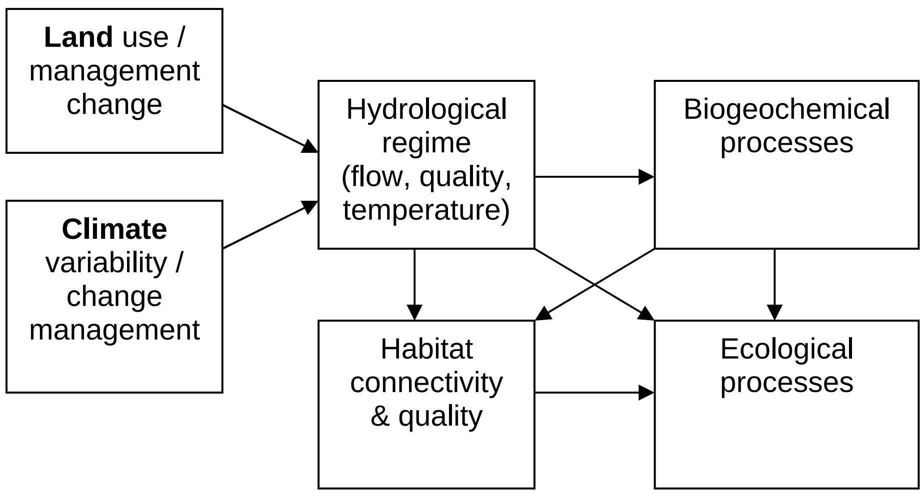
1. Identify hydrological models* best suited to quantifying the connectivity of water bodies on the floodplain.
2. Identify models* that will quantify the impacts of connectivity on aquatic habitats.
3. Identify models* that can quantify the key aquatic ecological responses to changes in connectivity and habitat.
4. Identify models* that will quantify the key bio-chemical process affecting water quality.
5. Identify models* that can quantify the key aquatic ecological responses to changes in water quality.
6. Identify key knowledge gaps that limit our ability to link hydrological and ecological models.

(*conceptual and quantitative models)

Key Questions:

1. What hydrological parameters do aquatic ecologists need as inputs to their habitat and ecological response models?
2. At what space and time scales are these parameters required?
3. What hydrological and hydraulic models can produce these parameters?
4. How can we link ecological response to these hydrological parameters?

Starter Conceptual Model



Appendix 3

Participants of the Hydro-ecological Workshop

Name	Affiliation	Email Address
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Appendix 4

Hydro-ecological Modeling Workshop Agenda

19 April 2007		
08.30	Introduction	Jim Wallace
Session I: Floodplain hydrology and water quality		**Chair: George Lukacs**
09.00	Paper 1: Floodplain hydro-dynamic modeling of water quality and wetland connectivity	Jim Wallace
09.30	Paper 2: Inundation modeling in the Murray-Darling	Ian Overton
09.50	Paper 3: Water quality behaviour under different hydrological regimes	Jon Brodie
10.10	Paper 4: The filter function of wetlands	Dave McJannet
10.30	Tea/coffee break	
11.00	Paper 5: Estuarine bio-geochemical modeling	Ian Webster
11.20	Paper 6: Freshwater/marine water quality interactions	Eric Wolanski
11.40	Discussion	
12.30	Lunch	
Session II: Hydrological and ecological connectivity		**Chair: Darren Baldwin**
13:30	Paper 7: Water and ecosystem health	Richard Pearson
14:00	Paper 8: Russell-Mulgrave case study	Niall Connolly
14:20	Paper 9: Hydro-ecological interactions	Angela Arthington
14:50	Paper 10: Hydrology, connectivity and larval fish	Paul Godfrey
15:10	Tea/coffee break	
15:40	Paper 11: Fish passage	Ross Kapitzke
16:00	Paper 12: Ecological response modeling	Nick Marsh
16:20	Discussion	Richard Pearson
16:50	Introduction to conceptual models for Day 2	Angela Arthington
17.00	Close	
19:00	**Dinner at the Ibis Hotel, Palmer Street**	
20 April 2007		
Session III: Development of conceptual models		
08.00	Introduction – breakout groups	Richard Pearson
08.30	Break-out groups to develop *draft disciplinary models*: a) Hydrology and water quality b) Hydrological and ecological connectivity	GL: Bristow; Rap: Kroon GL: Sheaves; Rap: Waterhouse
10.00	Tea/coffee break	
10.30	Breakout report (2 x 15 mins each + 15 mins discussion) a) Hydrology and water quality (Rap a) b) Hydrological and ecological connectivity (Rap b)	Chair: Angela Arthington
11:15	Break-out groups to develop *integrated system models*: c) Group I d) Group II	GL: Gehrke ; Rap: Pusey GL: Dale ; Rap: Oliver
12.45	Lunch	
13.45	Breakout report (2 x 15 mins each + 15 mins discussion) c) Group I (Rap c)	Chair: Bunn/Fabricius/Raynor

	d) Group II (Rap d)	
14:30	Summary of conceptual models	Ian Webster
14:45	Next steps	Jim Wallace
15.00	Tea/coffee and close	