Department of Science, Information Technology, Innovation and the Arts

Review of Water Resource (Burnett Basin) Plan 2000 and Resource Operations Plan

Appendix A–Assessment of critical water requirements for selected ecological assets

April 2013

Great state. Great opportunity.

Queensland Government

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Contents

Preface 7

Executive Summary 7

1 Introduction 9

2 Methodology 10

2.1 Representation of flow-dependent ecosystem components and processes using ecological assets 11

2.2 Ecological asset identification 12

2.3 Determining specific flow requirements 12

2.4 Defining assessment and measurement endpoints 12

2.5 Establishing critical flow requirements (eco-hydraulic rules) 12

2.6 Defining thresholds of concern (ToC) 13

3 Results 15

3.1 Ecosystem components–vertebrates and fish 16

3.1.1 *Neoceratodus forsteri* (Australian Lungfish) 16

Appearance 16
Distribution 16
Habitat 17
Reproduction 18
Ecological value it supports 18
Assessment end point 19
Measurement end point 19
Eco-hydraulic rules 19
Threshold of concern 20
Spatial relevance 20

3.1.2 *Elseya albagula* (White-throated snapping turtle) 21

Appearance 21
Distribution 21
Habitat 22
Reproduction 22
Ecological value it supports 23
Assessment end point 23
Measurement end point 23
Eco-hydraulic rules 23
Threshold of concern 24
Spatial relevance 24

3.2 Ecosystem process–estuarine brackish habitat 25

3.2.1 Background 25

Existing ambient estuarine water quality monitoring data 25
Estuarine salinity mapping 26
Burnett River 26
Kolan River 27
Elliott River 27
Summary of discharges to provide estuarine brackish conditions in Burnett WRP estuaries 28
Eco-hydraulic rules for estuarine brackish habitat 29

3.2.2 Estuarine brackish habitat–*Lates calcarifer* (Barramundi) brackish habitat and Year Class Strength (YCS) 29

Appearance 29
Distribution 29
Habitat 30
Reproduction 31
Ecological value it supports 33
Assessment endpoint 33

Measurement endpoint 33
Eco-hydraulic rules 33
Relationship between estuarine brackish habitat for L.calcarifer and freshwater flow 33
Relationship between L.calcarifer Year Class Strength (YCS) and freshwater flow 33
Threshold of concern 34
Estuarine brackish habitat for L. calcarifer 34
L. calcarifer YCS 34
Spatial relevance 34

3.2.3 Estuarine brackish habitat–*Fenneropenaeus merguiensis* (Banana prawn) growth 35

Appearance 35
Distribution 35
Habitat 35
Reproduction 35
Ecological value it supports 36
Assessment endpoint 36
Measurement endpoint 36
Eco-hydraulic rules 36
Relationship between estuarine brackish habitat for F. merguiensis *and freshwater flow* 36
Relationship between F. merguiensis *growth and freshwater flow* 36
Threshold of concern 37
Estuarine brackish habitat for F. merguiensis 37
Growth of F. merguiensis 37
Spatial relevance 37

3.2.4 Estuarine brackish habitat–*Mugil cephalus* (Sea mullet) 38

Appearance 38
Distribution 38
Habitat 38
Reproduction 38
Ecological value it supports 39
Assessment end point 39
Measurement end point 40
Eco-hydraulic rules 40
Threshold of concern 40
Spatial relevance 40

3.2.5 River Mangrove (*Aegiceras corniculatum*) 41

Appearance 41
Distribution 41
Habitat 41
Reproduction 41
Ecological value it supports 42
Assessment endpoint 42
Measurement endpoint 42
Eco-hydraulic rules 42
Threshold of concern 43
Spatial relevance 44

3.3 Ecosystem services–waterhole persistence 45

3.3.1 Waterholes as refugia 45

Description 45
Ecological value it supports 54
Assessment endpoint 54
Measurement end point 54
Eco-hydraulic rules 54
Threshold of concern 54
Spatial relevance 54

4 Summary 56

References 59

List of figures

Figure 1: Ecological Risk Assessment framework for flow-dependent ecosystem components, processes, and services. 11

Figure 2: Example of development and application of eco-hydraulic rules in the case of guild of stable flow spawning fish 13

Figure 3: Gauging stations within the Burnett Basin WRP area. 15

Figure 4: Recorded distribution of *N. forsteri* in the Burnett Basin. 17

Figure 5: Recorded distribution of *E. albagula* (red dots) in South-East Queensland. 21

Figure 6: Observed cumulative proportion of *E .albagula* nests inundated with water level rises above the water level at time of nesting (May to July)..........22

Figure 7: Comparative salinity gradients for the Burnett River estuary under flow (17/09/10) and no-flow (09/09/09) scenarios. 26

Figure 8: Comparative salinity gradients for the Kolan River estuary under no-flow conditions (03/09/2009) and flow conditions (06/04/2010). 27

Figure 9: Comparison of the salinity profile during no-flow conditions in estuaries within the Burnett WRP plan area 28

Figure 10: Waterhole assessment locations in the Burnett Basin. Naming based on the associated gauge station name. 48

Figure 11: Bathymetric map of the Burnett River waterholes..........49

Figure 12: Bathymetry of Grays waterhole on the Burnett River..........50

Figure 13: Bathymetry of Elliott River waterholes 51

Figure 14: Bathymetry of Dr Mays waterhole..........52

Figure 15: Bathymetry of the Bunyip Waterhole on Three Moon Creek. 53

List of tables

Table 1 Physiochemical requirements of adult *Neoceratodus fosteri* (Brooks & Kind 2002; Kemp 2008)..........17

Table 2 Life history attributes of *Neoceratodus forsteri* 18

Table 3 Eco-hydraulic rules for *Neoceratodus forsteri* 19

Table 4 ToC and node failure threshold for *Neoceratodus forsteri*..........20

Table 5 IQQM nodes that were used to model reproductive opportunities for *Neoceratodus forsteri*..........20

Table 6 Life history attributes of *Elseya albagula* 23

Table 7 Eco-hydraulic rules for *Elseya albagula* 24

Table 8 ToC and node failure threshold for *E. albagula* 24

Table 9 IQQM nodes that were used to model reproductive opportunities for *Elseya albagula*..........25

Table 10: Peak discharge volumes required to provide brackish habitat (15‰) up to their respective mid-points. 28

Table 11 Eco-hydraulic rules for estuarine brackish habitat 29

Table 12 Microhabitat requirements of *L. calcarifer* based on different phases of the life cycle 30

Table 13 Life history attributes of *Lates calcarifer*..........31

Table 14 ToC and node failure threshold for *Lates calcarifer* 34

Table 15 IQQM nodes that were used to model risk to *Lates calcarifer*..........34

Table 16 ToC and node failure threshold for *F. merguiensis* 37

Table 17 IQQM nodes that were used to model risk and growth for *F. merguiensis*..........38

Table 18 Life history attributes of *Mugil cephalus* 39

Table 19 ToC and node failure threshold for *M. cephalus* 40

Table 20 IQQM nodes that were used to model risk to *M. cephalus* 40
Table 21 Life history attributes of *Aegiceras corniculatum* 42
Table 22 Eco-hydraulic rules for *Aegiceras corniculatum* 43
Table 23 ToC for *Aegiceras corniculatum* 43
Table 24 IQQM nodes that were used to model recruitment opportunities for *Aegiceras corniculatum* 44
Table 25 Surveyed waterhole properties including statistics on associated water extraction information. 46
Table 26 Eco-hydraulic rules for waterholes 54
Table 27 IQQM nodes that were used to establish maximum no-flow spells for waterholes. 55
Table 28 Summary of eco-hydraulic rules for selected ecological assets within the Burnett Basin 56

Preface

This report is part of a suite of documents contributing to the environmental assessment for the Burnett Basin Water Resource Plan (WRP) review. These reports have been prepared by the Department of Natural Resources (DNRM) and Department of Science, Information Technology, Innovation and the Arts (DSITIA).

The objective of these reports is to provide an environmental assessment of the key flow-related surface water and groundwater dependent ecosystems of the Burnett Basin. A key aim is to identify environmental risks associated with a range of potential water allocation and management scenarios. Management recommendations will address these risks and propose strategies to protect the ecological values of the plan area.

The outcome of the project is presented in the following stages:

Environmental assessment report

Appendix A—Assessment of critical water requirements for selected ecological assets

Appendix B—Risk assessment for selected ecological assets

Appendix C—Assessment of existing environmental management rules

Appendix D—Assessment of groundwater-dependent ecosystem reporting nodes in the Coastal Burnett Groundwater Management Area

Appendix E—Assessment of alternative environmental management rules

Appendix F—Related planning processes

Appendix G—Response to independent science review

Executive Summary

Eco-hydraulic rules are a defined set of rules that represent triggers for an ecological response to different parts of the flow regime (magnitude, duration, timing and rate of change)–though water quality parameters may also be incorporated. As documented in the Burnett Ecological Asset Selection Report (Appendix B in Implementation Review Report), a number of ecological assets were selected based on whether there was:

1. adequate information about the critical water requirements of each assets; and
2. environmental data to determine the risk to the asset resulting from changes to the critical water requirements.

The selected ecological assets include the Australian lungfish (*Neoceratodus forsteri*), White-throated snapping turtle (*Elseya albagula*), estuarine brackish habitats and waterholes. Since estuaries are a specific habitat type that represents a continuum of water salinities, and species within this habitat have specific water requirements, the asset was assessed as several estuarine components including barramundi (*Lates calcarifer*), sea mullet (*Mugil cephalus*), banana prawns (*Fenneropenaeus merguiensis*) and river mangrove (*Aegiceras corniculatum*).

This report establishes the critical water requirements and associated abiotic factors (e.g. water quality) for each selected asset. Combined with information from ongoing assessment through the Queensland Government's Environmental Flows Assessment Program (EFAP), data was gathered from scientific literature and expert knowledge to develop eco-hydraulic rules for each asset. Both simulated and gauged hydraulic data were used for this process.

The critical water requirements and eco-hydraulic rules for each asset have been summarised below:

- The Australian lungfish requires small trigger flows during late winter to early summer to trigger spawning. Flows need to be of a minimum size to allow for migration and site selection, and the duration of the flow is important for egg development.
- The white-throated snapping turtle nests in aggregations in the lower Burnett River. To prevent nest inundation, it is important to maintain a consistent water level during incubation. An increase in water levels of greater than 1.3 m during incubation increases risk of egg mortality by upward of 20%. This is important as there is evidence that nest predation has already altered the demographics of the population. Minimising nest inundation maximises the chance of eggs hatching and is believed to be vital in maintaining this species.
- The delivery of freshwater flows to an estuary creates a salinity gradient. This salinity gradient provides the brackish habitat that drives important biological processes for a number of species.
- Banana prawns, sea mullet and barramundi each require brackish habitat for growth and recruitment. Changes to the frequency, timing, magnitude and duration of freshwater flows can increase risk to the critical water requirements of these species.
- River mangroves also require brackish habitat for seedling establishment and growth. Changes to the frequency, timing, magnitude and duration of estuarine flows can alter community distributions and increase risk to the critical water requirements of species that rely on this habitat.
- Waterholes are distributed throughout the Burnett Basin. Waterhole persistence is a function of the waterhole depth, the periods between flows and the volume extracted from the waterhole. Extending the period between flows can increase the risk to the critical water requirements of waterhole refugia.

1 Introduction

Evaluating the risk to ecological assets from WRP and Resource Operations Plan (ROP) implementation informs the review of a plan's effectiveness.

For water planning purposes, an *ecological asset* is defined as *an ecosystem component that occurs naturally in a plan area and is critically linked to flow i.e. is dependent on the conditions provided by flow to support its long term integrity. An ecological asset may be a species, a group of species, a biological function, an ecosystem or a place of natural value.*

Ecological assets for the Burnett Basin were selected and prioritisation for monitoring as part of phase 1 of the Environmental Flows Assessment Program (EFAP) (Appendix B of the Implementation Review Report). These assets were selected to represent the whole ecosystem and enable a manageable method for monitoring water management decisions.

The purpose of this report is to consolidate the current scientific understanding of these selected ecological assets. This report summarises the critical water requirements for each asset and then derives a range of eco-hydraulic rules for each. For each eco-hydraulic rule, a threshold of concern was established that if exceeded represents an increase in risk to the asset. For example, a species of fish may require a low flow to initiate spawning. Looking at the life history, the species may also require this flow annually. In this instance the low flow represents the eco-hydraulic requirement of the species and the annual recurrence of this flow forms the threshold of concern.

The eco-hydraulic rules alongside the corresponding threshold of concern established in this report form the basis for testing each assets response to the water resource management strategies in the Burnett Basin WRP (Appendix B).

2 Methodology

In this report, eco-hydraulic rules for each prioritised ecological asset were established through the quantification of data from a range of sources, into discrete formats that enabled a risk assessment to be undertaken. Simulated, gauged and physicochemical data form the basis from which comparative risk was determined for each asset's critical link before, and after, water resource development. For example, eco-hydraulic rules for Australian lungfish were established through a combination of scientific literature, research and monitoring undertaken by the department's EFAP, as well as consultation with relevant experts. Together, this information enabled the conceptual description of critical spawning requirements for Australian lungfish. The next step involved the synthesis of this information into discrete knowledge sub-sets including location, timing, magnitude, duration, frequency, habitat features and water quality parameters. This enables the overlay of discrete parameters, critical to the ecological response, onto hydraulic (modelled or gauged) and physicochemical data, which formed the basis of the risk assessment.

The environmental assessment uses an eco-hydraulic modelling approach to assess the risk to aquatic ecosystem components and processes from the water resource development scenarios developed (Figure 1). The assessment focuses on ecological assets that:

(i) represent the ecological values of the plan area,

(ii) are dependent on aspects of the flow regime (including both surface and groundwater), and

(iii) are vulnerable to the types of flow alteration reflected in the WRP.

The assessment uses a desktop modelling approach drawing on existing information and knowledge about the ecological values of the Burnett Basin as well as relevant flow-ecology information. The approach used is consistent with the *Framework for assessing the Environmental Water Requirements of Groundwater Dependent Ecosystems Report 1 Assessment Toolbox* (Clifton et al. 2007) and the principles outlined in *Ecological Risk Assessment of Water Resource Plans* (Marshall & McGregor 2006).

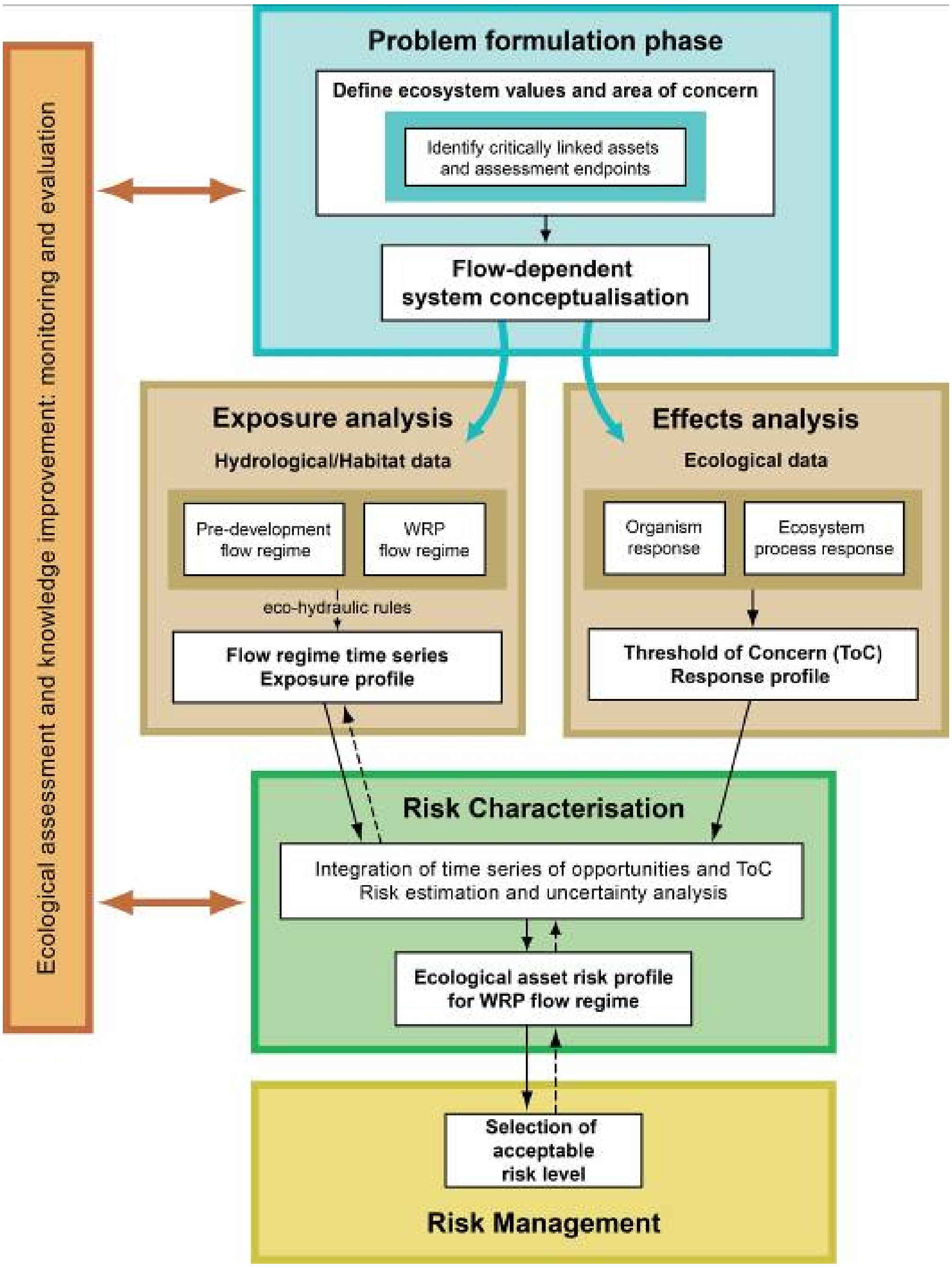

Figure 1: Ecological Risk Assessment framework for flow-dependent ecosystem components, processes, and services.

2.1 Representation of flow-dependent ecosystem components and processes using ecological assets

Predicting potential ecological responses to altered flow regimes is complicated by interactions between the flow and ecosystem components and processes at multiple scales. This is further complicated by the confounding effects of non-flow related stressors present in the system (i.e. land use, toxicants, exotic species, etc.). Consequently general measures of ecological responses to managed flow regimes are rarely observed (Kennard et al. 2010; Poff et al. 2010). To deal with this uncertainty, a practical approach for managing flow regimes for specific ecological outcomes requires identifying and partitioning the critical flow dependencies of ecosystem components and processes and consideration of their specific water requirements over time. These components and processes are effectively indicators of flow modification and therefore broadly representative of the ecosystem response.

Known as *ecological assets*, these indicators are highly valued components of the ecosystem for which aspects of the flow regime (i.e. duration, timing, variability, predictability, magnitude, rate of rise and fall) are critical to support their long term viability. Ecological assets may be a species, a group of species, a biological function, an ecosystem or a place of natural value. They occur naturally in the area of interest (this excludes translocated and exotic species), have an aspect(s) of its life history or process requirement critically linked to the flow regime, and is sensitive to the nature of flow regime relevant to the area of interest. Each WRP area contains a unique set of ecological assets and related ecological outcomes. Consequently ecological assets selected for each WRP area will differ across the state. Additionally, the flow requirements of a specific ecological asset may also vary between WRP areas due to the different eco-hydrologic settings that characterise each basin. The risk to ecological assets from water resource development represented by the WRP is the focus of the environmental assessment process.

2.2 Ecological asset identification

Ecological assets for the Burnett Basin WRP were selected following a comprehensive review of available data and information in the peer reviewed scientific literature, grey literature sources, government databases, and through consultation with relevant technical experts (see Appendix B of the Implementation review Report).

2.3 Determining specific flow requirements

The environmental assessment uses an eco-hydraulic modelling approach to assess the risk to ecological assets from water resource development. A detailed review of the scientific literature and consultation with relevant technical experts was conducted for each ecological asset. This information was distilled into discrete aspects of the flow regime with respect to location, timing, magnitude, duration, frequency, habitat features and associated water quality attributes where relevant. This expression of flow regime facets in terms of supporting critical life history or process events forms the basis for determining how the managed flow regime alters the provision of these opportunities over time, and hence represents a risk to the asset's long term viability.

2.4 Defining assessment and measurement endpoints

Assessment endpoints are used to explicitly define the environmental values of concern and provide the focus for analysis and characterisation in ERAs. They can include species and life stages, multiple levels of organisation and numerous structural and functional attributes. Assessment endpoints are those characteristics/attributes of the valued ecological entity which are believed to be at risk (i.e. vulnerable). In this context the assessment endpoints are the flow-dependent ecological components, processes, and services of the Burnett WRP area. The assessment endpoint has two components (i) the entity–which is the valued aspect of the ecosystem (i.e. ecological asset such as a fish, plant, turtle, waterhole, etc.) and (ii) the attribute of the entity–such as abundance, fecundity, recruitment, extirpation, persistence, etc. Assessment endpoints are generally estimated using measurement endpoints.

Measurement endpoints (also known as measures of effect) are expressions of observed or measured responses to the stressor, a measurable characteristic that is related to the assessment endpoint. Examples include; measures of fecundity, recruitment and survival. Measurement endpoints are derived via laboratory or field based observational studies that are used to estimate the effects on an assessment endpoint or exposure to a stressor. Measurement endpoints are typically the focus of the risk assessment and link the assessment endpoints to the risk assessment.

When an assessment endpoint can be directly measured, the measurement and assessment endpoints are the same. In most cases, however, the assessment endpoint cannot be directly measured, so a measurement endpoint (or a suite of measurement endpoints) is selected that can be related, either qualitatively or quantitatively, to the assessment endpoint (U.S. EPA 1992). For most of the species based ecological assets considered in this assessment, the measurement endpoints relate to spawning and recruitment opportunities linked to aspects of the flow regime. Measurement endpoints for ecological process and service related ecological assets vary; however typically they relate to the provision of critical habitat, or the conditions which support ecosystem structure and/or function.

2.5 Establishing critical flow requirements (eco-hydraulic rules)

The exposure analysis phase of the ERA (Figure 1) uses information on the flow requirements of the prioritised ecological assets to develop a time series of opportunities for each water resource development scenario as it relates to a specific ecological response defined as the measurement endpoint. The requirements of ecological assets in terms of aspects of the flow regime (e.g. magnitude, duration, timing, rate of change) are defined and expressed as *eco-hydraulic rules*. For each ecological asset, best current scientific understanding is used to describe the nature of the flow dependency by defining the flow related conditions needed to trigger an ecological response. This understanding is then used to formulate eco-hydraulic rules that define an opportunity for the ecological response in terms of facets of the flow regime.

For example:

spawning trigger flow = X magnitude for Y period between T1 – T2 time of the year (Figure 2).

These eco-hydraulic rules are then applied to a daily flow time series representing a water resource development scenario to generate a time series of opportunities for the ecological response. This likelihood or exposure data represents the probability of an ecological asset/indicator experiencing the critical conditions required when and where they are needed over the assessment period.

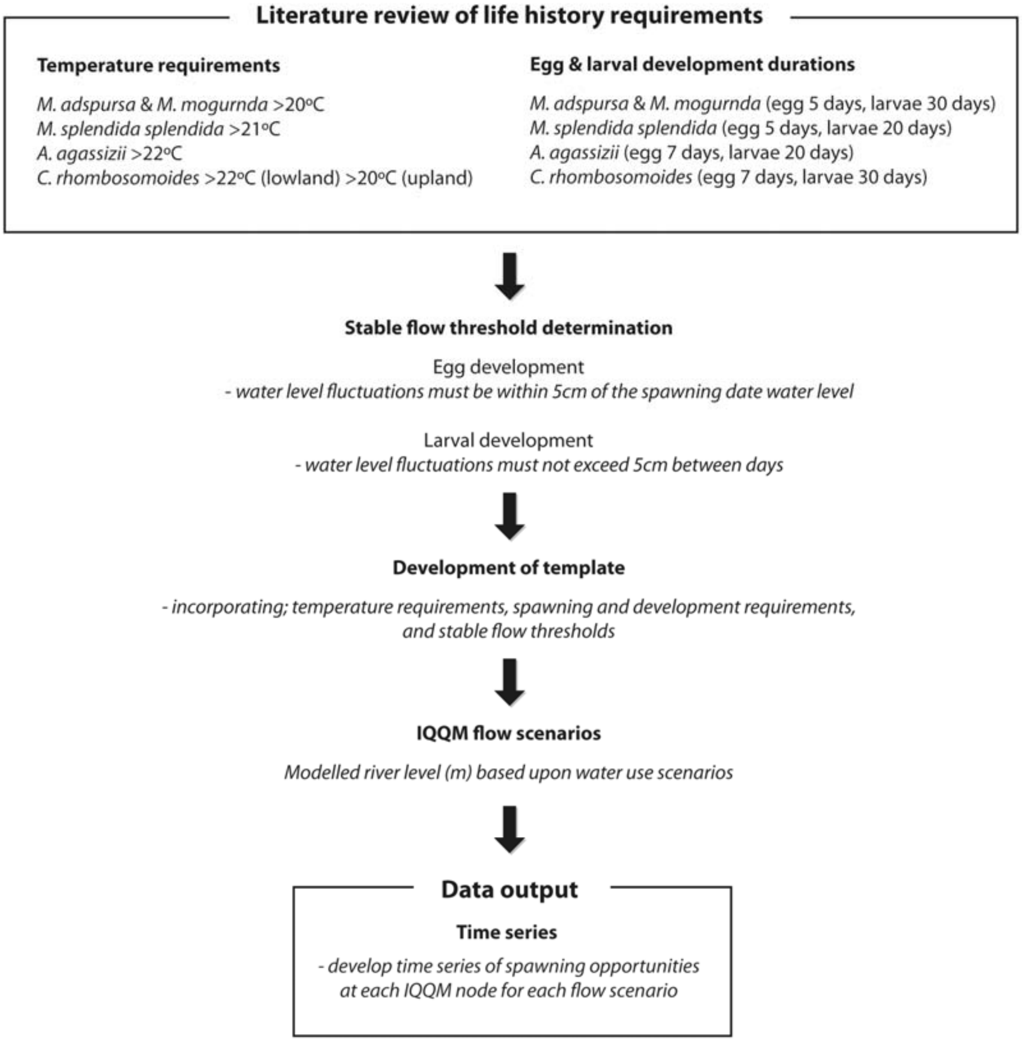

Figure 2: Example of development and application of eco-hydraulic rules in the case of guild of stable flow spawning fish

2.6 Defining thresholds of concern (ToC)

The effects analysis phase of the ERA (Figure 1) uses information on the consequence of altering the provision of the critically-linked response to the long term viability of the ecological asset. Defining what constitutes *sufficient opportunities* for an ecological response to maintain the viability of an ecological asset remains a global knowledge gap in the scientific literature for a great many flow dependent species and processes. The application of coarse hydrological metrics such as percentage of pre-development flow regime represents an oversimplification of the temporal hydrological sequence experienced by the ecology. These statistics ignore the obvious relevance of timing, spell durations, and represent an oversimplification of complex interactions between the hydrology and ecology. In this ERA flow context, consequence or effects data is the characterisation of an adverse ecological effect or response. Consequence is the impact of the valued attributes of an ecological asset/indicator of not providing the conditions it critically requires.

Ideally defining sufficient opportunities is informed by response functions derived from controlled observational or manipulation-based studies of flow-ecology interactions. In the absence of widely applicable general response functions, best available science can be used to derive step functions or thresholds which represent critical change or failure points along a response gradient. In this WRP application, Thresholds of Concern (ToC) (*sensu* Rogers & Biggs 1999) are defined to represent the frequency of opportunities required to protect asset viability. ToCs represent failure points for the ecological

asset and as such can be considered minimum water requirements. Therefore, the probability of achieving a desired ecological outcome is directly related to meeting a ToC over time. Where possible, ToCs are based on the biology or process knowledge of the asset. In most cases, ToCs represent the known time species-based ecological assets will survive without experiencing a flow-based opportunity (for responses related to maintenance and persistence dependencies) or the reproductive life time of the asset (for responses related to regeneration and recruitment dependencies). For those ecological assets without a clear life history basis for setting a ToC, thresholds can be related to the frequency of opportunity provision modelled to occur under the pre-development flow regime. Because even natural flow regimes are not without risk to ecological assets, the risk from management scenarios will be considered relative to the risk from the pre-development flow regime.

The process outlined above requires both a sound conceptual understanding of the flow dependent ecological assets and detailed biological and/or process knowledge relating to their critical flow dependencies. The synthesis of this knowledge is presented in this report for each ecological asset, or group of assets (guild) and forms the basis for the ecological model development and setting of ToCs. This will subsequently be used for the quantification of risk to those assets from various water resource development scenarios. The risk characterisation phase of the ERA (Figure 1) is presented in Appendix B of the Environmental Assessment Report.

3 Results

The eco-hydraulic rules for seven ecological assets were further described. These included ecosystem components (fish and reptiles), ecosystem processes (estuarine brackish habitat for barramundi, sea mullet, banana prawns and river mangroves) as well as ecosystem services (waterhole persistence). Summary information on each ecological asset is provided in subsequent sections, including assessment and measurement endpoints, ToC and eco-hydraulic rules used to model the risk from water resource development. A map showing the location of all gauge stations within the basin follows which can be used to identify relevant stations listed in future sections (Figure 3).

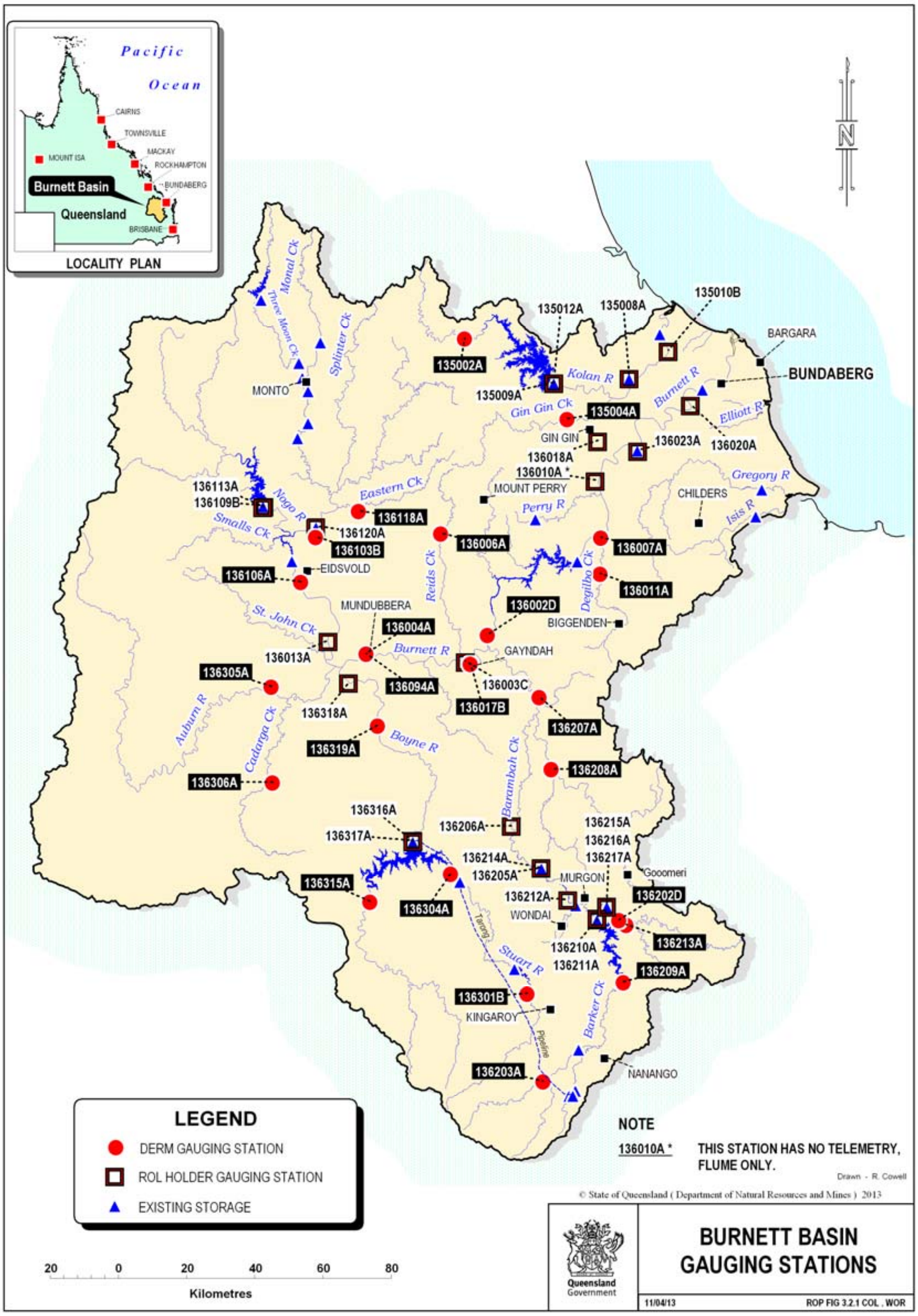

Figure 3: Gauging stations within the Burnett Basin WRP area.

3.1 Ecosystem components–vertebrates and fish

3.1.1 *Neoceratodus forsteri* (Australian Lungfish)

Appearance

Neoceratodus forsteri is a long, heavy-bodied freshwater fish typically about 1m long and weighing 7.5 kg (Brooks & Kind 2002). Although they can grow as long as 2 m and weigh up to 48 kg (Environment Australia 2003ab; Grigg 1975). Adult are olive-green or grey-brown above, and yellow-orange below, with some whitish colour on the belly and underside of the head. They have large, overlapping scales and a small mouth with large teeth on the palate and lower jaw (Allen 1989a; Grigg 1975). Juveniles are dark olive, brown or yellow with a mottled pattern above and a dull pink belly (Kemp 1995; Brooks & Kind 2002). They have five pair of gills and a single lung. The species is able to breathe aquatically using its gills, and aerially using its lung. It usually uses its gills, surfacing to breathe when its activity requires more oxygen. For example, it breathes air more often at night while foraging, when swimming in floodwaters, and when spawning (Grigg 1964, 1975; Kemp 1984; Merrick & Schmida 1984).

Distribution

Restricted to south-eastern Queensland, *N. forsteri* is currently found in the Burnett, Mary River, North Pine (including Lake Samsonvale) and Brisbane rivers (including Lake Wivenhoe), and Enoggera Reservoir (Brooks & Kind 2002; Johnson 2001; Kemp 1995). Its natural distribution is the Mary and Burnett River systems and was translocated to other sites, with varying success. Kemp (1986) argued that the Brisbane and North Pine populations are unlikely to have expanded from such a small number of translocated fish, and therefore probably form part of the historical distribution. A genetic study published by Frentiu et al. (2001) was unable to resolve this ongoing debate.

N. forsteri is widely distributed within the Burnett River (Figure 4), found from Ben Anderson Barrage to upstream of John Golby Weir (around 335 km from the mouth of the river). They are most abundant between Ben Anderson Barrage and 275 km upstream. It is also found in several Burnett River tributaries (Brooks 1995; Brooks & Kind 2002) including Three Moon Creek, Boyne River from its junction with the Burnett River as far as Boondooma Dam, Barambah Creek below Barambah Gorge, and Auburn River below the falls/gorge.

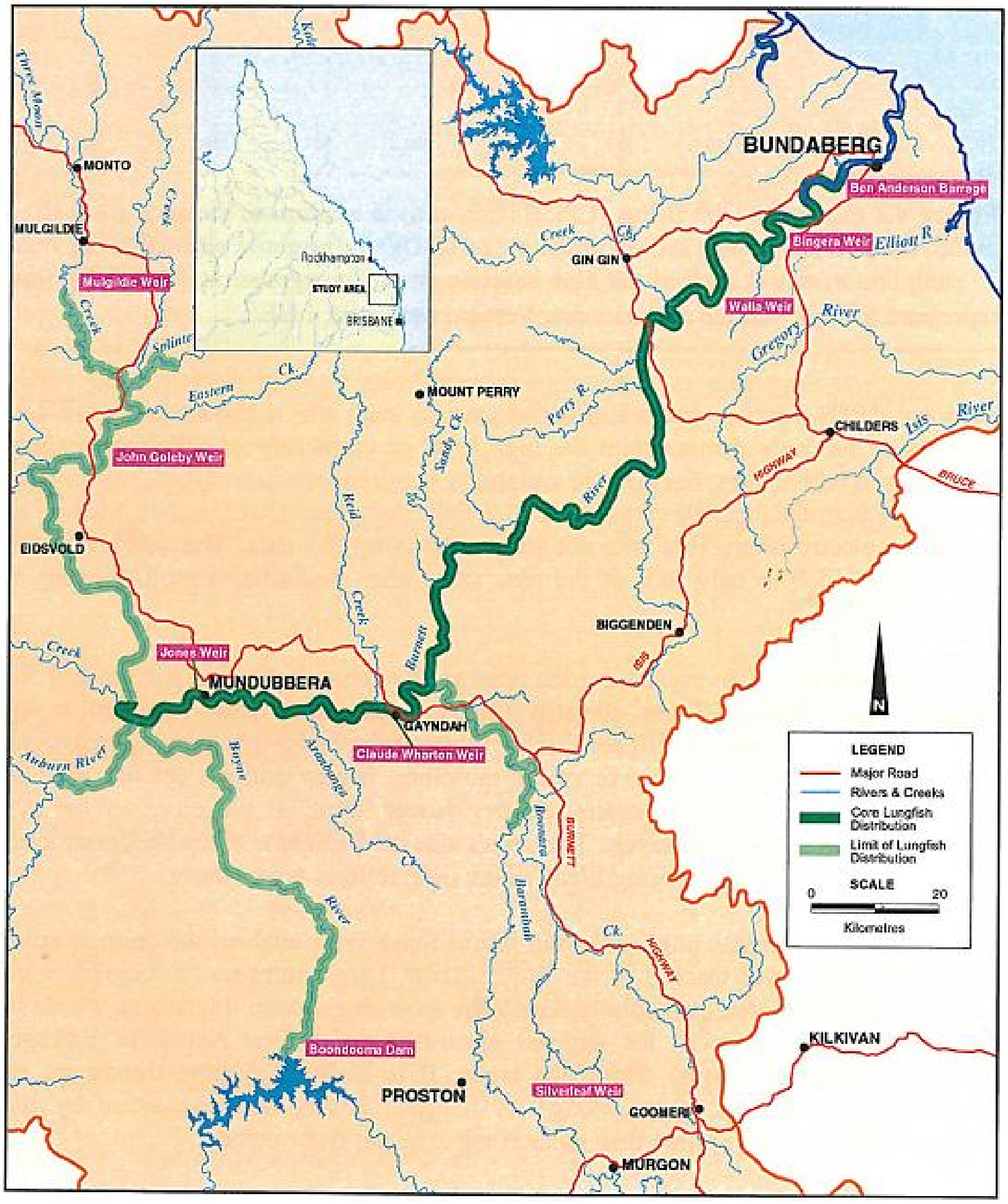

Figure 4: Recorded distribution of *N. forsteri* in the Burnett Basin.

(Copied from Figure 4-1, Pg 25 Brooks and Kind 2002).

Habitat

The preferred habitat of adult *N. forsteri* is the slow-flowing stretches of deep riverine habitat. However the species has been found in abundance in impoundments between these reaches (Brooks & Kind 2002). Their habitat is restricted to areas of permanent water (Brooks & Kind 2002). The species has been found to perish in saline waters when they have overtopped flowing tidal barrages and cannot migrate through sea water. The species requires still to slow-flowing, shallow, vegetated reaches to spawn and feed (Allen 1989a; Merrick & Schmida 1984; Espinoza et al. unpub.). The physiochemical requirements of adult *N. forsteri* are summarised in Table 1.

Table 1: Physiochemical requirements of adult *Neoceratodus fosteri* (Brooks & Kind 2002; Kemp 2008)

Parameter	Min	Max
Water temperature (°C)	13	25
pH	6	7.8
Conductivity (µS/cm)	421	1165

Reproduction

N. forsteri is long-lived species that require highly specific conditions for reproduction (Table 2). Spawning predominately occurs in shallow riverine habitat within submerged aquatic plant beds during spring and early summer. This generally coincides with periods of low river flows (Kemp 1984; Brooks 1995; Brooks & Kind 2002). Recent research has found, however, that spawning is generally preceded by a small elevated flow in the river (Espinoza et al. unpub.). A preceding flow with a rise of 0.3 m provides access - and stimulates migration - to spawning grounds.

Maintaining these low flows for ~ 30 days is important for both spawning and egg development (Kemp 1984; Brooks 1995; Brooks & Kind 2002). Eggs are laid amongst dense aquatic macrophyte beds (>90% coverage) provides shelter and optimal environmental conditions for eggs and hatchling survival (Brooks & Kind 2002). Flow velocities less than 0.5 m/s appear to best suit the ability for eggs to adhere to macrophytes. Low flows provide hydraulic habitat and food resources, increasing the likelihood of reproductive success.

Table 2: Life history attributes of *Neoceratodus forsteri*

Characteristic	Description (reference for data is Brooks & Kind 2002 unless otherwise specified)	
Longevity/Lifespan	50–100 years. Specimens aged at least 67 years (James et al. 2010)	
Age at sexual maturity	Males	15 years
	Females	20 years
Spawning season	Between August and December (peak time in October)	
Spawning frequency	Annually (Kemp 1998)	
Spawning cues	Spawn in both still and flowing water post small river rise (0.3 m) (Espinoza et al. unpub.) based in spring on increasing photoperiod and water temperature (Kemp 1984)	
Fecundity	Between 50 and 100 eggs	
Time to hatching	Eggs hatch after 30 days. Egg survival is greatest in shallow water with dense macrophyte cover. The highest egg survival rate is in water depths between 200 mm and 800 mm	
Egg characteristics	Eggs are 3 mm in diameter Coated in an adhesive gel that adheres to macrophytes Eggs sink when first laid Eggs survivorship in temperatures between 10ºC and 30ºC	
Spawning habitat	Generally within macrophytes that grow in a dense mass in shallow water over a substrates from gravel to mud.	

Ecological value it supports

N. forsteri is listed as Vulnerable under the Environment Protection and Biodiversity Conservation Act 1999. While not a threatened species under the Nature Conservation Act 1992, it is protected under the Queensland Fish and Oyster Act 1914. It is currently protected from fishing, and collection requires a permit under the Fisheries Act 1994. A draft Survival Strategy for the species has been prepared that aims to guide recovery of the species (Kind et al. 2008). The species also has significant cultural value to the Gubbi Gubbi traditional owners. They do not kill or eat the fish, but have sought to ensure that it is protected from harm as it has a sacred (totemic) value (Kind et al. 2008).

The species can be associated with the general and specific ecological outcomes of the Water Resource (Burnett Basin) Plan 2000:

- *6(e)(iii) Water is to be managed and allocated to provide to provide for community aspirations about protecting species of significant conservation value, including for example, lungfish and turtles.*
- *7(a) Water is to be managed and allocated to maintain pool habitats, and native plants and animals associated with the habitats, in watercourses.*
- *7(c) Water is to be managed and allocated to provide flow regimes that favour native plants and animals associated with watercourses and riparian zones.*
- *9 Water in the Barambah Creek and Stuart River catchments is to be managed and allocated to maintain and improve existing riverine habitats that sustain native plants and animals, in the catchments.*
- *10(a) Water in the Boyne River catchment is to be managed and allocated to maintain existing riverine habitats upstream of AMTD 5.0km that sustain native plants and animals, in the catchments.*
- *11(2) Water in the Burnett River is to be managed and allocated to provide for lungfish habitat in the river particularly lungfish habitat downstream of Gayndah at AMTD 200km.*

Assessment end point

Viability of *N. forsteri* populations within the Burnett Basin WRP area.

Measurement end point

Spawning success over the IQQM simulation period.

Eco-hydraulic rules

The flow requirements for *N. forsteri* spawning success can best described as small pulses of flow, with subsequent persistence and stability, in riverine habitat (Table 3). Based upon a synthesis of the information presented, success was assumed to occur when the following conditions were met:

- Low flow–0.3 m rise in stream flow above the cease to flow,
- With low flow persistent for 30 days
- Between August and December

Table 3: Eco-hydraulic rules for *Neoceratodus forsteri*

Critical flow requirement	Small fresh pulse followed by stable low-flow[1,5]
Location	Riverine habitat between impoundments downstream of Gayndah[1]
Flow Class	Low flow[2,3,4]
Magnitude	0.3 m rise in river followed by base-flow[1,]
Timing	August to December [2,3,4]
Duration	30 consecutive days[6]
Frequency	August to December
Habitat Features	Short (0.1 m to 0.5 m) and dense macrophyte beds (>90%) for egg deposition[4] Depth: 0.1m to 0.6 m[1] Velocity: Maximum velocity for egg deposition = 0.5 m/s[4]
Rates of Change	Recession of hydrograph to mimic natural rate and duration. Minimal fluctuations to subsequent baseflow[1]
Water Quality	Dissolved oxygen: > 4 mg/L[1,4] Water temperature: 13 ºC to 25°C[1,4]

References	[1]DERM 2011, [2]Kemp 1984, [3]Brooks 1995, [4]Brooks & Kind 2002,[5]Espinoza et al. unpub., [6]Kemp 1982

Threshold of concern

A threshold of concern (ToC) was defined which represents the consequence of altering spawning and embryonic development opportunities for the local (IQQM node) population persistence (Table 4). A relationship between the annual provision of spawning and embryonic development opportunity with population maintenance was calculated based on population attributes derived from the literature, and through consultation with relevant local experts (Dr Peter Kind). Where these parameters were not available, they were estimated using a four-step interval elicitation procedure (Speirs-Bridge et al. 2010).

The ToC was based on having at least a successful recruitment opportunity every five years to maintain equilibrium in the local population size (i.e. recruitment required to replace annual population mortality). If the number of recruitment opportunities is lower than the ToC, the local population abundance is assumed to decline, representing a potential threat to the persistence of the local population. Although the maximum natural lifespan of the species is expected to be ~50–100 years and the species being sexually mature at ~20 years, this species only lays an average of ~50–100 eggs annually. Based on the size structure of the population, the population appears to have a disproportionally low number of juveniles (Brooks & Kind 2002). Dr Kind suggested that five consecutive years with flows not meeting the ToC will represent a significant threat to the persistence of a local population (i.e. potential local population failure).

Table 4: ToC and node failure threshold for *Neoceratodus forsteri*

Threshold of Concern	Node failure threshold
One recruitment opportunity every five years	5 consecutive years with no recruitment opportunities

Spatial relevance

N. forsteri is widely distributed within the Burnett River (Figure 4), found from Ben Anderson Barrage to upstream of John Golby Weir (around 335 km from the mouth of the river). It is also found in tributaries of the Burnett River such as Three Moon Creek, Boyne River, Barambah Creek and Auburn River. Analysis of the core habitat described by Brooks & Kind (2002) and assessment of flow data required for spawning reduced the number of IQQM nodes suitable for assessment.

Table 5: IQQM nodes that were used to model reproductive opportunities for *Neoceratodus forsteri*

Catchment	Gauging Station(s) / IQQM Node (s)
Burnett	136008A/ 211, 136007A/ 12, 136002D/ 141, 136207A/ 91and 96, 136318A/ 45and 47, 136094A/ 125

3.1.2 *Elseya albagula* (White-throated snapping turtle)

Appearance

Elseya albagula has only recently been isolated as a distinct species within the Northern Snapping Turtle (*Elseya dentate*) (Thomson et al. 2006). It is distinguished from similar species by more prominent irregular white or cream markings most notable on the female's throat and lower sides of the face. It is the largest species of snapping turtle with a carapace (upper shell) length reaching 420 mm. Females are generally largely than males and typical of short necked chelids, mature males are easily distinguished by their much longer tail.

The adult carapace is dark brown to black in colour. It is often heavily stained and has a smooth surface. The carapace may or may not have growth rings and generally lacks lustre (Thomson et al. 2006).

Distribution

E. albagula occurs in the Fitzroy, Burnett, Mary and several other smaller basins of South-East Queensland (Figure 5). Although widespread within these basins, nesting mainly occurs in the upper extent of the barrage ponds (Hollier 2010).

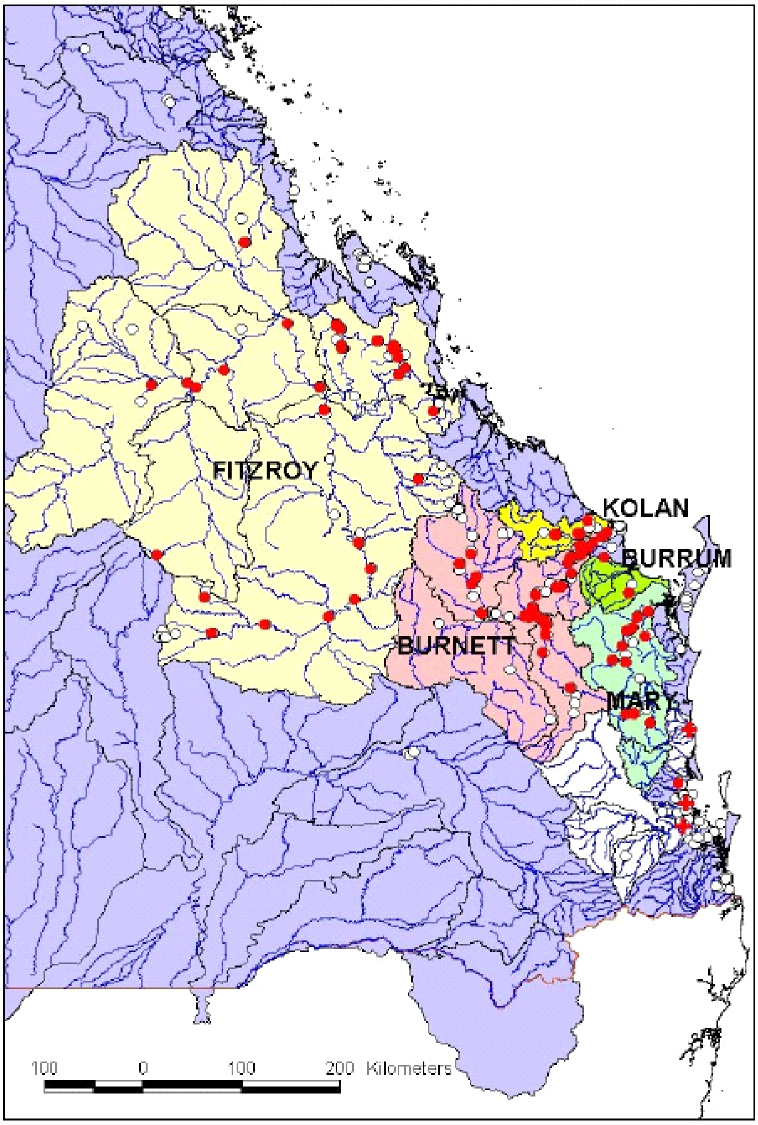

Figure 5: Recorded distribution of *E. albagula* (red dots) in South-East Queensland.

White dots denote sites where no *E. albagula* were found. Red crosses denote sites where *Elseya* sp. was found. (Copied from Figure 4–1, page 43 Hamann et al. 2004).

Habitat

E. albagula prefers flowing waters with a subsurface structure of logs, undercut banks and rocks. They are rarely found in standing waters impounded like dams or weirs, unless these are associated with free-flowing streams. The turtles do not inhabit brackish waters. The turtles migrate from the riverine habitat to the nesting grounds.

While the turtles nests throughout the Burnett Basin (Hamann et al. 2004), 90% of the observed nests have been found within the ponded area of Ben Anderson Barrage (Hollier 2010).

The diet of *E. albagula* consists of predominantly freshwater sponges, filamentous algae, ribbonweed (*Vallisneria nana*) as well parts of overhanging riparian vegetation (Armstrong & Booth 2005). Its diet also includes fallen fruit (e.g. native figs) and occasionally aquatic insects, molluscs and even small cane toads.

Reproduction

E. albagula have an expected lifespan of between 40 and 60 years and sexual mature at around 20 years (Hamann et al. 2004). The turtles breed annually, with most activity occurring between autumn and winter (May and July).

Most females lay one clutch per year (average 14 eggs) digging a shallow nest on the front face and top of steep sloping river banks (Hamann et al. 2004). Nesting sites are selected based on the current standing water levels (Hollier 2010). On average, *E. albagula* nests are located around 5 m from the water's edge and at a height of 3 m above the water level (Hamann et al. 2004). However, studies have found that up to 20% of nests are within 1.3 m of the standing water level at time of nesting (Figure 6) (data from Duncan Limpus, pers comm. 2010 and Hollier 2010), leaving these nests susceptible to inundation (Tucker et al. 1999; Hamann et al. 2004).

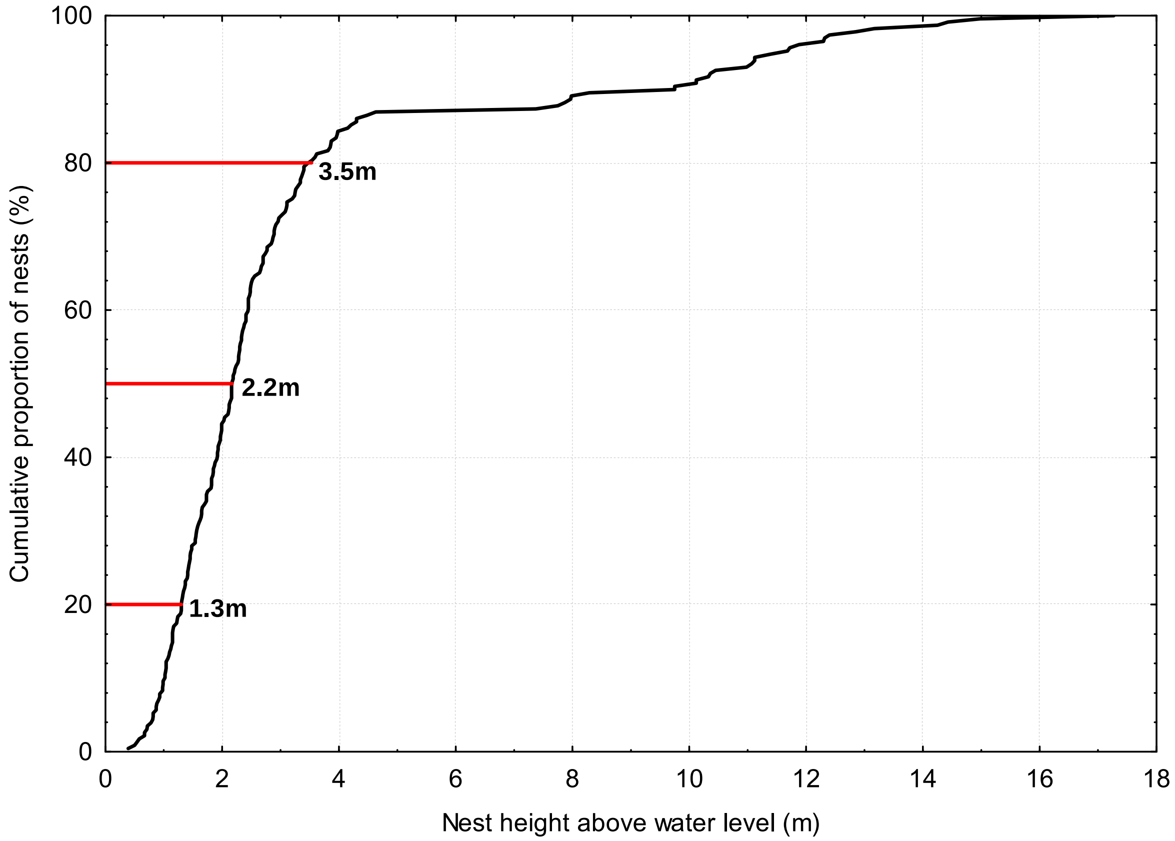

Figure 6: Observed cumulative proportion of *E .albagula* nests inundated with water level rises above the water level at time of nesting (May to July).

This is significant as it is believed that the population could become up to 96% extinct within one and possibly extinct within two turtle generations (Hollier 2010). This is because of other pressure on the population particularly from nest predation by feral cats, foxes, goannas and dingoes. Maximising nesting success is instrumental in maintaining the population while other ongoing land management activities address problems like nest predation. It is recommended that ongoing monitoring of predation pressure effects on nesting success needs to also take into account the influence of nest location in relation to water level. Following an incubation period of around 24 weeks, hatchlings generally emerge between December and January, but may hatch as early as October (Thomson et al. 2006).

Table 6: Life history attributes of *Elseya albagula*

Characteristic	Description (reference for data is Hamann et al. (2004) unless otherwise specified)
Longevity/Lifespan	40–60 years
Age at sexual maturity	20 years
Nesting season	Nests laid mostly between May and July, hatching in December (Duncan Limpus, pers comm. 2010)
Nesting frequency	Annually
Nesting cues	Unknown, but the species nests during the cooler months of the year, potentially to reduce competition for nesting locations with other turtle species.
Fecundity	On average 14 eggs
Time to hatching	September to January, mostly December in the Ben Anderson Barrage (Duncan Limpus, pers comm. 2010)
Egg characteristics	Hard shelled Incubation period of 24 weeks.
Nesting habitat	Sand/loam banks with generally sparse canopy, and little ground cover. Nesting at the top of a sloping bank that is not obstructed at water level (Hollier 2010)

Ecological value it supports

E. albagula is listed as Least Concern in Queensland (*Nature Conservation Act 1992*). This listing is currently under review and is likely to be elevated (Duncan Limpus, pers comm. 2011). Under the Department of Environment and Resource Management "Back on Track species prioritisation framework" it is identified as high priority and is listed as Endangered under the International Union for Conservation of Nature (IUCN).

The species can be associated with the general and specific ecological outcomes of the *Water Resource (Burnett Basin) Plan 2000*:

- *6(e)(iii) Water is to be managed and allocated to provide for community aspirations about protecting species of significant conservation value, including for example, lungfish and turtles.*
- *7(a) Water is to be managed and allocated to maintain pool habitats, and native plants and animals associated with the habitats, in watercourses.*
- *7(c) Water is to be managed and allocated to provide flow regimes that favour native plants and animals associated with watercourses and riparian zones.*

Assessment end point

Viability of *E. albagula* populations within the Burnett River.

Measurement end point

Nest inundation over the IQQM simulation period.

Eco-hydraulic rules

The water related flow requirement for *E. albagula* can be best described as maintaining a stable water level post-nesting. Based upon a synthesis of the information, nesting success (i.e. nesting and hatching) for population persistence was assumed to occur when less than 20% of nests are inundated during incubation which requires the following conditions to be simultaneously met:

- Water level – must have a stable water level (<1.3 m rise)
- Seasonality – water level must be stable between May and July (when nesting occurs) and December

The maximum water level rise (<1.3 m) was based on population attributes derived from the literature, and through consultation with relevant local experts: Dr Col Limpus (Chief Scientist – Aquatic Threatened Species and Threatening Processes) and Duncan Limpus (Senior Technical Officer – Aquatic Threatened Species and Threatening Processes). It is assumed that 80% nest success would be required to account for predation pressure as well as adult mortality caused when they are swept over overtopping weirs upstream, or lost downstream to the saline waters below the barrage.

Table 7: Eco-hydraulic rules for *Elseya albagula*

Critical flow requirement	Stable water levels post-oviposition[1]
flow class	Low flow
magnitude	Rises less than 1.3 m between nesting and hatching Steady baseflow to keep waterholes connected
nesting timing	May to July[1,2]
nesting duration	90 days
incubation timing	July to December
duration	240 days[2,3]
habitat features	Stable water levels to prevent nest inundation while still providing sufficient nesting area[1] Clear access i.e. nesting banks not obstructed by hyacinth or fallen trees[1] Front slope (highly variable from 4° to 67°[2])
rates of change	n/a
water quality	n/a
references	[2]Hollier 2010, [3]Hamann et al. 2004

Threshold of concern

A threshold of concern (ToC) was defined which represents the consequence of altering nesting and hatching success for the local population (IQQM node). A relationship between the provision of nesting and hatching opportunity and population maintenance was estimated based on population attributes derived from the literature, and through consultation with relevant local experts: Dr Col Limpus (Chief Scientist – Aquatic Threatened Species and Threatening Processes) and Duncan Limpus (Senior Technical Officer – Aquatic Threatened Species and Threatening Processes). Where these parameters were not available, they were estimated using a four-step interval elicitation procedure (Speirs-Bridge et al. 2010).

Although they have a very long reproductive lifespan, this species has a small clutch size with an average 14 eggs annually (Hollier 2010). The population of *E. albagula* also appears to be aging. Recent studies have found that approximately 4% of the population are juvenile. Combined with the continuing threat of nest predation, experts suggest that two consecutive years with less than 80% nesting success will represent a significant threat to the persistence of a local population (i.e. potential local population failure). This is a very conservative approach as this species is long-lived, and has a long reproductive period. Additionally, the species has a small clutch size, and other threats have limited the nesting locations as well as caused increased adult mortality. Based on this information, the local experts have suggested this conservative ToC to ensure the long-term viability of the species.

Table 8: ToC and node failure threshold for *E. albagula*

Threshold of Concern	Node failure threshold
80% annual nesting success	2 consecutive years with ≤ 80% nesting success

Spatial relevance

Within the Burnett WRP area, limited specimens have been found in the Kolan River. Burnett River population regarded as a discrete management unit based on genetics (Hamann et al. 2004). Two IQQM nodes were used to model the ToC for *E. albagula.*

Table 9: IQQM nodes that were used to model reproductive opportunities for *Elseya albagula*.

Catchment	Gauging Station(s) / IQQM Node (s)
Burnett	136020A,136005A/ 233, 211

3.2 Ecosystem process–estuarine brackish habitat

Estuarine habitats represent a complex interaction between riverine and marine environments. They provide spatial and temporal variability of abiotic processes that determine biotic distribution (Pierson et al. 2002). While not occurring in isolation, salinity has been identified as one of the main drivers underlying these patterns (Beouf & Payan 2001).

One of the most important saline related estuarine processes is the formation of brackish habitat. Defined when salinity ranges between 5 and 25 parts per thousand (‰), brackish habitat is created by the mixing of estuarine and freshwater flows. The flow regime required to create brackish habitat varies depending on peak discharge, volume, tidal influences and estuarine morphology (Halliday & Robins 2007).

The value of creating brackish habitat is that it is known to facilitate growth and recruitment for species adapted to these conditions. Commercial and recreational fisheries represent a significant industry that relies on the productivity of the estuarine environment. Economically important estuarine fishery species include banana prawns (*Fenneropenaeus merguiensis*), barramundi (*Lates calcarifer*) and sea mullet (*Mugil cephalus*). A number of studies have positively correlated freshwater flow entering estuaries with catch, growth and vigour of these species (Robins et al. 2005; Platten & Sawynok 2008).

The interaction of freshwater and the marine environment also drive the presence of other habitats within the estuary. Mangroves are a unique set of plant species adapted to reproduce and thrive in the highly variable saline environment of an estuary. Many of these mangrove species can tolerate the whole range of estuarine salinities present. For example, the grey mangrove (*Avicennia marina*) can be found right through the whole length of the estuary, whereas the red mangrove (*Rhizophora stylosa*) is generally restricted to the more marine environment near the river mouths behind the seaward fringe (Lear & Turner 1977). In contrast, other species such as the river mangrove (*Aegiceras corniculatum*) have specific habitat requirements and are found wholly within the upper estuary where there is interaction with freshwater (Clarke et al. 2001).

Estuaries also provide ecosystem services such as receiving waters for nutrients. They act as locations where these nutrients are temporarily bound and utilised by mangrove species. This reduces the impact of land disturbance on less nutrient and sediment tolerant ecosystems such as the marine tropical reef systems. They also act as nursery grounds for many marine species and act as a conduit to the riverine and freshwater resources (Pusey et al. 2004).

Therefore, the flow regime that drives the mixing of estuarine and freshwater to form brackish habitat is an ecosystem process that supports the type and stability of the estuarine habitat.

3.2.1 Background

To determine the eco-hydraulic rules that provide brackish habitat in the Burnett Basin WRP area and the corresponding threshold of concerns, an assessment of the relationship between salinity and flow data was conducted. Additionally, real time salinity profiles in the Burnett, Kolan and Elliott Rivers, as well as a reference point - Baffle Creek, were sampled under different flow conditions.

Existing ambient estuarine water quality monitoring data

The department has a near-continuous dataset of monthly ambient estuarine water quality sampling in all of the major estuaries in the Burnett Basin WRP area dating as far back as 1994 (Central Queensland Ambient Estuary Program). This estuarine monitoring is conducted at the same locations and on the same tidal phase. It is used as one of the monitoring techniques to determine the effectiveness of resource operations plan environmental management rules (See Appendix A of the Implementation Review Report).

Near-surface salinity measurements were plotted against discharge to determine the spatial and temporal influence of different sized freshwater flows on the salinity profiles for each estuary in the Burnett Basin WRP area (Figure 49 of Appendix A of the Implementation Review Report). However, the interpretation of these plots need some level of care as salinity was recorded monthly, making it difficult to correlate with a peak discharge. As a result discharges were interpolated from the plots that are believed to have created the recorded salinity conditions (See Table 12 of Appendix A of the Implementation Review Report). For comparison, the relationship between freshwater flows and brackish habitat in the Baffle Creek estuary were also examined. This estuary represents a reference point as this it has no stream barriers and has a near-natural flow regime.

These studies found that flows rarely influenced the salinity levels at the estuary mouth. Looking at sites further up the estuary, the proportion of time that the sites experienced brackish conditions increased. In all estuaries, except the Elliott River and Baffle Creek, tidal barriers have not only reduced the estuarine extent but also impact on tidal variances. In these more regulated systems, near marine conditions where even found to occur up to the tidal barriers during extended periods of no flow.

By viewing the literature on estuarine salinity and the specific tolerances of ecological assets used in the risk assessment, it was decided that a salinity of 15‰ at the midpoint would create a brackish habitat that would support the different ecological functions of the estuary. A salinity level of 15‰ aligns with the requirements of the selected estuarine ecological assets for growth and recruitment. For example, Vance et al. (1990) showed that during the wet season, *F. merguiensis* were found primarily where the salinity was ~15–20 ‰ in the Embley River in the Gulf of Carpentaria. In addition, brackish habitat through half the estuary (upper estuary) provides the preferred habitat to support these vulnerable life stages (see Eco-hydraulic rules sections of each of the estuarine ecological assets in this report). Therefore this point has been identified as a ToC where changes to the period between these events would have a negative impact on the ecological function of the estuary.

Estuarine salinity mapping

Burnett River

The Burnett River estuary was mapped on the 9th September 2009 with no significant rainfall over the previous 13 weeks (www.bom.gov.au). A slight salinity gradient was detected between Burnett Heads and the Ben Anderson Barrage with salinity ranging from ~33‰ at the mouth to ~19‰ at the barrage (Figure 7). Freshwater inputs were detected at Bundaberg Port and AMTD 12km (Kirby's Rd) with salinities dropping to ~21‰ and ~17‰, respectively.

The Burnett estuary was mapped for a second time on the 17th September 2010 following significant releases from Paradise Dam over the previous 2 weeks (www.sunwateronline.com.au). The peak of the discharge was ~8 000 ML/d. A significant salinity gradient was detected between Burnett Heads and the Ben Anderson Barrage with salinity ranging from ~23‰ at the port to ~3‰ at Tallon bridge (AMTD 18.5km) (Note, sampling did not proceed all the way to Ben Anderson Barrage due to weather conditions). Freshwater signatures were again detected at Bundaberg Port and AMTD 12 km (Kirby's Rd). This mapping also found the estuary volume to be ~ 27 000 ML.

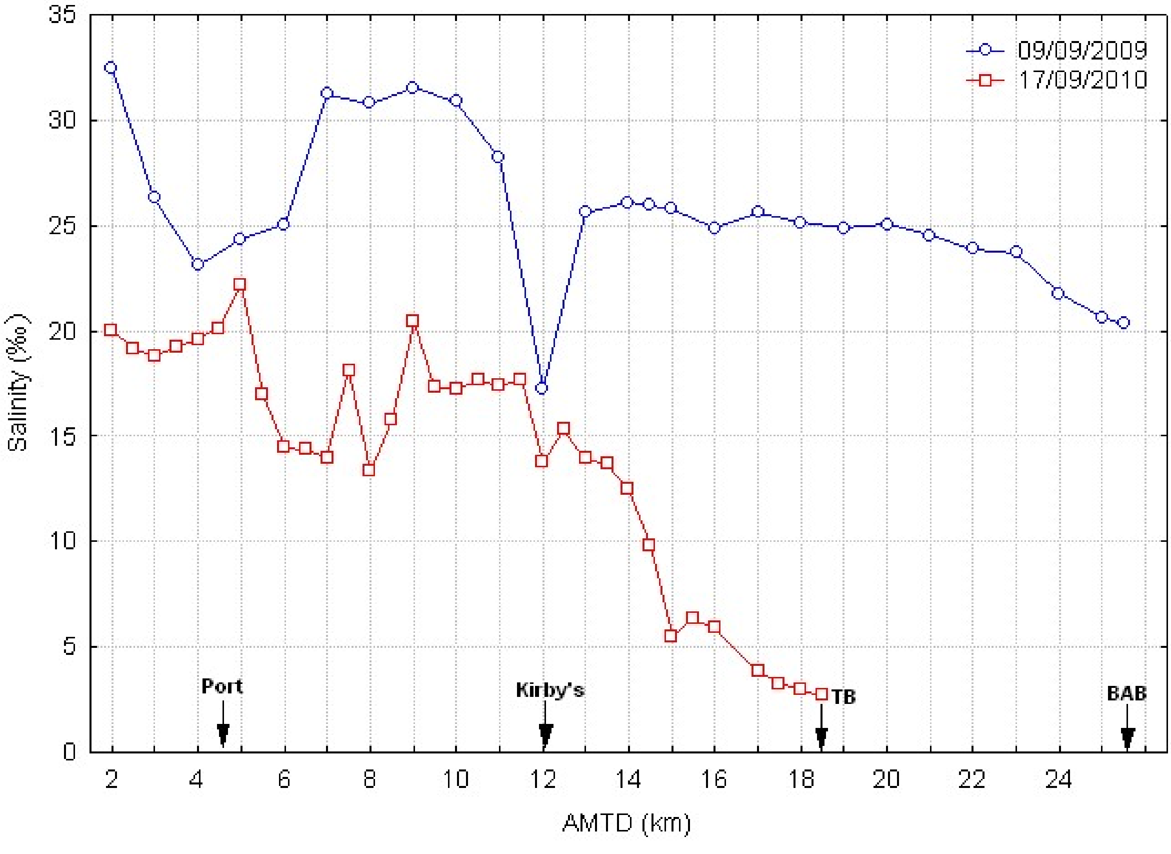

Figure 7: Comparative salinity gradients for the Burnett River estuary under flow (17/09/10) and no-flow (09/09/09) scenarios.

Port = Bundaberg port, Kirby's = Kirby's rd, TB = Tallon bridge and BAB = Ben Anderson Barrage.

Kolan River

The Kolan River estuary was mapped on the 3rd September 2009 with no significant rainfall over the previous 13 weeks (www.bom.gov.au). A slight salinity gradient was detected between Miara (AMTD 2km) and the Kolan Barrage tailwater (AMTD 14.5 km) with salinity ranging from ~33‰ at the mouth to ~19‰ at the barrage (Figure 8). No significant freshwater inputs were detected.

The Kolan River estuary was mapped a second time on the 6th April 2010 following significant flow overtopping, and released from, Bucca Weir over the previous 2 weeks (www.sunwateronline.com.au). These flows were initially overtopping events, followed by releases as per the medium to high flow strategy of the Water Resource Plan for Bucca Weir (~380 ML/d).

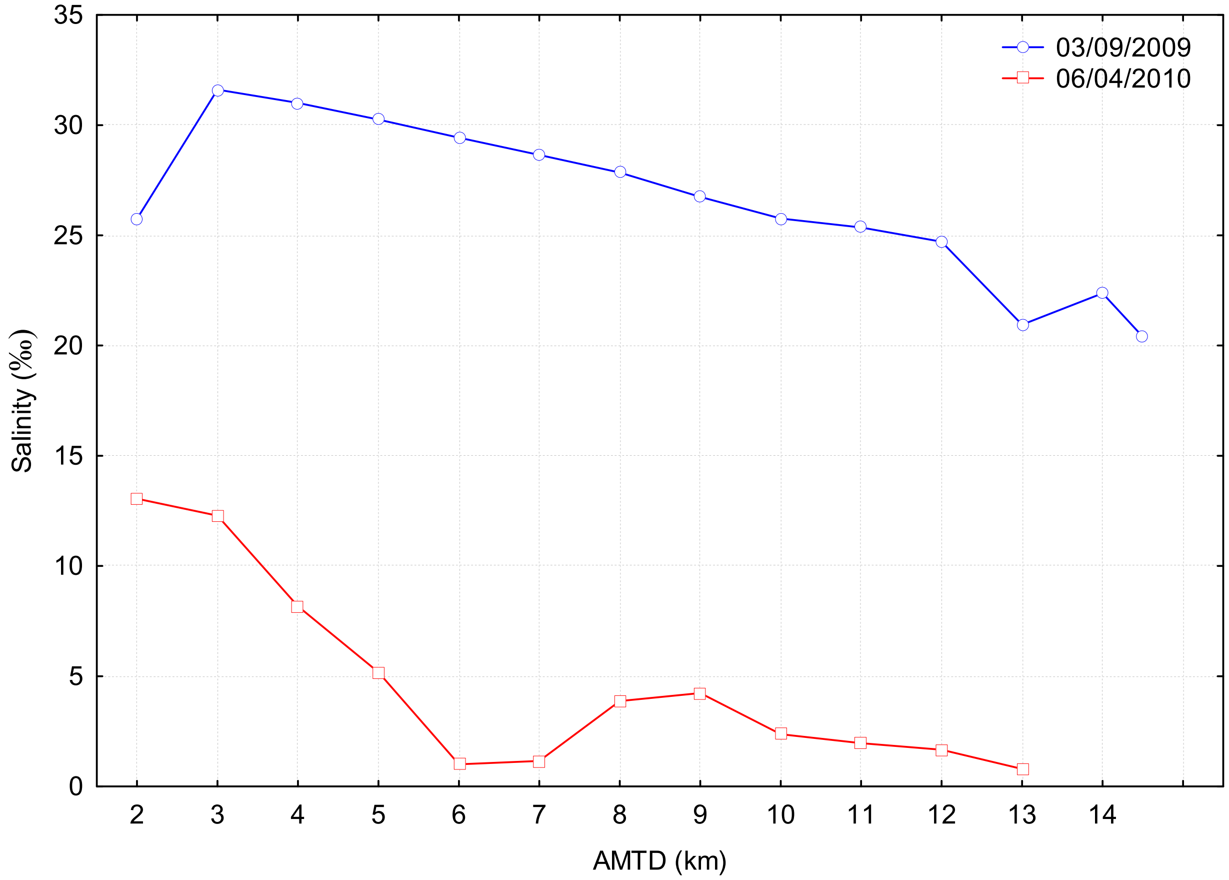

Figure 8: Comparative salinity gradients for the Kolan River estuary under no-flow conditions (03/09/2009) and flow conditions (06/04/2010).

The peak of the last flow was ~25 000 ML/d, with this peak occurring a month before sampling. A salinity gradient was detected between Miara (AMTD 2km) and downstream of Kolan Barrage (AMTD 14.5 km) with salinity ranging from ~13‰ to ~1‰, respectively. Previous natural freshwater flows made obvious impacts to brackish habitat throughout the estuary with subsequent releases enabling persistence of this habitat.

Elliott River

The Elliott River estuary was mapped on the 7th September 2009 with no significant rainfall over the previous 13 weeks (www.bom.gov.au). A more prominent salinity gradient was detected between Elliott Heads and AMTD 8 km with salinities ranging from ~32‰ at the mouth to ~11.5‰ upstream (Figure 9). No significant freshwater inputs were detected in the lower estuary. Low salinities in the upper estuary indicate the importance of groundwater for providing freshwater baseflow to the upper estuary.

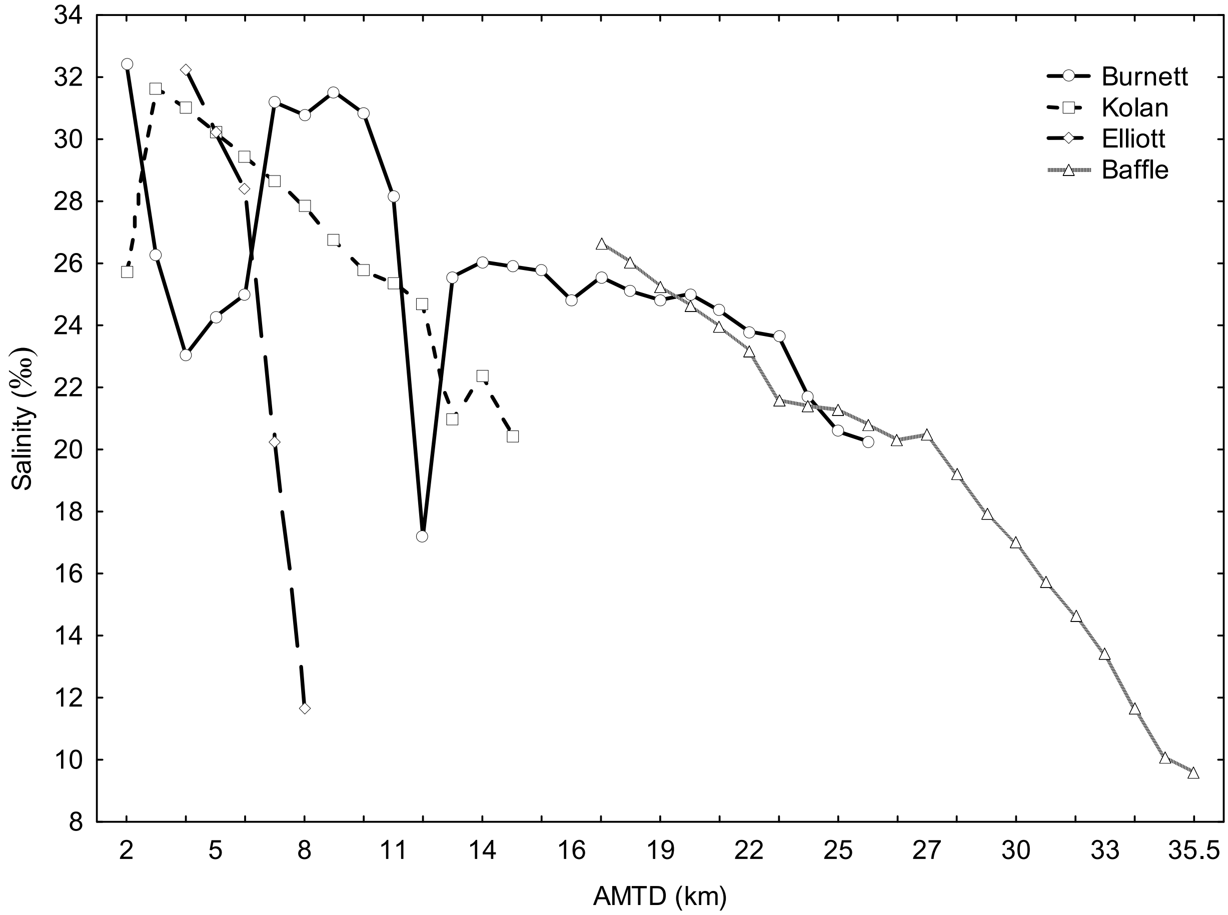

Figure 9: Comparison of the salinity profile during no-flow conditions in estuaries within the Burnett WRP plan area

Summary of discharges to provide estuarine brackish conditions in Burnett WRP estuaries

Based on the assessment of the long-term monthly salinity data, discharge data and estuarine salinity mapping, discharges that were found to produce brackish conditions (15‰) for 50% of the estuarine length were estimated (Table 10). The recurrence interval of flows of this magnitude approximated flows that occurred on average four times a year in the predevelopment IQQM time series. In the smaller estuaries (Elliott, Isis and Gregory), the discharges required to provide brackish habitat were of a magnitude smaller (~150 to 200 ML/d) and equated roughly to a similar recurrence interval of four to six times per year on average. Although these estuaries have different geomorphology (shape of estuary, depths and slopes etc.) the rainfall patterns are similar across basins and hence it is not unusual to have responses to flows of a similar recurrence within the regional area (Castro & Jackson 2001; Sweet & Geratz 2003). These discharge volumes are to be used as the thresholds of concern (ToC) for all estuarine brackish habitat ecological assets.

Table 10: Peak discharge volumes required to provide brackish habitat (15‰) up to their respective mid-points.

Estuary	**Current estuarine extent (km)**	**Volume for brackish flow event (ML/d)**
Burnett	25.9	~10,000
Kolan	14.7	~5,000
Elliott	10	~150
Gregory	14	~200
Isis	12	~200

Eco-hydraulic rules for estuarine brackish habitat

Eco-hydraulic rules for estuarine brackish habitat encompass a synthesis of the requirements of the estuarine ecological assets (Table 11). The main feature of the rules is that it should be targeted for spring and summer. This is an important time of year for breeding, migration and recruitment for all the species observed. In addition, the upper estuary is where the water quality requirements exist for the key phases of each of the ecological asset and hence the focus is on providing brackish conditions for this part of the estuary. As the absolute value of salinity required for each ecological asset varied slightly, 15‰ was selected as it most closely represented the salinity requirements of all the species.

Table 11: Eco-hydraulic rules for estuarine brackish habitat

Critical flow requirements	Freshwater flows for creation of estuarine brackish habitat
location	Upper estuarine areas in all estuaries in the Burnett Basin WRP area
flow class	Med to High – sufficient to produce brackish conditions (50% seawater~15‰) for 50% length of the estuary
magnitude	Variable– sufficient to produce brackish conditions (50% seawater) for 50% length of the estuary for fruiting and germination
timing	September to March
duration	Pre-development flows of this magnitude vary from 8 days to months in duration.
frequency	Generally these events occur every year, with the average recurrence being approximately four to six times per year throughout the whole year.
habitat features	Creation of brackish habitat throughout the upper estuary
rates of change	Mimic natural as much as possible. Post-flood baseflows maintain brackish conditions in the estuary for extended periods. Predevelopment flows of this magnitude vary from 8 days to months in duration.
water quality	50% seawater or 15‰ salinity, and 22–30°C

3.2.2 Estuarine brackish habitat–*Lates calcarifer* (Barramundi) brackish habitat and Year Class Strength (YCS)

The assessment of risk to *L. calcarifer* uses two approaches. The first assesses the provision of freshwater flow during spring/summer to provide for downstream migration of adult males and the subsequent water quality cues for movement larval fish to suitable habitat in upstream mangrove creek systems. The second approach utilises an established process to assess the relationship between summer flow and the relative Year Class Strength (YCS). The former relates specific discharges to the provision of upper estuarine brackish habitat, whereas the latter relates overall summer flow changes to YCS based on research from the Fitzroy Basin (Robins & Halliday 2007).

Appearance

L. calcarifer is a euryhaline, catadromous centropomid that can reach a size of 150 cm and 55 kg (Grant 1997). The body is elongate and the mouth is large, slightly oblique and extending beyond the eye (Pusey et al. 2004). Body morphology changes with size, the dorsal hump above the head becomes more pronounced in larger individuals and body depth increases relative to length (Pusey et al. 2004). Adults are generally silver in colour, greenish or bluish-grey dorsally, with dusky brown to blackish fins (Allen et al. 2002). Very small juveniles may have pronounced vertical bars on the body whereas older juveniles are mottled brown with three white stripes on head and nape (Pusey et al. 2004).

Distribution

Widely distributed throughout the Indo-West pacific, including eastern Arabian Gulf, China, Taiwan, Japan, Papua New Guinea and northern Australia. Within Australia, *L. calcarifer* are widely distributed across northern Australia from Shark Bay in Western Australia to the Mary River in Queensland, occupying the majority of drainages within its range, although more common in larger rivers with well-developed flood plains (Pusey et al. 2004). *L. calcarifer* has been recorded from all coastal catchments within the Burnett Basin plan area.

Habitat

The microhabitat of *L .calcarifer* is composed of a critical chain of habitats used at different phases of the life cycle as shown below in Table 12.

Table 12: Microhabitat requirements of *L. calcarifer* based on different phases of the life cycle

Life cycle stage	Habitat requirements
mature fish	Post-1st spawning migration the male fish remain in estuarine reaches, along with mature females. They do not return upstream but subsequently spawn early in the wet season (resident in spawning grounds) (Pusey et al. 2004). Salinity – max 50‰. Tolerate sea water and hypersaline conditions, though duration of tolerance of elevated salinities unknown. Temperature – min 15.5ºC, max 35ºC (24ºC – 30ºC optimal). DO – 1.1 to 6.8 mg/L; susceptible to hypoxia. pH – 4.0 to 9.12 (Pusey et al. 2004).
larvae	25‰ for maximum larval survival, 30‰ for optimal hatching success (from hatcheries), pH 7.4 to 7.6, DO 6.5 to 7.6 mg/L. (Pusey et al. 2004). Metamorphosis is complete at 20–50 mm, although visual feeding commences at 10 mm (7+ days). Larvae typically hatch in estuarine and near-shore habitats and are passively dispersed into supralittoral (above the region or zone between the limits of high and low tides) swamps near river mouths – spawning timing with tides aids this dispersal (Pusey et al. 2004). Post larvae move upstream either into freshwater lagoons adjacent to the main river, upper tidal creeks or eventually into the freshwater reaches (Russell and Garrett 1983). Larvae observed entering adjacent nursery swamps a few days after hatching (Moore 1982). Survival of larvae is optimal at salinities of between 20 000 and 25 000 mg/L (Russell & Garrett 1985). Water temperatures between 27–28ºC are optimal for larval survival (Pusey et al. 2004). Russell and Garrett (1985) found larval *L. calcarifer* in surface water temperatures from 26.5 – 32.0 ºC.
juveniles	Access to flood-plain habitats is dependent on the flooding regime and impacted by in-stream barriers to fish movement. Juveniles remain in upstream habitats for 3–5 yrs (~600 mm) with a movement range of ~15 km (Pusey et al. 2004). Large numbers of juveniles were only found in semipermanent coastal swamps, tidal creeks and the freshwater reaches of rivers (Russell & Grant 1985). Juveniles appeared first in the swamp habitats in Feb and later appeared in the tidal creeks (around April) (Russell & Grant 1985).

Reproduction

Life history data for *L .calcarifer* is shown in Table 13.

Table 13: Life history attributes of *Lates calcarifer*

Characteristic	Description
Longevity/lifespan	Generally 9–14 years but up to 32 and possibly longer (Pusey et al. 2004; Staunton-Smith et al. 2004).
Age at sexual maturity	Minimum ages at maturity are 36 months (males) and 72 months (females). Males mature at ~3 yrs (600 - 720mm), with strong regional variation. Transition from male to female (inversion) occurs after spawning (December - January) at ~800 mm length (~5 – 6 yrs). By 1000 mm almost all fish will be female. Some fish are born female (primary females) and age at maturation is unknown (Pusey et al. 2004).
Spawning season	Timing is variable, from October to February in eastern Queensland, Oct - Dec in Northern Territory and Oct - Jan in the Gulf and Papua New Guinea. Spawning is thought to precede the wet season and onset of the monsoon (Pusey et al. 2004. Gonadal activity was highest between October and February (Russell & Grant 1985). There is a single annual spawning period in West Papua, with the average gonadosomatic index increasing markedly from September, peaking in November-January and declining sharply after January (Moore 1982). Spawning commences in October (Moore 1982).
Spawning frequency	Annual spawners, with argument over whether spawning is discrete or serial (Pusey et al. 2004). Some females probably shed all of their eggs at once, others only a portion so that further development results in subsequent spawning (Moore 1982). Small females of about 4 kg spawn all of their eggs at once, whereas the larger fish spawn only a portion and thus exhibit multiple spawning (Barlow in Moore 1982, Wongsomnuk in Moore 1982).
Spawning cues	Spawn at night, possibly in response to a combination of salinity, high water temperatures, high tides and the new or full moon (Pusey et al. 2004). In ponds, salt water is added to simulate the rising tide so that spawning will occur (not sure whether this response is to a rising tide, an increased water level or increased salinity) (Moore 1982). Spawners can be taken only during spring tides in the spawning season (Barlow in Moore 1982). Spawning normally occurs after the initial rains when the previously arid nursery swamps contain a few centimetres of water that has a very strong odour from decomposing vegetation. Wetting of this organic material could act as a stimulus to adult fish to spawn (Moore 1982).
Fecundity	Extremely fecund (10 million+ eggs for 1000 mm+ females). Fecundity varies from 2.3×10^6 to 32.2×10^6 within the weight range 7.7 – 20.8 kg (Moore 1982).
Spawning migration	Young males make a downstream migration prior to spawning commencing in August or September (in the Northern Territory), which coincides with a period of increased photoperiod and water temperature. Cues for this migration remain speculative. A fall in water level may trigger this migration in New Guinean stocks, whereas a rise in water levels may be the cue for movement downstream in Australian stocks (Pusey et al. 2004). In New Guinea, females also move upstream into inland waters and migrate to the sea for spawning (Moore 1982). Peak movement of adults to the coast in New Guinea occurs during spring tides (Moore 1982). Catadromous, with inland tagged fish being recaptured in coastal regions during the spawning season, and those tagged in coastal waters recaptured in inland areas during the non-spawning season (Moore 1982).
Critical physical/chemical attributes required at breeding site	Spawn in saline waters (cannot breed in freshwater) in the vicinity of river and creek mouths in areas protected from strong tides (by sand bars etc.) but within the path of lateral currents that transport eggs and larvae into supralittoral swamps (Pusey et al. 2004). Moore (1982) suggested that there was a single major spawning site for *L. calcarifer* in near shore coastal waters of the Gulf of Papua, with only smaller spawning grounds in the estuaries. However, there is no evidence to suggest that this is the case in Australian waters (Russell & Garrett 1985). Moore (1982) suggested a close relationship between known spawning grounds and high salinity, with high discharge (8,000 cumecs) precluding local spawning and necessitating migration to more suitable areas. Survival of larvae is optimal at salinities of between 20 000 and 25 000 mg/L (Russell & Garrett 1985).

Time to hatching	18 hours but may be as short as 12 hours; temperature dependent (Pusey et al. 2004.) Aquaculture reports suggest 17 hours at 28°C (Mackinnon unpubl.).
Egg characteristics	Temperature dependent hatching (17–18hrs @ 25ºC) within 12 or more hours (Pusey et al. 2004). Pelagic eggs are kept in suspension by slight currents (Pusey et al. 2004). Eggs are 0.7 – 0.8 mm in diameter, with a single oil globule 0.3 mm in diameter and a small or non-existent perivitelline space (Moore 1982). Eggs for fertilization should be round, non-adhesive and float well in seawater of 28 – 31 ‰ (Wongsomnuk in Moore 1982). Eggs become demersal when 'overripe'.
Duration of larval development	7 – 20 days (Pusey et al. 2004). Larvae develop into juveniles at between 4.5–8.4 mm total length (Moore 1982). Moore (1982) provides a detailed description of developmental stages.
Other relevant information	Gonad development does not normally proceed beyond stage 3 or 4 in inland habitats with ripe fish only being found in coastal waters (Moore 1982). The position of the spawning grounds will probably differ slightly from year to year depending on coastal salinities, which vary with the degree of discharge from the major rivers (Moore 1982). *L. calcarifer* are protandrous hermaphrodites changing sex to female at 6 – 7 years of age (85 – 90 cm total length (Moore 1982). The overall sex ratio is 3.8: 1 in favour of males (Moore 1979), with the possibility that some males do not undergo the change to female. Likely to be a rapid transition phase from male to female (Moore 1979) with females not detected in the population until they reached 73 cm total length (5 years approx). By 105 cm total length, females constitute 91.2% of the population and the size range 117 – 130 cm is exclusively female (Moore 1979). There is also thought to be a small percentage of 'primary' females developing directly from immature fish (Moore 1979). Freshwater triggers spawning of mature fish at the mouth of the estuary (although unlikely as high salinity water is required for the survival of *L. calcarifer* eggs). Affects the distribution of eggs and larvae; large flows may wash eggs and larvae away from the estuarine water (i.e. a negative effect). Creates chemical signals that cue larvae to enter the estuary. Connects the estuary and ephemeral supra-littoral nursery habitats (e.g. floodplains and coastal swamps); post-larval and small juveniles use these connections to enter these temporary nursery habits, which allow faster growth and better survival (i.e. enhances the available nursery areas). Connects the estuary and perennial freshwater habitats; large juveniles use the connections to move into freshwater habitats, which allow good growth and survival. Stimulates mature *L. calcarifer* to move downstream in preparation for seasonal spawning, although the stimulus is unknown. Potentially it could be changes in salinity for estuary-based individual or flow rates for freshwater-based individuals. Connects perennial freshwater habitats (including the overflow of impoundments) and the estuary, enabling mature individuals to move downstream and participate in seasonal spawning and enlarging the fished stock size. Enhances biological productivity of the estuary, thereby increasing the availability of food for juveniles, adolescents and adults resident in the estuary, which potentially results in improved growth, survival and 'condition' of the estuarine population (e.g. fat barramundi syndrome, leading to faster age-at-maturity or greater reproductive output for a season). *L. calcarifer* are catadromous (migrating from freshwater to saltwater to spawn), protandrous hermaphrodites (beginning life as males and changing into females soon after spawning) (Pusey et al. 2004). *L. calcarifer* are long lived species; their longevity is commonly 14–20 years (Pusey et al. 2004), with records of fish living up to 32 years (Staunton-Smith et al. 2004). *L. calcarifer* can grow to 150 cm in length and weigh up to 55 kg (Grant 1997). Despite the fact that numerous aspects of *L. calcarifer* life history appear to be highly responsive to freshwater flows there have been few studies worldwide that have aimed to quantify these relationships (Halliday & Robins 2007).

Ecological value it supports

L. calcarifer is one of the target species of valuable commercial and recreational fisheries in Queensland, as well as being important to indigenous communities (Pusey et al. 2004). The species is popularly regarded as one of Australia's premium recreational sport and food fishes (Grant 1997) with estimate revenue of $8 – $15 million p.a. in Queensland (Pusey et al. 2004). While *L. calcarifer* are non-threatened, there is the potential to be impacted as a result of human activities (Pusey et al. 2004). The maintenance of a viable *L. calcarifer* population and fishery directly links to the several of the environmental and social values as identified through the community consultation process.

The species can be associated with the general ecological outcomes of the *Water Resource (Burnett Basin) Plan 2000*:

- *7(d) Water is to be managed and allocated to provide wet season flow to benefit native plants and animals, including for example, fish and prawns, in estuaries.*
- *11(1) Water in the Burnett River basin is to be managed and allocated to, if practicable, minimise the frequency and duration of marine conditions in the estuary of the Burnett River.*
- *12(b)(ii) Water in the Elliott, Gregory and Isis River basins is to be managed and allocated to maintain existing estuarine habitats, particularly in fish habitat areas, that are dependent on estuarine processes.*
- *13(b)(ii) Water in the Kolan River basin is to be managed and allocated to maintain and improve existing estuarine habitats, particularly in fish habitat areas, that are dependent on estuarine processes.*

Assessment endpoint

For estuarine brackish habitat provision for *L. calcarifer*: Provision of brackish habitat for *L. calcarifer* within each coastal catchment in the Burnett Basin plan area.

For YCS: Annual catches indicating a sustainable *L. calcarifer* fishery in the Burnett Water Resource Plan area

Measurement endpoint

For *L .calcarifer* estuarine brackish habitat: Annual brackish habitat provision represented by the presence of 15‰ habitat for 50% of the length of each estuary over the IQQM simulation period.

For YCS: Annual *L. calcarifer* recruitment, represented by an index of Year Class Strength (YCS)

Eco-hydraulic rules

Relationship between estuarine brackish habitat for L. calcarifer and freshwater flow

There are several interacting factors driven by freshwater flows which contribute to improved population growth including migratory stimulus, connectivity, sediment/nutrient delivery, increased estuarine productivity and reduced osmoregulatory stress (Boeuf & Payan 2001; Halliday & Robins 2007). Recent hatchery studies have shown that brackish salinities improve larval and juvenile growth (Partridge & Lymbery 2008; Partridge et al. 2008). In the Burnett River, the higher discharges providing the brackish habitat also provide cues for migration of mature male fish (those 3 years and older) to migrate down from freshwater reaches, as well as providing low salinity water which provides increased food supply (Pusey et al. 2004), and reduced osmoregulatory stress (Boeuf & Payan 2001; Halliday & Robins 2007). The brackish habitat provided (50% estuary length) provides access for juveniles to freshwater reaches of major creeks in the upper estuaries in the plan area.

Relationship between L. calcarifer Year Class Strength (YCS) and freshwater flow

The *L. calcarifer* YCS model is based on the relationship between *L. calcarifer* age structure of commercially-caught individuals and summer flows. Based on these observations, Halliday & Robins (2007) developed the following linear relationship:

YCS = 0.7227 (Log$_{10}$ summer flow ML (Dec to Feb)) – 4.1011

Model outputs are derived as a yearly time series of YCS index for each development scenario.

Threshold of concern

Estuarine brackish habitat for L. calcarifer

A high risk profile (i.e. potential local population failure) is defined as a period where the number of consecutive years without estuarine brackish habitat exceeded a conservative longevity estimate for *L. calcarifer* of 11 years (based on a range of 9–14 years) (Table 13). A moderate risk profile is defined as a period where the number of consecutive years without estuarine brackish habitat was between the age of maturity for male fish which migrate downstream (3 years) (Pusey et al. 2004). All other years are deemed as being low risk to *L .calcarifer* populations. The overall risk from water resource development is considered as a relative change in risk profile (i.e. relative proportion of each risk category) between the pre-development scenario and any development scenarios.

L. calcarifer YCS

Using the YCS and population maintenance thresholds, strong recruitment years were identified (Halliday et al. 2007a) when annual YCS exceeded the median YCS under the modelled pre-development flow sequence.

Strong recruitment years are considered essential to maintain healthy *L. calcarifer* populations; the greater the number of years between these events, the higher potential risk to *L. calcarifer* populations (Cockayne et al. 2009). A high risk profile (i.e. potential local population failure) is defined as a period where the number of consecutive years without strong recruitment exceeded the conservative longevity estimate for *L. calcarifer* - 11 years (Table 13)). A moderate risk profile is defined as a period where the number of consecutive years without strong recruitment was between the average age of protandry (5 years) (Pusey et al. 2004, W.Sawynok pers. comm.). All other years are deemed as being low risk to *L. calcarifer* populations. The overall risk was considered as a relative change in the profile (i.e. relative proportion of each risk category) between the pre-development scenario and any development scenarios.

Table 14: ToC and node failure threshold for *Lates calcarifer*

Risk assessment endpoint	Threshold of Concern	Node failure threshold
Brackish estuarine habitat	Presence of 15‰ habitat for 50% of the length of each estuary between September - March	Medium risk: 3 to 10 consecutive years with brackish habitat< than the ToC High risk: ≥11 consecutive years with threshold< than the ToC
YCS	Annual YCS < median predevelopment YCS	Medium risk: 5 to 10 consecutive years with brackish habitat< than the ToC High risk: ≥11 consecutive years with YCS< than the ToC

Spatial relevance

L. calcarifer is present in all of the coastal catchments of the Burnett Water Resource Plan area. It is a freshwater/estuarine/marine asset, which is modelled in relation to the estuarine, end-of-system IQQM nodes.

Table 15: IQQM nodes that were used to model risk to *Lates calcarifer*

Catchment	Gauging Station(s) / IQQM Node (s)
Burnett	244
Kolan	293
Gregory	50
Elliott	137003A/ 003
Isis	21

3.2.3 Estuarine brackish habitat–*Fenneropenaeus merguiensis* (Banana prawn) growth

Appearance

Fenneropenaeus merguiensis is a short-lived marine and estuarine prawn species. It displays the following morphological characteristics: rostrum with high blade and teeth above and below, gastro-orbital ridge absent or very feebly defined. Body often yellow or translucent with no banding on body or antennae and speckled with reddish brown dots (Farfante & Kensley 1997).

Distribution

F. merguiensis is widely distributed throughout the Indo-West Pacific region. The species ranges from the Persian Gulf and Pakistan through the Malay Archipelago and South China Sea to Australia, where it is found from Western Australia around to the coast of northern New South Wales (Grey et al. 1983).

Habitat

F. merguiensis is an estuarine and costal species with adults occurring in waters up to 20 km from the coast and up to 45 m water depth (Halliday & Robins 2007; Grey et al. 1983). Mangrove lined creeks are the preferred habitat of post-larvae and juveniles where recruitment and growth occur.

Vance et al. (1990) showed that during the wet season, *F. merguiensis* were found primarily where the salinity was ~15–20 ‰ in the Embley River in the Gulf of Carpentaria. This compared well to previous work done by Staples (1980) that showed that catches before and after the wet season peaked at a distance of 48 to 72 km upstream from the mouth. Vance et al. (1990) observed that "from October through to March is therefore a critical period in the estuary for the production of adult banana prawns". As *F. merguiensis* spawn in spring, it is thought that this critical period extends therefore from September (Halliday & Robins 2007).

The nauplia, protozoel, and mysis stages have the highest survival in salinity of 30–35 ‰ showing that these early development stages are suited to the marine conditions of the spawning locations (offshore) (Halliday & Robins 2007). In contrast, post-larval stages have been found to grow and survive best at 20ºC and 20 ‰, however in terms of increase in biomass, this is thought to occur best at 28ºC and 25 ‰ (Staples & Heales 1991). These post-larvae are thought to feed primarily on epiphytic algae and plankton benefited by nutrient caused by freshwater flows (Halliday & Robins 2007).

Reproduction

Freshwater flow stimulates downstream movement of juvenile and sub-adult *F. merguiensis* to offshore areas, potentially increasing their catchability by the otter-trawl fishery. The stimulus is possibly salinity changes, although flushing may occur at high flow rates.

Large flood flows may reduce or delay larval immigration to estuarine habitats either by washing larvae away from the estuary or dilution of chemical cues (Staples & Vance 1985). Large freshwater flows affects the survival of newly settled post-larvae in estuarine habitats, with freshwater being unsuitable habitat for post-larvae. Additionally, this affects the area of favourable habitat for juveniles and adolescents, potentially through larger areas of decreased salinity, the creation of a salinity gradient between 5–30 ‰ or turbid conditions reducing predation, which increases the survival of juveniles and adolescents.

Freshwater flow enhances productivity of the estuary and increases the area of suitable salinity, thereby increasing the availability of food for post-larvae, juveniles and adolescents which results in improved growth, survival and condition of the *F. merguiensis* population, potentially leading to larger biomass and better reproduction. *F. merguiensis* have a one year life-cycle (Halliday & Robins 2007), with a maximum longevity of 18 months (Kailola et al. 1993).

Ecological value it supports

F. merguiensis is a significant target species in the otter and beam commercial trawl fisheries of Queensland. It is also a significant recreational species, with catches representing about a quarter of the commercial catch or ~200 tonnes annually (DEEDI 2011).

The species can be associated with the general and specific ecological outcomes of the *Water Resource (Burnett Basin) Plan 2000*:

- *7(d) Water is to be managed and allocated to provide wet season flow to benefit native plants and animals, including for example, fish and prawns, in estuaries.*
- *11(1) Water in the Burnett River basin is to be managed and allocated to, if practicable, minimise the frequency and duration of marine conditions in the estuary of the Burnett River.*
- *12(b)(ii) Water in the Elliott, Gregory and Isis River basins is to be managed and allocated to maintain existing estuarine habitats, particularly in fish habitat areas, that are dependent on estuarine processes.*
- *13(b)(ii) Water in the Kolan River basin is to be managed and allocated to maintain and improve existing estuarine habitats, particularly in fish habitat areas, that are dependent on estuarine processes.*

Assessment endpoint

Estuarine brackish habitat provision for *F. merguiensis*: Provision of brackish habitat for *F. merguiensis* within each coastal catchment in the Burnett Basin plan area.

F. merguiensis growth: Annual catch indicating a sustainable *F .merguiensis* fishery in the Burnett Water Resource Plan area

Measurement endpoint

F. merguiensis estuarine brackish habitat: Annual brackish habitat provision represented by the presence of 15‰ habitat for 50% of the length of each estuary over the IQQM simulation period.

F. merguiensis growth: Daily prawn growth (mm) based on the preceding 6 weeks flow and temperature conditions.

Eco-hydraulic rules

Relationship between estuarine brackish habitat for F. merguiensis *and freshwater flow*

Estuarine brackish habitat provides the conditions for high post larval *F. merguiensis* survival and growth. Freshwater flows provide the salinity (15–20 ‰) (Staples & Heales 1991) and the brackish habitat extent (50% of the length of the estuary) (Staples 1980). The eco-hydraulic rules established for estuarine brackish habitat were used for *F. merguiensis*.

Relationship between F. merguiensis *growth and freshwater flow*

Freshwater flows in estuarine streams and rivers are required for *F. merguiensis* recruitment and growth. Research suggests that both prawn growth rate and commercial catch increase with increasing flow (Robins et al. 2005). A model describing the flow requirements for *F. merguiensis* growth was developed following four years of fortnightly sampling between October and May, in the Fitzroy River estuary with the aim of determining the relationship between freshwater flows and prawn growth rate. The model developed by Halliday & Robins (2007) was previously utilised for the Fitzroy WRP ecological risk assessment (Cockayne et al. 2009).

The model was successfully applied in the Fitzroy and therefore it has also been chosen as a suitable model for use in the Burnett WRP environmental assessment where *F. merguiensis* are an important commercial species. The model was adjusted using gauged water temperature data from the Burnett River and utilising estuarine/end of system nodes where available to quantify total freshwater inflow to estuaries.

Banana prawn growth is estimated using a nonlinear von Bertalanffy equation:

Length2 = Length1 + (L∞ - Length1) * [1 – exp (- {a + kc * temp + kd * temp2 + ke * flow0 + kf * flow02 + kg * flow4 } * Days + b)]

with the following constants:

Days	Length1	L∞	a	b	kc	kd	ke	kf	kg
42	5	38	-0.0344	-0.0249	0.00297	-0.0000604	9.32E-08	-5.79E-13	5.57E-08

Flow0 is the total inflow to the estuary for the preceding two weeks and Flow4 is the total inflow during the four weeks prior to that, to account for a possible lag between the time of a flow event and the response in prawn growth. The term, flow, relates to flow at the start of the growth period. The terms, temp and temp2 refer to the temperature of the water at the start and finish of the growth period of the model.

Average daily growth is then calculated as: (Length2 – Length1)/42

Model outputs are expressed as daily prawn growth (mm) based on the preceding 6 weeks flow and temperature conditions which will be used to assess the relationship between freshwater flows and prawn growth rate. The likelihood of water resource development potentially affecting *F. merguiensis* growth is assessed for each season and on a yearly basis a proportional change between water resource development scenarios.

Threshold of concern

Estuarine brackish habitat for F. merguiensis

Access to brackish habitat is considered essential to maintain healthy *F. merguiensis* populations as these conditions provide the areas with highest growth and provide conditions to reduce predation on juvenile prawns. The greater the number of years between these conditions, the higher potential risk to *F. merguiensis* populations. A high risk profile (i.e. potential local population failure) is defined as a period where the number of consecutive years without provision of brackish conditions exceeded the longevity of the *F. merguiensis* (18 months ~2 years). A moderate risk profile is defined as a period where there was a single year without provision of brackish conditions, which equates to the lifecycle of the species (1 year). All other years were deemed as being low risk to *F. merguiensis* populations. The overall risk is considered as a relative change in risk profile (i.e. relative proportion of each risk category) between the pre-development scenario and any development scenarios (Cockayne et al. 2009). To satisfy the criteria, the threshold must be exceeded between the months of September and March inclusive.

Growth of F. merguiensis

Following the approach of Cockayne et al. (2009), a ToC has not been applied to *F. merguiensis* growth for this assessment. The likelihood of water resource development potentially affecting *F. merguiensis* growth is assessed for each season and on a yearly basis a proportional change between scenarios.

Table 16: ToC and node failure threshold for *F. merguiensis*

Risk assessment endpoint	Threshold of Concern	Node failure threshold
Brackish estuarine habitat	Presence of 15‰ habitat for 50% of the length of each estuary between September–March	Medium risk: 1 consecutive years with brackish habitat< than the ToC High risk: 2 consecutive years with brackish habitat< than the ToC

Spatial relevance

F. merguiensis is present in all coastal catchments of the Burnett Water Resource Plan area. It is an estuarine/marine asset, which is modelled in relation to estuarine/end-of-system IQQM nodes.

Table 17: IQQM nodes that were used to model risk and growth for *F. merguiensis*

Catchment	Gauging Station(s) / IQQM Node (s)
Burnett	244
Kolan	293
Gregory	50
Elliott	137003A/ 003
Isis	21

3.2.4 Estuarine brackish habitat–*Mugil cephalus* (Sea mullet)

Appearance

Mugil cephalus is one of the larger mullet species that reaches a maximum length of 900 mm and a weight of 10 kg (Pusey et al. 2004). Colour varies with habitat, with oceanic fish being bright silver. Freshwater specimens are often very dark on the dorsal area. Six or seven median lateral bands may be seen on specimens, hence why it is also commonly called striped mullet in some Australia states (Pusey et al. 2004). It is identified by the extent of fatty adipose tissue obscuring most of the eye and a large axillary scale.

Distribution

M. cephalus is a cosmopolitan species that inhabits coastal waters of all seas in the temperate, subtropical and tropical zones. It is found in all states of Australia (Pusey et al. 2004).

Habitat

M. cephalus is a catadromous species that utilise fresh, estuarine and coastal waters throughout their life-cycle (Kailola et al. 1993). Post-larval mullet move into estuaries from September with lowered salinities believed to be the main stimulus (Thomson 1963). Laboratory and hatchery research has shown that these reduced salinities have significant effects on sea mullet growth and recruitment (De Silva & Perera 1976; Murashige et al. 1991; Cardona 2000; Barman et al. 2005). Juvenile recruits then move up into freshwater habitats until they reach maturity (Halliday & Robins 2007).

Reproduction

Adult *M. cephalus* migrate from freshwater habitats downstream to the estuary in late summer before forming spawning aggregations in marine environments in winter. Maturity is attained at approximately 3 years of age (Pusey et al. 2004; Kailola et al 1993). It is thought that seasonal rain and freshwater flow is a cue for migration (Halliday & Robins 2007). Spawning occurs seaward of the surf zone, near the mouths of rivers in autumn and winter (Pusey et al. 2004). The species is highly fecund, producing millions of non-buoyant eggs. Developing eggs require seawater to survive, whereas newly hatched larvae can tolerate salinities down to 28 ‰. Fish as small as 20–69 mm are able to partially acclimatise to very low salinities, with osmoregulatory function dependant on the ambient water temperature (Halliday & Robins 2007). Life history data for *M. cephalus* is shown in Table 18.

Table 18: Life history attributes of *Mugil cephalus*

Characteristic	Description (reference for data is Pusey et al. (2004) unless otherwise specified)
Longevity/Lifespan	9 years
Age at sexual maturity	3 years
Spawning season	March to July
Spawning frequency	Annually
Spawning cues	Potentially cued by decreasing water temperature
Fecundity	1.57 to 4.77 x 10^6
Time to hatching	36 to 50 hours at 22 to 24°C
Egg characteristics	0.63 mm non-buoyant eggs. These must stay in suspension in order to develop, hence why the spawning location is suspected to be near the surf zone.
Duration of larval development	Metamorphosis completed by 28 to 42 days, at a length 11 to 18 mm.
Other relevant information	Juvenile migration to freshwater recorded in many months of the year. Cardona (2000) suggest that 'mullet with a total length between 40 and 300 mm are highly dependent on areas with low salinity and hence any human activity reducing the availability of such an environment will negatively affect the fisheries of this species'. The alteration of river systems through the construction of dams and weirs reduces the availability and accessibility of brackish and freshwater habitats for juvenile mullet. This could potentially be a factor limiting the productivity of the mullet population and have consequential impacts on the size of the resulting mullet fishery. The food source for the species is dominated by detritus and algae, suggesting a close link to nutrient supply by the water body the species inhabits. As they are trophically located low in the aquatic food webs, *M. cephalus* are important in the nutrient and energy dynamics of estuarine systems. Water regulation may be responsible for the reduction of the extent of recruited post larval fish.

Ecological value it supports

M. cephalus is a significant target species in the commercial net fishery of Queensland with average catches approximately 1500 to 1900 tonnes between 2006 and 2010 (DEEDI 2011). It is listed as Near Threatened under the International Union for Conservation of Nature (IUCN).

The species can be associated with the general and specific ecological outcomes of the *Water Resource (Burnett Basin) Plan 2000*:

- *7(d) Water is to be managed and allocated to provide wet season flow to benefit native plants and animals, including for example, fish and prawns, in estuaries.*
- *11(1) Water in the Burnett River basin is to be managed and allocated to, if practicable, minimise the frequency and duration of marine conditions in the estuary of the Burnett River.*
- *12(b)(ii) Water in the Elliott, Gregory and Isis River basins is to be managed and allocated to maintain existing estuarine habitats, particularly in fish habitat areas, that are dependent on estuarine processes.*
- *13(b)(ii) Water in the Kolan River basin is to be managed and allocated to maintain and improve existing estuarine habitats, particularly in fish habitat areas, that are dependent on estuarine processes.*

Assessment end point

Provision of brackish habitat for *M. cephalus* within each coastal catchment in the Burnett Basin plan area.

Measurement end point

M. cephalus estuarine brackish habitat: Annual brackish habitat provision represented by the presence of 15‰ habitat for 50% of the length of each estuary over the IQQM simulation period.

Eco-hydraulic rules

There are several interacting factors driven by freshwater flows which contribute to improved population growth including migratory stimulus, connectivity, sediment/nutrient delivery, increased estuarine productivity and reduced osmoregulatory stress (Boeuf & Payan 2001; Halliday & Robins 2007). Juvenile *M. cephalus* require the brackish habitat to provide a suitable habitat (low salinity), that also provides a nutrient and food resource (primary food source is algae and detritus). Adults utilise the elevated discharge to migrate downstream, with juveniles also using the chemical cues to migrate up to freshwater reaches from September onwards. The brackish habitat provided (50% estuary length) also provides access for juveniles to freshwater reaches of major creeks in the upper estuaries in the plan area. The eco-hydraulic rules established for estuarine brackish habitat were used for *M. cephalus*.

Threshold of concern

A high risk profile (i.e. potential local population failure) for *M. cephalus* has been defined as a period without estuarine brackish habitat that exceeds species longevity (9 years Table 18). A moderate risk profile is defined as a period where the number of consecutive years without estuarine brackish habitat was between the age of maturity (3 years) (Pusey et al. 2004) and the maximum age of the species. All other years are deemed as being low risk to *M. cephalus* populations. The overall risk from water resource development is considered as a relative change in risk profile (i.e. relative proportion of each risk category) between the pre-development scenario and any development scenarios.

Table 19: ToC and node failure threshold for *M. cephalus*

Threshold of Concern	Node failure threshold
Presence of 15‰ habitat for 50% of the length of each estuary between September–March	Medium risk: 3 to 8 consecutive years with brackish habitat < than the ToC High risk: ≥ 9 consecutive years with brackish habitat< than the ToC

Spatial relevance

M. cephalus is present in all of the coastal catchments of the Burnett Water Resource Plan area. It is a freshwater/estuarine/marine asset, which is modelled in relation to estuarine/end-of-system IQQM nodes.

Table 20: IQQM nodes that were used to model risk to *M. cephalus*

Catchment	Gauging Station(s) / IQQM Node (s)
Burnett	244
Kolan	293
Gregory	50
Elliott	137003A/ 003
Isis	21

3.2.5 River Mangrove (*Aegiceras corniculatum*)

Appearance

Aegiceras corniculatum grows up to 4 m high, forming stands of thick shrubs. Its leaves are alternate, ovate, ~70 mm long and 15–50 mm wide. They are leathery and minutely dotted with glands to secrete salt. Its fragrant, small, white flowers are produced as umbellate clusters of 10–30 petals. The fruit is curved and cylindrical or horn-shaped, light green to pink in colour between 20–75 mm long. The bark is smooth, and grey in colour (AIMS 2003). Examination of aerial photographs has found that stands have remained largely unchanged for over 50 years (Clarke 1995).

Distribution

A. corniculatum is one of the more widely distributed mangrove species within Australia, with a coastal range of ~7400 km. They are found predominately in the intertidal zone of most estuaries (Clarke et al. 2001). The distribution of *A. corniculatum* within the estuaries of the Burnett Basin matches that described by Clarke et al. (2001), and has been found predominantly from the midpoint of the estuary to the natural tidal limits (EFAP unpublished mangrove mapping; Dowling 1978).

Habitat

Once established, mangrove ecosystems provide habitat for a diverse range of organisms due to the interactive effects of the tidal cycle and transition between marine and freshwater states (Pierson et al. 2002). Importantly, reduced salinities have been shown to play a key role in the development and establishment of various species within mangrove communities (Clark & Hannon 1970; Downton 1982; Clough 1984; Smith III 1988; Ball 2002). It is thought *A. corniculatum* has a competitive advantage over other mangrove species as it is well adapted to growth and reproduction in brackish habitat and is less prone to predation of propagules by crabs within established stands (Clarke & Kerrigan 2002).

Reproduction

A. corniculatum produce live seedlings but these are still contained within the seed coat when they drop from the plant. The seeds predominantly sink and settle quickly (<7 days) regardless of water salinity (Clarke 1995). This is in contrast to many other mangrove species that have floating seeds. This sinking attribute may allow this species to colonise more brackish habitat. The shooting and seedling development also tolerates low salinities (0–50% seawater) (Clarke 1995; Clarke et al. 2001). The time from bud formation to the abscission of the propagules is approximately 12–14 months (Clarke 1995).

A. corniculatum produces flowers from September and fruit mature by March. It is known to be able to produce fruit from ~18 months to 2 years of age, with most specimens being able to reproduce by the age of 5 years (Peter Clarke 2011 pers. comm.). A high energy demand is placed on producing only ~360 seeds/year for *A. corniculatum*, as compared to *Avicennia marina* (~2000 seeds).

Table 21: Life history attributes of *Aegiceras corniculatum*

Characteristic	Description
Longevity/Lifespan	50 + years (Clarke 1995)
Age at sexual maturity	~2 yrs (Peter Clarke 2011 pers. comm.)
Reproductive season	September to March (AIMS, 2003)
Reproductive frequency	Annually. Takes~12-14 months from bud formation to abscission of propagules (Clarke 1995)
Reproductive cues	n/a
Fecundity	~360 seed/year (Clarke 1995)
Seed and Seedling Characteristics	Propagules are curved and elongated (4 cm), contain one seeded fruit (Clarke et al. 2001). Propagules sink within a week in brackish conditions (Clarke 1995). Increased proportions of shoots and seedlings found in 0 to 50% seawater (Clarke 1995; Clarke et al. 2001)

Ecological value it supports

A. corniculatum is listed as 'Least Concern' under the IUCN Red List. It is provided habitat protection through Fish Habitat Areas throughout the Burnett Basin Area. It is one of the few mangrove species that has a limited estuarine distribution due to its intolerance of saline conditions for seedling establishment. Hence this species represents the presence of brackish conditions in the upper estuary as the ecological value.

The species can be associated with the general and specific ecological outcomes of the *Water Resource (Burnett Basin) Plan 2000*:

- *7(d) Water is to be managed and allocated to provide wet season flow to benefit native plants and animals, including for example, fish and prawns, in estuaries.*
- *11(1) Water in the Burnett River basin is to be managed and allocated to, if practicable, minimise the frequency and duration of marine conditions in the estuary of the Burnett River.*
- *12(b)(ii) Water in the Elliott, Gregory and Isis River basins is to be managed and allocated to maintain existing estuarine habitats, particularly in fish habitat areas, that are dependent on estuarine processes.*
- *13(b)(ii) Water in the Kolan River basin is to be managed and allocated to maintain and improve existing estuarine habitats, particularly in fish habitat areas, that are dependent on estuarine processes.*

Assessment endpoint

Viability of *A. corniculatum* populations within estuaries of the Burnett Basin WRP area.

Measurement endpoint

Germination and seedling growth success over the IQQM simulation period.

Eco-hydraulic rules

A summary of eco-hydraulic rules are given in Table 22.

Table 22: Eco-hydraulic rules for *Aegiceras corniculatum*

Critical flow requirement	Freshwater flows to *A. corniculatum* for germination and growth[1,2,4,5,6,7]
location	Upper estuarine areas, particularly shallow muddy flats in the upper 50% of the estuary[1,2,3,4]
flow class	Medium to High – sufficient to produce brackish conditions (50% seawater~15‰) for 50% length of the estuary for fruiting and germination[1,4]
magnitude	Variable– sufficient to produce brackish conditions (50% seawater) for 50% length of the estuary for fruiting and germination[1,4]
timing	Flowers (October to February) and fruits until March [6,7]. It is suggested to potentially begin flowering as early as September in subtropical areas[5]
duration	Roots initiated in seeds 8 days[4]
frequency	At least 1 significant flow event every 2 years to allow full cycle of recruitment to occur and to allow frequent regeneration events to outcompete *A. marina*[1,5]
habitat features	Freshwater flow for creation of brackish habitat which increases seedling establishment and growth[1,4]
rates of change	Mimic natural. Post-flood baseflows maintain brackish conditions in the estuary for extended periods
water quality	10 to 50% seawater, 3 to 15‰ salinity[1,4]
references	[1]Clarke 1995, [2]DERM EFAP unpublished mangrove mapping,[3]Dowling 1978, [4] Clarke et al. 2001, [5]Peter Clarke pers comm. 2011, [6]Clarke 1994, [7]AIMS 1993

Threshold of concern

A ToC was defined to establish the consequence of altering the germination and high growth opportunities for the local (IQQM node) *A. corniculatum* population persistence. A relationship between the annual provision of suitable brackish habitat for germination and high growth opportunities with population maintenance was calculated based on population attributes derived from the literature, and through consultation with relevant experts (Associate Professor Peter Clarke). Where these parameters were not available, they were estimated using a four-step interval elicitation procedure (Speirs-Bridge et al. 2010).

A high risk profile (i.e. potential local population failure) is defined as a period where the number of consecutive years without providing suitable habitat for germination and high growth opportunities exceeded the maximum age of maturity (age at which all individuals should be mature – 5 years). This relates to the increased potential for more salt-tolerant and fecund species such as *Avicennia marina* to invade and encroach on the habitat of *A. corniculatum* (Clarke 1995). A moderate risk profile is defined as a period where the number of consecutive years without providing suitable habitat for germination and high growth opportunities was between the minimum age of maturity (2 years) and the maximum age of maturity (5 years). All other years are deemed as being low risk to *A. corniculatum* populations. The overall risk from water resource development is considered as a relative change in risk profile (i.e. relative proportion of each risk category) between the pre-development scenario and any development scenarios.

Table 23: ToC for *Aegiceras corniculatum*

Threshold of Concern	Node failure threshold
Presence of 15‰ habitat for 50% of the length of each estuary between September–March	Medium risk: 2 to 5 consecutive years with brackish habitat< than the ToC High risk: ≥5 consecutive years with brackish habitat< than the ToC

Spatial relevance

A. corniculatum is present in all estuaries of the Burnett Water Resource Plan area (Burnett, Kolan, Gregory, Elliott and Isis). It is an estuarine/marine asset, which is modelled in relation to end-of-system/estuarine IQQM nodes.

Table 24: IQQM nodes that were used to model recruitment opportunities for *Aegiceras corniculatum*

Catchment	Gauging Station(s) / IQQM Node (s)
Burnett	244
Kolan	293
Gregory	50
Elliott	GS137003A/ 003
Isis	21

3.3 Ecosystem services–waterhole persistence

3.3.1 Waterholes as refugia

Description

The long term persistence of many aquatic species within a catchment depends on the availability of suitable waterhole habitat (refugia) (Bunn et al. 2006; Arthington et al. 2010; Beesley & Prince 2010; Sheldon & Fellows 2010). There are three major attributes of waterhole refugia which contribute to their ability to sustain biota: the length of time they retain water during no-flow events, or *persistence*; their refuge *quality* which encompasses factors such as water quality, habitat availability and intact food webs; and *connectivity* between waterholes, enabling recolonisation and gene flow (DERM 2010).

Waterholes were selected as an ecological asset for the Burnett Basin due to their critical links to flow for overall persistence. These pools serve as the only available habitat for much of the year, particularly during periods of drought. Waterholes require water to function as a refuge, thus a change in flow regime reduces the abundance and duration of recharge events causing the waterhole to dry out quicker and more often.

Waterholes in the Burnett Basin are subject to extraction for agricultural use, particularly during dry periods when flow in the river has ceased. Drawdown of these waterholes below cease-to-flow levels reduces littoral habitat, which is used by many species as refuge and also by the Australian lungfish as spawning habitat. In addition, connectivity may be affected for subsequent flow events which can affect the natural migration patterns of aquatic species.

Eco-hydrologic rules for waterholes focused on dry spells between flow events in the Burnett Basin. Spell analyses were undertaken on a number of waterholes within the basin to identify the maximum period of no-flow. Waterhole morphology affects the persistence of individual waterholes, with maximum depth being a major factor in the persistence (DERM 2010).

The bathymetry of a number of waterholes within reaches the Burnett Basin was conducted to establish the morphology as well as attributes of persistence such as maximum depth. These areas focused on the Burnett River, Elliott River and Three Moon Creek (Figure 10). The waterholes on the Burnett River were chosen as there had been concern that there had been considerable drawdown of individual waterholes downstream of Claude Wharton Weir during a dry period in 2009 (Dwyer 2010) (Figure 11). The Bunyip Waterhole on Three Moon Creek (Figure 15), as well as Grays Waterhole (Burnett River) (Figure 12) were surveyed as they are waterholes of significant indigenous value (Department of Natural Resources 2000). Waterholes within the lower Elliott River were surveyed as part of a separate project to determine the influence of groundwater input (See Implementation Review Report) (Figure 13). Dr Mays Waterhole (Figure 14) on the Elliott River was selected as it is the most significant waterhole within this reach, is close to the tidal influence and it acts as additional habitat for catadromous fish species (Craig Broadfoot DEEDI 2011 pers. comm.).

The waterholes downstream of Claude Wharton Weir were surveyed in June 2010 to determine maximum depth, depth/volume curves and to determine the location of pumping sites (Dwyer 2010). The volume of each waterhole, along with maximum depth and extraction information is presented in Table 25. Similar information is presented for Bunyip and Dr Mays waterholes.

The majority of waterholes upstream of the Barambah Creek junction on the Burnett River were dominated by sandy substrate and contained significant sediment that had been accumulated over a number of years (F.Dwyer DERM 2011 pers comm.). In January 2011, these waterholes were substantially scoured and hence the waterhole volume and bathymetry data is not thought to be applicable and has been supplied only to document a baseline for any future assessments.

The waterholes downstream of the Barambah Creek junction are dominated by bedrock substrate and controls and are generally deep, with some of these waterholes having sections greater than 20 m deep. As these waterholes have significant deep sections, eve with moderate water extraction pressure during periods of no-flow in 2009, there was very little drawdown on the waterholes. Maximum estimated and measured waterhole drawdown did not exceed 1.5 m (Table 25).

Table 25: Surveyed waterhole properties including statistics on associated water extraction information.

Waterhole location (AMTD)	Waterhole volume in 2010 (ML)	Maximum depth (m)	Nominal volume (ML/y)	Hectare Allocation (ha)*	Actual metered water extraction 2001-2009 min.-max (average)(ML)	Usage July – Dec 2009 drought (ML) (% waterhole volume)	Observed maximum drawdown (m)	Persistence time (days)	Annual evaporation rate (mm)
Burnett River									
161.9 – 163.8	126	23.2	61.5			6.8 (5.3%)	1		
170.6 – 173.1	764.5	11.7	765			444 (58%)	1 – 1.5		
174.6 – 176.35	559.6	16.6	621			238 (42%)	1		
179.1 – 181.05	1022	24.7	24			23.24 (2.3%)	1		
181.1 – 183.15 *(Gray's waterhole, Goonanga#)*	892.6	10.3	280			95.6 (10.7%)	0.2	1980	1899
183.2 – 186.4	737.4	6.3	621			102.2 (13.8%)	1 – 1.5		
187.1 – 1 (Barambah Ck)	208**	5.9	10			0			
187.4 – 189.5	172.7**	4	285			108.4	1 – 1.2		
189.5 – 191.6	228**	7.7	605			195.1	1.5 - 2		
191.6 – 192.6	110**	8.7	1			0			
192.6 – 193.6	184**	7	3			0			
194.2 – 197.6	262.4**	4	916			253.1	1 – 1.2		
197.7 – 198.4	70**	5.6	70			19.9			
198.47 – 199.14	40.3**	4.5	60			4			
Elliott River									
9.43 – 10.96	50.3	7.2		94	18-94 (40)		1.5		
10.98 – 14.15 (Dr	496	11		161	560-971 (793)		1.5	2290	1753

Mays)									
14.83 – 16.21	53.3	11.2		110	21-282 (147)		1.5		
Three Moon Creek									
30.83 – 31.50 *(Bunyip waterhole#)*	98.5	9.6						2028	1728

*Water extraction volume based on up to 6 ML per hectare allocation (Water Resource (Burnett Basin) Plan 2000). Approximately 58 ha not metered (or about 348 ML).

#Grays waterhole - known as ‘Goonanga’, and Bunyip waterhole listed as of cultural significance (Department of Natural Resources, 2000a)

**Waterhole volume is expected to be significantly different after the 2011 floods as these waterholes had a sand substrate base and had significant sedimentation present at the time of survey.

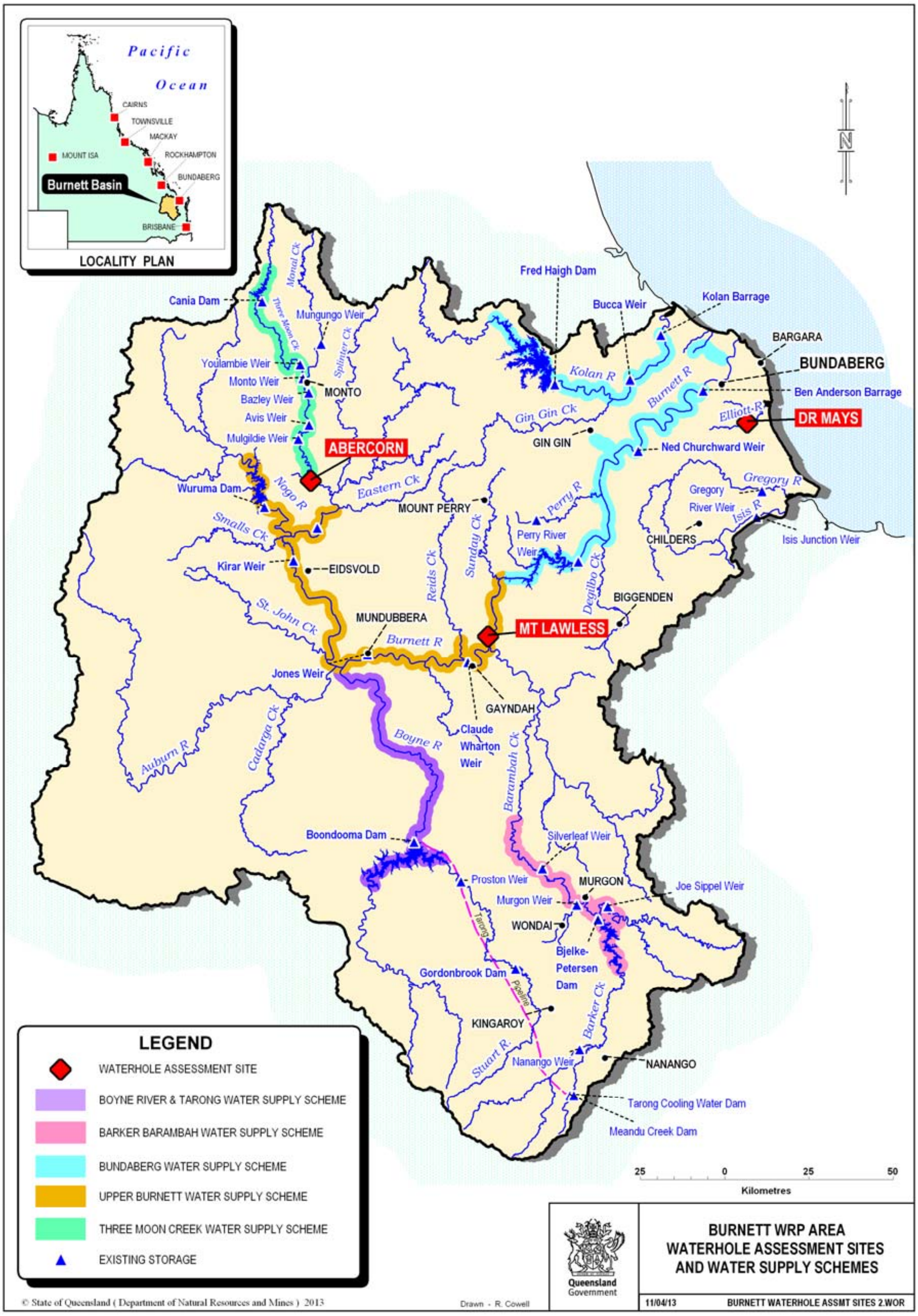

Figure 10: Waterhole assessment locations in the Burnett Basin. Naming based on the associated gauge station name.

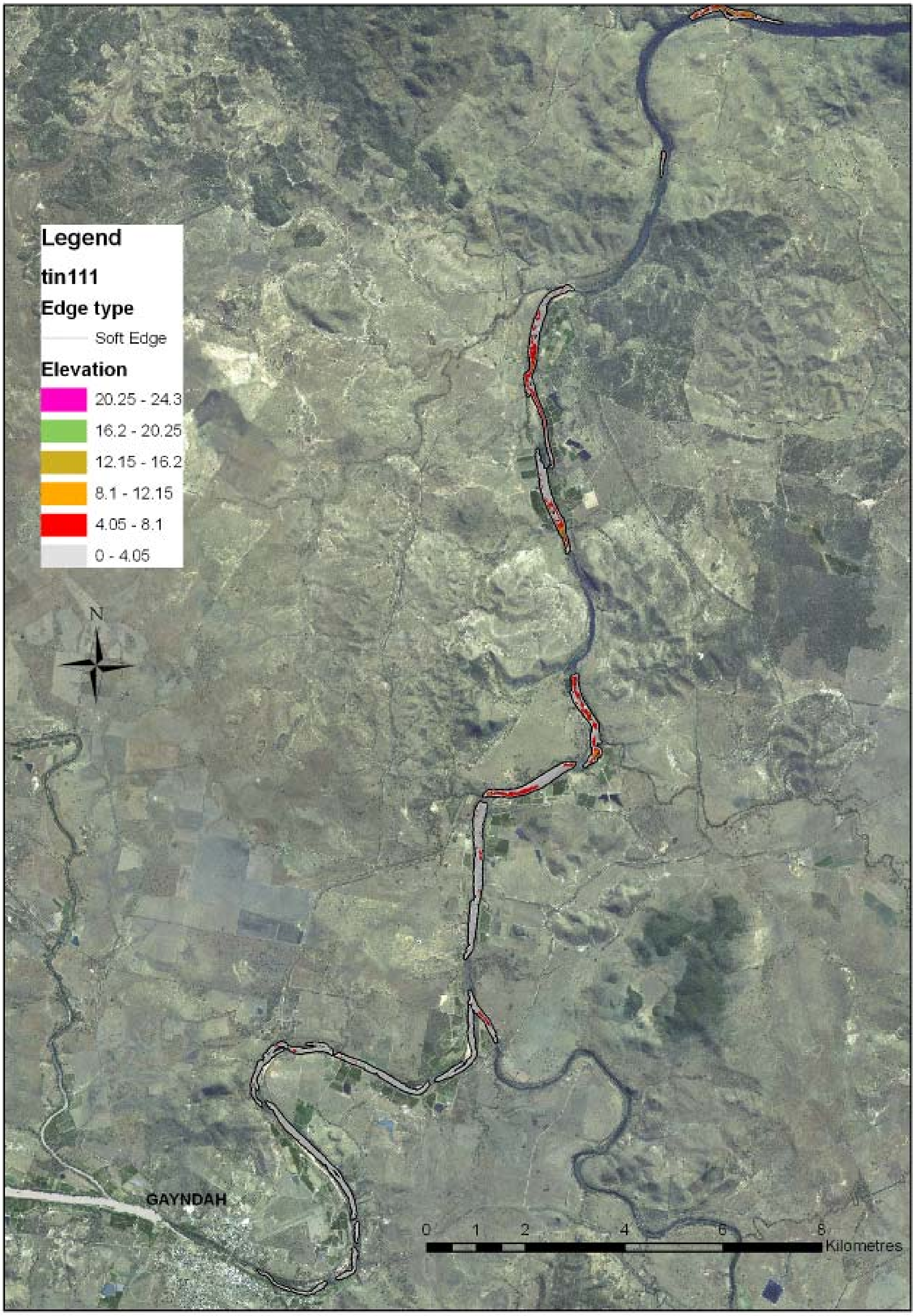

Figure 11: Bathymetric map of the Burnett River waterholes

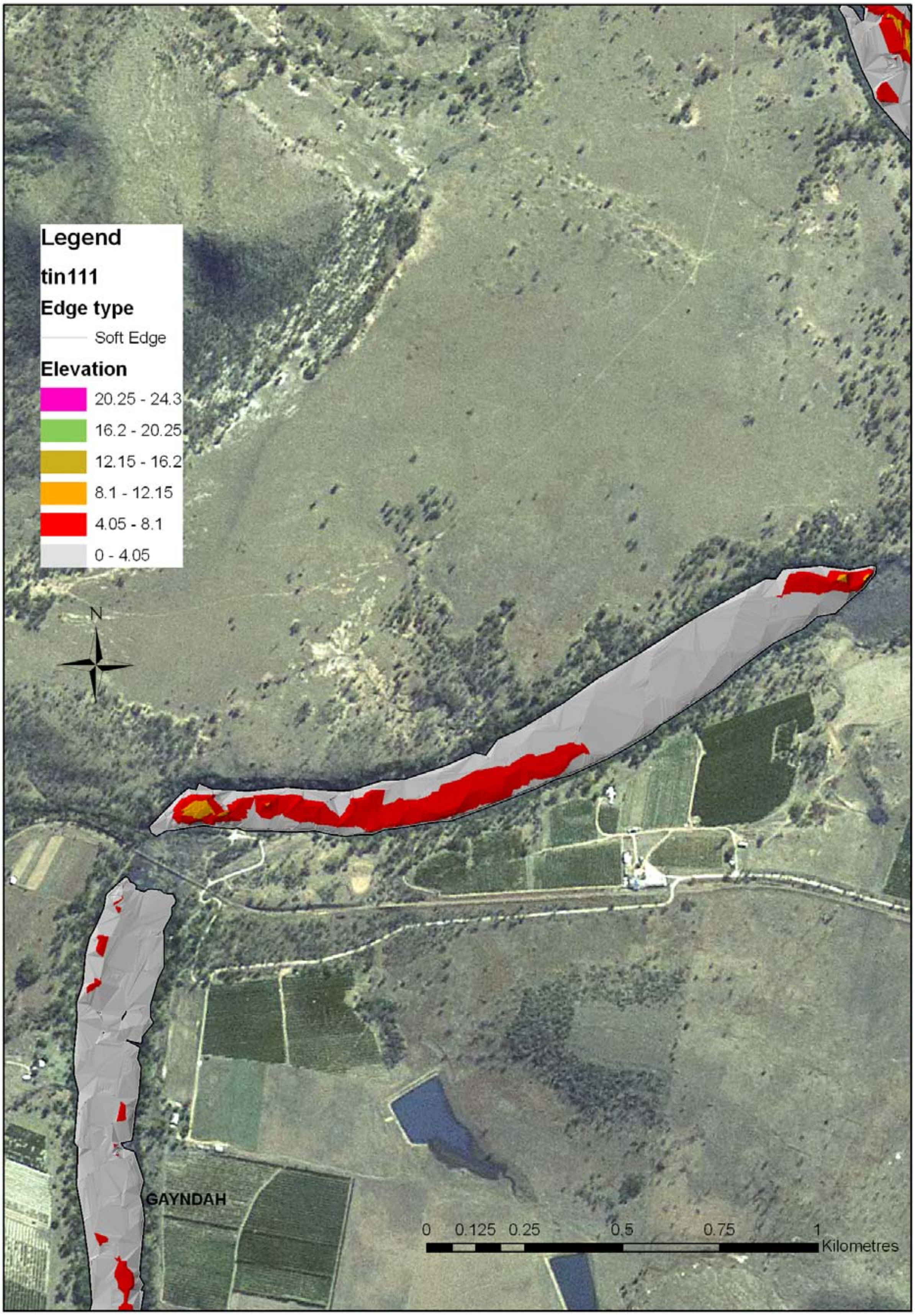

Figure 12: Bathymetry of Grays waterhole on the Burnett River.

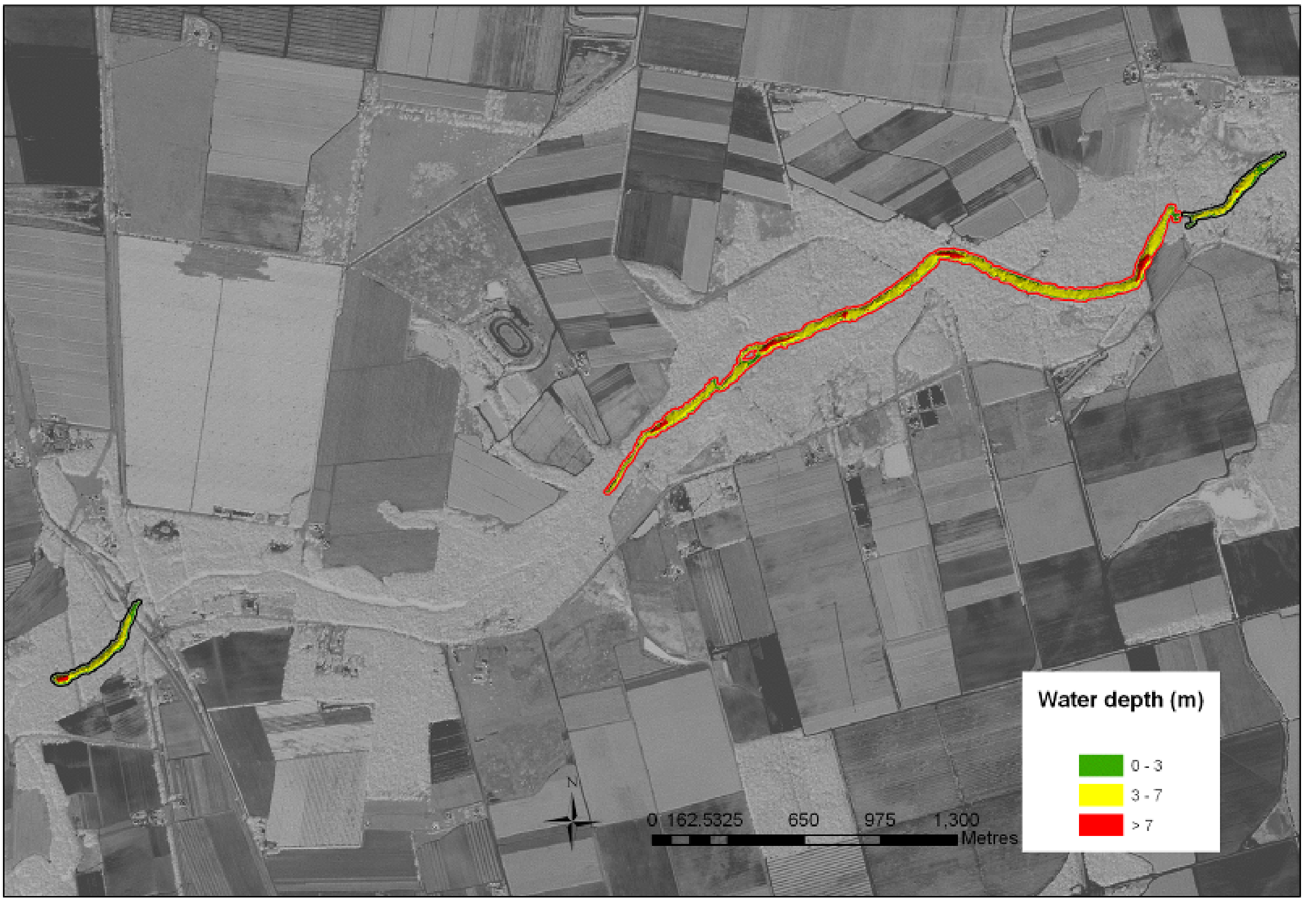

Figure 13: Bathymetry of Elliott River waterholes

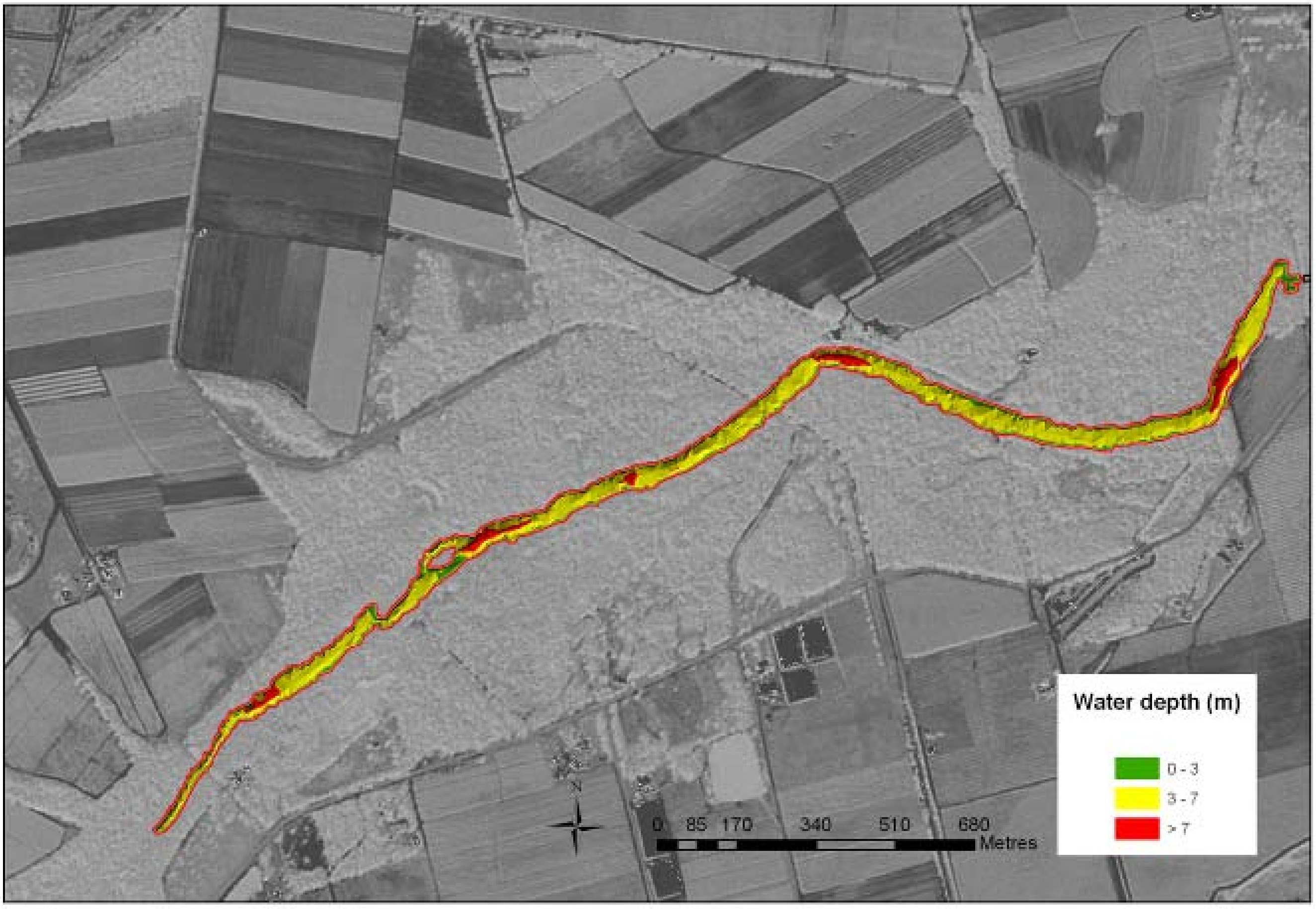

Figure 14: Bathymetry of Dr Mays waterhole

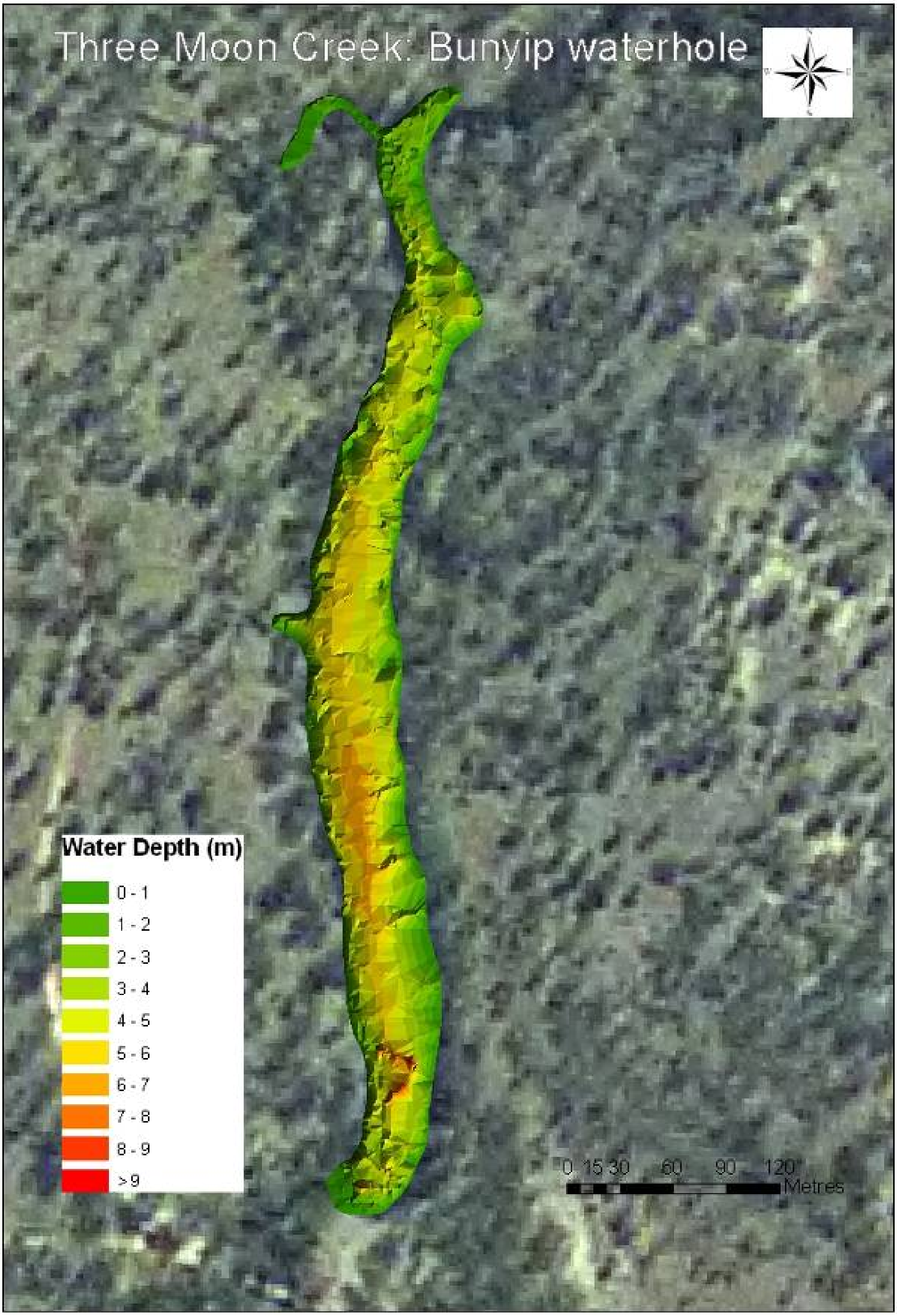

Figure 15: Bathymetry of the Bunyip Waterhole on Three Moon Creek.

Ecological value it supports

Waterholes are generally the most productive of riverine habitats, supporting a complex diversity of macro- and microphytic assemblages (e.g. macrophytes, benthic macro- and microalgae and cyanobacteria, fungi and bacteria) and animals (e.g. macroinvertebrates, fish, reptiles and amphibians). Waterholes are often occupied by many obligate and sometimes rare and sensitive rheophilic taxa specially adapted to cope with the fast flowing conditions. Within the Burnett, there are species that are thought to be reliant upon the existence and long term persistence of waterholes.

Assessment endpoint

Viability of waterholes to act as refugia within the Burnett Basin. It is assumed that waterholes provide this refugial habitat whilst water remains within the waterholes.

Measurement end point

Waterhole persistence over the simulation period.

Eco-hydraulic rules

The eco-hydraulic rules for waterholes are presented in Table 26.

Table 26: Eco-hydraulic rules for waterholes

Critical low requirement	Freshwater flows to maintain waterhole volume and persistence
location	Throughout catchment. Waterholes selected include those of cultural significance (Bunyip waterhole – Three Moon Creek, Grays Waterhole – Burnett River)[1] and those that provide additional habitat for catadromous fish species (Dr Mays Waterhole)[2].
flow class	No/Low
magnitude	No flow (<2 ML/d based on accuracy of the Burnett IQQM)
timing	n/a. No flow periods can start and finish at any time of year. Timing is irrelevant.
duration	Maximum no-flow spell is less than the persistence time for each waterhole determined by the annual evaporation rate and the maximum depth of each waterhole.
frequency	Frequency of drying events (those that cause complete drying of the waterhole) should match those of the natural frequency (predevelopment IQQM case)
habitat features	Deep sections of waterholes to provide refugial habitat during drought periods to maintain water quality.
rates of change	n/a
water quality	n/a. Quantitative data unavailable of the links between waterhole drawdown and thresholds of water quality as this is waterhole specific.
references	nil

Threshold of concern

The threshold of concern (ToC) for waterholes is the estimated persistence time for each waterhole based on the maximum depth and the estimated annual evaporation rate. There is a node failure if the IQQM case contains a no-flow spell that exceeds this time period.

Spatial relevance

The waterholes to be used in the assessment are from three river systems.

Table 27: IQQM nodes that were used to establish maximum no-flow spells for waterholes.

Catchment	Gauging Station(s) / IQQM Node (s)
Burnett	GS136002D/ 141
Three Moon	GS136101C /83
Elliott	GS137003A/ 003

4 Summary

Table 28: Summary of eco-hydraulic rules for selected ecological assets within the Burnett Basin

Type	Ecological asset	Eco-hydraulic rule (s)	Timing	Duration	Rate of change	Link to hydrology	Catchment
Ecosystem Component – Vertebrate - Fish	*Neoceratodus forsteri* (Australian lungfish)	Small flow event (>0.3 m rise in water level) followed by stable baseflow for a period exceeding 30 days.	August–December	30 days	Recession of hydrograph to mimic natural rate and duration. Minimal fluctuations to subsequent baseflow	Small flows followed by stability	Burnett River
Ecosystem Component – Vertebrate–Reptile	*Elseya albagula* (White throated snapping turtle)	Stabilisation of water level to reduce inundation of nest sites. Water levels not to exceed 1.3 m.	Nesting (May-July) Incubation/hatching (July–December)	240 days	n/a	Stable water levels	Burnett River
Ecosystem Process – estuarine brackish habitat	*Lates calcarifer* (barramundi)	Freshwater flush of the estuary to produce 15‰ at 50% length of the estuary.	September–March	Predevelopment flows of this magnitude vary from 8 days to months in duration.	Mimic natural as much as possible. Post-flood baseflows maintain brackish conditions in the estuary for extended periods. Predevelopment flows of this magnitude vary from 8 days to months in duration.	Freshwater flows of sufficient magnitude to provide brackish habitat.	Burnett River, Kolan River, Elliott River, Isis River, Gregory River
Ecosystem Process – estuarine brackish habitat	*Mugil cephalus* (sea mullet)	Freshwater flush of the estuary to produce 15‰ at 50% length of the estuary.	September–March	Predevelopment flows of this magnitude vary from 8 days to months in duration.	Mimic natural as much as possible. Post-flood baseflows maintain brackish conditions in the estuary for extended periods. Predevelopment flows of this magnitude vary from 8 days to months in duration.	Freshwater flows of sufficient magnitude to provide brackish habitat.	Burnett River, Kolan River, Elliott River, Isis River, Gregory River

Type	Ecological asset	Eco-hydraulic rule (s)	Timing	Duration	Rate of change	Link to hydrology	Catchment
Ecosystem Process – estuarine brackish habitat	*Fenneropenaeus merguiensis* (banana prawn)	Freshwater flush of the estuary to produce 15‰ at 50% length of the estuary.	September–March	Predevelopment flows of this magnitude vary from 8 days to months in duration.	Mimic natural as much as possible. Post-flood baseflows maintain brackish conditions in the estuary for extended periods. Predevelopment flows of this magnitude vary from 8 days to months in duration.	Freshwater flows of sufficient magnitude to provide brackish habitat.	Burnett River, Kolan River, Elliott River, Isis River, Gregory River
Ecosystem Process – estuarine brackish habitat	*Aegiceras corniculatum* (river mangrove)	Freshwater flush of the estuary to produce 15‰ at 50% length of the estuary.	Flowers (October to February) and fruits until March. It is suggested to potentially begin flowering as early as September in subtropical areas	Roots initiated in seeds 8 days	Mimic natural. Post-flood baseflows maintain brackish conditions in the estuary for extended periods	Freshwater flows of sufficient magnitude to provide brackish habitat.	Burnett River, Kolan River, Elliott River, Isis River, Gregory River
Ecosystem Service – waterhole persistence	Waterhole	Maintenance of baseflow to limit the no-flow period to maintain pool persistence.	n/a. No flow periods can start and finish at any time of year. Timing is irrelevant.	Maximum no-flow spell is less than the persistence time for each waterhole determined by the annual evaporation rate and the maximum depth of each waterhole.	n/a	Maintenance of baseflow	All (Burnett River, Three Moon Creek, Elliott River selected)

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