The Need For Environmental Flows To The Great Sandy Strait

Tanzi Smith, Greater Mary Association Inc.

Glenda Pickersgill, Save the Mary River Coordinating Group Inc.

Abstract

The Mary River, in South East Queensland, Australia, has escaped the construction of the proposed Traveston Crossing dam, but the system remains under pressure through extraction for the South East Queensland Water Grid to the south as well as prospects of more interbasin transfer and increases in local extraction. The Federal Environment Ministers' decision in December 2009 to reject the proposed dam highlighted the significance of key species in the freshwater ecosystem of the river, but what of the estuarine ecosystem? The estuary of the Mary River is internationally recognised through Ramsar listing and inclusion in the Great Sandy Biosphere. It is a sand passage estuary sandwiched between the mainland and World Heritage listed Fraser Island which supports significant commercial and recreational fishing industries and is an important site for migratory birds, dugongs, migratory cetaceans and the rare Indo-Pacific Humpback dolphin. The Mary Basin Water Resource Plan currently provides no guarantee of environmental flows to this estuary. This paper draws on a selection of research into water quality, hypersalinity and ecology of the Great Sandy Strait to emphasise the need for environmental flow requirements to be established and delivered to the estuary. Preliminary estimates of these requirements are provided together with recommendations regarding further research.

1 Introduction & Background

The Mary River is located in south east Queensland with the headwaters of the river rising in the hinterland of the Sunshine Coast approximately 100 km to the north of Brisbane (see Figure

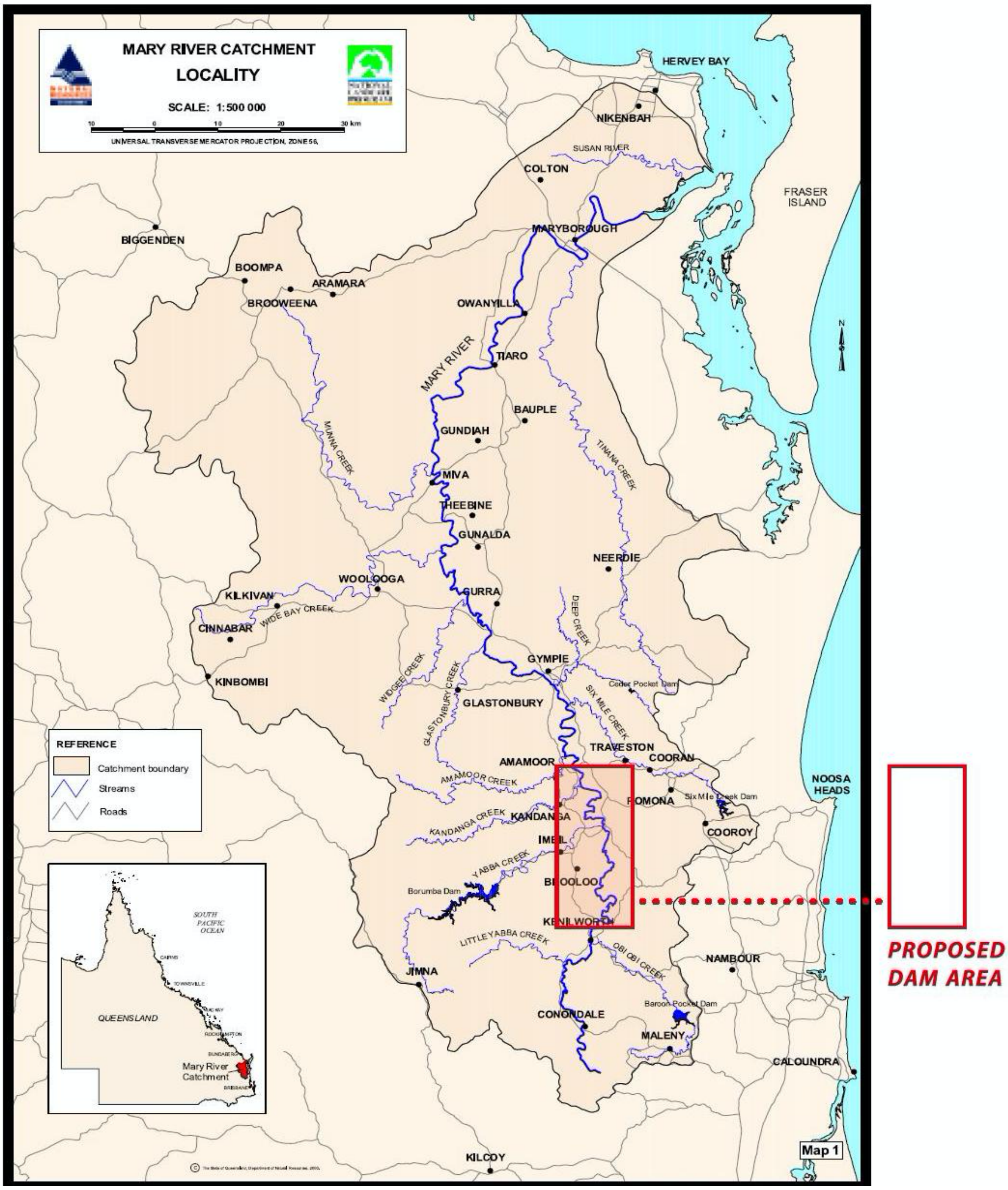


Figure 1 Map of Mary River Catchment showing the position of the defunct proposed Traveston Crossing Dam

1). The river runs north for 310km (MRCCC 2010) through a catchment with diverse rainfall, vegetation and landuse and enters the ocean in the Great Sandy Strait adjacent to World Heritage listed Fraser Island. The total catchment area is 10,540 km^2 (Prange & Duke 2004) and the river and her tributaries support the urban water supply of several towns in the catchment, the largest populations being located in Gympie and Maryborough. The river also supports irrigated agriculture including dairy, beef, sugar cane, horticulture as well as forestry, tourism, sand and gravel extraction, small industry and cottage arts and craft (MRCCC 2010).

Through construction of the Northern Pipeline Interconnector (NPI) stage 1 (completed in 2008) and 2 (under construction) there is also now a facility through which water can be pumped from the Mary River into the South East Queensland Water Grid. Communities within the Mary River catchment are not part of this grid. The Federal Government approval for NPI Stage 2 permits interbasin transfers of 6 500 GL/a. The Queensland Governments stated objective is to transfer 23, 725 GL/a (65 ML/d) from the two stages of the project into the grid (Department of Infastructure and Planning 2009). This water will be taken from existing urban allocations which have never been fully utilised.

According to the classification system proposed by Kennard et al (2010) the flow regime of the Mary River can be described as "*unpredictable intermittent*". Kennard et al's (2010) classification is based on the fact that daily and annual flow are highly variable, and that the timing of maximum flows are variable and intervals between them high compared to other river systems. In this class of river, flows rarely cease and baseflows and runoff are intermediate compared to other systems.

The Mary River has been described by Arthington and Bunn (2008, p. 2) as the most significant unregulated coastal river in south east Queensland from a biodiversity and conservation perspective. Species that were significant in Minister Garrett's decision to reject the proposed Traveston Crossing dam include the endangered and endemic Mary River Turtle (*Elusor macrurus*) (Kuchling 2008), the vulnerable Australian Lungfish (*Neoceratodus forsteri*) (Arthington 2009) and the critically endangered Mary River Cod (*Maccullochella peelii mariensis).* Fifteen other endangered, vulnerable or rare species of fish, birds (including one of Australia's most endangered birds the Coxen's fig parrot) and plants were listed in the referral of the project under the Environment Protection and Biodiversity Conservation Act. More detail regarding the significance of the aquatic biodiversity of the Mary River is available in Stockwell et al (2004).

In addition the Mary River supports a Ramsar listed estuary which extends from within the river itself out into the entire Great Sandy Strait. The Great Sandy Strait is a sand passage estuary in the lee of Fraser Island. The extent of the Ramsar area is provided in Figure 2. This area is significant ecologically, being a Ramsar site, a Marine Park, part of the recently recognised Great Sandy biosphere and adjacent to Fraser Island World Heritage Area. According the Australian Heritage Database (2010), the Great Sandy Strait contains one of the largest areas of seagrass in Queensland and supports six species of turtles, a resident population of dugong and provides important roosting and feeding site for twenty four species of migratory birds, including eighteen species included in international migratory bird agreements with Japan and China. The populations of eastern curlew (Nemenius madagascariens), bar tailed godwit (Limosa limosa), Mongolian plover (Charadrius mongulus) and grey tailed tattlers (Tringa brevipes) are particularly significant. The rare indo pacific humpback dolphin reside in the are and humpback whales visit during their migration. The mangroves at the river mouth also provide a home to a population fo the threatened illidge's ant blue butterfy (Acropidsas illidgei). This estuarine system also supports recreational and commercial fishing and nature based tourism, which combined make a significant contribution to the local economy.

A study completed in 2008 by the Burnett Mary Regional Group in collaboration with the Queensland Environment Protection Agency rated the Mary River estuary condition as fair (an overall assessment of C-) and identified a high risk of impact from human activities (Burnett Mary Regional Group 2008). Consequently there is a need to be proactive to minimise these risks and maintain the significant environmental values of the Great Sandy Strait.

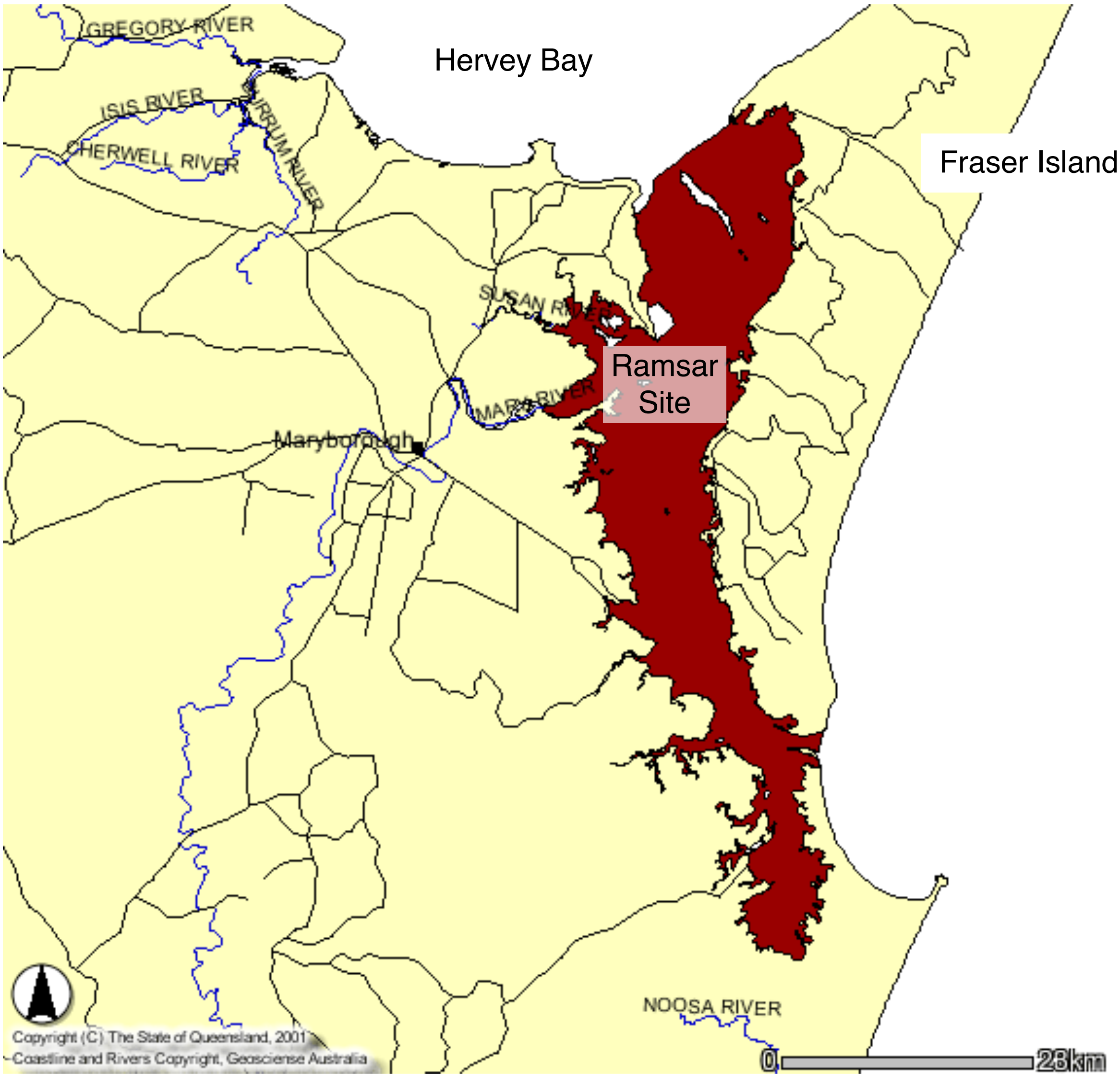


Figure 2 Great Sandy Ramsar site

The Mary River is also the primary source of freshwater (Ribbe 2008a) and a significant source of sediment (Beach Protection Authority Queensland (BPA) 1989; Piorewicz 1997) for Hervey Bay (see Figure 3), which is situated to the north of the Great Sandy Strait and considered an important resting area for humpback whales during their annual migration.

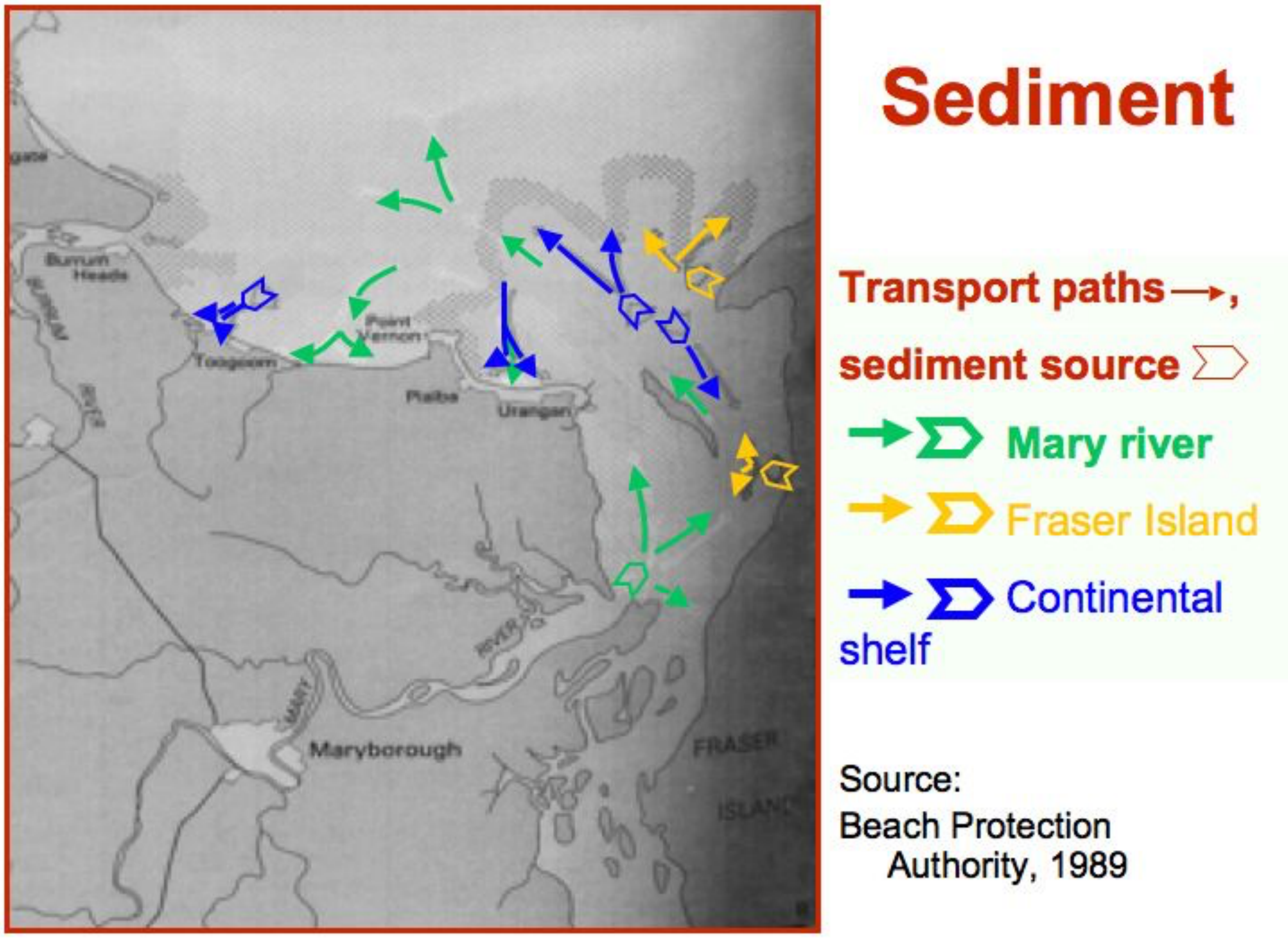


Figure 3 – Patterns of sediment transport in the northern Great Sandy Strait and Hervey Bay (Beach Protection Authority Queensland (BPA) 1989)

Catchment management programs and community involvement in the catchment have a long standing history in the Mary River Catchment. The Mary River Catchment Coordinating Committee (MRCCC) was formed in 1995, making it one of the first integrated catchment management groups in Australia. Community involvement in river health includes a waterwatch program which involves 80 volunteers monitoring water quality at 100 sites. Other largely volunteer based programs in the catchment include monitoring of Mary River turtle nesting sites (since 2001), seagrass watch monitoring program at several sites in the Great Sandy Strait and Hervey Bay and a Mangrove Watch program has started in 2009.

The Mary River came to prominence in national politics in November 2009 when the then Federal Environment Minister Peter Garrett rejected the Queensland Government's proposal to construct a dam on the main trunk of the Mary River to provide drinking water to Brisbane. The then Premier Peter Beattie announced the proposed Traveston Crossing dam in April 2006. In his decision, Minister Garrett was required to consider four Matters of Naitional Environmental Significance listed in the Environment Protection and Biodiversity Conservation Act which the proposal had triggered (under Part 3 of the Act). The controlling provisions were:

- World Heritage Areas (sections 12 and 15A)
- Wetlands of International importance (section 16 and 17B)
- Listed threatened species and communities (section 18 and 18A)
- Listed Migratory species (section 20 and 20A)

The proposal was rejected under Section 18 and 18A pertaining to listed threatened species, with the minister indicating that "this project would have serious and irreversible effects on nationally listed species such as the Australian lungfish, the Mary River turtle, and the Mary River cod" (Garrett 2009).

This paper focusses on the estuarine areas of the Mary River system. In particular it considers the role that environmental flows play in maintaining the health of estuaries, and specifically the Mary River estuary, the Great Sandy Strait and Hervey Bay. The need for this paper arises from water planning processes in the cathcment having largely overlooked this aspect of water management. This pattern is not restricted to the Mary River. As Scheltinga et al (2006) p 7 have identified:

> "...although estuaries are not excluded from the water reform agenda or NWI (National Water Initiative), they are not included explicitly and thus tend to be less well considered than freshwater areas. This, combined with the large number of knowledge needs around the influence of flows on estuaries, and thus their flow requirements, means that

estuaries are difficult to include in water planning arrangements and may simply end up with ‘what is left over’ after other entitlements and allocations have been determined. However, the Queensland Government’s proposal to dam the Mary River at Traveston Crossing dam placed a spotlight on all aspects of water management in the catchment. This paper explores a selection of existing research into the links between environmental flows and estuaries and some specific analysis of fish catch and salinity in the Mary River itself. Based on this research preliminary environmental flow estimates are outlined and suggestions for further research are provided. Such an exploration is timely given that the Resource Operations Plan (ROP) for the Mary Basin Water Resource Plan is currently out for public comment.

2 Current environmental flow arrangements in the Mary River estuary system

An appropriate starting point for analysing environmental flow requirements to the estuary is the current status. Factors that have affected the flows to the estuary to date are briefly outlined, followed by a consideration of the limitations of the existing regulatory and jurisdictional frameworks to deliver adequate flows.

2.1 Factors affecting environmental flows to the estuary

The flows to the estuary are impacted by two primary factors. The first is the reduction in flow associated with extraction, particularly during dry seasons and during drought periods. The second impact is due to the barrages on the main trunk of the Mary River near Tiaro (the Mary River Barrage) and on the Tinana Creek tributary of the Mary River (the Tinana Barrage).

With regard to reductions in flow both the total volume of water extracted and the timing are relevant. As of 2007, according to the draft Traveston Crossing Dam Environmental Impact

Statement (p 6-17) the total supplemented allocation available within the catchment was 103,652 ML/yr. If all water allocations within the catchment are utilised, a 23% reduction in median daily flow to the river mouth would result (Max Winders and Associates 2008). This corresponds with a reduction in Mean Annual Flow from 2,517,000 ML/a to 2,273,000 ML/a (Max Winders and Associates 2008). Actual extraction from the river “is considerably more benign than the ‘full utilisation of current allocations’ scenario” (Burgess 2009a).

Figures 4 and 5 illustrate the way in which full allocations (listed as current allocations in the Figure) would exceed environmental flow objectives established in the Mary Basin Water Resource Plan. Figure 4 displays performance at two sites – the river mouth, and Home Park 89km from the river mouth (and upstream of the Mary River barrage pondage). As indicated current allocations exceed the environmental flow objectives based on median flow.

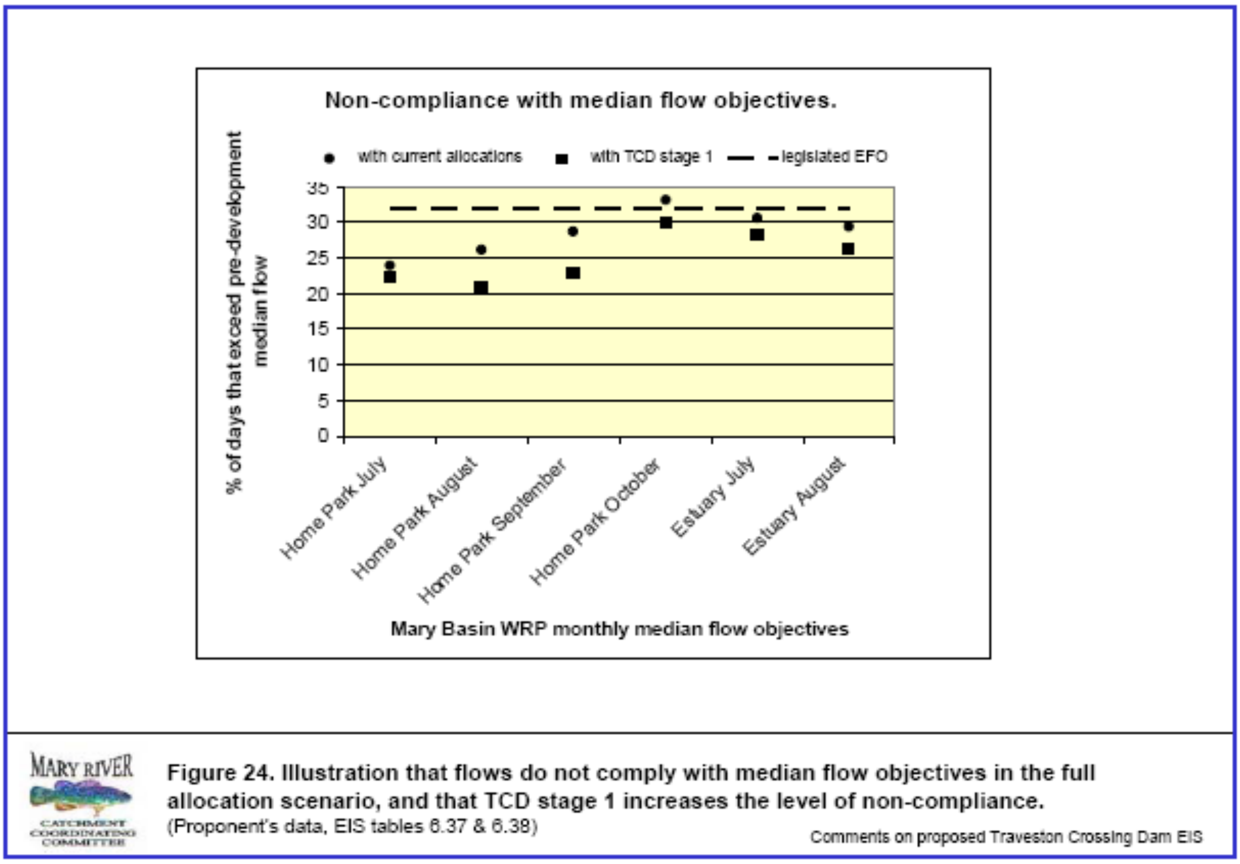


Figure 4 Illustration of current allocations not meeting Environmental Flow objectives (Burgess 2008)

The consequences of these low flow periods have been discussed previously by Burgess (2009a; 2009b) and others.

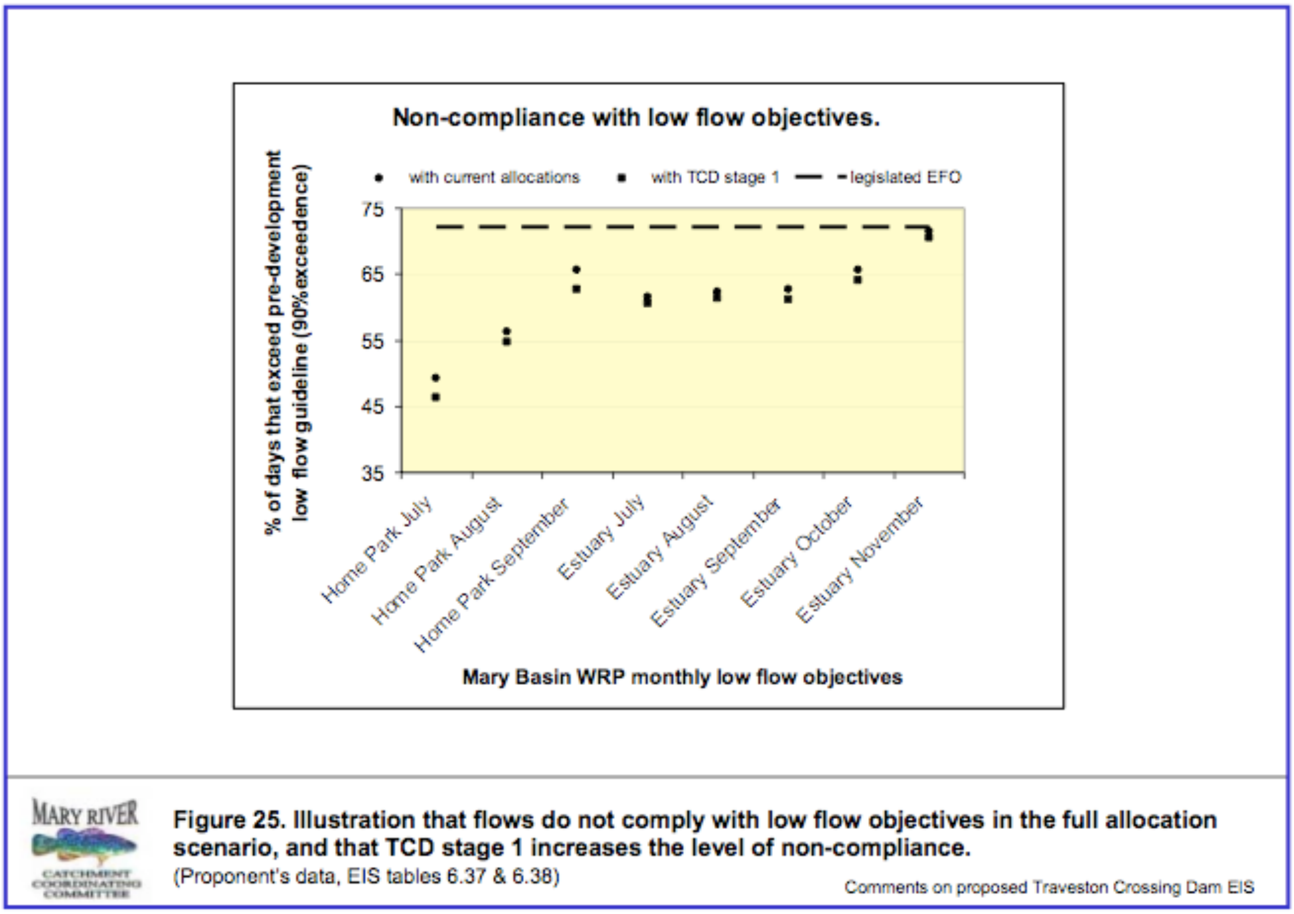


Figure 5 Illustration of the current allocations not meeting low flow Environmental Flow objectives (Burgess 2008)

These illustrations are based on a long term simulation period and indications are that the future flows in the Mary River may be substantially less than the historical record. It is of great concern that during the past decade streamflow in the Mary has decreased significantly compared to the historical record. For example, in the simulation of river flow, mean annual freshwater flow at the river mouth between 1999-2007 was 58% of that between 1890 and 1999 (Burgess 2008). In addition, climate change predictions for the Mary River are for increased variability in streamflow and a likely decrease in streamflow overall. The result is likely extended low flow periods. Work in the Mary shows similar trends to other Australian rivers that a 10% decrease in rainfall is roughly correlated with 30% decrease in streamflow (Burgess 2008).

The second significant influence on the estuary are the tidal barrages which have been installed to provide water to irrigation industries and for urban water supply. The focus here is on the Mary River Barrage. The tidal barrage was installed in 1982 to benefit irrigators, particularly of sugar cane, who wanted access to freshwater for longer periods of time. It has created a ponded area which extends about 30 km upstream and which has raised the water level in this section of the river. Although there is a fishway on the barrage which has been upgraded twice since construction, during low flow months often the water level is drawn down below the level that the fish way can operate. Water quality in the barrages declines when water stops flowing through the barrages, and levels down to zero oxygen have been recorded where there are large rafts of aquatic weeds such as salvinia and water hyacynth. Extensive fish kills have also occurred and over 18 km of water hyacinth and salvinia rafts during the 2006/2007, have occurred at levels of extraction much less than full allocation. Conversely, marked improvements in this oxygen regime have been seen in the Mary Barrage when 21 ML/day flows through the fishway. (MRCCC unpublished data).

The barrage has several effects on the estuary. The barrage acts as a barrier to fish migration during times when the fishway is not operating. It also creates a permanent limit to the upper reach of the estuary (which previously moved up and down the river according to the dynamics between freshwater flows and tidal influences) and impacts on the extent to which salinity gradients and salinity based ecotones are present within the estuary. Some of the effects of the barrage on the estuary have been recorded in water quality monitoring. A review of long term monitoring records available from the Queensland EPA conducted by Max Winders and Associates (2008) identified that the barrage has had marked effects on water quality. Results for electrical conductivity presented by Max Winders and Associates are reproduced in Table 1.

A similar pattern was observed with respect to organic nitrogen levels. Although a more comprehensive analysis is required to fully understand the causes of these changes and impacts on ecology these records of electrical conductivity provide an indication of the way in which the barrage has impacted on water quality along the length of the estuary.

Table 1: Electrical conductivity 80th and 20th percentiles before and after construction of the Mary River barrage commenced (1979) (source; Max Winders and Associates, 2008)

distance from river mouth (km)	EC 80th % (mS/cm) pre-1979	EC 80th % (mS/cm) post-1979	EC 20th % (mS/cm) pre-1979	EC 20th % (mS/cm) post-1979
50.2	0.98	6.10	0.20	0.30
45.4	0.90	10.82	0.30	0.30
42.2	1.10	13.50	0.30	0.34
39.1	1.20	16.10	0.30	0.36
36.1	1.70	18.94	0.20	0.38
32.8	3.90	22.38	0.30	0.40
27.5	10.75	28.44	0.38	0.76
22.5	20.04	36.98	0.76	5.38
17.7	29.00	42.90	1.30	13.20
12.2	40.10	48.10	7.00	25.62

These empirical observations are also supported by anecdotal evidence that suggest that since the barrage was constructed in 1982 there has been a change in the river. For example, mangroves were not to be found in the vicinity of Maryborough and people speak of periods in the year when the river at Maryborough was fresh. Boats could be moored there without the need for antifoulant paints that are now required.

These observations may also be linked to the pattern of increased salinity that has been observed in Hervey Bay. Hervey Bay is an inverse estuary and becomes hypersaline as a result of high evaporation and low rainfall and river runoff (Ribbe 2008). The ecological impacts of this hypersalinity and in particular the trend toward increases in salinity are not well understood. However, when considering water planning in the catchment these would appear to be issues worthy of attention particularly given the national and international ecological significance of the Great Sandy Strait and Hervey Bay. This issue is considered further in section 3.2.1.

Apart from the increase in extraction discussed above, a likely contributing factor to these observed changes in water quality is the way in which the barrage has been operated since it was constructed. There has been no scientifically derived strategy of providing releases through the barrage. Instead there is a practice of operating the barrage as a storage dam which has provided irrigators in the Lower Mary Water Supply Scheme with irrigation security levels in excess of the legislative requirement (and considerably higher than irrigators further upstream). If the water level is high enough and the fish way is open, water can flow out through the fishway. The Mary River Water Resource Plan (WRP) has been in place since 2006 and theoretically this legislation should seek a balance between the different demands for water in the lower end of the river system and address some of these issues. To date this legislation has not engaged with these concerns. The following section considers some of the history of the WRP and its failure of in this regard.

2.2 Mary Basin Water Resource Plan and Resource Operations Plan

Management of rivers in Queensland is overseen by the Water Act 2000. The Water Act requires development of Water Resource Plans for river basins. Development of Water Resource Plans involves collaboration between technical advisory panel (TAP) and a community reference panel (CRP). In the case of the Mary Basin, the first Water Resource Plan (WRP) was released in 2006 four months after the proposed Traveston Crossing dam was announced. This plan had been the subject of several years of development. However when it was released it was met with significant disapproval due to changes made in the final document. The community reference panel indicated they had been “profoundly deceived”. This plan remains in operation and the Queensland Department of Environment and Resource Management (DERM) has recently released for public comment the draft Resource Operations Plan (ROP) which will translate the WRP into practice.

The Mary Basin Water Resource Plan and consequently, the Resource Operations Plan are problematic for several reasons. The WRP has no specific objectives written into the text of the plan which relate to protecting the health of the estuary. This is in stark contrast to the water resource plans of the neighbouring catchments, the Burnett, Moreton and Logan all of which have specific objectives to protect their estuarine and marine environments.

Another fundamental flaw was the 150,000 ML strategic reserve identified in the WRP was not scientifically based and was required to allow for the operation of the now defunct Traveston Crossing Dam proposal. (150,000 ML is the exact volume of the combined Stage 1 and Stage 2 of the proposed Traveston Crossing Dam). As already illustrated, during dry months of the year and during dry years, the flow in the river falls short of the environmental flow objectives established in the WRP. If this strategic reserve were utilised it more than double the current supplemented allocations of 103,000 ML and would exacerbate the difficulties the river experiences during dry times, particularly the JASON months (July – November).

Although the draft Resource Operations Plan (ROP) does not provide access to the so-called strategic reserve there is concern that when the ROP is finalised (potentially mid 2011), the introduction of water trading could drive the system towards full utilization of all existing allocations. This situation has not been experienced in the river to date and as Figure 4 and 5 show, several of the environmental flow objectives set out in the WRP will not be satisfied. As Burgess (2009a; 2009b) has indicated, the river would be placed under severe stress under these circumstances. The stress would likely extend into the estuary.

2.3 Jurisdictional limitations

A feature which appears to have a significant bearing on the environmental flow management of the Mary River estuary is the jurisdictional boundary created by the tidal barrage located at AMTD 59.5 km.

Currently the main mechanism by which freshwater flow occurs during low flow periods is through the barrage is via the fishway. One obvious mechanism for improving environmental flow to the estuary and reducing the barrier to fish migration that the barrage often creates would be for the Resource Operations Plan to stipulate operation of the barrage so that the fishway runs more often (if not continually). The water resource plan and the Water Act through which the WRP is enacted is the responsibility of DERM. Fishway operation is the responsibility of the Department of Employment Economic Development and Innovation (DEEDI) and enacted through the Fisheries Act. Consequently, the draft ROP, which implements the WRP does not mandate operation of the fishway. Instead the draft ROP sets a minimum operating level of the barrage of 0.5m which is well below the level at which the fishway operates (at 1.7m). The process that must be followed is that the licence holder for the barrage i.e Sunwater must negotiate with DEEDI staff responsible for the Fisheries Act to make agreement regarding the operation of the fishway.

In the case of the Mary barrage this jurisdictional disconnect has contributed to the WRP overlooking environmental flows to the estuary. It would appear that there is a need for the Water Act and Fisheries Act to be able to address issues such as this.

In the next section, the argument for environmental flows to the estuary are considered. The jurisdictional issues just discussed are revisited in the later sections of the paper which consider what these environmental flow requirements should be and how they might be delivered.

3 Arguments for estuarine environmental flows

3.1 Regulatory impetus for the inclusion of estuarine environmental flows

There are frameworks at both the state and federal level which support the inclusion of estuarine environmental flow requirements into water planning processes.

At the national level the National Water Initiative provides consideration of estuarine impacts. Schedule E of the Nation Water Initiative (NWI) (COAG 2004, p. 35) specifies that in developing water plans and planning processes States and Territories should consider:

> 5iii) impacts on water users and the environment that the plan may have downstream (including estuaries) or out of its area of coverage, within or across jurisdictions

The Queensland Government have in principle adopted this perspective. In their state implementation plan (Queensland Government 2006, p. 94), which outlines how the state will achieve the key actions of the NWI, Queensland states that:

> "Water resource plans (WRPs) developed under the Water Act 2000 provide a framework for the provision of environmental flows to maintain river and estuary health. These flows are delivered through flow management strategies and rules specified in resource operations plans (ROPs). "

The state also identifies that estuarine health is an indicator that will be used to monitor the effectiveness of the water planning process and lists research that seeks to address gaps in knowledge in relation to interconnections between rivers, groundwater and estuaries.

The Water Act 2000 (Qld) is the primary vehicle by which the NWI outcomes are to be achieved. According to s 10(1) of the *Water Act* 2000 (Qld), with regard to allocation and sustainable management (chapter 2) the purpose is to "to advance sustainable management and efficient use of water and other resources by establishing a system for the planning, allocation and use of water". The term "sustainable management" is defined in s 10(2) of the Act as management that:

(a) Allows for the allocation and use of water for the physical, economic and social well being of the people of Queensland and Australia within limits that can be sustained indefinitely; and

(b) Protects the biological diversity and health of natural ecosystems; and

(c) Contributes to the following:

(i) Improving planning confidence of water users now and in the future regarding availability and security of water entitlements;

(ii) The economic development of Queensland in accordance with the principles of ESD;[1]

(iii) Maintaining or improving the quality of naturally occurring water and other resources that benefit the natural resources of the State;

[1] "Principles of ecologically sustainable development" (ESD) are defined in the *Water Act* 2000 (Qld), s 11

Consideration of estuarine health is explicitly detailed in the text of Water Resource Plans for the river basins to the north and south of the Mary River and in plans put in place well before the Mary Basin e.g. for the Burnett. For example, the Moreton Basin Water Resource Plan (2007) identifies the minimizing changes to brackish water habitats as an ecological outcome of the plan. The Moreton Basin Plan also specifies that the impacts on estuarine reaches should be considered in relation to decisions regarding taking of the strategic reserve (S26 1c(ii)), granting of licences for infrastructure (s37 1a (iii)) and extraction of water from a waterhole or lake (s23 2a(ii). The Moreton Basin Plan also specifies monthly low flow environmental objectives of the mouth of the river. In contrast, the Mary Basin WRP include no text which specifies that the Mary River estuary or river mouth should be protected.

Having identified that the regulatory framework for incorporation of estuarine health in water planning processes already exists and is being used in other river basins in Queensland, the next section presents the ecological argument for the need for environmental flows to the Mary River estuary.

3.2 Ecological argument for environmental flows

The inclusion of estuarine concerns in water resource planning in Queensland to date (with the Mary River as one exception to this pattern) is consistent with the growing evidence of the important role that freshwater flows play in estuarine health (Alber 2002; Arthington et al. 2010; Gippel et al. 2009; Halliday & Robins 2007; Loneragan & Bunn 1999; Meynecke et al. 2006; Pierson et al. 2002; Robins et al. 2005; Scheltinga et al. 2005; Staunton-Smith et al. 2004).

There are three discernable and significant estuarine systems associated with the Mary River which each requite separate consideration in relation to estuarine environmental flows. Firstly there is the Mary River estuary itself, from the Mary River mouth to the tidal barrages and the associated estuarine tributaries. Most notable of these is the Susan River, the entirety of which is incorporated in the Great Sandy Strait Ramsar wetland site and is a fisheries protected zone. Secondly, the Great Sandy Strait (the estuarine zone between Fraser Island and the mainland) is greatly influenced by the Mary River. Finally, the Mary River is also the most significant river influencing Hervey Bay, which has been classified as an inverse estuary (Ribbe 2008).

Alber (2002) summarised schematically the key factors which link freshwater flow and aspects of estuarine health and productivity (see Figure 6).

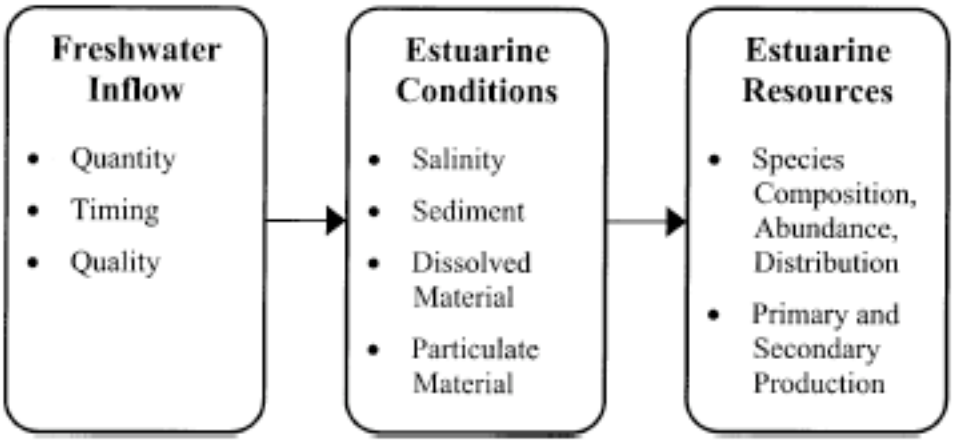


Figure 6 – Summary of relationships between freshwater flow, estuarine conditions and estuarine resources (Source: Alber, 2002)

As Figure 6 suggests, quality, quantity and timing of freshwater inflow are all important determinants of characteristics of the estuarine environment (called estuarine conditions), which in turn impact on species composition, abundance, distribution and primary and secondary production. Scheltinga et al (2006, p. 26) have identified that the list of four key estuarine conditions proposed by Alber (2002) needs to be expanded for Australia conditions, resulting in the following list:

- salinity,
- sediment/turbidity,
- water temperature,
- nutrients and organic matter,
- dissolved oxygen,
- pH,
- hydrodynamics – including water velocity, shear stress, mixing and circulation patterns,
- geomorphology and abiotic habitat, and
- connectivity

In addition Scheltinga et al (2006) adapted Alber's (2002) conceptualisation to include terminology in more common use in Australia and to incorporate research from South Africa. The result of this synthesis is provided in Figure 7.

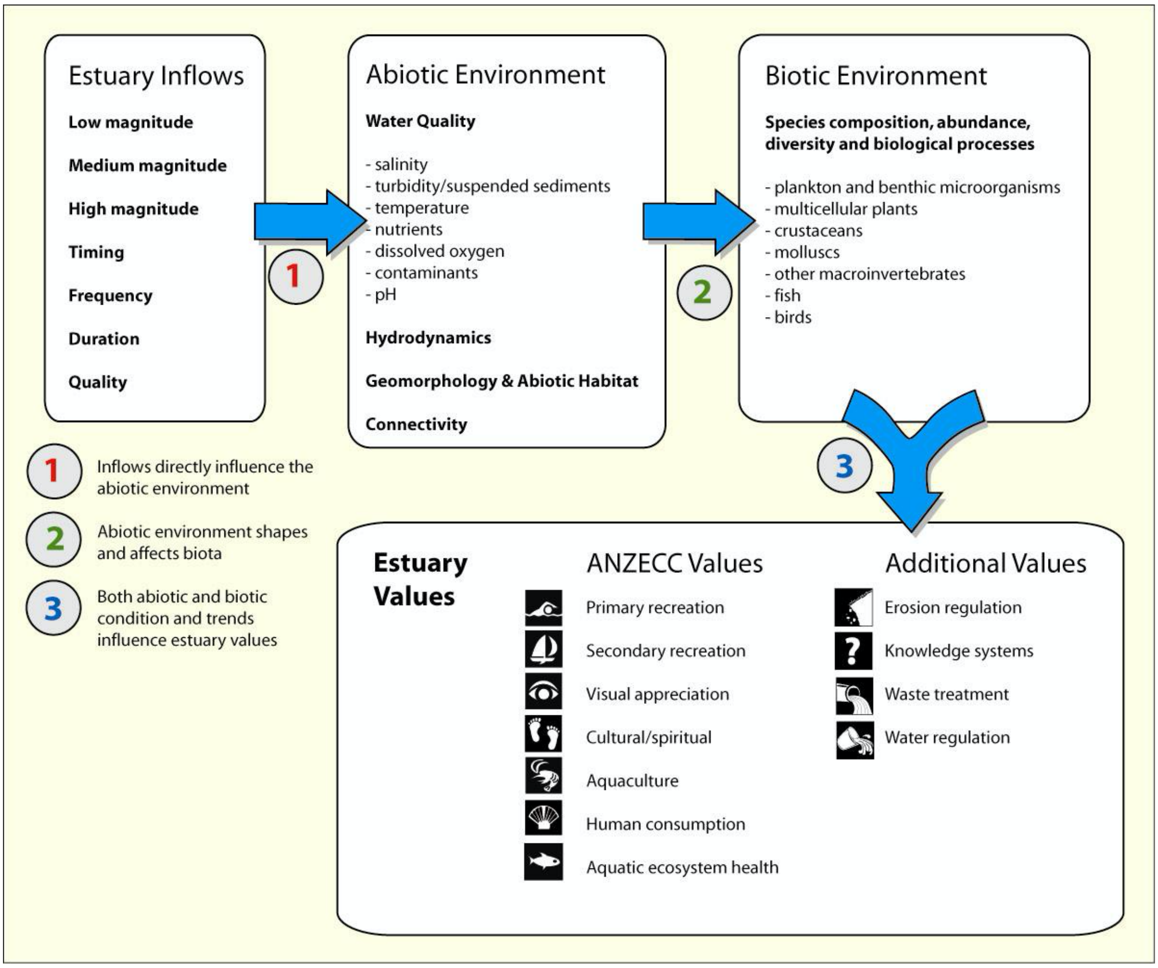


Figure 7 – Conceptual Model of the relationship between freshwater inflows and estuaries (Source: Scheltinga et al 2006)

The unpredictable and intermittent flow regime of the Mary River combined with the complex geomorphological and hydrological characteristics of the Great Sandy Strait and Hervey Bay suggest that freshwater flow patterns are likely to have a significant influence on the ecological characteristics of these systems. Hervey Bay has been shown to be increasingly hypersaline, in part as a result of reductions in river inflows over previous decades (Ribbe 2008). To demonstrate the need for environmental flows to urgently be addressed in water resource planning processes in the Mary Catchment and to contribute to this process, three key issues are considered below. These are salinity, fisheries productivity and conservation/ biodiversity status.

3.2.1 Salinity

With regard to salinity, as Scheltinga et al (2006) have highlighted, this is an important influence on estuarine ecosystems and it has been described as the ‘master factor’ governing estuarine biota distributions etc (Pierson et al, 2002 p 14).

Pierson et al’s (2002) list of major ecological processes which are intimately connected with salinity illustrate the importance of this aspect of water quality. They identified processes which affect salinity as being the most common and listed affected ecological processes. Table 2 summarises the salinity mediated processes grouped, as Pierson et al (2002) have done, according to three inflow categories of low flow, medium to high flow and across all flow magnitudes. The most notable affects of salinity arise during low flow or across all flow magnitudes.

As already mentioned above (see Table 1), changes in salinity have already been observed in the Mary River estuary since the barrage was installed. Keeping in mind that the barrage has never been operated to provide environmental flow, the changes in salinity presented in Table 1 indicate that the barrage has had a long term impact on salinity throughout the estuary. Commonly experienced salinity (as indicated by the 80% percentile) is higher throughout the entire estuary, with the greatest changes occurring in the middle reaches of the estuary (in terms of the order of magnitude change). These changes are likely to have had dramatic impacts on the ecology of the Mary River estuary. As the list of salinity mediated processes provided in Table 2 indicates, the influences of salinity not only includes the impact of water quality on ability of species to survive, but on the distribution of suitable habitat and behavioural cues that impact on various stages of the life cycle. Anecdotal reports of the failure of the Mary River based fishing industry following the barrage construction suggest the magnitude of the impacts.

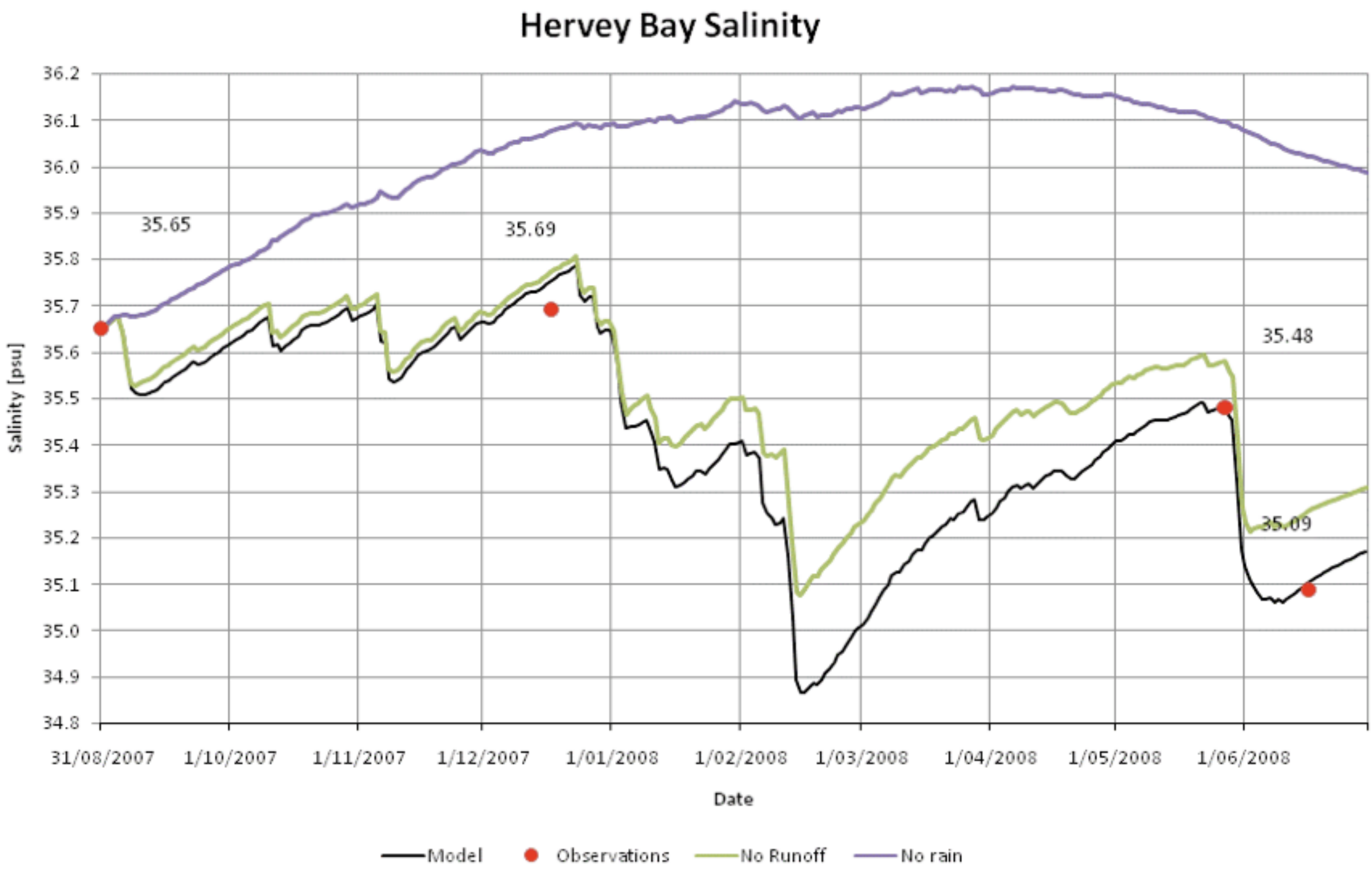
Table 2 - Summary of Salinity mediated processes (Source: Pierson et al, 2002)

Inflow group	Impact of change in freshwater inflow	Ecological Processes affected
Low – 2	Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna	Fauna with low salinity tolerance may include eggs, larvae, juveniles or adults. Physiological stress or competition from lower estuary species are a concern. *The Mary River Barrage may exacerbate this issue by truncating the estuary and decreasing salinity gradients particular during periods of no or low discharge.*
Low – 3	Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive flora	Riparian or instream plants unaccustomed to elevated salinity may die and impact on the habitat, back stability and water quality.
Low – 4	Extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota	Physiological stress and/or competition with species from marine environments
All – 1	Altered variability in salinity structure	Likely to disrupt lifecycles due to influence of migration and breeding cues
All – 2	Dissipated salinity/chemical gradients used for animal navigation and transport	Pierson et al refer to evidence that juvenile estuarine fish & invertebrate species use salinity gradients to navigate. *Connectivity with periods of hypersalinity in Hervey Bay and patterns of salinity in the GSS and Marthe inverse nature of the Hervey Bay estuary and the salt fountain off the continental* shelf
Low – 1	Increased hostile water-quality conditions a depth	Reduced inflows impact on vertical mixing. Demersal eggs and large-size taxa a most at risk.
Low – 7	Aggravation of pollution problems	Low DO is aggravated by high salinity.

An estuarine environmental flow regime could help ameliorate the impact of the barrage. The figures provided in Table 1 indicate that the barrage has changed the day to day physical characteristics of the estuary. Consequently, frequent environmental flows are necessary to contribute to a downward shift in commonly occurring salinity throughout the estuary. The magnitude of these flows and their frequency is discussed further in section 4.

Salinity patterns in Hervey Bay have also been studied in some detail and the findings from this research suggest another piece of the puzzle regarding the requirement for estuarine environmental flows. Ribbe (2006, 2008) confirmed that Hervey Bay is often an inverse estuary, meaning that rather than salinity increasing with distance from the coast, it decreases. This pattern is attributable to a layer of hypersaline water that is created by evaporation exceeding inputs via rainfall and river flow. Hypersalinity and its associated patterns of temperature and density are significant in that they may influence ecological processes via many of the measures listed by Pierson et al (2002) through not only changing water quality by driving different flow patterns. The research into hypersalinity has indicated that the Mary River can have a significant influence on this pattern. For example, Ribbe's (2008a)final sampling run in August 2008 followed significant rainfall events and he attributed the erosion of the hypersalinity zone observed at this time to flows from the Mary River combined with earlier conditioning (reduction) of salinity caused by rainfall in Hervey Bay itself.

Using a simple salt balance model, Ribbe (2008b) has subsequently proposed preliminary estimates of the impact flows from the Mary River have on salinity in Hervey Bay. He analysed rainfall, river flow and evaporation patterns between August 2007 and July 2008. The results of this analysis are shown in Figure 8. In this preliminary analysis, removal of the February 2008 flood event is predicted to cause a elevation of salinity of about 0.2ppt (200ppm) (Ribbe 2008b). Gradients across Hervey Bay of 1.4 ppt (parts per thousand) (August 2007) and 0.7ppt (December 2007) and 0.4 ppt (May 2008) were associated with the presence of the inverse estuary characteristic (Ribbe 2008a). Therefore a reduction in the order of 0.2 ppt associated with reduction in river flow is not insignificant and could potentially influence salinity distributions and gradients and associated habitats and currents.



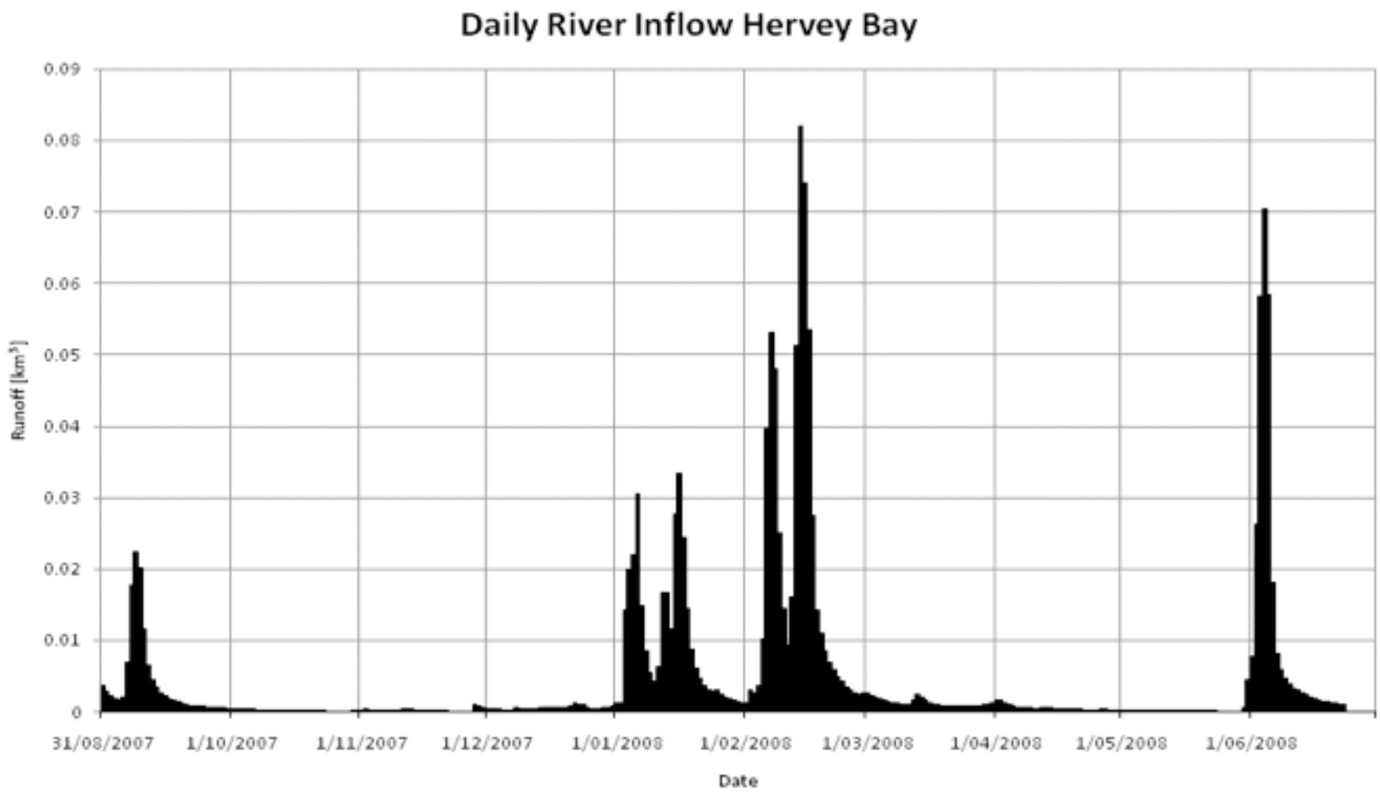


Figure 7: Response of modelled salinity in Hervey Bay to flows from the Mary River (Ribbe 2008b)

In addition, the maximum salinities associated with hypersalinity experienced in Hervey Bay exceed the upper limit of 35ppt prescribed in water quality guidelines for aquaculture and for optimum productivity of marine species (Environment Protection Agency 2010). Even during June 2008 when the inverse estuary had dissipate, average salinity exceed the guideline and was 35.15ppt (compare maximums in the vicinity of 36ppt during the other three sampling periods) (Ribbe 2008a).

Evidently, the modeled salinity is based on removal of all river flow and therefore represents a worst case scenario. However it does provide an indication of the direct relationship between Mary River flow and Hervey Bay salinity and suggests that there is merit in considering the impact of reductions in flow pulses across a range of magnitudes on Hervey Bay salinity. This aspect of environmental flows is worthy of attention in light of the fact that demand for water from the Mary River are likely to increase in the future (particularly from the large population in South East Queensland) and as the impacts of climate change become more apparent.

To the best of the authors knowledge, salinity patterns in relation to the Mary River have not been studied in the Great Sandy Strait. Given the Great Sandy Strait provides the link between the Mary River estuary and Hervey Bay the interconnections between river flow and salinity levels would logically extend to this body of water as well.

Salinity is revisited in section 4 as it formed the basis of one of the estimates of environmental flow requirements to the estuary considered in that section. The impact of environmental flows on fisheries is the focus of the next section.

3.2.2 Fisheries

Research into the relationship between freshwater flows and productivity of estuarine fish species has revealed that freshwater plays and important role in the life cycle of many fish, including those of commercial and recreational significance. According to Scheltinga et al (2006), in Australia mullet (*Mugil* sp.), barramundi (*Lates calcarifer*) and flathead (*Platycephalus* sp.) showed a positive relationship between catch and increased freshwater flow while whiting (*Sillago* sp.) showed no significant correlation (Loneragan and Bunn, 1999; Robins *et al.*, 2005).

Halliday and Robins (2007) have proposed three main causal mechanisms linking freshwater flows and fisheries:

- freshwater may enhance overall biological productivity via inputs of organic and inorganic matter into the foodchain
- freshwater flows impact on recruitment and abundance of species by affecting access to important nursery habitats
- catchability of particular species may be increased by freshwater flows that trigger behaviours that increase the likelihood of fish being caught (this is relevant because Catch Per Unit Effort is one of the key measures of fisheries productivity).

It is suspected that all three mechanisms may play a role by the contribution of each remains unclear.

The significance of the fishery of the Great Sandy Strait has been recognized at the Commonwealth level through the contribution that this feature made to the declaration of the area as a Ramsar site. At a state level, several Fish Habit Areas have been declared as has a Marine Park (FRC Environmental 2007). Commercial and recreational fisheries are significant industries in the Mary River affected estuaries and are estimated to contribute approximately

$200million per annum into the local economy (Smith 2008).

To illustrate the possible impact of freshwater flows on fisheries the Mary River associated estuaries the example of the mullet is considered in further detail below. The mullet is significant because of its diadromous life cycles, its commercial value and because of the role it is believed to play in the diet of the critically endangered Mary River cod (Stockwell et al. 2004). Figure 8 depicts the conceptual model of the life cycle of the sea mullet proposed by Halliday and Robbins (2007). As Figure 8 indicates there are six hypotheses about the role that freshwater plays in a mullet's life and throughout their life cycle they move through fresh, estuarine and marine waters. Figure 9 presents historical records of monthly mullet catches in the Mary River affected estuaries (corresponding to grids v33, v34, w33,w34) which are available from the Chrisweb database (http://chrisweb.dpi.qld.gov.au/chris/) together with monthly flows out of the Mary River during the period between February 1988 and Dec 2004.

Figure 9 shows a positive correlation between total annual flow and the tonnage of mullet caught, particularly during non-flood years. If the three flood events which exceed the average annual flow of the river (shown in Figure 9) are excluded from the analysis, the correlation is strongest and has pearson correlation coefficient of 0.74 (it is 0.50 with the floods included). It is reasonable to exclude the flood events because catch effort is likely to be affected by poor weather conditions and in some instances cyclonic weather that occurred in these years.

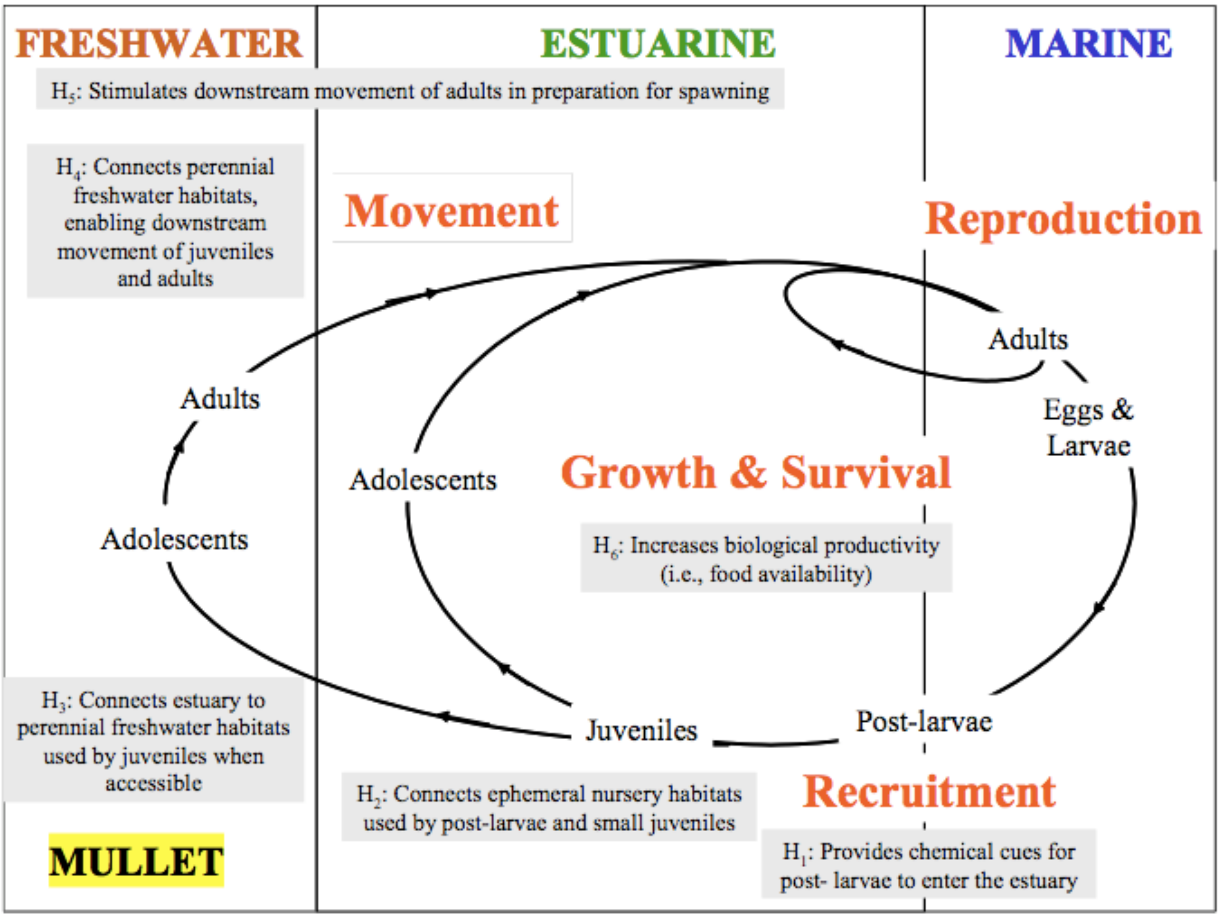


Figure 8 Conceptual model of the life cycle of sea mullet, showing six hypotheses for the role of freshwater in their life cycle (Halliday & Robins 2007)

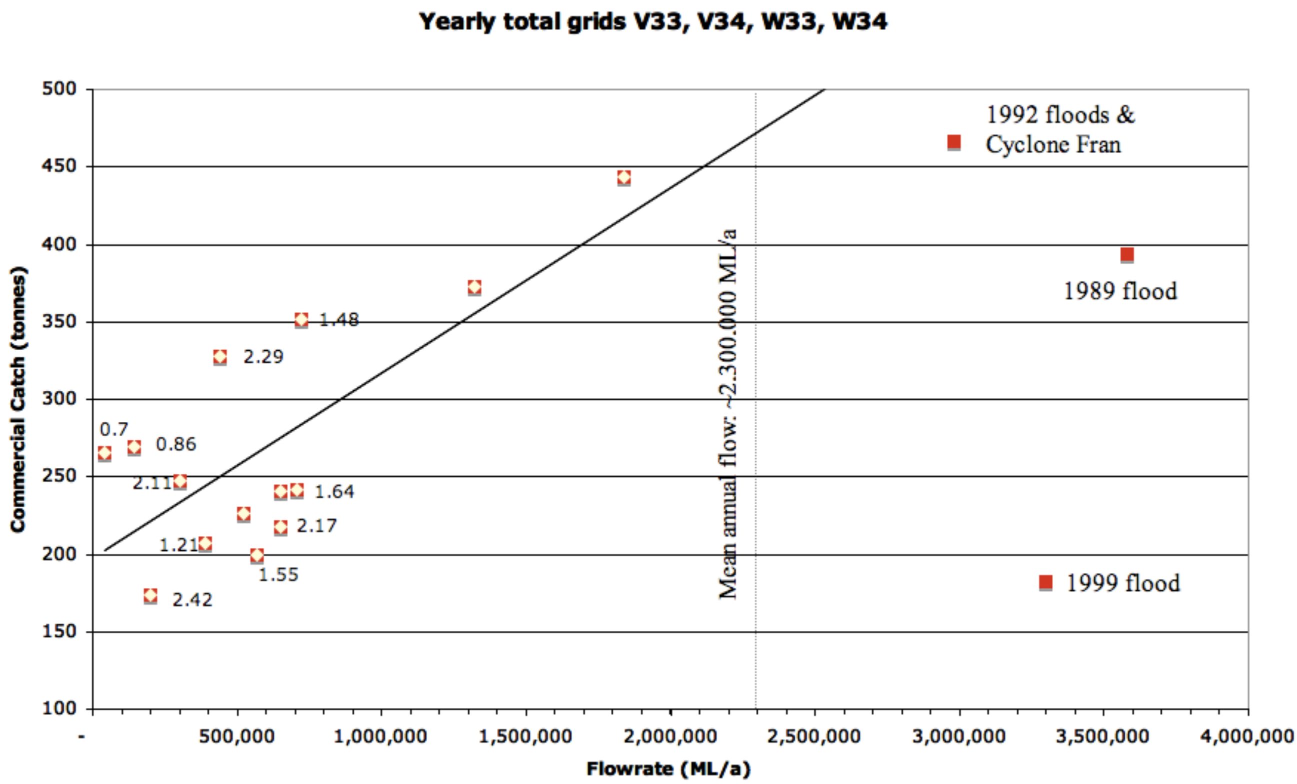


Figure 9: Relationship between annual catch of mullet and Mary River annual flowrate between 1988 and 2004 (showing the coefficient of variation for select flows)

In terms of environmental flows, the relationship between flow and catch presented in Figure 9 suggest two important factors. It shows a tendency for mullet catch to be proportional to flowrate across a range of flows, from low flow up to the mean annual flow. Secondly, the high variability in catch volume below annual flow of 300,000 ML/a may be an indicator of the way in which different flow regimes deliver different patterns of flow over the barrage and how this impacts on the ability of the mullet to move through the freshwater stage of their life cycle (Figure 9). The coefficient of variation figures (based on monthly flow data) provided adjacent to a selection of data points in Figure 10 illustrate that the low flow years with the highest catch had less variability in flow compared to other low flow years shown. This may suggest the important role for baseflow. Further research could readily evaluate the veracity of this hypothesis and use the findings to determine the magnitude and patterns of flow that are required to meet the mullet's need for biopassage at the barrage and also support productivity in the estuary. In absence of this research the data presented here underscores the fact that freshwater flows is a critical part of mullet ecology and suggests that both base flow and higher flow magnitudes are beneficial to the species.

The mullet is only one species caught in the Mary River associated estuaries that is know to be affected by freshwater flows. Others include Australian Bass, Barramundi, Blue Catfish, Bull Shark, Marbled Eel, Mangrove Jack, Snub-nosed Garfish, Flathead, Banana Prawns, Bay Prawns, and King Prawns (FRC Environmental 2007). Some of these species are of commercial and recreational significance. Consequently, economic benefits would be expected to result from provision and protection of estuarine environmental flow and fish passage. For example, over the period depicted in Figure 10, the mullet catch was worth an average of more than $830,000 a year at the point of landing (ie excluding transport and marketing costs). In total, commercial fisheries are estimated to be worth $50million annually.

Freshwater flows have also been linked to fisheries outside of estuaries. For example Hoedt and Dimmlich (1995) reported “links between anchovy spawning, zooplankton productivity and freshwater flows into nearshore and shelf habitats” (in Scheltinga et al 2006). This is significant given that Hervey Bay has been identified as an anchovy spawning area (Ward et al. 2003).

Consideration of the mullet provides a starting point. However, it would be preferable to assess the relationship between environmental flows and fisheries by performing an analyses of the type presented here for a wider range of species and to gain a picture of the impact freshwater flow has throughout the seasons, and throughout wet and dry years. The data required to conduct an analysis of the relationship between these species and river flow is available and could be used in much the same way as similar data is used to develop flow regimes for aquatic species such as the Mary River Cod. It could also be used to identify ‘flow related guilds’ or ‘habitat related guilds’ (Arthington et al. 2010) of species which share responses to changes in the hydrological regime or share similar habitat needs. The economic, cultural or social significance of these species could also be incorporated into the analysis as Arthington et al (2010) have alluded to in their call for Integrated Water Resource Management. Such an approach would extend beyond fisheries. In the next section, the focus broadens beyond fish and the relationship between environmental flows, biodiversity and conservation in the Mary River estuary is considered.

3.2.3 Biodiversity and conservation

Although much focus has been placed on the contribution of freshwater to fisheries productivity, it follows that some of the same factors which impact on fisheries will also impact on other species within an estuary and therefore have an impact on biodiversity and conservation objectives. In addition to the way in which changes in water quality and hydrodynamics might influence availability of appropriate habitats, the impact of freshwater flows on availability of trophic pathways which are significant for biodiversity and conservation purposes is an important consideration. Figure 10 shows a conceptual model of the food web in the Great Sandy Strait which is based on work by Gehrke (2007). It shows the interconnections between various primary producers, detritivores, omnivores and carnivores.

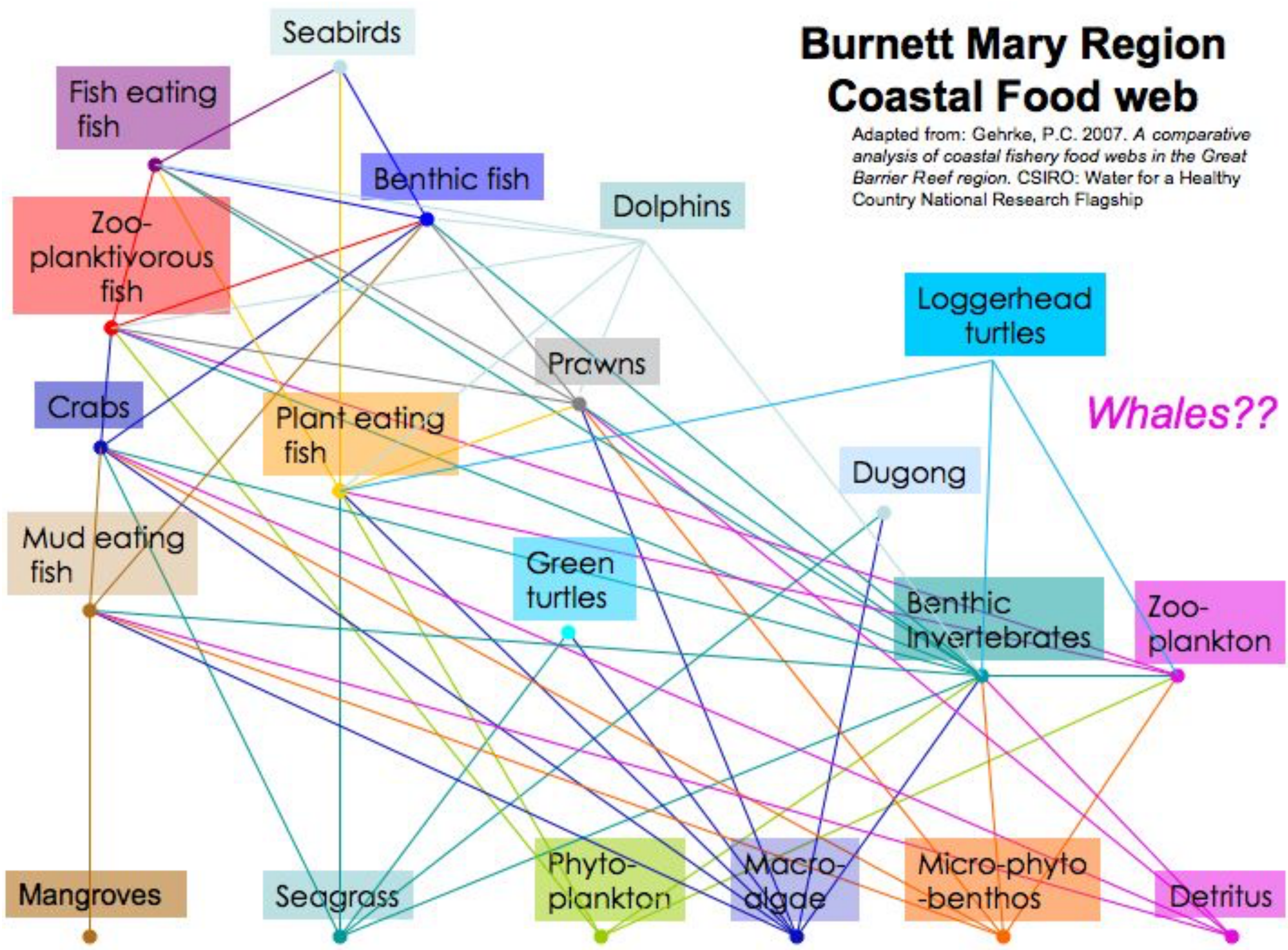


Figure 10: The Food Web of the Great Sandy Strait (Gehrke 2007) illustrating interconnection between the various tropic groups (omits migratory birds which feed on euryhaline invertebrates see Scheltinga et al 2006)

Importantly, Figure 10 clearly illustrates the crucial role that benthic species play in estuarine foodwebs. Pierson et al (2002), in their analysis of the impacts of flow changes repeatedly referred to the vulnerability of benthic species to changes in flow regimes. Gaining an understanding of environmental flow requirements needed to maintain productivity in conservation significant trophic pathways would be a logical approach to water planning.

Due to the complexity of food webs, a simplified approach to trophic pathways could be adopted by focusing on multi level food chains which have a species of conservation significance at their peak. There are numerous possible candidates for high level species in these trophic pathways. Two possibilities include birds and cetaceans.

Migratory birds are a critical feature which as contributed to the classification of the area as a Ramsar site and listing of the region under the JAMBA and CAMBA agreements. Many of these birds spend time in the Great Sandy Strait to feed and regain body weight before they return to breeding grounds in the northern hemisphere. They rely on benthic invertebrates for their diet. The largest migratory bird, the Eastern Curlew (Numenius madagascariensis) is a particularly significant species because the Great Sandy Strait provides an overwintering spot for a larger proportion of the total population leaving the northern hemisphere (Driscoll & Ueta 2002). It may be instructive to develop an understanding of the role that freshwater flows play in meeting the trophic needs of the Eastern Curlew.

The rare indo-pacific humpback dolphin (Sousa chinensis) is one of the most important resident cetacean species utilising the Great Sandy Strait (Berry 2009). They are estuarine feeders and are dependent on productivity in the lower levels of the food web to provide their diet of fish and prawns. Research into the role of freshwater flows in the trophic pathway of this species could also provide important insights for estuarine environmental flows required to protect these species and encompass other conservation values.

In the next section, existing estimates of environmental flow needs for the Mary River estuaries are presented and extended in light of the evidence presented thoughout this paper.

4 Estimates of estuarine environmental flow needs

Arthington et al (2010, p. 3) have identified that there at least 200 methods of estimating environmental flows in use, however “there still remains a critical need for greater understanding of flow-ecological response relationships and enhanced modelling capacity to support river flow management and ecosystem conservation”. However, there is sufficient knowledge to incorporate estuarine health considerations within an adaptive management framework. In this section existing research which has provided estimates of environmental flow requirements to the estuary are provided as a preliminary indication of the needs.

The Mary River Council of Mayors commissioned Max Winders and Associates (MWA) to conduct an assessment of the impacts of the proposed Traveston Crossing Dam on estuarine ecology (Max Winders and Associates 2008). As part of this analysis, MWA use hydrodynamic (RMA-11) and water quality (RMA-2) finite element models to develop a preliminary estimate of environmental flow needs to the estuary. Their approach was based on identifying a desirable (ostensibly) minimum continual flow through the Mary River Barrage and to propose quarterly pulse that mimic the size of natural medium pulses (see Burgess, 2008).

In formulating their recommendations MWA drew on the impact of the barrage on water quality, particularly salinity. The RMA-11 modelling found that when flow over the barrage stops, it takes approximately 8 weeks for the river downstream of the barrage and approximately 3 weeks for the river mouth and adjacent areas of the Great Sandy Strait to reach the salinity of seawater. Organic nitrogen levels decayed over a similar 8 week period in the absence of a significant flow over the barrage. With a continuous flow of freshwater over the barrage of 400 ML/d the upper estuary was prevented from reaching seawater salinity almost indefinitely. With a flow of 200 ML/d it took 7-10 days.

Based on these observations, MWA recommended an environmental flow regime based on a baseflow of 200-400 ML/d and pulse flows of 1500 ML for three weeks approximately every eight weeks.

With regard to what MWA referred to as medium flow pulses Pierson et al (2002) identified five ways in which medium to high flows influence ecological processes in estuaries. These are summarised and the ecological consequences in Table 3.

Table 3 - Summary of ecological process affected by reductions in medium to high flow to estuaries (source Pierson et al, 2002)

Inflow group		**Ecological processes affected**
M/H - 1	diminished frequency that the estuary bed is flushed fine sediments and organic material (physical-habitat quality reduction)	Reduced flushing of fine sediments and organic material impacts on reproductive success of many fauna species that lay eggs on or within hard substrates
M/H - 2	diminished frequency that deep sections of the estuary are flushed of organic material (subsequent water quality reduction)	Possible creation of hostile water conditions at depth, place demersal eggs and poorly mobile taxa at risk
M/H - 3	diminished frequency that deep sections of the estuary are flushed of organic material (subsequent water quality reduction)	Similar impact to M/H – 2 plus, lower estuary may be affected if greater deposition of marine sediments at river mouth affects connectivity and water quality by reduced flushing
M/H - 4	reduced inputs of nutrients and organic material	Reduce primary productivity, followed by reduced zooplankton abundance and reduce fish and crustacean abundance
M/H - 5	reduced lateral connectivity and reduced maintenance of ecological processes waterbodies adjacent to the estuary.	Reduce mobility of mobile fauna, affect ecological process that need to be activated or maintained by connectivity.

In the low flow range, Burgess (2009b) has identified that up to 20, 000 ML/a of dedicated environmental flow would be needed to maintain natural low flow regime. However the volume required would vary significantly from year to year. Providing the flow required to operate the barrage on the Mary River (21 ML/d) at all times has also been identified as an important step toward river and estuary connectivity.

These estimates of environmental flow provide a good starting point for meeting the needs of the estuary. Further research would enable refinement of these figures.

5 Recommendations for the future

While further research is required to gain a more comprehensive understanding of the interaction between flows and the Mary River estuaries, there is sufficient knowledge available now to act and make changes to current mechanisms governing the flow regime. As outlined above there is also adequate regulatory support to enable provision of estuarine flow in the water planning process in the Mary River. The actions that can be taken in the short term are outlined, followed by an explanation of policy and research needs that would enable implementation and refinement of longer term actions.

5.1 Actions in the short term

Many of the opportunities that exist in the short term arise from the Resource Operations Plan which is currently out for public comment.

- Currently there is no fishway management plan for the barrages under the Fisheries Act and there are no restrictions put on the operation rules to maintain water flow through the fishway. It is recommended that the minimum operating levels for the barrages should be at least the operating fishway heights eg for the Mary River Barrage this is above 1.7 m. The impact of this change on the security of irrigation entitlements needs to be established, but given that security currently exceeds the legislative requirement, it is anticipated that changes could be made without violating the legislation.

- The Resource Operations Licence for the barrage could be modified to require environmental releases from the barrage, just as the draft ROP incorporates environmental flow requirements for other pieces of infrastructure in the Mary Basin. This environmental flow could be based on the work by MWA. In addition to the flow required to maintain fish passage and lower salinity in the upper estuary, medium flow pluses could be passed through the barrage as they arrive so that the flow regime mimics the natural pattern. This should also be the subject of modelling to determine impact on water security, but as suggested in relation to the previous point there is room to move within the current entitlements.

- The Resource Operations Licence should also incorporate a comprehensive monitoring program to enable the impact of these environmental releases to be established.

5.2 Policy needs

Three key policy needs have been identified:

- Although some WRPs do address estuarine flows, the jurisdictional disconnect that the barrage on the Mary River creates has been used to justify the lack of environmental flows in the Mary River. Given that the Water Act's purpose is to provide for sustainable use of water resources, it seems that there should be a mechanism through which the Water Act and Fisheries Act can be integrated to automatically provide for fish passage and environmental flows across tidal barrages.

- The Mary Basin Water Resource Plan review is due by 2016. The new plan needs to be modified to include provision for environmental flows to the estuary that protect water quality and meet the ecological needs of the three estuarine systems connected with the Mary River.

- Future demand for water both from within the catchment and through interbasin transfers needs to be moderated by strong support and incentives for efficient use of water.

5.3 Research needs

The work by MWA (2008) and Burgess (2009b) on environmental flows provides a good foundation for future analysis. Future development of this work would be supported by research into the following issues:

- The contribution of an environmental flow regime that is more irregular so that it mimics the natural flow variability. This would follow the classification of the Mary River as intermittent and unpredictable (Kennard et al. 2010), and would also be consistent with Loneragan and Bunn's (1999) finding in the Logan River that flow variability is likely to be equally important as flow magnitude.

- Site specific analysis of the role environmental flows play in estuarine ecology of Mary River estuary, Great Sandy Strait and Hervey Bay. This could include consideration of water quality and key ecological functions. The latter approach could revolve around the identification of conservation and economically significant species/guilds and trophic pathways that, combined with knowledge of natural flow patterns, can be used to refine flow magnitudes and patterns.

These research and policy instruments could be used to inform at comprehensive and scientifically based approach to estuarine environmental flows in the Water Resource Plan review due in 2016.

6 Conclusion

This paper has considered the case for environmental flows to be provided to the estuarine systems associated with the internationally significant Mary River in South East Queensland. The current State water planning process has to date overlooked this aspect of management in this particular river. However, the precedent for inclusion of estuarine environmental flows at the State level exists and is supported by the National Water Initiative. A range of existing evidence including current flow patterns in the Mary River, evidence of water quality impacts of the Mary River barrage, hypersalinity in Hervey Bay, mullet catch data in the region and the food web in the Great Sandy Strait were used illustrate the need for estuarine environmental flows. Existing estimates of environmental flow based on salinity profiles, low flow regime and biopassage through the barrage were described. Actions that can be taken now to improve the situation include provision of sufficient flow and operating levels that allow fish passage through the barrage. The Resource Operations Plan provides the opportunity to make these changes prior to the review of the Water Resource Plan due in 2016. Beyond these immediate actions, future policy and research that could improve the review process was outlined. These measures aim to facilitate the delivery of environmental flows which are continually refined based on the interconnections between environmental flows, water quality, fisheries productivity and the overall biodiversity and conservation significance of the Mary Rivers' three estuarine systems.

7 References

Alber, M. 2002, 'A Conceptual Model of Estuarine Freshwater Inflow Management ', *Estuaries* vol. 25, no. 6B, pp. 1246-1261, viewed 31 December 2007.

Arthington, A. 2009, 'Australian lungfish, *Neoceratodus forsteri*, threatened by a new dam', *Environmental Biology of Fishes*, vol. 84, no. 2, pp. 211-221.

Arthington, A. & Bunn, S. 2008, *Submission to the Traveston Crossing Dam EIS for the Mary River Region*.

Arthington, A.H., Naiman, R.J., McClain, M.E. & Nilsson, C. 2010, 'Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities', *Freshwater Biology*, vol. 55, no. 1, pp. 1-16.

Australian Heritage Database 2010, *Great Sandy Strait - Hervey Bay Area, Hervey Bay, QLD*, Environment Australia, viewed 18 October 2010.

Beach Protection Authority Queensland (BPA) 1989, *Hervey Bay Beaches*, Beach Protection Authority, Queensland.

Berry, E. 2009, *No flow - no rare dolphin?*, Our Great Sandy, viewed 18 October 20101 <http://www.ourgreatsandy.com/index_files/Page8692.htm>.

Burgess, S. 2008, *Hydrological Analysis of the Flow and Storage Data Presented in the Environmental Impact Statement for the Proposed Traveston Crossing Dam* Mary River Catchment Coordinating Committee, Gympie.

Burgess, S. 2009a, 'Traveston Crossing', *Water Engineering Australia*, vol. February, pp. 27-29.

Burgess, S. 2009b, 'Why the Mary is at risk from low flows', *The Environmental Engineer - Journal of the Society for Sustainability and Environmental Engineering,* , vol. 10, no. 2, pp. 10-13.

Burnett Mary Regional Group 2008, *Mary River Estuary Report*, viewed 6 Octoboer 2010 <http://www.sharky-web.com/bmrg/soee/Mary.pdf>.

COAG 2004, *Intergovernmental Agreement on a National Water Initiative*, viewed 3 October 2010 <http://www.nwc.gov.au/resources/documents/Intergovernmental-Agreement-on-a-national-water-initiative.pdf>.

Department of Infastructure and Planning 2009, *Projects - Northern Pipeline Interconnector Stage 2*, viewed 8 October 2010 <http://www.dip.qld.gov.au/projects/water/northern-pipeline-inter-connector-stage-2.html>.

Driscoll, P.V. & Ueta, M. 2002, 'The mirgration route and behaviour of Eastern Curlews Numenius madagascariensis', *Ibis*, vol. 3, pp. E119-E130.

Environment Protection Agency 2010, *Hervey Bay Environmental Values and Water Quality Objectives: Basin No. 137 and 139* DERM.

FRC Environmental 2007, *Traveston Crossing Dam EIS: Estuarine and Marine Ecology* Brisbane.

Garrett, P. 2009, *Proposed "No" Decision for Traveston*, Minister for the Environment, Heritage and the Arts.

Gehrke, P.C. 2007, *A comparative analysis of coastal fishery food webs in the Great Barrier Reef region*, CSIRO: Water for a Healthy Country National Research Flagship.

Gippel, C., Brett Anderson, Harty, C., Bond, N., Sherwood, J. & Pope, A. 2009, *Gap analysis and strategy development for national level estuary environmental flow policies*, National Water Commission.

Queensland Government, Q. 2006, 'Queensland's National Water Initiative State Implementation Plan'. viewed 16 October 2010 <http://www.nwc.gov.au/resources/documents/QLD-NWI-Implementation-Plan.pdf>

Halliday, I. & Robins, J. 2007, *Environmental flows for sub-tropical estuaries: understanding the freshwater needs of estuaries for sustainable fisheries production and assessing the impacts of water regulation* The State of Queensland, Department of Primary Industries and Fisheries, the Coastal Zone with the Cooperative Research Centre and the Fisheries Research Development Corporation.

Kennard, M.J., Pusey, B.J., Olden, J.D., Mackay, S.J., Stein, J.L. & Marsh, N. 2010, 'Classification of natural flow regimes in Australia to support environmental flow management', *Freshwater Biology*, vol. 55, no. 1, pp. 171-193.

Kuchling, G. 2008, *Independent Expert Review of the Information provided in the Traveston Crossing Dam EIS that relates to the Mary River Turtle (EPBC Referral 2006/3150)*, Department of the Environment, Water, Heritage and the Arts, Subiaco.

Loneragan, N.R. & Bunn, S.E. 1999, 'River flows and estuarine ecosystems: Implications for coastal fisheries from a review and a case study of the Logan River, southeast

Queensland ', *Australian Journal of Ecology*, vol. 24, no. 431-440.
Max Winders and Associates 2008, *Impact of the Proposed Traveston Crossing Dam on the Estuarine Ecology of the Mary River and the Great Sandy Region*, Mary River Council of Mayors.
Meynecke, J.-O., Lee, S.Y., Duke, N.C. & Warnken, J. 2006, 'Effect of rainfall as a component of climate change on estuarine fish production in Queensland, Australia', *Estuarine, Coastal and Shelf Science*, vol. 69, no. 3-4, pp. 491-504.
MRCCC 2010, *Home Page*, <http://mrccc.org.au/index.html>.
Pierson, W.L., Bishop, K., Senden, D.V., Horton, P.R. & Adamantidis, C.A. 2002, *Environmental Water Requirements to Maintain Estuarine Processes*, *Environmental Flows Initiative Technical Report No 3*, Commonwealth of Australia, Canberra, viewed 6 September 2009 <http://www.environment.gov.au/water/publications/environmental/rivers/nrhp/estuarine.html>.
Piorewicz, D.J. 1997, *Hervey Bay Beaches - Present Situation and Recommendations for Beach Protection*
Prange, J.A. & Duke, N.C. 2004, *Marine and Estuarine Water Quality and Wetland Habitats of the Burnett Mary Region*, Burnett Mary Regional Group for Natural Resource Management.
Ribbe, J. 2008a, *Final Report: A0074 - Monitoring and Assessing Salinity and Temperature Variations in Hervey Bay*, University of Southern Queensland Toowoomba.
Ribbe, J. 2008b, 'Hervey Bay salinity and the role of rainfall, evaporation, river runoff in controlling salinity', paper presented to the *The River, Bay and the Strait: A public forum on the downstream impacts of the proposed Traveston Crossing Dam*, Hervey Bay, 5 October 2008.
Robins, J.B., Halliday, I.A., Staunton-Smith, J., Mayer, D.G. & Sellin, M.J. 2005, 'Freshwater-flow requirements of estuarine fisheries in tropical Australia: A review of the state of knowledge and application of a suggested approach', *Marine and Freshwater Research*, vol. 56, pp. 343-360.
Scheltinga, D.M., Bell, A., Heydon, L. & Fearon, R. 2005, *Assessment of Information Needs for Freshwater Flows into Australian Estuaries - Initial Discussion Version*, Fisheries Research and Development Corporation & Land and Water Australia.
Scheltinga, D.M., Bell, A., Heydon, L. & Fearon, R. 2006, *Assessment of Information Needs for Freshwater Flows into Australian Estuaries - Final Report*, Fisheries Research and Development Corporation & Land and Water Australia.
Smith, T. 2008, 'Submission to draft Traveston Crossing Dam EIS', unpublished, Greater Mary Association.
Staunton-Smith, J., Robins, J.B., Mayer, D.G., Sellin, M.J. & Halliday, I.A. 2004, 'Does the quantity and timing of fresh water flowing into a dry tropical estuary affect year-class strength of barramundi (Lates calcarifer)?' *Marine and Freshwater Research*, vol. 55, pp. 787–797.
Stockwell, B., Hutchinson, M., Wedlock, B., Ford, E., Anderson, T., Thomson, C. & Stephens, K. 2004, *Freshwater Aquatic Biodiversity in the Burnett Mary Region - Peer Reviewed Technical Paper*, Burnett Mary Regional Natural Resource Managment Group.
Ward, T.M., Staunton-Smith, J., Hoyle, S. & Halliday, I.A. 2003, 'Spawning patterns of four species of predominantly temperate pelagic fishes in the sub-tropical waters of southern Queensland', *Estuarine, Coastal and Shelf Science*, vol. 56, no. 5-6, pp. 1125-1140.