Appendix 6

Ramsar wetland study

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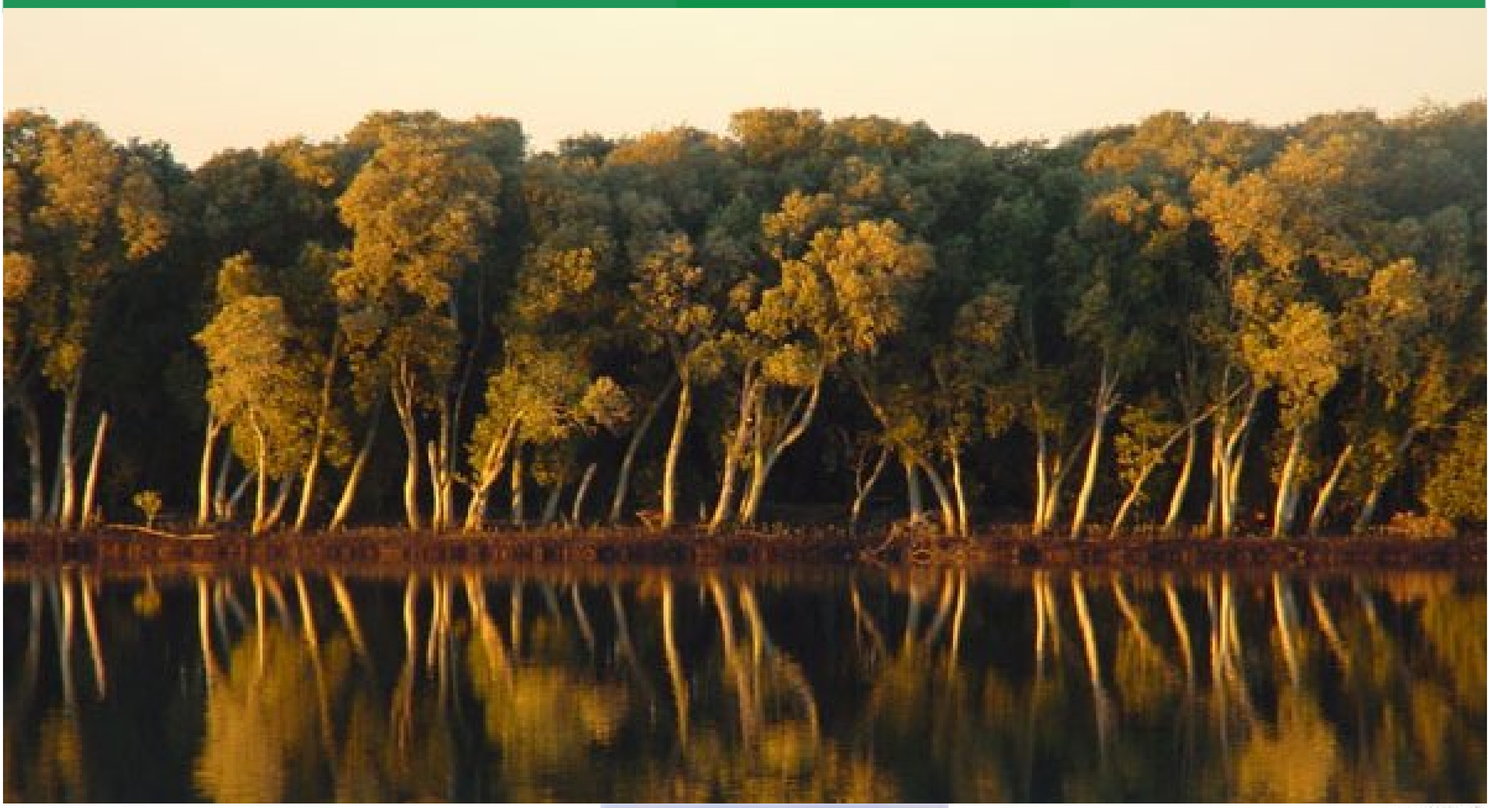
INSTITUTE FOR LAND, WATER AND SOCIETY

TILLEGRA DAM RAMSAR WETLAND IMPACT ASSESSMENT

Prepared for
Hunter Water Corporation

July 2009



TILLEGRA DAM

HUNTER ESTUARY RAMSAR WETLAND IMPACT ASSESSMENT

PREPARED FOR	Hunter Water Corporation
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Abbreviations and Glossary

ABBREVIATION/ GLOSSARY	DESCRIPTION
10 year flood	A flood that occurs on average once every 10 years. Also known as a 10% flood. See annual exceedance probability (AEP) and average recurrence interval (ARI).
100 year flood	A flood that occurs on average once every 100 years. Also known as a 1% flood. See annual exceedance probability (AEP) and average recurrence interval (ARI).
20 year flood	A flood that occurs on average once every 20 years. Also known as a 5% flood. See annual exceedance probability (AEP) and average recurrence interval (ARI).
5 year flood	A flood that occurs on average once every 5 years. See annual exceedance probability (AEP) and average recurrence interval (ARI).
AEP	Annual Exceedance Probability
AHD	Australian Height Datum. A common national plane of level approximately equivalent to the height above sea level. All water levels presented in this report have been provided in metres AHD.
Annual Exceedance Probability	AEP (measured as a percentage) is a term used to describe flood size. AEP is the long term probability between floods of a certain magnitude. For example, a 1% AEP flood is a flood that has a 1% probability of occurring in any given year. The AEP is closely related to the ARI.
ARI	Average Recurrence Interval. ARI (measured in years) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year. For example, a 100 year ARI flood is a flood that occurs or is exceeded on average once every 100 years.
Average Daily Flowrate	The value (which can also be expressed in m^3/s) determined from measured or modelled daily flows (typically expressed in ML/day). It represents the average flow rate over a 24 hour period and is different to peak or instantaneous daily flow.
CAMBA	Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and their Environment
Centre for Water Research	The Centre for Water Research was created in 1981 as a result of a joint University of Western Australia and WA State Government initiative.
DECC	NSW Department of Environment and Climate Change

DEWHA	Commonwealth Department of Environment, Water, Heritage and Arts
DGR	Director General Requirements
Digital Elevation Model	A digital representation of ground surface topography or terrain. Also known as a Digital Terrain Model (DTM)

Dry Weather Concentration	Average concentration of a particular constituent such as TN determined from measurements collected during dry weather conditions.
ECD	Ecological Character Description
EEC	Endangered Ecological Community
ELCOM	Estuary, Lake and Coastal Ocean Model. Three-dimensional hydrodynamics model developed by CWR suitable for predicting the velocity, temperature and salinity distribution in natural water bodies subjected to external environmental forcing such as wind stress, surface heating or cooling.
EP&A Act	Environmental Planning and Assessment Act 1979
EPBC Act	Commonwealth Environmental Protection and Biodiversity Conservation Act
Event Mean Concentration	Average concentration of a particular constituent such as TN determined from measurements collected during wet weather conditions or rainfall events.
Flood Level	The height of the flood described either as a depth of water above a particular location (e.g. 1m above a floor, yard or road) or as a depth of water related to a standard level such as Australian Height Datum (e.g. flood level was 7.8mAHD). Terms also used include flood stage and water level.
HCRCMA	Hunter Central Rivers Catchment Management Authority
HHWSS	Higher High Water Solstice Spring (also known as King tides) are higher high waters that occur around December. The average of all higher high waters observed over a sufficiently long period of time.
Hunter Estuary Ramsar Wetlands	The Hunter Estuary Ramsar Wetlands comprise Shortland Wetlands and Kooragang Nature Reserve (NR)
Intergovernmental Panel on Climate Change	Is a scientific body tasked to evaluate the risk of climate change caused by human activity.
ISLW	Indian Spring Low Water is the level of the mean of the lower low waters at spring time.
JAMBA	Agreement between the government of Australia and the government of Japan for the protection of migratory birds and birds in danger of extinction and their environment
Kt	Kilo Tonnes
LACs	Limits of acceptable change
mg/L	Milligrams Per Litre
MHL	Manly Hydraulic Laboratory is a business unit of the NSW Department of Commerce providing specialist services in the area of water, coastal and environmental solutions.
MHW	Mean High Water is the average of all high waters observed over a sufficiently long period of time.
MHWN	Mean High Water Neap is the average of all high water observations at the time of neap tide over a sufficiently long period of time.

MHWS	Mean High Water Spring is the average of all high water observations at the time of spring tide over a sufficiently long period of time.
MLW	Mean Low Water is the average of all low waters observed over a sufficiently long period of time.
MLWN	Mean Low Water Neap is the average of all low water observations at the time of neap tide over a sufficiently long period of time.
MLWS	Mean Low Water Spring is the average of all low water observations at the time of spring tide over a sufficiently long period of time.
mm	Millimetres
MSL	Mean Sea Level is the average limit of tides and is calculated as the arithmetic mean of hourly heights of the sea at the tidal station observed over a sufficiently period of time.
NPWS	NSW National Parks and Wildlife Service
NTU	Nephelometric Turbidity Unit
Peak Flow rate	The highest discharge (typically expressed in m3/s) found in a river channel in response to a particular rainfall event. The peak flow corresponds to the point of the hydrograph that has the highest flow.
Percentage Exceedance	The value of a variable above which a certain percent of observations fall. The 20% exceedance is the value (or score) below which 80 percent of the observations may be found. That is, only 20% of the observations exceed the value.
Percentile	The value of a variable below which a certain percent of observations fall. The 20 percentile is the value (or score) below which 20 percent of the observations may be found.
PINNENA	Database developed and managed by the NSW Department of Land and Water Conservation.
ppt	Parts Per Thousand
SLR	Sea Level Rise is the long-term increases in mean sea level.
Total Nitrogen	The sum of organic (i.e. ammonia, ammonium, organic nitrogen) and inorganic nitrogen (i.e. nitrite and nitrate)
Total Organic Carbon	The sum of carbon bound in an organic compound.
Total Phosphorus	The sum of organic phosphorus and inorganic phosphorus (i.e. orthophosphate).
TSC Act	NSW Threatened Species Conservation Act
TSS	Total Suspended Sediments
TUFLOW	One-dimensional (1D) and two-dimensional (2D) flood and tide simulation software developed by BMT WBM. It simulates the complex hydrodynamics of floods and tides using the full 1D St Venant equations and the full 2D free-surface shallow water equations.
WaterCAST	Catchment model developed as part of the eWater Cooperative Research Centre.

Executive Summary

1. Hunter Water Corporation has proposed the construction of the Tillegra Dam on the Williams River at Tillegra Bridge on Salisbury Road, approximately 15 km from the town of Dungog and 100 km north-west of Newcastle in the Hunter Valley of NSW. The dam will impound 450,000 megalitres and will supply town water to the Lower Hunter Region.

2. The construction of the dam has been identified by the Department of Environment, Water, Heritage and Arts (DEWHA) as a Controlled Action under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act). The controlling provision is "Wetlands of International Importance", specifically the Hunter Estuary Wetlands Ramsar site, and the action is subject to the assessment and approval process under the EPBC Act. In line with the Commonwealth and NSW State Government bilateral agreement, supplementary Director Generals Requirements (DGRs) have been prepared, subsequent to the initial DGRs for Tillegra Dam as part of the *Environmental Planning and Assessment Act 1979* (EP&A Act) approvals process.

3. This report contains information obtained by Hunter Water Corporation to address the supplementary DGRs and comprises: i) a review of the Ramsar Convention on Wetlands; ii) a description of the ecological character of the Hunter Estuary Wetlands; iii) modelling of water flows, nutrients and sediment to the Hunter Estuary and Hunter Estuary Wetlands; iv) assessment of the impacts of the modelled changes on the Hunter Estuary and Hunter Estuary Wetlands; v) identification of information gaps and limitations of the methods; vi) recommendations to avoid or mitigate the impacts from Tillegra Dam; and vii) conclusions about the level of impact that might result from Tillegra Dam, based on the results of this investigation.

The Ramsar Convention on Wetlands

4. The Ramsar Convention on Wetlands is an intergovernmental treaty adopted in 1971 in the city of Ramsar in Iran. It is popularly known as the Ramsar Convention and formally as the Convention on Wetlands. The mission of the Convention is "*the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world*". The keystone concepts within the Convention are "wise use" and "maintenance of the ecological character" of all wetlands.

5. Countries that join the Convention accept four main commitments: to designate at least one wetland for inclusion in the Ramsar List of Wetlands of International Importance; to promote the wise use of wetlands in their territory; to establish nature reserves in wetlands and to promote training in wetland research, management and wardening; and to consult with other Contracting Parties about implementation of the Convention, especially in regard to transboundary wetlands, shared water systems, and shared species.

6. The designation of a Ramsar site is done using criteria established by the Convention and through an Information Sheet which provides a summary description of the ecological character of the wetland. The Australian Government has decided that a more detailed description of the

ecological character of all Australian Ramsar sites is required and has initiated a process of updating and extending the description of sites already on the Ramsar List. Until this is done the Information Sheet submitted to the Convention comprises the formal description of the ecological character for that site and provides the baseline reference for assessing change.

7. Contracting Parties are expected to establish management planning and monitoring mechanisms for all wetlands which they have designated for the Ramsar List to ensure their ecological character is maintained and, where necessary, restored. The management plan provides the formal mechanisms for maintaining the ecological character of Ramsar listed wetlands, including the criteria for which the site was listed as internationally important.

8. Once adverse change has been recorded or is regarded as likely to occur at a Ramsar site the Contracting Party is expected to submit a report to the Ramsar Secretariat – known as an Article 3.2 report. On-site responses to the information contained within an Article 3.2 report would be addressed through the relevant management planning processes.

9. One of the complex issues that arise when assessing adverse change in ecological character is determining the significance of the change. The Australian proforma for describing the ecological character of a wetland recommends the setting of limits of acceptable change for the critical components, processes, benefits and services of the wetland. The information required for these purposes can be collected through an integrated and ongoing inventory, assessment and monitoring program within the appropriate management plan.

10. Australia addresses its Ramsar site obligations through the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), the *Environment Protection and Biodiversity Conservation Regulations 2000* and national, state and territory wetland policies and natural resource management programmes. The EPBC Act identifies Ramsar sites as matters of national environmental significance and provides the legal framework for the listing, protection and management of Ramsar wetlands and for ensuring that the 'ecological character' of all Australian Ramsar sites is retained. The Act also sets out the consultation and notice requirements for nominations and establishes a process for assessing and approving actions that are likely to have a significant impact on the wetland.

11. The state and territory governments are responsible for facilitating and coordinating the nomination of wetlands as Wetlands of International Importance under the Ramsar Convention within their respective jurisdiction. They are responsible for presenting formal nomination documentation to the Australian Government to support the site being designated as a Ramsar wetland. The Commonwealth Government has more recently taken a leading role in assisting jurisdictions meet the requirements of the Convention.

Documentation of the ecological character of the Hunter Estuary Wetland

12. The Hunter Estuary Ramsar Wetlands is comprised of two discrete areas, the Shortland Wetlands, occupying an area of just over 45 ha and Kooragang Nature Reserve, and includes Fullerton Cove, the North Arm of the Hunter River, Stockton Sand Spit and associated estuarine habitats comprising 2,926 ha. The Hunter Estuary Ramsar Wetlands are not to be confused with the Hunter Estuary National Park, which although it includes Kooragang Nature Reserve it also includes other areas (i.e. Ash Island and Hexham Swamp Nature Reserve) and does not represent the formal Ramsar boundary.

13. In order to assess the magnitude of potential impacts of Tillegra Dam on the Hunter Estuary Ramsar Wetlands the baseline status of the Ecological Character of the wetlands was evaluated. In line with the requirements for listing the wetland as internationally important under the Convention an Information Sheet covering both parts of the Ramsar Wetland was prepared and submitted to the Convention in 2002; the Information Sheet provides the formal description of the ecological character of the Hunter Estuary Wetland.

14. A more detailed Ecological Character Description (ECD) has been compiled for the Shortlands Wetlands, but not for the entire site. An ECD, when available, is appended to the Information Sheet and provides further information for management purposes. Maintenance of the ecological character is provided by steps outlined in the management plans that have been implemented for both Shortland Wetlands and Kooragang Nature Reserve.

15. Prior to the development of the Shortland Wetlands, the area was subject to modification with significant impacts on the structure and ecology of the wetlands. These activities obstructed the natural drainage regime and restricted tidal intrusion, changing the wetlands from a partly brackish to a fresh water regime. Part of the site also consisted of an abandoned building, sports fields constructed on filled wetlands, and areas of mildly disturbed wetlands. Despite these changes the site supported nesting colonies of waterbirds and other ecological values. Remediation of the drainage regime of Ironbark Creek and the adjacent Hexham Swamp is being managed by the Hunter-Central Rivers Catchment Management Authority and includes the reintroduction of saline tidal waters through the opening of floodgates to encourage regeneration of 750 ha of saltmarsh. The Shortland Wetlands part of the site was designated as a Wetland of International Importance (Ramsar site) in 2002.

16. Until the early 1900s the Hunter River estuary contained seven islands separated by narrow channels, with the low lying areas used for fruit growing, timber harvesting and salt extraction. With the exception of the development of a ship building industry in the 1920s, no other major industry occurred on the island until 1960 when the island and the entire area were zoned for heavy industrial use. Alterations to the river flow during the development of the Hunter River as a port had already modified the natural flow regime, whereby the seven islands were consolidated to form Kooragang Island in 1967. By 1971 some 704 ha of wetlands had been partially or fully reclaimed with subsequent reclamation being slowed by public concern over the effect on flood regimes in the lower Hunter River and about the pollution threat to adjacent residential areas. In 1984 the NSW Government designated Kooragang Island Nature Reserve as a Wetland of International Importance. This designation was replaced with the Hunter Estuary Wetlands designation in 2002.

17. The Shortland Wetlands component of the Hunter Estuary Wetlands was designated as a Ramsar site on the basis of the following criteria:

Criterion 1: Shortland Wetlands is unique in that it has a combination of high conservation value near-natural wetlands and high conservation value artificial wetlands. It is the only complex of this type found within the Sydney Basin biogeographic region. The melaleuca swamp forest in particular represents a wetland type that, although once widespread, is poorly represented in the Sydney Basin biogeographic region.

Criterion 4: Shortland Wetlands supports a large number of species, some in very large numbers, at a critical seasonal stage of their breeding cycle and as a refuge during adverse conditions. Twenty-eight bird species have been recorded as breeding at the site and it provides drought refuge for a number of species during critical inland drought episodes. The site is also important during dry periods for resident ducks, herons and other waterbirds.

18. The Kooragang Nature Reserve component of the Hunter Estuary Wetlands was designated as a Ramsar site on the basis of the following criteria.

Criterion 3: Kooragang Nature Reserve is ecologically diverse and represents a significant genetic pool for wetland species in the Sydney Basin biogeographic region. The mangrove and saltmarsh areas are particularly good examples of these plant communities. The wetlands are also important for maintaining a high diversity of birds within the biogeographic region with over 250 species recorded.

Criterion 4: Kooragang Nature Reserve is widely recognised for its importance in the conservation of migratory birds with at least 38 species of migratory birds recorded. The Reserve regularly supports 15 species of migratory shorebird, and also supports a large number of species at a critical seasonal stage of their breeding cycle with 24 breeding species recorded. In 2000, 4,800 migratory shorebirds were recorded in the Estuary.

Criterion 6: Kooragang Nature Reserve regularly supports between 2% to 5% of the East Asian-Australasian Flyway population of Eastern Curlew, with counts from 1989-2000 ranging from 320-900 birds.

19. The Shortland Wetlands contain seven discrete ponds ranging in volume from 5,000-20,000 m^3. Historically, part of a shallow estuarine swale that was connected to the Hunter River through Ironbark Creek the wetlands are now freshwater environments. They receive water from direct precipitation and runoff from adjacent urban areas.

20. The Kooragang Nature Reserve is a shallow (generally less than 5 m deep) and has a tidal range of about 1-1.5 m. Estimates are that on average the entire Hunter estuary contains 45 GL of water. The largest contribution to the water budget of the estuary is from tides (approximately 92% of total volume) with the next largest input coming from the combined river inflows from the Hunter (3%), Williams (1.4%) and Paterson (1%) Rivers, and from local runoff (1.9%). River flows are extremely variable, often dropping well below the mean flow and can exceed 45 GL/day during severe floods. Groundwater discharge into the Hunter Estuary occurs from two adjoining aquifers. Evaporative losses from the estuary are estimated to be approximately 0.24% of the total water budget.

21. Salinity within the Shortland Wetlands varies depending on conditions and location, and ranges from 1.05-0.28 ppt. Simulations for the Kooragang Nature Reserve indicate inter-annual high variability of river flows with concomitant high variability of the salt distribution in the Hunter River estuary. During high flow periods saline tidal waters are pushed towards the opening of the estuary, with sufficiently severe floods sweeping most of the salt out of the estuary so that the estuary effectively becomes a river emptying directly into coastal waters. In periods of low river flows the estuary is vertically well mixed and gradual horizontal mixing causes the slow transportation of salt up-stream in the form of a salt wedge. Salinity was generally lower in the Williams River upstream of Seaham Weir than in the Hunter River, presumably as a result of the weir presenting a physical barrier to the salt wedge.

22. Turbidity within the Shortland Wetland ponds is variable depending on weather conditions and ranges from 1.15-435 NTU. Turbidity in the estuary is generally highest further up the Hunter

estuary where the water becomes riverine. Turbidity is highest during high flow events with a gradual drop as floods recede and saline waters penetrate upstream. Turbidity readings in the Hunter Estuary, including the estuarine portions of the Kooragang Nature Reserve, from 8-30 NTU are encountered during normal conditions, whilst during flood events readings are between 300-600 NTU.

23. Very high concentrations of nutrients (nitrogen and phosphorus) are found throughout the Shortland Wetland ponds, with substantial increases observed during wet weather periods. Total nitrogen ranges from 4.6-11.5 mg/L and total phosphorous from 0.62-3.66 mg/L within the seven ponds. The large number of birds, sometimes in excess of 20,000 individuals, along with nutrients from urban stormwater represents the likely major source of nutrients to the wetlands. Nutrients entering Kooragang Nature Reserve are largely from tidal inputs (80% of total phosphorus; 75% of total nitrogen; 79% of carbon), with the remainder being relatively small contributions from river inputs and local catchment surface flow.

24. Vegetation communities within the Hunter Estuary Wetlands include 4 Endangered Ecological Communities listed under the NSW *Threatened Species Conservation Act (1995).* These are Swamp Sclerophyll Forest, Swamp Oak Forest, Freshwater Wetland, and Coastal Saltmarsh in the NSW North Coast, Sydney Basin and South East Corner Bioregions.

25. The Hunter Estuary Wetlands provide important habitat for frogs, including the Green and Golden Bell Frog, listed as endangered under both the NSW *Threatened Species Conservation Act* and the Commonwealth *Environment Protection and Biodiversity Conservation Act*; being recorded as a captive animal at Shortland Wetlands and a free ranging population at Kooragang Nature Reserve. An additional 8 native frog species have been recorded at the Shortland Wetlands and 3 species at Kooragang.

26. A total of 13 native reptile species have been recorded at Shortland Wetlands, however, none are currently listed as threatened. Reptile surveys of Kooragang have not been completed.

27. Only three species of native mammal have been recorded in Kooragang, including the Grey-headed Flying Fox listed as vulnerable under both the NSW *Threatened Species Conservation Act* and the Commonwealth *Environment Protection and Biodiversity Conservation Act*, and four species have been recorded at the Shortland Wetlands.

28. Over 160 species of native bird have been recorded in Kooragang and 196 species in Shortland Wetlands, of which migratory wading birds form a major component. Key sites for migratory waders within the Hunter Estuary Wetland comprise roosting and foraging habitat and include the Stockton Sand Spit, Kooragang Dykes, Fullerton Cove and Shortland Wetland Centre. Several other important migratory wader sites also occur in the Hunter Estuary Ramsar and Hunter Estuary in general.

29. The Shortland Wetlands have a diversity of macroinvertebrate fauna including molluscs, bloodworms, caddisfly and dragonfly larvae, gastropods, beetles and copepods. Aquatic invertebrates such as worms, gastropods, molluscs and crustaceans are extremely abundant in Fullerton Cove, making this a vital foraging area for shorebirds.

30. Saltmarsh communities that fringe the estuary and occur within the Kooragang Nature Reserve provide important habitat for crabs. Saltmarshes are recognised as a key source of crab larvae in estuaries, with these larvae being an important food source for juvenile fish.

31. Surveys conducted at Ironbark Creek, Kooragang Island, Fullerton Cove and Tomago (West) have reported that 45 species of fish and crustaceans occur in the Kooragang component of the Hunter Estuary Wetland, including up to 19 species of fish or crustaceans that are used for commercial or recreational fishing. A total of five native fish species have been recorded in the Shortland Wetlands.

32. A total of 55 threatened and migratory waterbird species have been recorded or are considered likely to occur within the Hunter Estuary Ramsar wetland. The occurrence of these species illustrates the importance of the wetlands and the wetland types within the site. Maintenance of the wetland types (habitats) within the Ramsar wetland is important to ensure the survival of these species. The overall importance of the estuary for waterbird conservation is widely recognised and a key criterion for listing the wetlands as a Ramsar site.

33. Ecological processes are the dynamic forces that shape and maintain the wetland. They include processes that occur between organisms and within and between populations and communities, including interactions with the nonliving environment that result in existing ecosystems and bring about changes in ecosystems over time. Important processes within the Hunter Estuary and the Hunter Estuary Wetland that could be affected by the Tillegra Dam project include the hydrology, sediment and nutrient dynamics that maintain animal and plant populations, as well interactions between the biota. As the ecological character description of the wetland contains general rather than detailed specific information on these important processes the likely impact of the Dam on these processes have been assessed using modelling and mass balance approaches.

34. The key ecosystem services, or the benefits, that people obtain from the Hunter Estuary Wetlands include pollution control, hazard control such as flood mitigation, erosion control, nutrient cycling, recreational and education opportunities, as well as the biodiversity value represented by the Ramsar status. As the ecological character description of the wetland contains general rather than detailed specific information on these important benefits the likely impacts of the Dam on these have been addressed by relating the services of interest to the processes that underpin them, e.g. the hydrology and sediment and nutrient dynamics.

Identification of perceived threats and Limits of Acceptable Change

35. The supplementary DGRs issued for the Tillegra Dam proposal required an assessment of the impacts that the action will have on the ecological character of the Hunter River Estuary as outlined in relation to the EPBC Act, particularly for Matters of National Environmental Significance (2006) for Wetlands of International Importance. While further detailed assessment of the ecological processes and ecosystem services is required for wider management purposes the overall assessment was that the proposed Tillegra Dam was not likely to alter the ecological character of the Hunter Estuary Wetlands.

36. There were two main perceived threats to the Hunter Estuary Wetlands from the proposed Tillegra Dam – from changes in the hydrology and changes in the material budgets and chemical composition of the water in the estuary. These were of more concern for the Kooragang Nature Reserve due to a relatively uninhibited hydrological link with the Dam on the Williams River; although any effects would be mediated by the presence of Seaham Weir. The Shortland Wetlands were not considered to be at risk due to the inhibited hydrological link with the Williams River caused by the operation of the Ironbark Creek floodgates.

37. The potential impacts from the Dam were also considered within the context of other factors impacting on the estuary, such as tidal and oceanic influences, climate change and sea level rise, and activities in the wider catchment area. The modelling indicates there will be minimal hydrodynamic changes to the estuary, particularly when the predicted changes are evaluated in the context of daily tidal fluctuations and predicted impacts from climate change and sea level rise, and the broad environmental tolerances of most estuarine species are taken into account.

38. Hydrological changes are predicted to create small differences in tidal height (low water mark is predicted to be within ±1cm of current levels; high water mark is predicted to be within -1.2 cm to +1 cm of current levels) or maximum salinity (up to a ~3 ppt change in salinity levels) and have little affect on the key ecosystem processes. Freshwater will continue to enter all areas of the estuary and the majority of nutrients entering the estuary will continue to come from the ocean or cycled within the estuary itself.

39. Given the anticipated magnitude of changes in the estuary due to climate change and sea level rise it will be difficult to separate the potential impacts from the operation of Tillegra Dam. The vulnerability of the Hunter Estuary Wetlands to climate change and sea level rise has not been specifically assessed, but the effects of sea level rise in particular on the ecological character of the wetland are expected to greatly exceed those predicted from the dam.

40. While Limits of Acceptable Change for the Shortland Wetland have been previously reported in the Ecological Character Description similar information is not available for the Kooragang Nature Reserve. As a consequence, conservative Limits of Acceptable Change have been derived from the information collected in this assessment to ensure in particular that the important ecological features of the wetlands are maintained. These limits should be updated based on a completed Ecological Character Description for the Kooragang Nature Reserve when it is available.

Modelling of flows and mass balance of nutrients and sediment

41. The modelling investigations undertaken to assist with the assessment of potential impacts of Tillegra Dam on the Hunter Estuary Wetland are comparative-type assessments that focus on change in model results relative to existing conditions. This was undertaken with a sensitivity model (using ELCOM modelling software) to determine the sensitivity of changes in water level and salinity in the vicinity of the study area in response to flow changes at Seaham Weir from the Williams River. Three sea level rise scenarios were also investigated to highlight the dominating influence of the ocean on the water levels and salinity contractions experienced in the study area.

42. In preparing the sensitivity scenarios, minor modifications were made to the ELCOM model in order to ensure suitable output from hydrodynamic and advection / dispersion modules within the model. The ELCOM model provides all necessary detail between the ocean and Seaham Weir including the South Arm and North Arm of the Hunter River, Williams River and Paterson River. The model as adopted is considered representative of the study area and appropriate for such an assessment and was used to estimate the impacts on flood levels and the relative change in peak flood levels that may result from the proposed Tillegra Dam. A flood frequency analysis of daily flow data was used to determine the relationship between design flood flows and their recurrence intervals. The difference between the relationships for pre- and post-Tillegra conditions was used to prepare representative design flood hydrographs at Seaham

Weir for the future (with Tillegra Dam) condition. Analyses of LiDAR and hydrosurvey data and tidal data were undertaken to complement the numerical modelling and to assess the proportion of the wetland inundated by tidal waters on a regular basis.

43. Change in peak flood level for more frequent recurrence intervals are generally less than 0.05 m within the Hunter Wetland Estuary. The Tillegra Dam would reduce the peak flow at Seaham Weir during flood events by around 80% for all events based on the flood frequency analysis. Even with this level of change at the weir there was minimal change in the simulated water level near the wetland due to the control of flows at Seaham Weir. The presence of the weir and its effect on the pre and post Tillegra Dam flows to the wetland is very important when considering the potential impact of the dam on the wetland.

44. The simulation of salinity concentrations in the Hunter River show relatively minor differences (typically less than 0.5 ppt) in salinity as a result of changes in flow at Seaham Weir along the South Arm and North Arm of the Hunter River. The greatest difference in salinity are estimated under 90%ile flow conditions at Seaham Weir coupled with median flow conditions in the Hunter River and Paterson River. Differences in the average salinity concentration are greatest (approximately 3 ppt) near the upstream extents of the Ramsar site (approximately 20 km upstream of the ocean). In the vicinity of the study area between Hexham and Newcastle Harbour the difference in salinity is typically less than 0.5 ppt under 25%ile flow conditions, 1 ppt under 50%ile flow conditions, 2 ppt under 75%ile flow conditions and 3 ppt under 90%ile flow conditions. The results of the sea level rise scenarios show that the concentration of salinity in the vicinity of the study area (situated between 10 km and 20 km from the ocean) could increase by around 3 ppt or 4 ppt as a consequence of greater tidal inundation within the lower estuary caused by an increase of 0.73 metres.

45. The simulated changes in water level resulting from projected sea level rise conditions are more significant than those arising from the dam. This arises as the wetland is located close to the ocean. The LiDAR and tidal data and ground level frequency analysis highlighted the sensitivity of the wetland to changing inundation resulting from tide levels. A large proportion of the Hunter Estuary Wetlands lie within the inter-tidal zone (i.e. the area between maximum high tide and lowest low tide) with mangroves fringing the waterways and with low-lying saltmarsh areas. A notably significant proportion of the wetland lies between 0.6 m AHD and 1.0 m AHD and includes more elevated saltmarsh areas around Kooragang Island and Fullerton Cove.

46. Shortland Wetlands was assumed to be disconnected from remainder of the study area and this assumption is supported by the data analysis. Levels within the site are typically greater than 1.0 m AHD (only 20% of the area is less than 0.9 m AHD). Higher elevations and the presence of hydraulic structures (e.g. flood gates, flap gates etc) effectively remove hydraulic connection between the Shortland and Hunter sites under 'normal' conditions (although there is a connection during flood events).

47. The largest contributor to the water and nutrient budgets, on an average annual basis, was exchange with the ocean by tides. The water volume contribution from river inflows and catchment runoff are the next largest contributors with the Hunter River being the largest of all three (approximately 56%, with the Paterson and Williams Rivers contributing the remainder).

48. Although the concentration of total phosphorus and total nitrogen is much higher in river inflows and catchment runoff, the load of total nitrogen and total phosphorus is greatest from the tide due to the very large volumetric contribution from the ocean. Contributions from licensed

discharges, although very high in total nitrogen and total phosphorus, are negligible due to the small annual volumes generated. The impact of Tillegra Dam is estimated to reduce the volume of water and concentration of total nitrogen and total phosphorus at the outlet to the Tillegra Dam catchment. The modelled reduction in the volume of water at Seaham Weir was 22%.

49. The modelling and analysis suggest that the total nitrogen and total phosphorus loads would be reduced by 1.1% and 1.3% respectively, and this can be attributed to the expected reduction in flow volume downstream of Tillegra Dam.

50. The results of the water and nutrient budget illustrate the relatively small contribution of loads to the estuary from the Williams River catchment. Flow inputs from the Williams River are less than 1.5% of the total volume of inputs considered by the budget. Consequently, changes to the concentration of total organic carbon (TOC) as a result of Tillegra Dam are not expected to result in considerable changes within the Hunter Estuary Wetland.

51. Based on an estimated average annual flow volume reduction of 0.3% from the Williams River alone, the percentage reduction of the total organic carbon load into the system from the sources included in the assessment would be approximately 0.7% (i.e. a reduction from 3.1% pre- Tillegra to 2.4% post-Tillegra). Tides play an important role in flushing of the lower estuary in which the study area is located and is considered to play a more dominant role in the expected water quality conditions during average annual conditions.

Limitations of the methods and impacts assessment

52. The information base for the Hunter Estuary Wetlands comprised an Information Sheet and a more detailed ECD for the Shortland Wetlands, both done in 2002. An ECD was not available for the Kooragang Nature Reserve. As an ECD provides more information than an Information Sheet for describing the ecological character of the wetland a rigorous information and literature review was undertaken to complement the information available. It is anticipated that a formally accepted ECD would provide further information for the Ramsar wetland, but in the absence of an ECD the Information Sheet constitutes the official description of the ecological character of the wetland under the EPBC Act.

53. Given the absence of the ECD for the Kooragang Nature Reserve an assessment of Limits of Acceptable Change was undertaken using that available for the Shortland Wetlands as a guide and presented in a conservative manner. Given the marginal changes that would result from the proposed Tillegra Dam the relevant Limits of Acceptable Change are not expected to be exceeded.

54. The hydrological, salinity, sediment and nutrient assessments have been undertaken primarily using numerical modelling. Whilst the modelling has undergone a rigorous calibration and validation process care should still be exercised in interpreting the results. There are likely to be other factors influencing hydraulics and water quality within the Hunter estuary (both locally and more broadly) that are not included in the numerical analysis. As such, actual values generated by the model should be considered to have a maximum potential error of +/- ~10%. As the assessment of potential impacts from Tillegra Dam is essentially based on comparisons between different modelling scenarios, the results actually highlight differences between these scenarios (and thus the potential impacts of the dam) to a much higher degree of accuracy.

Conclusions

55. The potential impact of Tillegra Dam on the Hunter Estuary Wetland has been assessed in line with the supplementary Director Generals Requirements (DGRs) and with reference to the ecological character of the wetland as summarised in the Information Sheet submitted in 2002 to the Ramsar Convention on Wetlands. Based on these analyses it was concluded that the ecological character of the wetland would not be significantly changed by the construction of the Tillegra Dam.

56. The potential impacts of Tillegra Dam are discussed below, with respect to each of the relevant matters outlined in the guidelines for Matters of National Environmental Significance.

Areas of the wetland being destroyed or substantially modified - No areas of the Hunter River Estuary wetland will be destroyed or substantially modified.

Substantial and measurable change in the hydrological regime of the wetland - Extensive modelling of potential changes to the hydrological regime of the wetland have been undertaken with no substantial or measurable changes predicted, especially as 92% of the water to the wetlands comes from ocean tides. The low water mark is predicted to be within ±1cm of current levels and the high water mark within -1.2 cm to +1 cm compared to the current daily tidal range under average tidal condition of 0.7–1.45 m. Modelled changes in inundation height are predicted to be in the magnitude of 1-2 cm.

The habitat or lifecycle of native species dependent upon the wetland being seriously affected - There will be no direct impacts on native species or vegetation communities within the wetlands given the minor alterations in nutrient and salinity regimes and water inundation levels. The vast majority of nutrients entering the Hunter River Estuary come from tidal sources while the Dam will result in a small decrease in the amount of nutrients entering the estuary, due to the trapping of sediments and nutrients within the dam. As the predicted changes in flow regime are minor the habitat areas available for most flora and fauna of the estuary will not be affected.

A substantial and measurable change in the water quality of the wetland – As the estuary is dominated by oceanic influences with approximately 92% of the water entering the estuary coming from ocean tides it is unlikely that there will be any substantial or measurable change in the water quality of the estuary. Modelled scenarios changes in salinity are predicted to be 1-3 ppt and nutrients less than 2%.

An invasive species that is harmful to the ecological character of the wetland being established - As the construction and operation of the Dam will not connect the Hunter River Estuary to any new waterways it does not present an invasion pathway for aquatic pests to enter the estuary. Neither will the dam change conditions to the extent that current pest species will be affected.

57. Based on the available description of the ecological character of the Hunter Estuary Wetland cumulative impacts from the construction and operation of the Tillegra Dam are not expected to occur. In making this conclusion the potential impacts of climate change and, in particular, sea level rise, on the wetland were recognized – these could be severe given current climate scenario and vulnerabilities of estuarine wetlands, and are expected to outweigh the magnitude of any change associated with the Dam.

58. Consideration of cumulative impacts on the wetland is difficult to quantify due to the dynamic nature of the wetlands and influences from sources that are external to the wetland, such as the potential impacts from climate change and other developments, and impacts on migratory bird breeding habitat in other countries. Despite the difficulties or uncertainties these external impacts need to be considered and taken into account by managers; the limited extent of change that would result from the proposed Dam provides some confidence that it will not substantially contribute to any cumulative impacts or changes to the Hunter Estuary Ramsar.

Recommendations

59. Given the limited degree of likely change to the estuary and Ramsar wetlands that would result from the proposed Tillegra Dam in all river flow scenarios, recommendations have focused on providing direction on improvements to the management of Seaham Weir. Low and moderate Williams River flows received at the Hunter Estuary Wetlands are largely controlled by operations at Seaham Weir. This existing situation will continue to occur with or without the proposed Tillegra Dam. Consequently, Tillegra Dam will have limited impact on these flows received at the Ramsar site, due to the existing management rules governing the operation of the weir, as well as design limitations within the existing gate structure on the weir that precludes alternate operational rules being adopted.

60. Improved flow connectivity between the upper Williams River and the Hunter Estuary Wetlands could however occur if the Seaham Weir fishway was upgraded. A new vertical slot fishway with the capacity to allow additional transparent flows across the weir to 20ML/day is recommended. This would result in improvements to the ecological health of the river system. Specifically such an upgrade would facilitate the movement of aquatic biota between the river and the estuary as well as improve flow conditions immediately below the weir, contributing to improvements to the overall health of the estuary and therefore, the Ramsar estuary wetlands further downstream.

61. Monitoring of water levels, water quality and ecological characteristics downstream of the weir would enable the measurement of Seaham Weir upgrade benefits as well as providing additional baseline data that would provide the foundation to the ongoing and adaptive management of Seaham weir. Monitoring of improvements made to the weir is therefore recommended both immediately downstream of the weir, as well as extending past the confluence of the Williams and Hunter River's at Raymond Terrace.

62. Such monitoring would also support or complement existing monitoring programs being undertaken by the managers of the Ramsar wetland and would also contribute to the holistic management of the estuary. HWC should make information available from its monitoring program available to other natural resource managers including the Department of Environment and Climate Change, the Hunter Central Rivers Catchment Management Authority, the Department of Primary Industries, The Hunter Wetlands Centre, the Kooragang Wetland Rehabilitation Project and the Commonwealth Department of Environment, Heritage, Water and the Arts.

63. Monitoring of water levels, water quality and biota to confirm whether the upgraded fishway and improved connectivity within the low flow regime had contributed to improved environmental health below the weir would also assist Ramsar wetland managers with a direct interest in the estuary further downstream. Such information could be combined with wider data sources to continue to refine projections for nutrients, sediment and carbon budgets within the estuary.

64. No recommendations are made in relation to managing the proposed dams' impacts on high flows. High flows including floods will be suppressed by the dam along the length of the Williams River, however, at the estuary, including the Hunter Estuary Ramsar Sites, flood modelling in this study has shown that differences in the volume of water reaching the sites, affecting the extent and scope of flooding is marginal at best. Hence no corrective action is warranted.

65. Whilst flow changes from the proposed dam are masked by the intervening influence of the existing Seaham Weir, as well as being subsumed by larger dominant flows from the Hunter River, integrated management of the Williams River system is essential for maintaining the environmental health of the overall river system. This includes the Hunter Estuary Ramsar Site. Hunter Water Corporation has noted that as part of its response to managing potential riverine impacts below the proposed dam, that an aquatic offsets package for the Williams River would be formulated. Such a package may include a small grants scheme to fund environmental improvement works along the river. As a consequence, it is recommended that any such scheme be extended to allow the sponsorship of any beneficial environmental works of merit along the entire river system, including within the broader estuary and the specific Hunter Estuary Ramsar sites.

1 Introduction

1.1 Description of the Project

The Tillegra Dam project is the proposed construction of a 450,000 mega litre (ML) dam on the Williams River to supply town water to the Lower Hunter Region. The project location of the dam is approximately 100 km northwest of Newcastle, in the Hunter Valley of NSW, on the upper Williams River at Tillegra bridge on Salisbury Road, approximately 15 km from the town of Dungog (Figure 1).

Tillegra dam has been identified by the Department of Environment, Water, Heritage and Arts (DEWHA) as a Controlled Action under the Commonwealth Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act). The controlling provision is Wetlands of International Importance, namely the Hunter Estuary Wetlands, and the action is subject to the assessment and approval process under the EPBC Act. In line with the Commonwealth and NSW State Government bilateral agreement, supplementary Director Generals Requirements (DGRs) have been prepared (Appendix A), subsequent to the initial DGRs for Tillegra Dam as part of the *Environmental Planning and Assessment Act 1979* (EP&A Act) approvals process.

In order to address the supplementary DGR's, Hunter Water Corporation engaged the collaborative efforts of consultant experts to fulfil the objectives of this investigation, which included:

- Review of the Ramsar Convention, undertaken by the Institute for Land, Water and Society, Charles Sturt University;
- Documentation of the ecological character, condition, values and limits of acceptable change of the Hunter Estuary Wetlands, undertaken by Eco Logical Australia;
- Modelling of peak flows, low to moderate channel flows (ELCOM model) and mass balance modelling of nutrients and sediment under pre- and post-Tillegra conditions in the Hunter Estuary Wetlands, undertaken by BMT WBM;
- Identification of perceived threats of Tillegra Dam on the Hunter Estuary Wetlands, undertaken by Eco Logical Australia;
- An assessment of the impacts of the modelled changes on the Hunter Estuary Wetlands in accordance with the DGRs and the EPBC Act Significant Impact Guidelines Matter of National Environmental Significance, undertaken by Eco Logical Australia;
- Identification of the limitations of the methodology applied and subsequent impacts assessment, undertaken by Eco Logical Australia and BMT WBM;
- Identification of recommendations to be implemented to avoid or mitigate the impacts on the Hunter Estuary Wetlands that might result from Tillegra Dam, undertaken by Eco Logical Australia and BMT WBM; and
- A conclusion of the level of impact on the Hunter Estuary Wetlands that might result from Tillegra Dam, based on the results of this investigation.

1.2 Statement of Purpose

The purpose of this report is to present an assessment of the magnitude of potential impacts of Tillegra Dam on the Hunter Estuary Wetlands which have been designated as a Wetland of International Importance (known as a Ramsar site or wetland) in accordance with criteria established by the Ramsar Convention on Wetlands. To do this, it was necessary to evaluate the baseline status of the Ecological Character of the Ramsar wetlands.

“Ecological character is the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time." (Resolution IX.1, Ramsar Convention on Wetlands).

As part of the process for listing the Hunter Estuary Wetland under the Ramsar Convention, an Information Sheet on the Wetland was prepared in 2002 (see Section 4 below) and represents the current standing legal document for describing the ecological character. Therefore, all proposed actions that may have a potential impact on the Hunter Estuary Wetland are to use this Information Sheet as the basis of ecological character for the wetlands. Despite the lack of a formal Ecological Character Description for the Hunter Estuary Ramsar Wetland, additional, specific information on the wetlands, in line with the National Framework and Guidance for Describing the Ecological Character of Australia’s Ramsar Wetlands (DEWHA 2008) has also been compiled and is provided in Section 4.

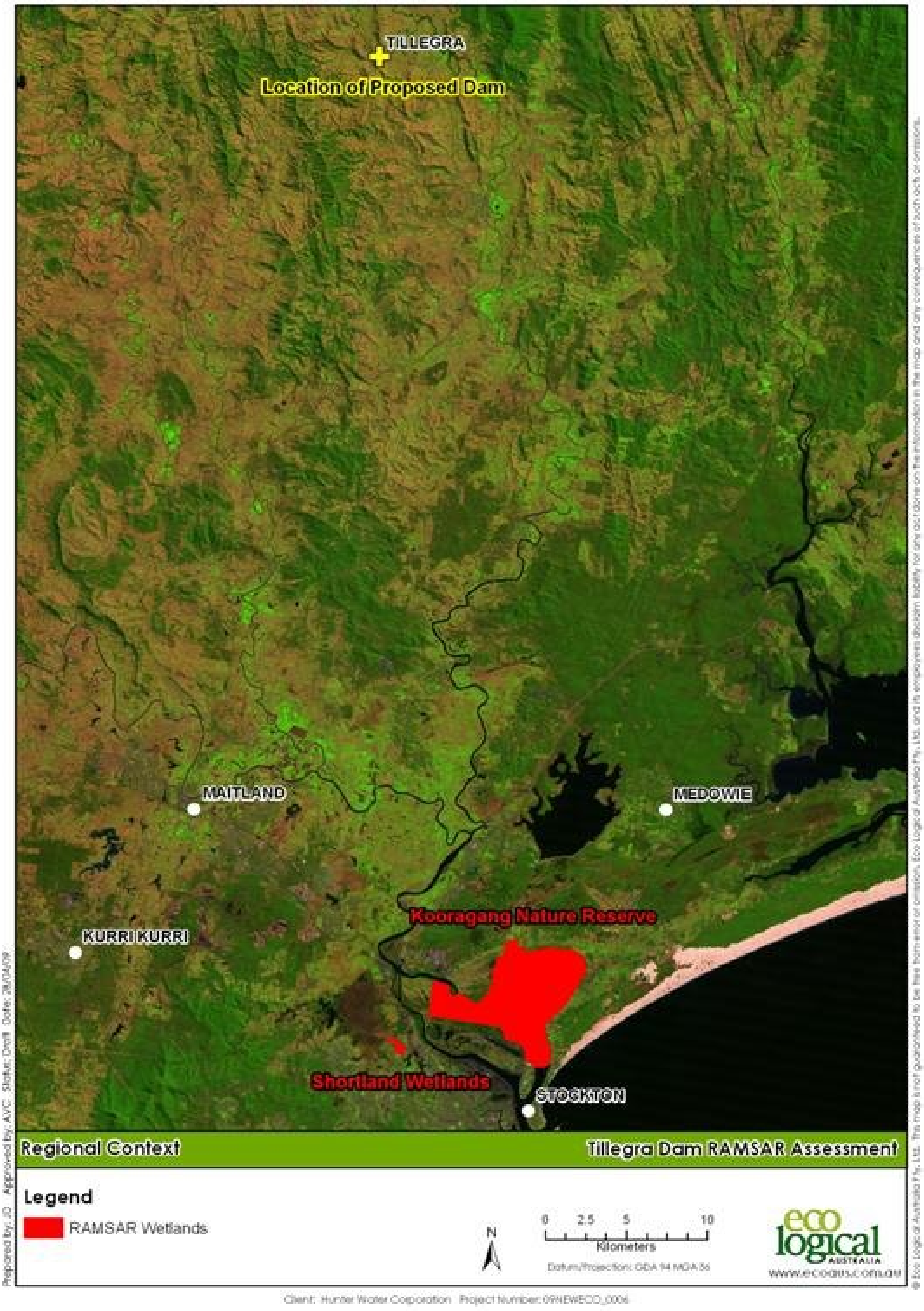


Figure 1: Study locality and regional context.

2 Overview of the Ramsar Convention on Wetlands

2.1 The Ramsar Convention on Wetlands

The Ramsar Convention on Wetlands is an intergovernmental treaty adopted in 1971 in the city of Ramsar in Iran (Box 1). The development and implementation of the Convention have been described by a number of authors, including Matthews (1983), de Klemm and Créteaux (1995), Hails (1997), Ramsar Convention Secretariat (2006) and Kuijken (2006). Information from these sources has been used to provide an outline of the background and objectives of the Convention and the implications for management of Australian wetlands. Information on the implementation of the Convention in Australia has largely been drawn from information available from the Department of Environment, Heritage and the Arts which is the formal Administrative Authority for the Convention in Australia.

Box 1: Development of the Ramsar Convention

The development and history of the Convention is outlined by Matthews (1993; http://www.ramsar.org/lib/lib_history.htm) while current mechanisms are outlined in a manual produced by the Ramsar Convention Secretariat (2006; http://www.ramsar.org/lib/lib_manual2006e.htm).

The text of the Convention was signed at a conference in the city of Ramsar, Iran, on 2 February 1971 with representatives from 18 countries recommending the text to their governments. Signatory nations included Belgium, Denmark, Finland, France, Germany (Federal Republic), India, Iran, Ireland, Jordan, Netherlands, Pakistan, South Africa, Spain, Sweden, Switzerland, Turkey, Union of Soviet Socialist Republics, and the United Kingdom. The conference also included representatives from the Food and Agricultural Organization of the United Nations (FAO), and the United Nations Educational, Scientific and Cultural Organization (UNESCO) and a number of Non-Governmental Organisations. The evolution of the Convention and development of the conference were supported by the International Union for the Conservation of Nature and Natural Resources (IUCN), International Wildfowl Research Bureau (IWRB) and World Wildlife Fund (WWF).

2.1.1 Background / Objectives

The Convention is popularly known as the Ramsar Convention and more formally as the Convention on Wetlands, although the official name is The Convention on Wetlands of International Importance Especially as Waterfowl Habitat. The official name reflects the emphasis in the late-1960s on the conservation and wise use of wetlands primarily as habitat for waterbirds. Over the years the Contracting Parties of the Convention have responded to changing world perceptions, priorities, and trends in environmental thinking and further developed and interpreted the articles of the Convention and broadened its scope to cover all aspects of wetland conservation and wise use, recognizing wetlands as ecosystems that are extremely important for biodiversity conservation and for the well-being of human communities. Whilst seen initially as focussing on waterbirds the Convention text did include the concepts of 'wise use' of wetlands and maintenance of their 'ecological character' – concepts that are as important today as they were in 1971.

The Convention is seen as the first of the modern global intergovernmental treaties on the conservation and sustainable use of natural resources, but, compared with more recent treaties its provisions are relatively straightforward. It formally came into force in 1975 and as of May 2009 had 159 Contracting Parties, or member States. The central message promoted by the Convention is the need for the conservation and wise (sustainable) use of all wetlands. The “flagship” is the List of Wetlands of International Importance (the “Ramsar List”) – presently, the Contracting Parties have designated more than 1,842 wetlands for special protection as “Ramsar sites”, covering 180 million hectares (1.80 million square kilometres) (Figure 2).

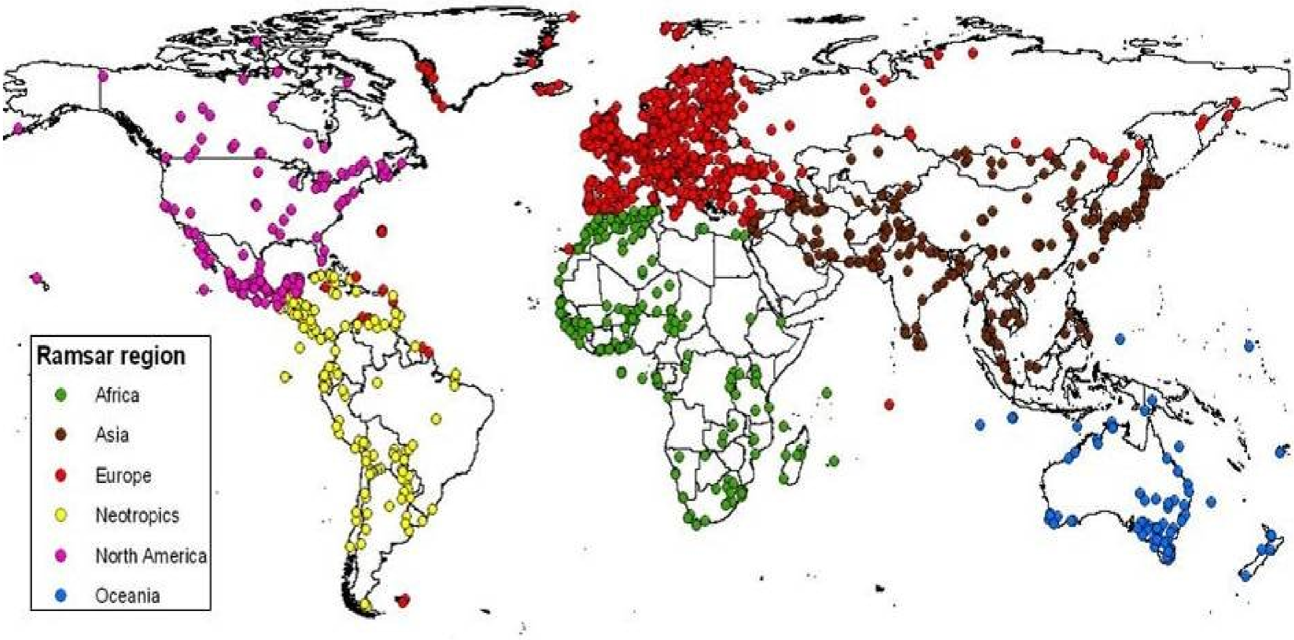


Figure 2: Distribution of Ramsar sites (from Rebelo et al. 2009).

The Convention is not part of the United Nations system of environmental conventions and agreements, although the United Nations Educational, Scientific and Cultural Organization (UNESCO) is the formal Depositary for the Convention.

The implementation of the Convention is a continuing partnership between the Contracting Parties, the Standing Committee, and the Convention Secretariat, with the advice of the subsidiary expert body, the Scientific and Technical Review Panel, and the support of the International Organization Partners (Box 2). Every three years, representatives of the Contracting Parties meet as the Conference of the Contracting Parties, the policy-making organ of the Convention which adopts decisions to administer the work of the Convention and improve the way in which the Parties are able to implement its objectives.

Box 2: Structure of the Ramsar Convention on Wetlands

The Conference of the Contracting Parties (COP) is the policy-making organ of the Convention. Government representatives from each of the Contracting Parties meet every three years to receive national reports on the preceding triennium, approve the work programme and budgetary arrangements for the next three years, and consider guidance for the Parties on a range of ongoing and emerging environmental issues. Representatives of non-member States, intergovernmental institutions, and national and international non-governmental organizations (NGOs) may participate in these meetings as non-voting observers.

The Standing Committee is the inter-sessional executive body that represents the COP between its triennial meetings, within the framework of the decisions made by the COP. The Standing Committee is elected by each meeting of the COP to serve for the three years until the next COP. It contains representatives from each of the Conventions six global regions – Africa, Asia, Europe, Neotropics, North America and Oceania – and generally meets annually to address matters previously approved by the Conference; prepare documentation for consideration at the next COP; and supervise implementation of policy by the Ramsar Secretariat and execution of the Secretariat's budget.

The Convention Secretariat carries out the day-to-day coordination of the Convention's activities. It is located in the headquarters of the IUCN in Gland, Switzerland and is headed by a Secretary General, who supervises the work of a small number of staff.

The Scientific and Technical Review Panel of the Ramsar Convention was established in 1993 as a subsidiary body of the Convention to undertake scientific and technical review and provide guidance to the Conference of the Parties, the Standing Committee, and the Secretariat. Members serve in their own capacity as experts in the scientific areas required by the STRP's Work Plan and not as representatives of their countries.

The International Organization Partners (IOP) of the Convention comprises five global Non-Governmental Organizations (NGOs), four of which have been associated with the treaty since its beginnings. The five IOPs are BirdLife International, The International Union for the Conservation of Nation (IUCN), The International Water Management Institute, Wetlands International, and the World Wide Fund for Nature (WWF-International). The IOPs provide support for the work of the Convention at global, regional, national, and local levels.

The mission of the Convention, as adopted in 1999 and refined in 2002, is "*the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world*".

This is an ambitious goal and whilst there have been many successes the future of many wetlands globally is still threatened by economic development, especially associated with agriculture and water infrastructure (Millennium Ecosystem Assessment 2005).

2.1.2 Commitments of Contracting Parties

The Convention is open to any country that is a member of the United Nations or of one of the Specialized Agencies or of the International Atomic Energy Agency or Party to the Statute of the International Court of Justice. No country is too small to join as long as it can designate a wetland which meets one or more of the criteria for identifying Wetlands of International Importance. Countries that join the Convention accept four main commitments, as outlined below.

Listed sites (Article 2 of the Convention)

The first obligation under the Convention is to designate at least one wetland at the time of joining the Convention for inclusion in the List of Wetlands of International Importance (the Ramsar List) and to promote its conservation, and to continue to designate suitable wetlands for the List. Specific criteria and guidelines have been agreed for identifying sites for inclusion in the List – Australia has listed 65 sites (Figure 3). The Parties have also committed themselves to be informed at the earliest possible time if the ecological character of any listed wetland has changed, or is changing or is likely to change as the result of technological developments, pollution or other human interference.

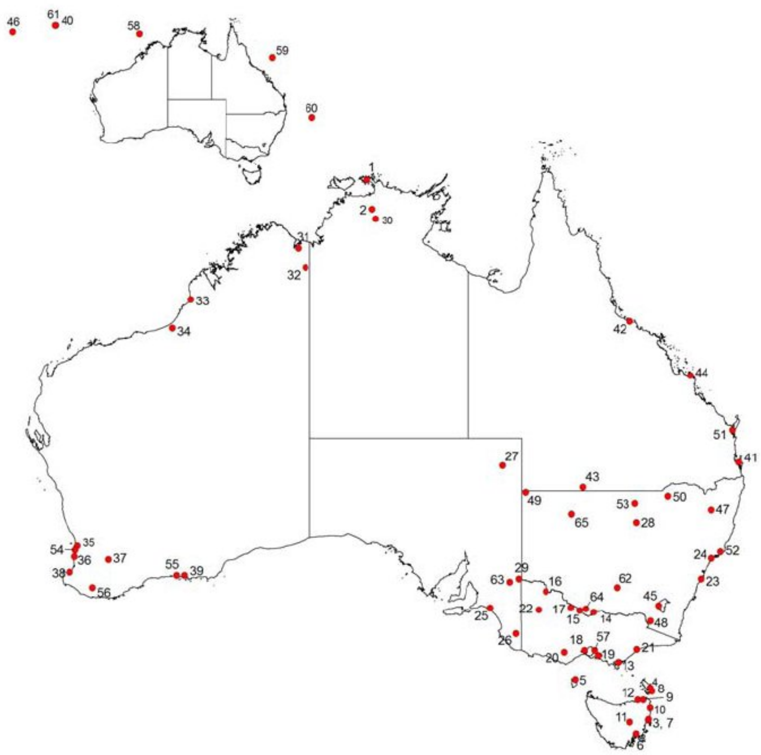


Figure 3: Australian wetlands listed as internationally important (from www.environment.gov.au/water/publications/environmental/wetlands/pubs/ramsar.pdf).

Wise use (Article 3 of the Convention)

Under the Convention there is a general obligation for the Contracting Parties to consider wetland conservation in their national land-use planning. Through this planning they have committed themselves to promote, as far as possible, the wise use of wetlands in their territory. The COP has approved guidelines on how to achieve “wise use” as well as provided detailed guidance on the development of national wetland policies and on management planning for individual wetlands.

Reserves and training (Article 4 of the Convention)

Contracting Parties have also undertaken to establish nature reserves in wetlands, whether or not they are included in the Ramsar List, and they are also expected to promote training in the fields of wetland research, management and wardening.

International cooperation (Article 5 of the Convention)

Contracting Parties have also agreed to consult with other Contracting Parties about implementation of the Convention, especially in regard to trans-boundary wetlands, shared water systems, and shared species. In this respect Australia has placed particular emphasis on the management of migratory shorebirds; this effort has largely been undertaken through separate bilateral agreements with China, Japan and South Korea.

2.1.3 Compliance with commitments

The Ramsar Convention is not a regulatory regime and does not have punitive measures for defaulting on commitments. Nevertheless, its articles do constitute a solemn treaty and are binding in international law. The success of the Convention is based on an expectation of common and equitably shared transparent accountability. Failure to live up to the commitments under the Convention could lead to political and diplomatic discomfort in international fora or the media, and would prevent any Party concerned from getting the most out of what would otherwise be a robust and coherent system of checks and balances and mutual support frameworks. Australia has embodied its commitments under the Convention through the federal Environment Protection Biodiversity Conservation Act 1999.

Over the years, the COP has interpreted and elaborated upon the major obligations and through formal Resolutions has developed guidelines for assisting the Parties in their implementation. These guidelines are published in the Ramsar Handbook series and on the Ramsar Web site. Although Resolutions are not seen as having the same legal force as commitments specified in the convention text, the Contracting Parties have used them to elaborate their expectations in support of the formal commitments.

2.1.4 Reporting

An extremely important part of the responsibilities accepted by Contracting Parties is to report on the implementation of the Convention. The Parties report on their progress in meeting their commitments under the Convention by submitting triennial National Reports to the Conference of the Contracting Parties – these are prepared following a format adopted by the Parties which follows the Strategic Plan of the Convention, and they become part of the public record.

In addition, under Article 3.2 of the Convention, Parties are expected to report to the Secretariat any changes or threats to the ecological character of their listed wetlands and to respond to the Secretariat's inquiries about such reports received from third parties. They may also decide to list the site on the Montreux Record of Ramsar sites where changes in ecological character have occurred, are occurring or are likely to occur.

2.2 Key Concepts

The text of the Convention makes reference to a number of key concepts that have largely been elaborated in further decisions made by the Contracting Parties. These are explained in the text that follows.

2.2.1 Definition and classification of wetlands

The Ramsar Convention has taken a broad approach in determining the wetlands that come under its aegis and have defined them as:

"…..areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres".

In addition, for the purpose of ensuring the conservation and wise use of wetlands the Convention has further determined that wetlands included in the Ramsar List may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands.

The Convention has recognized three generalized types of wetlands, namely Marine and Coastal, Inland, and Human-made, that were further separated into 42 categories or wetland types (Appendix D). The categories listed in the classification were not intended to be scientifically exhaustive, but to provide a broad framework for the rapid identification of the main wetland habitat types represented at each site, with the "dominant wetland type" clearly indicated.

The Convention includes a wider range of ecosystems than traditionally considered as wetlands, encompassing marine, estuarine, lacustrine, riverine and palustrine ecosystems. In addition, there are human-made wetlands such as fish and shrimp ponds, farm ponds, irrigated agricultural land, salt pans, reservoirs, gravel pits, sewage farms and canals. Marine wetlands are generally seen as not exceeding 6 metres depth; lakes and rivers are covered in their entirety, regardless of their depth. The Ramsar definition has caused some confusion when considering the global extent of wetlands - current estimates based on available information and using the Ramsar definition suggest a tentative minimum of 12.8 millions km^2 (Finlayson et al. 1999).

2.2.2 Wetlands of International Importance

At the time of joining the Convention, each Contracting Party undertakes to designate at least one site for inclusion in Ramsar List. The inclusion of a site in the List confers upon it the prestige of international recognition and embodies the government's commitment to take all steps necessary to ensure the maintenance of the ecological character of the site. While inscription on the Ramsar List acknowledges the international importance of the site it does not prejudice the exclusive sovereign rights of the Contracting Party in whose territory it is situated.

Following accession, Contracting Parties are expected to designate additional wetlands for the Ramsar List or extend the boundaries of those already included. They select wetlands within their territories on the basis of their international significance in terms of ecology, botany, zoology, limnology or hydrology, as gauged by reference to the Convention's criteria for identifying wetlands of international importance (Box 3) and the strategic framework and guidelines for the future development of the List of Wetlands of International Importance. Guidance for the application of each criterion has also been developed to assist Contracting Parties to take a systematic approach to listing sites.

Box 3: Criteria for the designation of Wetlands of International Importance

The Criteria for designating sites, along with the long-term target the Convention has agreed for each, are presented.

Criterion 1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.

Target - to have included at least one suitable representative of each wetland type, according to the Ramsar classification system, which is found within each biogeographic region.

Criterion 2: A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.

Target - to have included those wetlands which are believed to be important for the survival of vulnerable, endangered or critically endangered species or threatened ecological communities.

Criterion 3: A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.

Target - to have included those wetlands which are believed to be of importance for maintaining the biological diversity within each biogeographic region.

Criterion 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.

Target - to have included those wetlands which are the most important for providing habitat for plant or animal species during critical stages of their life cycle and/or when adverse conditions prevail.

Criterion 5: A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.

Target - to have included all wetlands which regularly support 20,000 or more waterbirds.

Criterion 6: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.

Target - to have included all wetlands which regularly support 1% or more of a biogeographical population of a waterbird species or subspecies.

Criterion 7: A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity.

Target - to have included those wetlands that support a significant proportion of indigenous fish subspecies, species or families and populations.

Criterion 8: A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.

Target - to have included those wetlands which provide important food sources for fishes, or are spawning grounds, nursery areas and/or on their migration path.

Criterion 9: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of wetland-dependent non-avian animal species.

Target – to have included all wetlands which regularly support 1% or more of a biogeographical population of one non-avian animal species or subspecies.

Wetlands to be added to the Ramsar List must be designated by the national government, specifically by the agency within the national government that has been authorized to represent the nation in implementing the Convention. Contracting Parties have their own procedures for the nomination of Ramsar sites within their countries – nominations in Australia are prepared by the relevant Government (State, Territory or Australian) and submitted to the Australian Government for formal acceptance and onward submission to the Ramsar Secretariat.

The designation of a Ramsar site is done using the Ramsar Information Sheet (RIS) which also provides a summary description of the ecological character of the wetland. The Convention is currently reviewing the data fields and information contained in the RIS and possibly rationalising them with those proposed for inclusion in further guidance on the description of the ecological character of a wetland. The Australian Government has already decided that a more detailed description of the ecological character of all Australian Ramsar sites and has initiated a process of updating and extending the description of sites already on the Ramsar List.

2.2.3 Wise use of wetlands

The Contracting Parties have also agreed to formulate and implement their planning to promote the conservation of the wetlands included in the List, and as far as possible the wise use of wetlands in their territory. Through the concept of "wise use" the Convention continues to emphasize that human use on a sustainable basis is entirely compatible with Ramsar principles and wetland conservation in general. Further, the wise use concept applies to all wetlands and water resources in a Contracting Party's territory, not only to those sites designated as Wetlands of International Importance.

While a definition of wise use was not provided in the Convention text it was emphasise that the wise use of wetlands involved the maintenance of their ecological character as a basis not only for nature conservation, but also for sustainable development. The connection between conservation and sustainable development was formalised in 1987 and strengthened further in 2002 in response to the emphasis in the Millennium Ecosystem Assessment (2005) on the ecosystem services provided by wetlands. The wise use of wetlands is now defined as:

"… the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development."

The importance of wise use within the Convention is reinforced through the Mission statement that commits Contracting Parties to the conservation and wise use of all wetlands. It is also supported by guidance that has emphasised the importance of: i) adopting national wetland policies, involving a review of existing legislation and institutional arrangements to deal with wetland matters (either as separate policy instruments or as part of national environmental action plans, national biodiversity strategies, or other national strategic planning); ii) developing programs of wetland inventory, monitoring, research, training, education and public awareness; and iii) taking action at wetland sites, involving the development of integrated management plans covering every aspect of the wetlands and their relationships with their catchments. The suite of guidance on wise now available from the Convention is presented in the Ramsar Handbooks for the Wise Use of Wetlands (see www.ramsar.org/lib/lib_handbooks2006_e.htm). Each handbook brings together the guidance adopted by the COPs, supplemented by additional material from COP information papers, case studies and other relevant publications. Figure 4 provides an outline of the guidance available superimposed on the framework of the Millennium Ecosystem Assessment that was used to assess the impact of direct and indirect drivers of change on wetlands and their ecosystem services.

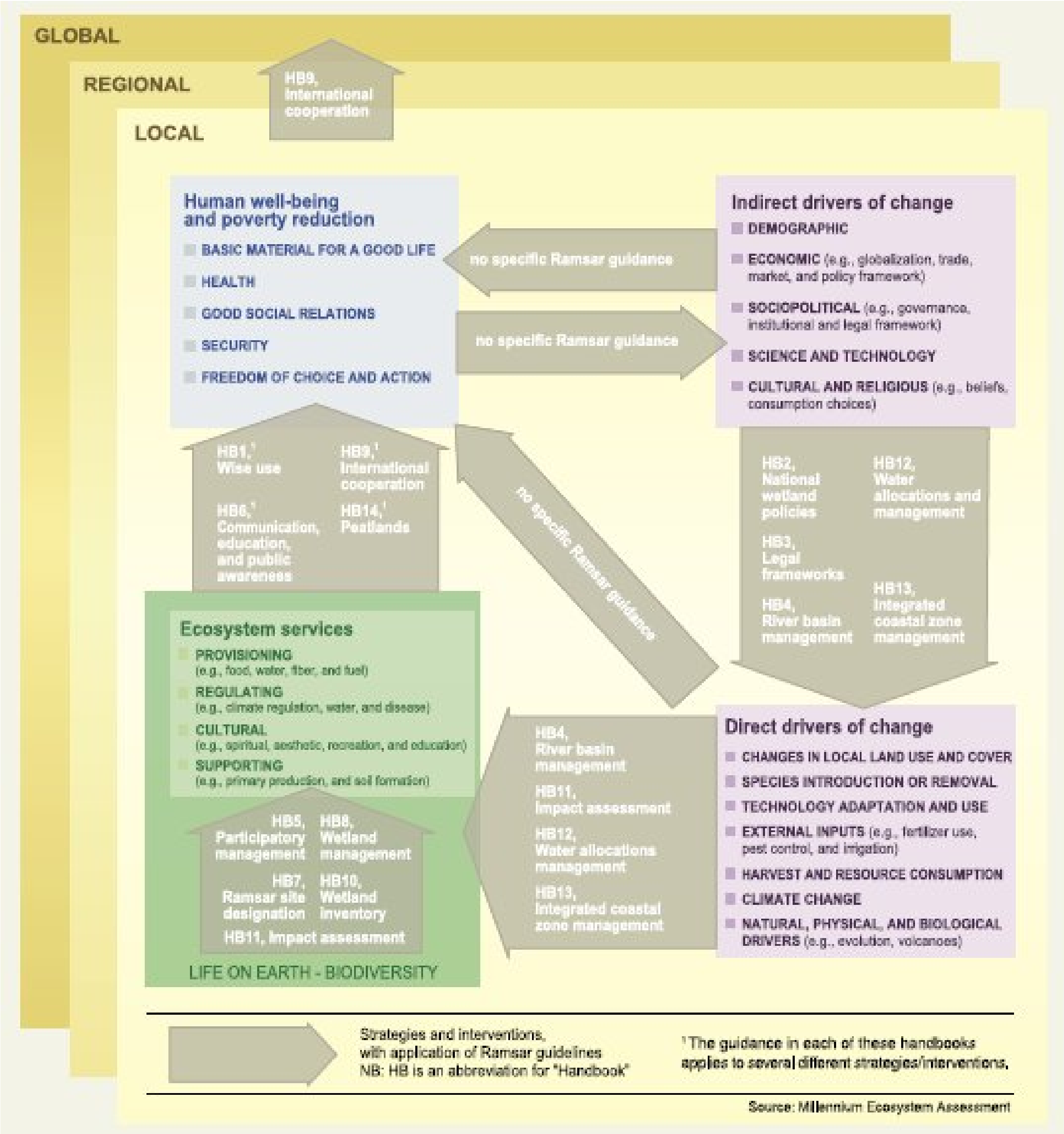


Figure 4: The strategies and interventions contained in the Ramsar Wise Use Handbooks superimposed on the conceptual framework of the Millennium Ecosystem Assessment (2005).

Figure 4 illustrates where interventions using each of the Ramsar Wise Use Handbooks can be applied in the conceptual framework. Many of the current Ramsar wise use guidelines concern interventions that apply directly to ecosystems and their processes. Others, such as those concerning river basin management, water allocations and management for maintaining wetland ecosystem functions, and impact assessment, form interventions that address the direct drivers of change to ecosystems. Only two sets of Ramsar guidelines, those on national wetland policies and on reviewing legislative and institutional frameworks, deal wholly with indirect drivers of change. Some guidelines, such as those that cover international cooperation, global action for peatlands, and communications, education, and public awareness, and also the Convention’s original “wise use” guidelines, include strategies and interventions that apply to several parts of the conceptual framework. The Figure also demonstrates that there are only a small number of levels in the framework for which Ramsar Wise Use Handbooks do not provide at least some guidance.

2.2.4 Ecological Character

The description of the ecological character of sites on the Ramsar List is one of the core features of the Convention as it provides the baseline reference for assessing change. Given the importance of the concept it has attracted a lot of debate with the decision taken in 2005 to incorporate ecosystem services into the definition marking a far-reaching change from the previous situation. The previous definition, in line with more traditional conservation thinking, considered that ecosystem services were derived from, not part of the ecological character of a wetland. The current definition was developed after consideration by the COP of the concepts and information provided by the Millennium Ecosystem Assessment (2005). Therefore, ecological character is now defined as "…*the combination of the ecosystem components, processes and benefits /services that characterise the wetland at a given point in time"*.

The concept of ecological character is shown pictorially in Figure 5. Ecosystem components are the physical, chemical and biological parts of a wetland, from large-scale to very small-scale, whereas ecosystem processes are the dynamic forces within an ecosystem and include the interactions between organisms and within and between populations and communities, excluding interactions with the non-living environment. Ecosystem services are defined as the benefits that people receive from ecosystems. The concept of ecosystem services was taken from the Millennium Ecosystem Assessment (2005) and comprises four categories of services:

Provisioning services — the products obtained from the ecosystem such as food, fuel and fresh water;

Regulating services — the benefits obtained from the regulation of ecosystem processes such as climate regulation, water regulation and natural hazard regulation;

Cultural services — the benefits people obtain through spiritual enrichment, recreation, education and aesthetics; and

Supporting services — the services necessary for the production of all other ecosystem services such as water cycling, nutrient cycling and habitat for biota.

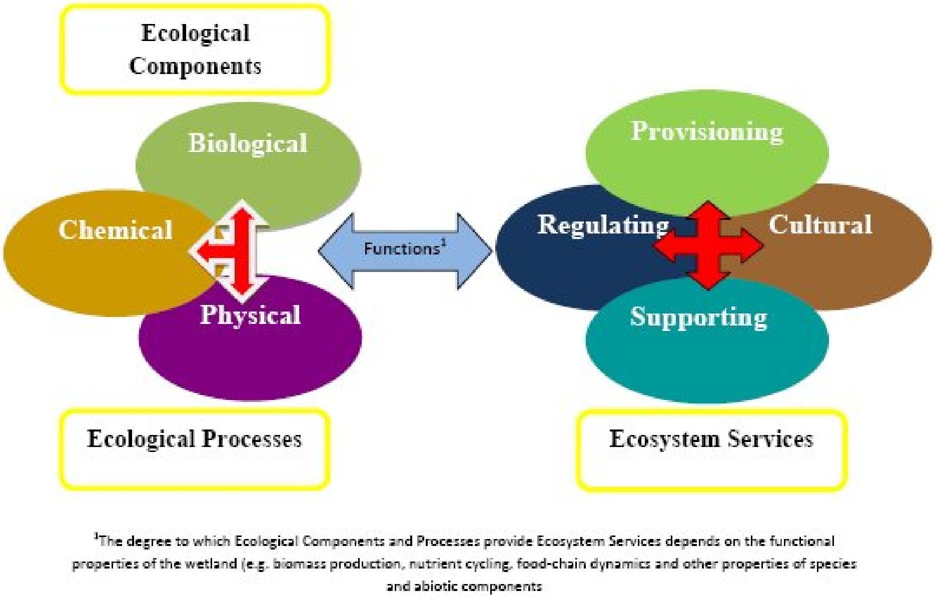


Figure 5: The concept of ecological character showing the relationships among ecological components and processes that comprise a wetland and the ecosystem services they deliver (from de Groot et al. 2006).

The Contracting Party provides a summary of the ecological character through information contained in the RIS provided at the time of listing, and updated every 6 years or sooner as required. This information is often seen as providing a reference condition at a point in time against which further change can be judged. A reference condition need not represent the ecological character at the time of listing – the Contracting Party may choose to nominate a reference condition and undertake management actions to reach this condition whilst maintaining the features that confer international importance on the site.

Contracting Parties are expected to establish management planning and monitoring mechanisms for all wetlands which they have designated for the Ramsar List to ensure their ecological character is maintained and, where necessary, restored. Australia has developed a proforma for describing in some detail the ecological character of its Ramsar sites and implemented an active program to ensure all sites have adequate descriptions, and hence established reference conditions for assessing any change. Within the context of the Convention, change in ecological character is considered to be human-induced adverse alteration of any ecosystem component, process, and/or ecosystem benefit/service.

Where the ecological character has changed (adversely) and under exceptional circumstances the boundaries of a site could be changed to exclude such areas, or the site even removed from the Ramsar List, with adequate compensation measures taken. Under most circumstances active management or restoration steps are encouraged rather than compensation or removal from the List. (The latter is only required if the site does not meet, or cannot be rehabilitated to meet any criteria for listing as internationally important.)

Once adverse change has been recorded or is regarded as likely to occur at a Ramsar site the Contracting Party is expected to submit a report to the Ramsar Secretariat – known as an Article 3.2 report from the specific clause in the text of the Convention. In practice, very few Article 3.2 reports are received from Contracting Parties; most reports received by the Ramsar Secretariat about adverse change at Ramsar sites come from concerned third parties. In these instances the Secretariat then seeks a response from the Contracting Party.

Several response options and mechanisms are available to address and resolve identified adverse changes, or likely changes, in the ecological character of sites on the List, including: i) using an established management planning process to implement appropriate management action; ii) seeking advice on appropriate issues to take into account in addressing the matter; and iii) voluntarily placing the site on the Montreux Record.

The Montreux Record was adopted in 1990 as a record of Ramsar sites where changes in ecological character have occurred, are occurring or are likely to occur, and to distinguish between sites where preventive or remedial action has not as yet been identified, and those where the Contracting Party has indicated its intention to take preventive or remedial action, or has already initiated such action. Inclusion of a site on the Record is voluntary and is principally seen as a mechanism for highlighting particularly serious cases of adverse change and demonstrating national commitment to resolve these. Australia has not to date made use of the Montreux Record, choosing instead to focus on national mechanisms to address adverse change.

One of the complex issues that arise when assessing adverse change in ecological character is determining the significance of the change. For this to be done the range of natural variation in the components, processes and ecosystem services that comprise a site need to be known, as well as an understanding of the consequences of changes due to human-induced pressures. The former requires an adequate description of the variability that occurs within the wetland and the latter an understanding of the likelihood of adverse change occurring. The Convention provides guidance on monitoring, including early warning, and risk assessment approaches that can be used to assist in these situations. The Australian proforma for describing the ecological character of a wetland incorporates these concepts and recommends the setting of limits of acceptable change for the critical components, processes, benefits and services of the wetland.

2.2.5 Management Planning

The Convention provides an international framework for the wise use of wetlands and encourages effective management planning for maintaining the ecological character of all wetlands with particular emphasis on those designated as Ramsar sites. The implementation of an effective management plan or planning process involving all stakeholders is seen as necessary to ensure the ecological character of the wetland is maintained. It is expected that management planning processes designed for Ramsar sites will also be applicable for all wetlands.

The importance of management planning for wetlands was explicitly recognised by the Ramsar Convention in guidelines that promoted the establishment and implementation of a management plan for a Ramsar site (or other wetland) as part of an integrated management planning process that could, where necessary, include surrounding non-wetland buffer zones, habitat mosaics, catchment areas or coastal zones, and also be flexible and adaptable. Recognition of the importance of managing wetlands within the wider catchment or coastal zone context is an important concept with implications for managers and planners alike as it signals that wetlands should not be treated in isolation of the surrounding geography and land/water uses.

The integration of all planning elements in a single document will result in a management plan. The manner in which the information is compiled and presented is largely dependent on the legal requirements for a plan (whether a prescribed format has been provided) and the complexity of the wetland and the management issues. It is recommended that the format of the management plan should comprise the sections outlined below, although at times the section on communication and participation could be excluded from the operational plan if all ongoing activities were incorporated in the action plan.

- Communication and Participation
- Preamble and Policy Setting
- Description of the Wetland
- Assessment / Evaluation
- Management Objectives
- Action Plan

The exact format of the management plan is not prescribed – this is left to the wetland managers/planners to determine in line with legal requirements and local circumstances. In some circumstances the management plan could contain a lot of detail in support of the management actions, whereas in others it could be contained in separate documents. The main issue is not whether the information should be contained in a single document that could at times become bulky and unwieldy, but whether the necessary information has been collated and is readily accessible, including for stakeholders.

2.3 Implementation of the Convention

Australia addresses its Ramsar site obligations through the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), the *Environment Protection and Biodiversity Conservation Regulations 2000* and national, state and territory wetland policies and natural resource management programmes. The EPBC Act (Box 5) identifies Ramsar sites as matters of national environmental significance and provides the legal framework for the listing, protection and management of Ramsar wetlands and for ensuring that the 'ecological character' of all Australian Ramsar sites is retained. The Act also sets out the consultation and notice requirements for nominations and establishes a process for assessing and approving actions that are likely to have a significant impact on the ecological character of Ramsar wetlands.

Box 5: The Environment Protection and Biodiversity Conservation (EPBC) Act 1999

The EPBC Act 1999 provides a legal framework for ensuring that the ecological character of Ramsar sites is maintained (or rehabilitated) and a management plan is prepared to support Australia's obligations under the Convention.

The objects of the Act include:

- the protection of the environment, especially those aspects of national significance;

- promotion of ecologically sustainable development;

- promotion of the conservation of biodiversity;

- promotion of cooperation between governments and the wider community, including land-holders and indigenous peoples;

- assistance for the cooperative implementation of Australia's international responsibilities;

- recognition of the role of indigenous people in conservation; and

- promotion of the cooperative use of indigenous knowledge of biodiversity.

The Act recognises an appropriate role for the Commonwealth in relation to the environment and enhances Australia's capacity to ensure the conservation of its biodiversity by including provisions to enhance the protection and conservation of Ramsar sites through the maintenance of their ecological character.

More information on the Act is available at www.deh.gov.au/water/wetlands/epbc/index.html).

In addition to listing Ramsar sites, Australia has played an active role in the development and implementation of the Convention both nationally and internationally. This has included participation in the Standing Committee and the Scientific and Technical Review Panel and attendance at the triennial Conference of Parties to the Convention, including hosting the 6th Conference in Brisbane in 1996.

Australia's support for and participation in the Convention has enabled extensive involvement in the governance and operations of the Convention, including the development and approval of the formal decisions agreed by the COPs and the documentation that has been used by the Ramsar Convention Secretariat to produce the Ramsar Handbooks for the Wise Use of Wetlands. The "Wise Use Handbooks" have been developed by the Secretariat based on the documentation that has accompanied or been included in the formal decisions taken by the Contracting Parties at the triennial COPs.

The Convention operates through a formally nominated Administrative Authority in each Contracting Party – in Australia this is the Department of Environment, Water, Heritage and the Arts (DEWHA). DEWHA represents Australian interests in the Convention through direct contact and involvement in the Standing Committee. It also coordinates information, e.g. site nominations, on behalf of the States/Territories. Interaction between DEWHA and the States/Territories is undertaken formally through the Wetland and Waterbird Taskforce (Box 6). DEWHA also generally leads the Australian delegation to the COP; the delegation usually comprises representatives from DEWHA and other federal departments as well as the States/Territories and representatives from wetland-related non-governmental organisations and indigenous organisations. The composition of the delegation is facilitated through the Wetland and Waterbird Taskforce.

Box 6: Wetland and Waterbird Taskforce

The Taskforce is convened under the umbrella of the Natural Resource Management Standing Committee which supports the Natural Resource Management Ministerial Council. The Taskforce is responsible for advising the High Conservation Value Aquatic Ecosystems Taskgroup and Natural Resource Policies and Programs Committee on the implementation of the Ramsar Convention. The Taskforce consists of wetlands experts from the relevant Commonwealth, State and Territory agencies.

The Natural Resource Management Ministerial Council (NRMMC) consists of the Australian/State/Territory and New Zealand government ministers responsible for primary industries, natural resources, environment and water policy. This Council results from the amalgamation and reorganisation of the previous ministerial councils (ARMCANZ, ANZECC and MCFFA) that dealt with elements of these issues. The Council is the peak government forum for consultation, coordination and, where appropriate, integration of action by governments on natural resource management issues. The agreed objective of the Council is: *"to promote the conservation and sustainable use of Australia's natural resources"*.

Some of the key roles of DEWHA relating to Ramsar wetlands include the following:

- work cooperatively with the state and territory governments to manager wetlands within an integrated catchment management context;
- provide national policies, direction and advice to stakeholders in relation to the protection and management of Ramsar wetlands;
- liaise with the Ramsar Secretariat about Australia's Ramsar wetlands;
- work with the state and territory governments about Ramsar wetland policies, designation of Ramsar wetlands and development of plans of management for Ramsar sites;
- assess proposed nominations of sites for inclusion on the List of Wetlands of International Importance under the Ramsar Convention;
- assess management plans for Ramsar wetlands;
- manage Ramsar wetlands on Commonwealth land; and,
- assess projects that trigger the EPBC Act.

The state and territory governments are responsible for facilitating and coordinating the nomination of wetlands as Wetlands of International Importance under the Ramsar Convention within their respective jurisdiction. They are responsible for presenting formal nomination documentation to the Australian Government to support the site being designated as a Ramsar wetland. They are also responsible for:

- implementing the Ramsar Convention in their respective state or territory;
- developing complementary state policies on wetland protection and management;
- developing Ramsar nominations or working with other stakeholders on Ramsar nominations;

- developing or working with proponents to enure management plans are in place for Ramsar sites;
- managing Ramsar wetlands on state or territory land; and
- working with private landholders to manage their Ramsar wetlands; and

The above concepts are variously outlined in the wetland policies adopted by the Commonwealth and State/Territory Governments, although the legal basis for implementing the Convention within Australia comes from the EPBC Act.

3 Ecological Character Description of the Hunter Estuary Wetland

3.1 Description of the Catchment

The source of the Hunter River is the Barrington Tops footslopes with tributary flows from the Pages and Isis rivers, and Middle and Dart brooks in the Upper Hunter Valley. It joins the Goulburn River near Denman and from Denman it flows in a south-easterly direction through Singleton and Maitland, and includes inflows from Wollombi Brook (HCRCMA 2009a). The Paterson and Williams rivers drain from the northeast of the catchment, from the eastern portion of the Barrington Tops, entering the Hunter River in the lower reaches (HCRCMA 2009a) and eventually drain into the Hunter River Estuary. Estimates from the dimensions of the entire Hunter River Estuary indicate that on average the volume of water in the estuary is 45 GL of water (Sanderson et. al. 2002)

Based on the Hunter Estuary water budget which includes the three major rivers, the Hunter, Paterson and Williams, inflows from the Hunter River provides 56% of the combined river inflows, the Paterson 19% and the Williams 25%. The remaining components of the water budget include minor contributions from licensed discharges and direct rainfall (Sanderson et. al. 2002).

The rivers of the Hunter catchment have slightly summer dominant flow regimes, with catchment rainfall highest from January to March. However, rainfall patterns are highly variably and large floods can occur during any month (Ryder et al 2009)

The topography of the Hunter catchment is strongly controlled by the underlying geology. A major fault line separates Carboniferous rocks exposed along the northern side of the catchment, coal measure sequences of Permian age in the central and south-eastern areas, and Triassic sandstones in the south (HCRCMA 2009a).

The water quality, channel stability, and ecological health of the Hunter River and its tributaries are highly degraded following 200 years of intensive post-colonial land use within the catchment (HCRCMA 2009a). The River is largely regulated through dams and weirs, and irrigation places a significant demand on flows. The Hunter River supports a diverse range of land uses, industries and settlement.

Prior to the 1980s the Hunter Valley was characterised by an industrial and urban base in the lower part of the valley with the Upper Hunter (from Singleton upstream) dominated by rural industries. However, the resources boom of the 1980s changed this balance, with industry, in particular large scale coal mining, moving into the upper valley (Pardice et al 2008). It is a highly regulated and modified catchment.

3.2 Description of the Study Area

The Hunter Estuary Ramsar Wetlands is comprised of two discrete areas, the Shortland Wetlands (377780E 6362290N), occupying an area of just over 45 ha (DEWHA 2002), and the Kooragang Nature Reserve (384500E 6365330N) that includes Fullerton Cove, the North Arm of the Hunter River, Stockton Sand Spit and other associated estuarine habitats comprising 2,926 ha (Figure 6). The Hunter

Estuary Ramsar Wetlands are not to be confused with the Hunter Estuary National Park, which although it includes Kooragang Nature Reserve, comprises other areas (i.e. Ash Island and Hexham Swamp Nature Reserve) and does not represent the boundary of the Ramsar wetland site.

The Shortland Wetlands and the Kooragang Nature Reserve are separated by 2.5 km, but are to some degree linked hydraulically via Ironbark Creek, and the Hunter River (NPWS 1998), though the Ironbark Creek Floodgates and wetland bunding at the Shortland Wetlands inhibit the natural flow regime between the two sites. The two sites are considered as complementary as they provide a representative range of wetland types found in coastal estuaries within the Sydney Basin biogeographic region (DEWHA 2002) and together form the Hunter Estuary Wetlands.

Shortland Wetlands are located in the lower part of Ironbark Creek Catchment in the suburb of Shortland, 12 km northwest of Newcastle. The wetlands are situated on Quaternary estuarine/lacustrine sediments including silts and clays (Matthei 1995). The Kooragang Nature Reserve is located in the estuary of the Hunter River, approximately 7 km north of Newcastle. It incorporates Fullerton Cove, the north-eastern section of Kooragang Island, and adjacent intertidal and aquatic areas (Figure 6).

In providing the ecological character description for the study area, a 200 m buffer around the Hunter Estuary Ramsar has been factored into the study area, to account for conservation values that may fall directly adjacent to the Ramsar wetland and may potentially be impacted by the proposed activity. It is recognised that the wider estuary has similar characteristics to the Kooragang Nature Reserve portion of the Ramsar wetland and is relevant for the assessment; however, for the purpose of the Ecological Character Description, the actual Ramsar Wetlands and 200 m buffer were the focus.

Figure 6: Location of the Hunter Estuary Wetlands comprising the Shortland Wetlands and the Kooragang Nature Reserve.

The Ramsar Information Sheet for the Hunter Estuary Wetland was compiled in 2002 (Appendix C) and provides the current legal document description of the ecological character of the Ramsar wetland. This Information Sheet (DEWHA 2002) has been used as a basis to inform the Ecological Character Description of the Ramsar site, though additional data and information has been sourced as a supplement to conform to the more detailed ECD proforma more recently adopted for describing Australian Ramsar sites (DEWHA 2008). This section provides the ECD for the Hunter Estuary Ramsar wetland and incorporates relevant information from the Ramsar Information Sheet.

3.3 History and Landuse

3.3.1 Shortland Wetlands

Prior to the development of the Shortland Wetlands, the area was subject to several modifications associated with urban development. The most significant impacts on the structure and ecology of the wetlands included infilling and changes in the hydrology.

Originally, some of the wetlands were part of the estuarine wetlands of lower Ironbark Creek that flowed into the Hunter Estuary. At this time, saltmarsh and mangroves extended well into Shortland Wetlands (Winning 2006). Changes in the natural flow regime were caused by a number of factors. These included the construction of floodgates on Ironbark Creek, the establishment of Newcastle City Council's Astra Street garbage dump, the construction of a drainage canal from Sandgate Road to Ironbark Creek, and the construction of a power transmission line. These activities obstructed the natural drainage regime and restricted tidal intrusion, changing the wetlands from a partly brackish to a fresh water regime (Winning 1989). In 1984 the Shortland Wetlands site consisted of an abandoned building, sports fields constructed on infilled wetlands, and areas of mildly disturbed wetlands. Despite the impacts, Shortland Wetlands supported nesting colonies for four species of egrets, two cormorant species and other ecological values (Shortland Wetland Centre Site Management Plan 2006). Remediation of the drainage regime of Ironbark Creek and the adjacent Hexham Swamp is currently being managed by the Hunter-Central Rivers Catchment Management Authority (HCRCMA), including the re-introduction of saline tidal waters through the opening of the Ironbark Creek floodgates to encourage regeneration of 750 ha of saltmarsh habitat.

In 2002 the Shortland Wetlands was designated as a Wetland of International Importance and listed as a Ramsar wetland, in accordance with the Ramsar criteria provided in Section 3.4. The Hunter Wetlands Centre is the principal management authority for the wetland.

3.3.2 Kooragang Nature Reserve

Until the early 1900s the Hunter River estuary where Kooragang Nature Reserve now lies contained seven islands separated by narrow channels, with the low lying areas used for fruit growing, timber harvesting and salt extraction (NPWS 1998). With the exception of the development of a ship building industry in the 1920s, no other major industry occurred on the island until after World War II when the Newcastle Chamber of Manufacturers proposed a major industrial area for the island (NPWS 1998).

The entire area was zoned for heavy industrial use in 1960 and its development was provided for under the Kooragang Island Development Scheme by the Department of Public Works. Various alterations to the river flow during the development of the Hunter River as a port, such as the Walsh Island training wall in 1898 and reclamation works associated with the Newcastle Harbour Improvements Act (1953) had already modified the natural regime, whereby the original seven islands were consolidated to form Kooragang Island in 1967. By 1971 some 704 ha of wetlands had been partially or fully reclaimed (NPWS 1998).

In the early 1970's conversion of Kooragang Island to an industrial area was slowed by public concern over the effect on flood regimes in the lower Hunter River and about the pollution threat to adjacent residential areas. At the same time there was an increasing awareness of the environmental importance of the estuary. Conservation of Kooragang Island was seen as the ideal way to maximise the conservation value of the Hunter estuary (NPWS 1998).

Major studies (Dames and Moore; 1978; Kendall and Van Gessel; 1972, 1974; Briggs, 1978 and Pressey; 1982; Moss, 1983) and the findings of the Commission of Inquiry into Pollution on Kooragang Island (Coffey 1973) led to the NSW Government announcing its intention to establish a nature reserve in 1981 (NPWS 1998).

In 1984 Kooragang Island Nature Reserve was designated as a Wetland of International Significance and listed as a Ramsar site, in accordance with the Ramsar criteria provided in Section 3.4 (DEWHA 2002). The NSW Department of Environment and Climate Change (DECC) is the principal management authority for the wetland. In 2007 the Hunter Estuary National Park was created, which incorporated the Kooragang Nature Reserve. Despite having similar characteristics and management requirements, Hexham Swamp Nature Reserve and other areas included in the Hunter Estuary National Park (i.e. Ash Island) have not been incorporated into a revised Ramsar site boundary and therefore Ramsar considerations are only applied to Kooragang Nature Reserve (Figure 6).

3.4 Hunter Estuary Ramsar Listing criteria

The Hunter Estuary Wetland Information Sheet was compiled in 2002 and provides background information on the Ramsar wetland, including the Criteria for Ramsar listing (DEWHA 2002).

3.4.1 Listing criteria for Shortland Wetlands

Criterion 1: Shortland Wetlands is unique in that it has a combination of high conservation value near-natural wetlands (Melaleuca swamp forest, freshwater reed marsh, coastal estuarine mangrove-lined creek) and high conservation value artificial wetlands (constructed freshwater lagoons, coastal estuarine Casuarina-lined channel, model farm dam). It is the only complex of this type found within the Sydney Basin biogeographic region. The Melaleuca swamp forest in particular represents a wetland type that, although once very widespread, is poorly represented in the Sydney Basin biogeographic region.

Criterion 4: Shortland Wetlands supports a large number of species, some in very large numbers, at a critical seasonal stage of their breeding cycle and as a refuge during adverse conditions. Twenty-eight bird species have been recorded as breeding at Shortland Wetlands.

The Great Egret (*Ardea alba*), Intermediate (*Ardea intermedia*), Little (*Egretta garzetta*) and Cattle Egrets (*Ardea ibis*) are seasonal migrants to the site from long distance wintering locations in New Zealand.

Over 1000 Australian White Ibis (*Threskiornis molucca*) use the Melaleuca swamp forest as a night roost throughout the year, but numbers increase significantly over autumn and winter as migrants from inland breeding colonies come to the coast for non-breeding seasonal foraging.

Very few Straw-necked Ibis (*Threskiornis spinicollis*) are present during summer but huge numbers migrate to the region during autumn and winter. Up to 7000 of these birds use the Wetlands Centre Melaleuca swamp forest for night roosting.

Variable numbers (up to 200 birds) of Nankeen Night Herons (*Nycticorax caledonicus)* use the swamp forest for night foraging and for day roosting during the non-breeding season.

White-faced Heron (*Egretta novaehollandiae*), White-necked Heron (*Ardea pacifica*), Royal Spoonbill (*Platalea regia*) and Yellow-billed Spoonbill (*Platalea Flavipes)*, fluctuate in numbers from single birds up to about 30 or more, using the swamp forest as a night roost throughout the year.

The site provides drought refuge for a number of species during critical inland drought episodes, recognised by a dramatic increase in numbers or sudden appearance coinciding with the onset of inland drought; and a drop in numbers or disappearance coinciding with breaking of the drought. These species include Freckled Duck (*Stictonetta naevosa*) - 73 were counted in a survey in 1983, small numbers of one to five birds have appeared at intervals since; Pink-eared Duck (*Malacorhynchus membranaceus*): small flocks; Australian Pelican (*Pelecanus conspicillatus*): 87 have been recorded; and Glossy Ibis (*Plegadis falcinellus*) - often 100 or more (Albrecht and Maddock 1985).

The site is also important during dry periods for local resident ducks, herons and other waterbirds, with the numbers of ducks being as high as 2000 birds.

3.4.2 Listing criteria for Kooragang Nature Reserve

Criterion 3: Kooragang Nature Reserve is ecologically diverse and represents a significant genetic pool for wetland species in the Sydney Basin biogeographic region. Winning (1996) identified 112 species of vascular plants at Kooragang Island which form many distinct habitat types. The mangrove and saltmarsh areas are particularly good examples of these plant communities. Kooragang Nature Reserve wetlands are also important for maintaining a high diversity of birds within the biogeographic region with over 250 species recorded.

Criterion 4: Kooragang Nature Reserve is widely recognised for its importance in the conservation of migratory birds (Geering 1995; NPWS 1998). At least 38 species of migratory birds recorded at Kooragang are presently listed under International treaties including the Japan-Australia and China-Australia Migratory Bird Agreements (JAMBA and CAMBA). In 2000, 4800 migratory shorebirds were recorded in the Hunter Estuary (Straw 2000). Kooragang Nature Reserve regularly supports 15 species of migratory shorebird. Kooragang Nature Reserve also supports a large number of species at a critical seasonal stage of their breeding cycle. Twenty-four bird species have been recorded breeding at Kooragang.

Criterion 6: Kooragang Nature Reserve regularly supports between 2% to 5% of the East Asian-Australasian Flyway population of Eastern Curlew (*Numenius madagascariensis*), with counts ranging from 320 to 900 birds between 1989 and 2000 (Straw 2000). The 1% population threshold for this species is 210 individuals (Rose and Scott 1997).

The Information Sheet (DEWHA 2002) contains a list of 12 different wetland types (based on the Ramsar wetland typology) at the site. The most important wetland types at Kooragang Nature Reserve include mangrove forest and saltmarsh, along with swamp forest, saline and freshwater pasture, brackish swamps and standing open water, and mudflats and sandy beach. Wetland types at Shortland Wetland include semi-permanent freshwater ponds and marshes, freshwater swamp forest, and coastal estuarine creek.

3.5 Landscape. Geology and Soils

The Hunter Estuary Ramsar wetland is located in the lower Hunter River, a barrier estuary formed by the deposition of sediments in swamps and flats lying between the inner and outer coastal barrier sands. The Ramsar site is characterised by low relief, with elevations ranging from 10 m ASL at locations within Shortland Wetlands, to below sea level.

The Shortland Wetlands occur on a low coastal foot slope at Shortland, grading towards Ironbark Creek and Hexham Swamp. Several artificial wetlands occur that are situated on Quaternary estuarine lacustrine sediments including silts and clays (Matthei 1995).

The Kooragang Nature Reserve portion of the Ramsar site consists of 10 and 40 m of sands and sediments that over lie older bedrock of fine to medium grained massive grey sandstone and siltstone interspersed with shales and coal (Figure 7). Although the bedrock slopes upwards to the north there are no outcrops within the Ramsar (NPWS 1998).

The sediments on Kooragang Nature Reserve and adjacent estuarine areas comprise black silty and highly saturated soft clays to a depth of about 2 m which are underlain by light grey silty sand. Depending on their elevation above sea level, drainage pattern and their susceptibility to freshwater flooding, these sediments are more or less saline. Salinities may vary from saltier than seawater in evaporative salt marsh areas to fresh water salinities behind levees where the soil is generally more fertile and flooded regularly by fresh water. The extensive intertidal mudflats associated with Fullerton Cove and the banks of the Hunter River are being formed by deposition of layers of sediments from upstream which are trapped by mangroves and/or deposited by slow moving water (NPWS 1998).

Most soils of Kooragang Nature Reserve are only slightly acidic although small areas of sandy clays supporting brackish swamps can reach low pH levels and create the potential for acid sulphates to occur should they be dried out (NPWS 1998; DEWHA 2002).

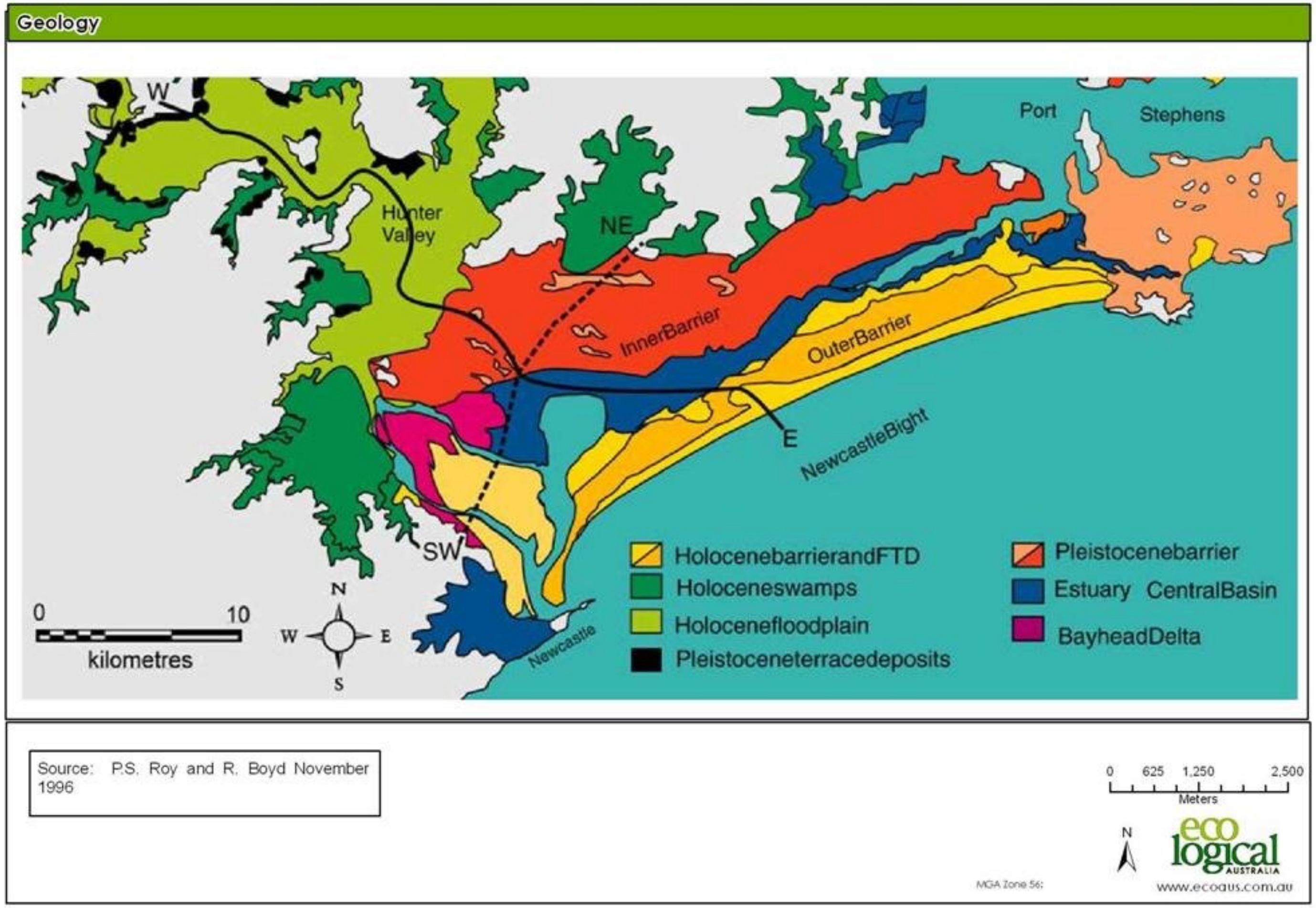


Figure 7: Geology of the region (Source Roy and Boyd 1996).

3.6 Hydrology

The Shortland Wetlands contain seven discrete ponds ranging in volume from 5,000 m³ to 20,000 m³. Historically part of a shallow estuarine swale that was connected to the Hunter River through Ironbark Creek, the wetlands, are now freshwater environments (BMT WBM 2008). The Shortland Wetlands receive water from the local catchment in the form of direct precipitation and runoff from adjacent urban areas.

Estuarine waters within Kooragang Nature Reserve are shallow (generally <5 m deep), with Fullerton Cove having a maximum depth of two to three metres at its centre (DEWHA 2002). The tidal range is approximately 0.1 to 2m and at low tide large areas of mudflats are exposed (DEWHA 2002). Estimates from the dimensions of the entire estuary (30 km long by 300 m wide by 5m deep) indicate that on average the volume of the estuary is 45 GL of water (Sanderson et. al. 2002). The largest contribution of the Hunter Estuary water budget comes from tides (approximately 92% of total volume). The next largest input to the system is the combined river inflows from the three main rivers, the Hunter, Paterson and Williams Rivers. The Hunter River provides the greatest proportion of the inflow volume (3.1% of total volume or 56% of combined river inflows) and the Paterson the least (1% of total volume or 19% of the combined river inflows). Other freshwater inflows entering the system are supplied by the Williams River (1.4% of total volume or 25% of the combined river inflows) and local catchment runoff (1.9% of total volume). The remaining components of the water budget include minor contributions from licensed discharges (0.04% of total volume) and direct rainfall (0.19% of total volume). Evaporative losses are estimated to represent approximately 0.24% of the total water budget. River flows are extremely variable, often dropping well below the mean flow and can exceed 45 GL/day during sufficiently severe floods (Sanderson et. al. 2002).

There are two groundwater aquifers that are in close proximity to the Kooragang Nature Reserve portion of the Ramsar wetland, namely, the Tomago Sandbeds and Stockton Sandbeds (Woolley et. al. 1995). Woolley et. al. (1995) mapped groundwater contours in the current study locality and extending to Port Stephens. These maps indicate that groundwater discharge into the Hunter Estuary and Ramsar, as well as in the lower reaches of the Hunter River (Hexham and Raymond Terrace area), occurs from both of the adjoining aquifers.

Recharge to Tomago Sandbeds and Stockton Sandbeds is almost entirely from local rainfall on the sand beds and enters the aquifers via highly permeable unconsolidated aeolian sediments (NSW Planning and Environment Commission 1977). Although some saline recharge into the aquifers is evident from the estuary and Hunter River (identified through groundwater water quality analysis), substantial ground water recharge from the Williams and Hunter Rivers was not reported, with ground water contours grading towards the rivers and estuary rather than from them (Woolley et. al. 1995).

3.7 Water Physicochemistry

3.7.1 Salinity

Salinity within the ponds of the Shortland Wetlands varies depending on conditions and pond location, but ranges from 1.05 parts per thousand (ppt) to 0.28 ppt (BMT WBM 2008).

Simulations for the Kooragang Nature Reserve indicate inter-annual high variability of river flows with concomitant high variability of the salt distribution in the Hunter River estuary (Sanderson et. al. 2002). During high flow periods saline tidal waters are pushed towards the opening of the estuary, with sufficiently severe floods sweeping most of the salt out of the estuary so that the estuary effectively becomes a river emptying directly into coastal waters (Sanderson et. al. 2002). In periods of low flow from the river system, the estuary is vertically well mixed and gradual horizontal mixing causes the slow transportation of salt up-stream in the form of a salt wedge (Sanderson et. al. 2002). With regard to salinity measurements within the major rivers entering the estuary, salinity was generally lower in the Williams River upstream of Seaham Weir (Raymond Terrace) than in the Hunter River, which is suggested to be a result of the weir presenting a physical barrier to the salt wedge (Sanderson et. al. 2002).

3.7.2 Temperature

Temperature within the Shortland Wetland ponds is variable depending on weather conditions and ranges from 15.35 to 19.96 Cº (BMT WBM 2008).

Temperature within the Hunter River estuary increased progressing up the estuary in the warmer months. Patterns of temperature distribution within the estuary are related to salinity, except for heat fluxes associated with hot or cold weather (Sanderson et. al. 2002).

3.7.3 Turbidity

Turbidity within the Shortland Wetland ponds is variable depending on weather conditions and ranges from 1.15 to 435 NTU (BMT WBM 2008).

Turbidity is often highest further up the estuary where the water becomes riverine. Further downstream, one localised region of high turbidity appears to be associated with strong tidal currents in a constricted portion of the estuary. During high flow events turbidity is highest, followed by a gradual drop in turbidity as floods recede and saline waters penetrate upstream (Sanderson et. al. 2002). Turbidity readings between 8-30 NTU are encountered during normal conditions, whilst during flood events readings were much higher at between 300 and 600 NTU (Sanderson et. al. 2002).

In terms of the Williams River, contributions to turbidity and the changes that Tillegra Dam may have on turbidity, Gipple and Anderson (2008) presented some modelled results for pre- and post-Tillegra Dam scenarios. Six sites along the Williams River were sampled for coarse sediments. Bedload transport rates were lower under the base case post dam (average of 16.81Kt for all sites) flow scenario than the pre-dam (average of 27.27 Kt for all sites) scenario in every case (Gipple and Anderson 2008). Gipple and Anderson (2008) also modelled suspended sediment loads, though it was acknowledged that these measurements were first order approximations, due to limited event-based water quality (TSS) data. Results suggested that the Williams River at Tillegra under the current flow regime conveys, on average, almost 10 000 tonnes of suspended load per year, with marked inter-annual variation.

3.7.4 Suspended Sediments

The Hunter River upstream of Oakhampton is the primary source of fluvial sediments that contribute to the Hunter Estuary. The Paterson River upstream of Paterson is also a contributor and bank erosion from the Williams River may also be a source of sediment. Seaham weir currently captures nearly all bedload material and the majority of suspended sediment particularly during low flow periods. Other sources of sediment in the estuary include marine sediments through the estuary entrance and urban sediments from areas such as Newcastle, Raymond Terrace and Maitland (Manly Hydraulics 2003).

Based on the catchment area (21,545 km^2), land use, topography and rainfall, the Australian Natural Resources website calculates the total suspended sediment (TSS) supplied from the entire Hunter River catchment as 2,950,924 tonnes per year (ANR 2002).

Of this, it is estimated 1 million tonnes of TSS enters the Hunter Estuary, 100,000 tonnes of which is accumulated within the estuary channels, such as the Ramsar site, with a typical accretion rate of 2.3 mm/yr. 414,000 tonnes is accumulated within Newcastle Harbour, and is dredged (and then dumped offshore), and 500,000 tonnes is transported out of the river and deposited on the offshore continental shelf (Manly Hydraulics 2003).

3.7.5 Dissolved Oxygen

Dissolved oxygen levels within the Shortland Wetland ponds are variable depending on weather conditions and range from 1.7 to 20 mg/L (BMT WBM 2008).

Dissolved oxygen levels are often observed to be lowest in the upper parts of the estuary following increased river flows, falling to less than 20% saturation following flood conditions in March 2001 (Sanderson et. al. 2002).

3.7.6 Nutrients

Very high concentrations of nutrients (nitrogen and phosphorus) are found throughout the Shortland Wetland ponds, with substantial increases observed during wet weather periods (BMT WBM 2008). Total Nitrogen (TN) ranges from 4.6 to 11.5 mg/L within the seven ponds (BMT WBM 2008). Total Phosphorous (TP) ranges from 0.62 to 3.66 mg/L within the seven ponds (BMT WBM 2008). The large number of birds, sometimes in excess of 20 000 individuals, along with nutrients from urban stormwater, represents the likely major source of nutrients to the wetlands.

Kooragang Nature Reserve is located in the lower reaches of the Hunter River catchment and is within direct influence of tidal waters. The concentration of heavy industry, shipping along the South Arm, agricultural and urban development within the Hunter River catchment, substantially influences water quality. There have been particular concerns for the water quality of the South Arm, with fishing banned in the South Arm at one time due to public health concerns.

3.8 Vegetation

3.8.1 Vegetation communities and Endangered Ecological Communities

Native vegetation communities within the Hunter Estuary Ramsar site are described below and their extent is shown in Figure 8. Mapping datasets used to compile the vegetation types and maps include Lower Hunter Central Coast Regional Environmental Management Strategy (LHCCREMS 2003) and Department of Primary Industries – Fisheries (2006). Field validation of these communities has not been undertaken as part of this investigation.

The mapped area has included a 200 m buffer around the Ramsar site, as well as Ironbark Creek, to account for indirect effects to the wetlands. Four Endangered Ecological Communities (EEC's) listed under the NSW Threatened Species Conservation Act (1995) (TSC Act) correspond with the vegetation communities identified; as noted below in the vegetation profiles and mapped in Figure 8. Mangrove vegetation, although not listed as an EEC, is considered and has been mapped as a sensitive ecological community.

MU15 Coastal Foothills Spotted Gum - Ironbark Forest *Approximately 2 ha*

Coastal Foothills Spotted Gum - Ironbark Forest is a moderately tall open forest dominated by *Corymbia maculata* (Spotted Gum) in combination with one or several ironbark species such as *Eucalyptus siderophloia* (Grey Ironbark), *Eucalyptus paniculata* (Grey Ironbark) or *Eucalyptus fibrosa* (Red Ironbark). *Eucalyptus acmenoides* (White Mahogany), *Eucalyptus umbra* (Broad-leaved White Mahogany) and *Syncarpia glomulifera* (Turpentine) are common associate trees. The upper mid-storey is composed of an open stratum of *Allocasuarina torulosa* (Forest Oak). Typically the shrub layer is open, with species such as *Persoonia linearis* (Narrow-leaved Geebung), *Polysicas sambucifolius* (Elderberry Panax), *Breynia oblongifolia* (Coffee Bush) and *Daviesia ulicifolia* (Gorse Bitter Pea). The ground cover is dominated by a number of common grasses including *Imperata cylindrica var. major* (Blady Grass), *Entolasia stricta* (Wiry Panic), *Themeda australis* (Kangaroo Grass) and *Microlaena stipoides var. stipoides* (Weeping Rice Grass).

MU33 Coastal Sand Apple-Blackbutt Forest *Approximately 9 ha*

Coastal Sand Apple-Blackbutt Forest occurs principally on Holocene sands, where protection from direct coastal salt-laden winds is available. It occupies dunes of higher elevations with improved soil development. Typically it takes the form of an open forest with a moderately open, shrubby understorey. *Angophora costata* (Smooth-barked Apple) and *Eucalyptus pilularis* (Blackbutt) are the key canopy species, the presence and abundance of each in the canopy is variable, and it is not uncommon for one to almost completely dominate. The shrub stratum is highly dependent on recent fire history, however, where present it is often composed of *Banksia serrata* (Old-man Banksia), *Acacia ulicifolia* (Prickly Moses), and *Dillwynia retorta* (Heathy Parrot Pea). A combination of herbs, ferns and grasses inhabit the understorey. *Pteridium esculentum* (Bracken) is the most dominant; however, others such as *Gonocarpus teucrioides* (Raspwort), *Aotus ericoides* and *Themeda australis* (Kangaroo Grass) are usually associated.

MU37 Swamp Mahogany- Paperbark Swamp Forest *Approximately 55ha*

Swamp Mahogany - Paperbark Swamp Forest occurs in areas of impeded drainage near coastal swamps, lagoons and along drainage lines on alluvial flats of Quaternary sands and sediments. Structurally, this community ranges from open forest to forest with *Eucalyptus robusta* (Swamp Mahogany) and *Melaleuca quinquenervia* (Broad-leaved Paperbark) forming the key diagnostic species either in combination or as monospecific stands.

This vegetation corresponds with *Swamp Sclerophyll Forest on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner Bioregions* EEC, listed under the NSW Threatened Species Conservation Act, as floristic composition and landscape position are suitable, though validation of diagnostic soil types has not been undertaken.

MU40 Swamp Oak - Rushland Forest *Approximately 100ha*

Swamp Oak - Rushland Forest occurs in low-lying areas and along coastal lagoon fringes where brackish-saline groundwater or periodic inundation by saline tidal waters exerts a strong influence on the range of species present. The low forest canopy ranges from moderate to open depending on the relative abundances of *Casuarina glauca* (Swamp Oak) and *Melaleuca quinquenervia*. This community is often characterised by monospecific stands of *Casuarina glauca*. In other areas where the saline influence is less pronounced, canopy species might include *Melaleuca ericifolia* (Swamp Paperbark), *Melaleuca quinquinervia*, *Eucalyptus robusta* and *Eucalyptus Tereticornis* (Forest Red Gum). Mid-storey vegetation is sparse and often absent, although when present it is usually characterised by tall reeds and rushes (2 to 3 m) such as *Phragmites australis* (Native Reed) and *Cladium procerum*. The dense ground layer is characterised by salt tolerant rushes, grasses and herbs including *Baumea juncea*, *Juncus kraussii subsp. australiensis* (Sea Rush), *Sporobolus virginicus* (Salt Couch) and *Apium prostratum* (Sea Celery).

This vegetation corresponds with *Swamp Oak Forest on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner Bioregions* EEC, listed under the NSW Threatened Species Conservation Act, as floristic composition and landscape position are suitable, though validation of diagnostic soil types has not been undertaken.

MU46 Freshwater Wetland Complex *Approximately 102ha*

Freshwater Wetland Complex occurs in low-lying areas permanently or periodically inundated by fresh water. Structurally, this community can range from open water with aquatic herbs, through closed sedgeland, to low woodland with a sedge understorey in areas only periodically inundated or on swamp margins. The community is highly variable with different individual or paired species almost completely dominating depending on localised conditions. The characteristic feature of this community is the dense understorey dominated by rushes, sedges and aquatic plants. These can include: *Ludwigia peploides subsp. montevidensis*; *Eleocharis sphacelata* (Tall Spike Rush); *Paspalum distichum* (Water Couch); *Juncus usitatus*; *Typha orientalis* (Bullrush); *Persicaria decipiens* (Spotted Knotweed); and *Azolla pinnata*. Along swamp margins the improved drainage enables emergent trees to merge with the sedge layer. Where this is the case the most common species found are *Melalleuca styphelioides* (Prickly-leaved Tea Tree), C*asuarina glauca*, *Melaleuca linariifolia* (Flax-leaved Paperbark) and occasionally *Eucalyptus tereticornis*.

This vegetation corresponds with *Freshwater Wetland on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner Bioregions* EEC, listed under the NSW Threatened Species Conservation Act, as floristic composition and landscape position are suitable, though validation of diagnostic soil types has not been undertaken.

MU47 Mangrove Estuarine Complex *Approximately 1470ha*

Mangrove Estuarine Complex occurs on intertidal mudflats, saltwater estuaries and along tidal river edges. It encompasses a broad range of structural forms from bare mud or saltmarsh on mudflats, to low closed mangrove forest. Bare mudflats are found in areas of recently deposited or reworked tertiary sediment, and are characterised by an almost total absence of vascular plants. Where mangroves occur, they may range structurally from scattered small trees over saltmarsh to low closed forest. There are two often co-occurring species of mangrove in the study area. *Avicennia marina subsp. australasica* (Grey Mangrove) and *Aegiceras corniculatum* (River Mangrove). *A. corniculatum* prefers less saline conditions and therefore may extend further up tidal rivers.

MU47a Saltmarsh *Approximately 400ha*

Saltmarsh occurs on mudflats often in conjunction with mangroves, and tolerates higher saline conditions than mangroves. This variation is often found in landward depressions behind mangroves where still shallow water and high evaporation rates result in increased relative salt content. Saltmarsh is primarily characterised by *Sarcocornia quinqueflora subsp. quinqueflora* (Samphire), however, in less saline conditions *Zoysia macrantha* (Prickly Couch), *S. virginicus*, *Triglochin striatum* (Streaked Arrowgrass), *Suaeda australis*, *Samolus repens* (Creeping Brookweed) and *Juncus kraussii subsp. australiensis* commonly occur.

This vegetation corresponds with *Coastal Saltmarsh in the NSW North Coast, Sydney Basin and South East Corner Bioregions* as floristic composition is suitable.

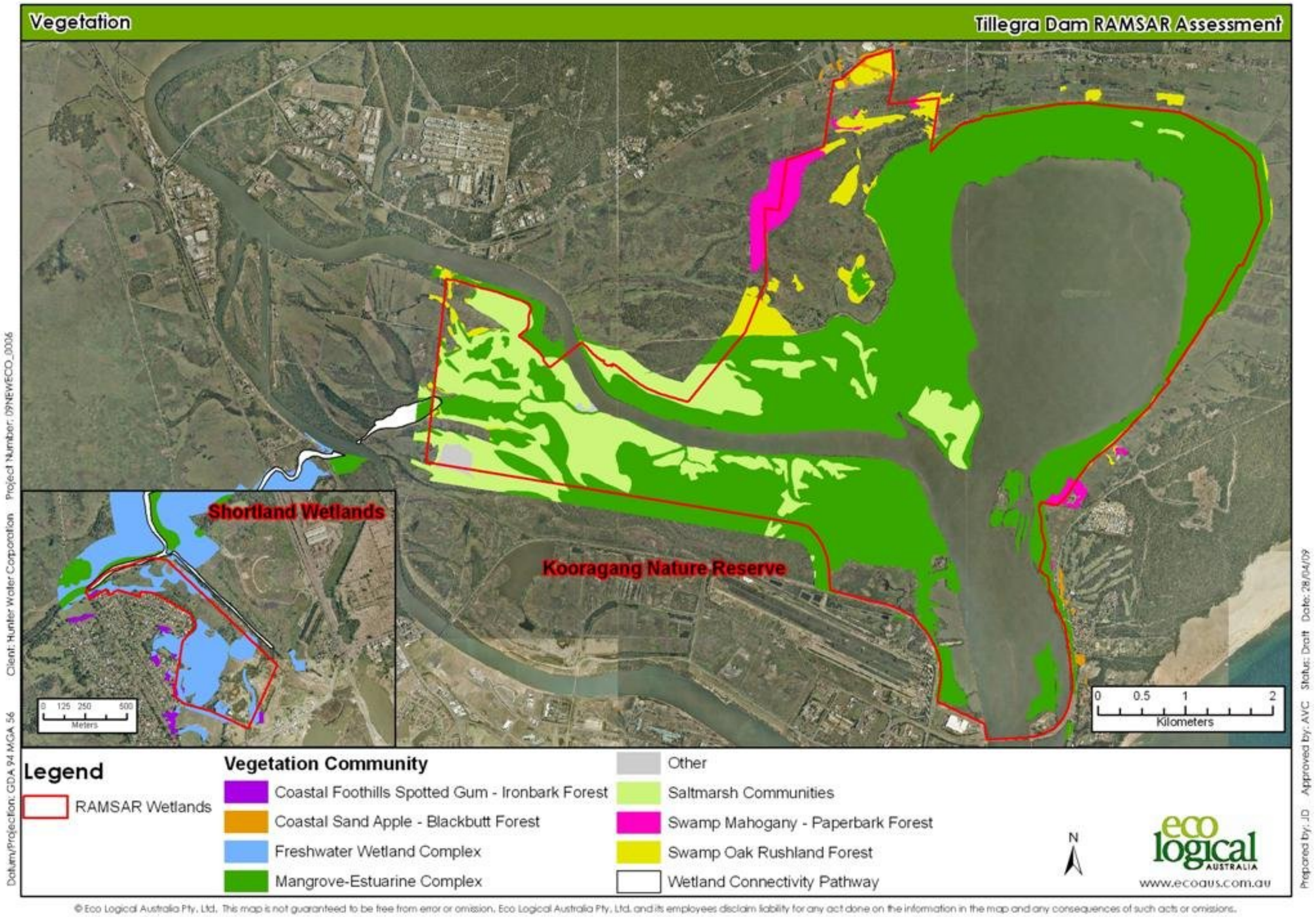


Figure 8: Vegetation communities (from LHCCREM 2003 and DPI 2006).

3.9 Fauna

3.9.1 Terrestrial Fauna

Reptiles and Amphibians

The Hunter Estuary Ramsar wetland area provides important habitat for frogs, including the Green and Golden Bell Frog (*Litoria aurea*), listed as endangered under both NSW Threatened Species Conservation Act and Federal Environment Protection and Biodiversity and Conservataion Act, being recorded as a captive animal at Shortland Wetlands and a free ranging populations at Kooragang NR (Ekert 2004, Markwell 1984). An additional 8 native frog species have been recorded at the Shortland Wetlands (Ekert 2004) and an additional 3 native frog species in Kooragang Nature Reserve (Markwell 1984).

A total of 13 native reptile species have been recorded at Shortland Wetlands; however, none are currently listed as threatened (Ekert 2004, MacDonald Wagner 1984). Reptile surveys of Kooragang Nature Reserve have not been completed.

Mammals

Only three species of native mammal have been recorded in Kooragang Nature Reserve, including the Grey-headed Flying Fox (*Pteropus poliocephalus*), listed as vulnerable under both NSW Threatened Species Conservation Act and Federal Environment Protection and Biodiversity Conservation Act (NPWS 1998). At Shortland Wetlands a total of six mammal species have been recorded, including the Grey-headed Flying Fox, Northern Brown Bandicoot (*Isoodon macrourus*) and the remainder being introduced species (Ekert 2004)

Birds

Over 160 species of native bird species have been recorded in Kooragang Nature Reserve (NPWS 1998), including between 2 to 5% of the East Asian-Australasian Flyway population of Eastern Curlew (*Numenius madagascariensis*). 196 species in Shortland Wetlands (Ekert 2004), of which migratory wading birds form a major component, including teal, Magpie Geese (*Anseranas semipalmata*), swans and many duck species and a seasonal evening roost for approximately 4000 Australian White Ibis (*Threskiornis molucca*) and Straw-necked Ibis (*Threskiornis spinicollis*) in winter months (Ekert 2004). Table 1 provides a list of threatened or migratory birds that have been recorded or considered likely to occur within the Hunter Estuary Wetland, as well as location specific information (Atlas for Wildlife May 2009, Ekert 2004, Geering 1995, Herbert 2007). Figure 9 provides key migratory wader sites according to Herbert (2007).

Key sites for migratory waders within the Hunter Estuary Wetland that comprise roosting and foraging habitat include the Stockton Sand Spit, Kooragang Dykes, Fullerton Cove and Shortland Wetland Centre (Herbert 2007). Several other important migratory wader sites also occur in the Hunter Estuary Ramsar and Hunter Estuary in general (Table 1, Figure 9).

3.9.2 Estuarine fauna

Macroinvertebrates

The Shortland Wetlands have a diversity of macroinvertebrate fauna including molluscs, bloodworms, caddisfly and dragonfly larvae, gastropods, beetles and copepods (Bischof & Brown 1996). Aquatic invertebrates such as worms, gastropods, molluscs and crustaceans are extremely abundant in Fullerton Cove, making this area a vital foraging area for shorebirds (Herbert 2007; NPWS 1998).

Saltmarsh communities fringing the estuary provide important habitat for crabs. Saltmarsh are recognised as a key source of crab larvae into estuaries, with these larvae being an important food source for juvenile fish.

Fish

Surveys conducted at Ironbark Creek, Kooragang Island, Fullerton Cove and Tomago (West) (HCR CMA 2009a) have reported that 45 species of fish and crustaceans occur in the Hunter Estuary and are relevant to the Kooragang Nature Reserve. This includes up to 19 species of fish or crustaceans used for commercial or recreational purposes (NPWS 1998), such as Sand Whiting (*Sillago ciliata*), Tailor (*Pomatomus saltatrix*), Yellowfin Bream (*Acanthapagrus australis*), Luderick (*Girella tricuspidata*), School Prawn (*Melapeneuaeus macleayi*), Eastern King Prawn (*Penaeus plebejus*) and Mud Crab (*Scylla serrata*). Juvenile Black Cod (*Epinephelus daemelii*), listed as vulnerable under the Fisheries Management Act could potentially be found in some parts of the Hunter Estuary past Stockton bridge.

A total of five native fish species have been recorded in the Shortland Wetlands (Macdonald Wagner 1984).

3.10 Threatened and Migratory Biodiversity

All threatened and migratory fauna that have been recorded or are considered likely to occur within the Hunter Estuary Wetland have been listed in Table 1. Threatened species records and known migratory bird habitat are shown in Figure 9, which can be cross referenced to descriptions of habitat and locations provided in the right hand column of Table 1.

Table 1: Threatened fauna, flora and migratory species recorded or considered likely to occur within the Hunter Estuary Wetland.

Scientific Name	Common Name	TSC Act	EPBC Act	Local Records and Suitable Onsite Habitat
Mammals				
Pteropus poliocephalus	Grey-headed Flying Fox	V	V	Recorded in Kooragang Nature Reserve. A roost site occurs at Fullerton Cove (Eby 2001)
Amphibians				
Litoria aurea	Green and Golden Bell Frog	E	E	Recorded in Kooragang NR & Shortland Wetlands. Generally, freshwater wetlands provide suitable habitat
Avian				
Anseranas semipalmata	Magpie Goose	V	—	Recorded in Shortland Wetland Centre. Generally, freshwater wetlands provide suitable habitat
Botaurus poiciloptilus	Australasian Bittern	V	—	Recorded in Shortland Wetlands. Terrestrial wetlands with tall dense vegetation, occasionally estuarine habitats
Calidris ternuirostris	Great Knot	V	—	Recorded in Kooragang NR. Diurnal Roost – Kooragang Dykes Auxiliary Diurnal Roost - Fullerton Cove Mouth, Stockton Bridge Sandspit Nocturnal Roost – east Moscheto Creek Foraging Area – Fullerton Cove, North Arm Sandflats, Stockton Sandspit
Charadrius leschenaultii	Greater Sand Plover	V	—	Potential habitat occurs on intertidal sand and mudflats in estuaries, roosting during high tide on sandy beaches or rocky shores
Charadrius mongolus	Lesser Sand Plover	V	M	Recorded in Kooragang NR. Roosting – Stockton Sandspit Foraging – Stockton Sandspit Also recorded in Fullerton Cove
Ephippiorhynchus asiaticus	Black-necked Stork	E	—	Recorded in Shortland Wetlands. Associated with tropical and warm temperate terrestrial wetlands, estuarine and littoral habitats, and occasionally woodlands and grasslands floodplains (Marchant & Higgins 1993).
Haematopus fuliginosus	Sooty Oystercatcher	V	—	Recorded at Kooragang NR. Roosting – Kooragang Dykes Foraging – Kooragang Dykes, Stockton Sandspit
Haematopus longirostris	Pied Oystercatcher	V	—	Recorded in Kooragang NR. Roosting – Kooragang Dykes, North Arm Sandflats Foraging - Fullerton Cove, Kooragang Dykes, North Arm Sandflats Also recorded at Stockton Sandspit
Irediparra gallinacea	Comb-crested Jacana	V	—	Recorded in Shortland Wetlands. Freshwater wetlands, such as lagoons, billabongs, swamps, lakes and reservoirs, generally with abundant floating aquatic vegetation
Ixobrychus flavicollis	Black Bittern	V	—	Recorded at Shortland Wetland Centre. Occurs in both terrestrial and estuarine wetlands generally in areas of permanent water and dense vegetation

Limosa limosa	Black-tailed Godwit	V	—	Potential habitat within the Ramsar. Primarily found along the coast on sandspits, lagoons and mudflats
Lophoictinia isura	Square-tailed Kite	V	—	Recorded at Shortland Wetlands. Foraging habitat in open grassland and woodland
Oxyura australis	Blue-billed Duck	V	—	Potential. Prefers deep water in large permanent wetlands and swamps with dense aquatic vegetation
Pandion haliaetus	Osprey	V	—	Likely. Recorded within the broader estuary system. The Hunter Estuary provides general foraging habitat and suitable nest sites may occur.
Rostratula benghalensis australis	Painted Snipe (Australian subspecies)	E	E	Potential, Recorded just outside of the Ramsar. Prefers fringes of swamps, dams and nearby marshy areas where there is a cover of grasses, lignum, low scrub or open timber
Sterna albifrons	Little Tern	E	—	Recorded in Kooragang NR. Observed in Fullerton Cove, Kooragang Dykes, Stockton Sandspit
Stictonetta naevosa	Freckled Duck	V	—	Recorded in Shortland Wetlands and Kooragang Nature Reserve. Associated with a variety of plankton-rich wetlands, such as heavily vegetated, large open lakes and their shores
Xenus cinereus	Terek Sandpiper	V	M	Recorded in Kooragang Nature Reserve and the Hunter Estuary Ramsar
Tyto novaehollandiae	Masked Owl	V	—	Recorded in Kooragang NR and Shortland Wetlands. Recorded at Fern Bay, Fullerton Cove & Hunter Wetlands Centre
Dasyurus maculatus *Dasyurus maculatus maculatus*	Spotted-tailed Quoll Spotted-tailed Quoll (SE Mainland Population)	V —	— E	Recorded on Kooragang Island
Potorous tridactylus *Potorous tridactylus tridactylus*	Long-nosed Potoroo Long-nosed Potoroo (SE Mainland Population)	V —	— V	Recorded on Kooragang Island
Chalinolobus dwyeri	Large-eared Pied Bat	V	V	Recorded on Kooragang Island. General foraging habitat occurs in terrestrial environments in the Ramsar
Falsistrellus tasmaniensis	Eastern False Pipistrelle	V	—	Potential. General foraging habitat occurs in terrestrial environments in the Ramsar
Miniopterus australis	Little Bent-wing Bat	V	—	Recorded on Kooragang Island. General foraging habitat occurs in terrestrial environments in the Ramsar
Miniopterus schreibersii oceanensis	Eastern Bent-wing Bat	V	—	Recorded at Shortland wetlands & on Kooragang Island. General foraging habitat occurs in terrestrial environments in the Ramsar
Myotis adversus	Large-footed Myotis	V	—	Recorded on Kooragang Island. General foraging habitat occurs in dams, streams and aquatic environments in the Ramsar
Pteropus poliocephalus	Grey-headed Flying-Fox	V	V	Recorded in Kooragang NR. Seasonal foraging on fruiting and myrtaceous trees is likely.
Saccolaimus flaviventris	Yellow-bellied Sheathtail-bat	V	—	Recorded on Kooragang Island. General foraging habitat occurs in terrestrial environments in the Ramsar
Scoteanax rueppellii	Greater Broad-nosed Bat	V	—	Recorded on Kooragang Island. General foraging habitat occurs in terrestrial environments in the Ramsar

MIGRATORY AND/OR TERRESTRIAL THREATENED SPECIES LISTED UNDER EPBC ACT (FAUNA)				
Haliaeetus leucogaster	White-bellied Sea-Eagle	—	M	Likely. Forages over large open fresh or saline waterbodies, coastal seas and open terrestrial areas
Hirundapus caudacutus	White-throated Needletail	—	M	Potential. Forages aerially over a variety of habitats usually over coastal and mountain areas, most likely with a preference for wooded areas
Merops ornatus	Rainbow Bee-eater	—	M	Potential. General foraging habitat occurs in terrestrial environments in the Ramsar.
Rhipidura rufifrons	Rufous Fantail	—	M	Potential. General foraging habitat occurs in terrestrial environments in the Ramsar
MIGRATORY WETLAND SPECIES LISTED UNDER EPBC ACT (Fauna)				
Ardea alba	Great Egret	—	M	Observed throughout estuary. Breeding recorded at Shortland Wetlands
Ardea ibis	Cattle Egret	—	M	Observed throughout estuary. Breeding recorded at Shortland Wetlands
Anseranas semipalmata	Magpie Goose	-	M	Recorded in Shortland Wetlands. Diurnal Roost – Shortland Wetlands Foraging Area – Shortland Wetlands
Arenaria interpres	Ruddy Turnstone	—	M	Recorded in Kooragang NR. Diurnal Roost – Kooragang Dykes, Stockton Sandspit Foraging Area – Hunter River
Calidris acuminata	Sharp-tailed Sandpiper	—	M	Recorded in Shortland Wetlands & Kooragang NR. Foraging Area – Shortland Wetlands mudflats Also recorded at Fern Bay & Stockton Sandspit
Calidris ferruginea	Curlew Sandpiper	—	M	Recorded in Kooragang NR & Shortland Wetlands. Diurnal Roost – Kooragang Dykes, Fullerton Cove Auxiliary Diurnal Roost - Fullerton Cove Mouth, Stockton Bridge Sandspit Nocturnal Roost – east Moscheto Creek Foraging Area – Fullerton Cove, Hunter River, North Arm Sandflats Shortland Wetlands mudflats Also recorded at Fern Bay
Charadrius mongolus	Lesser Sand Plover	V	M	Recorded in Kooragang NR. Diurnal Roost – Kooragang Dykes, Stockton Sandspit Foraging Area – Hunter River, Stockton Sandspit Also recorded at Fullerton Cove

Gallinago hardwickii	Latham's Snipe	—	M	Recorded at Shortland Wetland. Foraging Area – Shortland Wetland mudflats
Limicola falcinellus	Broad-billed Sandpiper	V	M	Recorded in Kooragang NR. Diurnal Roost – Kooragang Dykes Foraging Area – Fullerton Cove Also observed at Fern Bay & Stockton Sandspit
Limosa lapponica	Bar-tailed Godwit	—	M	Recorded in Kooragang NR. Diurnal Roost – Kooragang Dykes Auxiliary Diurnal Roost – Fullerton Cove Mouth, Stockton Sandspit, Fern Bay Nocturnal Roost – east Moscheto Creek, Juncus Swamp Foraging Area – Fullerton Cove, Hunter River, Kooragang Dykes, Stockton Sandspit
Limosa limosa	Black-tailed Godwit	—	M	Recorded in Kooragang NR. Diurnal Roost – Kooragang Dykes, Fullerton Cove Auxiliary Diurnal Roost – Fullerton Cove Mouth, Stockton Bridge Sandspit, Fern Bay Nocturnal Roost – East Moscheto Creek Foraging Area – Fullerton Cove, Kooragang Dykes , Stockton Bridge Sandspit,
Numenius madagascariensis	Eastern Curlew	—	M	Recorded in Kooragang NR. Diurnal Roost – Kooragang Dykes Auxiliary Diurnal Roost – Fullerton Coves Mouth, Stockton Bridge Sandspit, Fern Bay, East Moscheto Creek Nocturnal Roost - East Moscheto Creek Foraging Area – Fullerton Cove, Hunter River, North Arm Sandflats, Stockton Bridge Sandspit
Numenius phaeopus	Whimbrel	—	M	Recorded in Kooragang NR. Diurnal Roost – Fullerton Cove, Fern Bay, Hunter River, Kooragang Dykes, Stockton Sandspit Foraging Area – Fullerton Cove, Hunter River, North Arm Sandflats, Stockton Sandspit
Pluvialis fulva	Pacific Golden Plover	—	M	Recorded in Kooragang NR. Diurnal Roost – Kooragang Dykes, Stockton Sandspit, North Arm Sandflats Auxiliary Diurnal Roost - Kooragang Island Nocturnal Roost – Fullerton Cove Foraging Area – Fullerton Cove, Hunter River, Kooragang Dykes, North Arm Sandflats Also observed at Fern Bay
Rostratula benghalensis s. lat.	Painted Snipe	—	M	Recorded in Shortland Wetlands
Tringa nebularia	Greenshank	—	M	Recorded in Kooragang NR & Shortland Wetlands. Diurnal Roost – Kooragang Dykes, Fullerton Cove Auxiliary Diurnal Roost - Smiths Island, Stockton Sandspit Nocturnal Roost – east Moscheto Creek Foraging Area – Fullerton Cove, Hunter River, Kooragang Dykes, Stockton Sandspit, Shortland Wetlands mudflats Also recorded at Fern Bay,
Tringa stagnatilis	Marsh Sandpiper	—	M	Recorded in Kooragang NR & Shortland Wetlands. Diurnal Roost – Kooragang Dykes, Fullerton Cove Auxiliary Diurnal Roost - Smiths Island, Stockton Sandspit Nocturnal Roost – east Moscheto Creek Foraging Area – Fullerton Cove, Stockton Sandspit, Shortland Wetlands mudflats
Xenus cinereus	Terek Sandpiper	V	M	Recorded in Kooragang NR. Diurnal Roost – Fern Bay Auxiliary Diurnal Roost -Stock Bridge Sandspit, Kooragang Dykes, Sandy Island east channel, Fullerton Cove Foraging Area – Fullerton Cove, Fern Bay, North Arm Sandflats, Hunter River

MIGRATORY AND/OR TERRESTRIAL THREATENED SPECIES LISTED UNDER EPBC ACT (FLORA)				
Zannechellia palustris		E	—	Recorded in Kooragang NR. *palustris* inhabits shallow, still to slowly moving, waterbodies which contain either fresh or brackish waters
Cynanchum elegans		E	E	Recorded on Kooragang Island, immediately adjacent to the western end of the reserve.

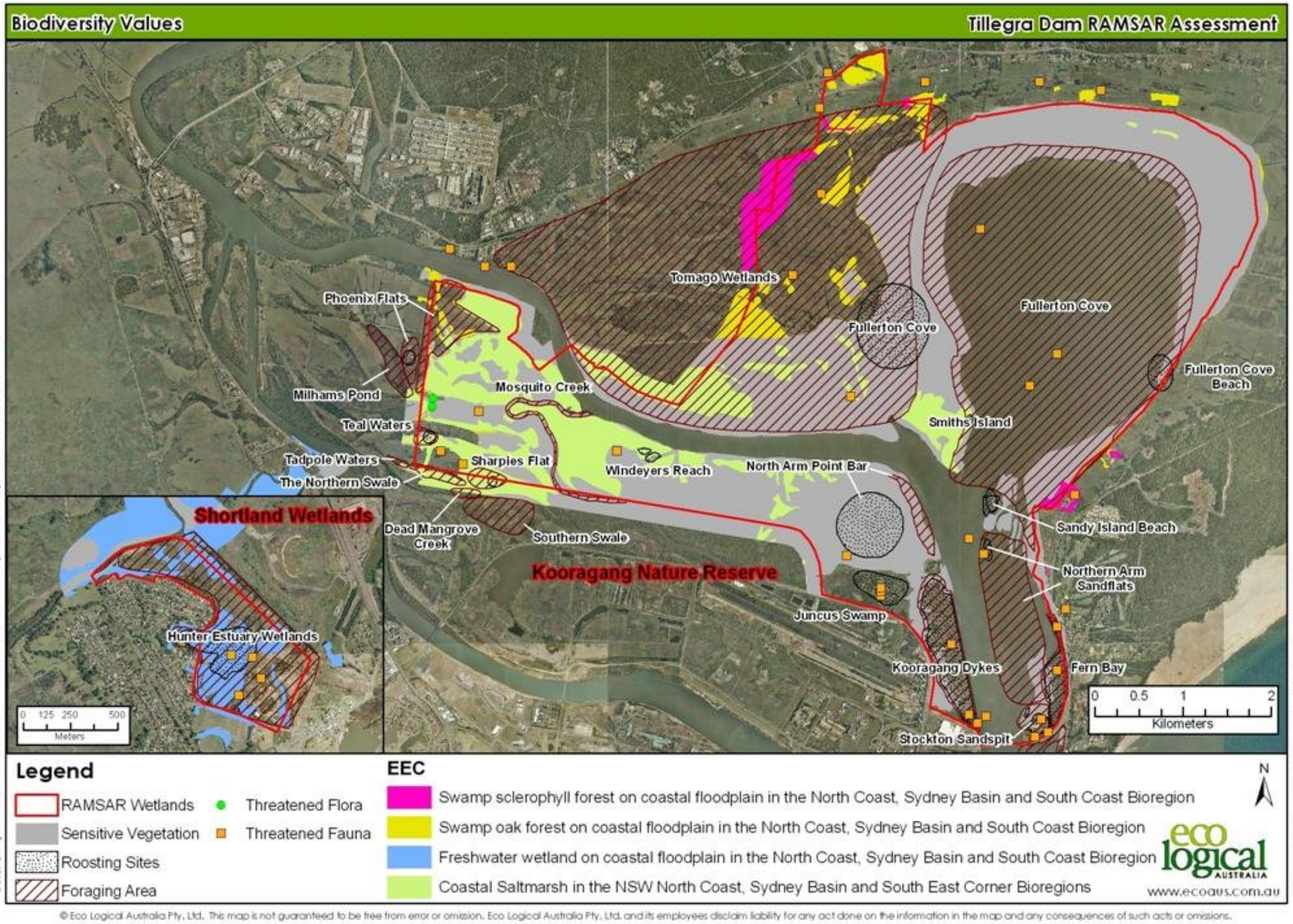


Figure 9: Threatened flora and fauna, Endangered Ecological Communities and migratory wader habitat (from: LHCCREMS 2003; DPI 2006; Atlas for Wildlife 2008; Herbert 2007).

3.11 Ecological Processes and Ecosystem Services

3.11.1 Ecological Processes

Ecosystem processes are the dynamic forces operating within an ecosystem and include the interactions that occur between organisms and within and between populations and communities, including interactions with the non-living environment that result in existing ecosystems and bring about changes in ecosystems over time (DEWHA 2008). An overview of the ecosystem processes most relevant to the Hunter Estuary Wetlands is presented in Table 2, and includes climate, geomorphology, hydrology, energy and nutrient dynamics, and processes that maintain animal and plant populations and species interactions. The information shown in Table 2 is on the whole general and not specific for the Hunter Estuary Wetland. This seems to be similar to that for many estuaries noting that whilst the importance of freshwater flows into estuaries is widely recognised the understanding of flow-related processes in estuaries it is generally limited (Environment Australia, April 2002).

Important processes in Australian estuarine wetlands are shown pictorially in Figure 10. The models illustrate the complexity of interactions between the biological and physical components of the wetland. The hydrology, energy and nutrient dynamics in particular are key ecosystem processes relevant to the assessment of the potential impact of the Tillegra dam on the Hunter Estuary Wetland. The formal Information Sheet for the Kooragang Nature Reserve does not contain a large amount of detail on these processes. Further information on the hydrology and sediment/nutrient loads to the wetland is available from the modelling exercises undertaken following section of this report.

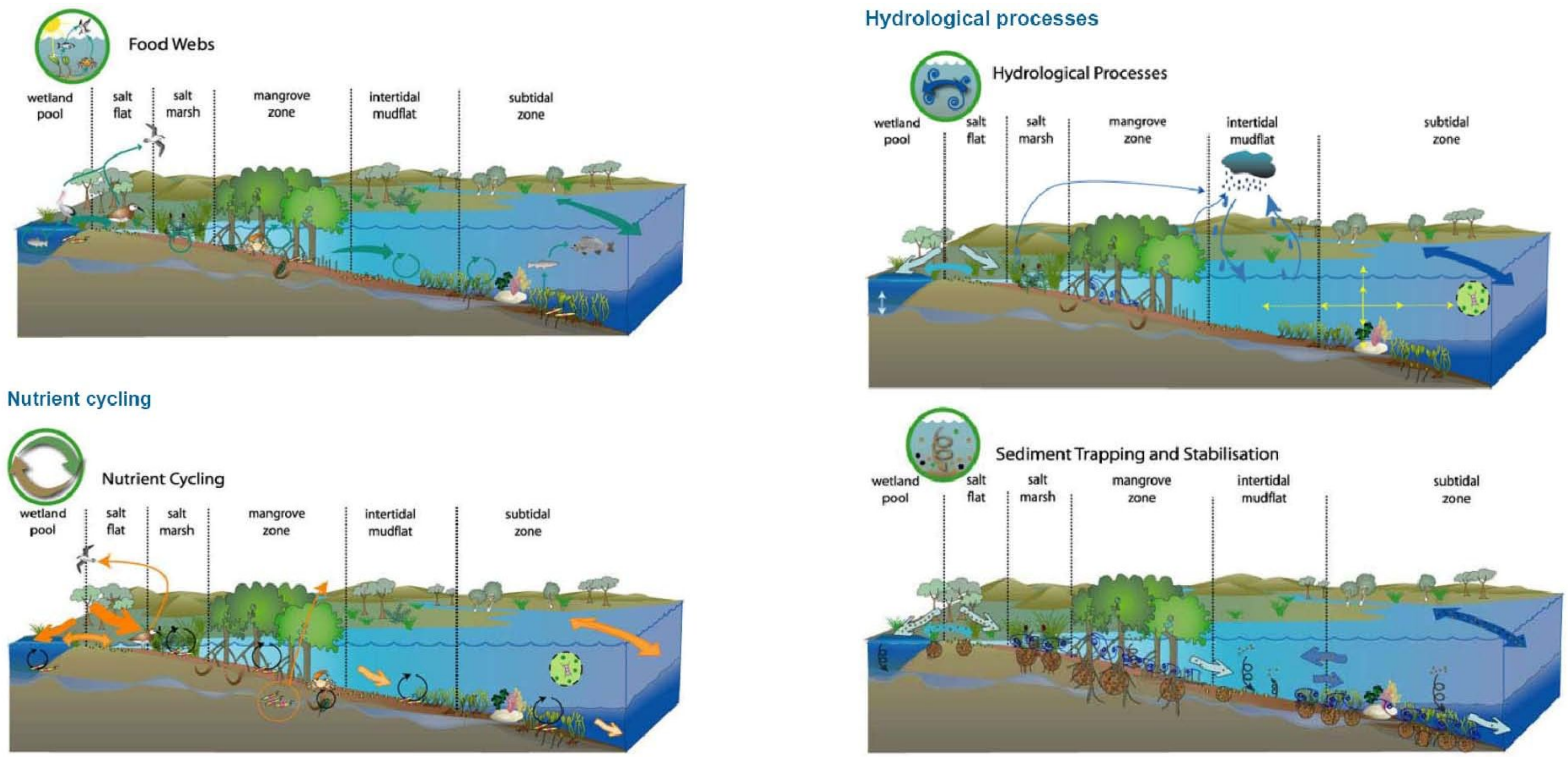


Figure 10: Conceptual models of ecological processes within estuarine wetlands.

An explanation of the symbols is available at http://www.ozcoasts.org.au/conceptual_mods/introduction.jsp

Table 2: Ecosystem processes in the Hunter Estuary Wetland.

Ecosystem Processes	Description for the Hunter Estuary Wetland
Climate	**Temperature:** Mean Maximum Temperature 21.8 ºC; Mean Minimum Temperature 14.2ºC (BOM 2009). **Average Annual Rainfall:** 1139.6mm (BOM 2009). With higher rainfall averages received between the months of February to June.
Geomorphology	The lower Hunter River is a barrier estuary formed by the deposition of sediments in swamps and flats lying between the inner and outer coastal barrier sands. Sediments on Kooragang Nature Reserve and adjacent estuarine areas comprise black silty and highly saturated soft clays to a depth of about two metres underlain by light grey silty sand (NPWS 1998). Intertidal vegetation such as mangroves create eddies and barriers to water movement, thereby reducing water flow and velocity. This allows suspended sediments to settle out of the water column. Once settled, roots and rhizomes of estuarine vegetation bind the sediment together and prevent further transport downstream. In this way the wetlands act as sediment filters and water often leaves a wetland with less suspended sediment than when it entered. The same process works for sediments brought into the estuary on tidal flows (NPWS 1998).
Hydrology	Water entering the Hunter Estuary Ramsar and in particular the Kooragang Nature Reserve portion of the Ramsar, comes from a number of sources, including: • Flow from the Hunter River and its tributaries, including those from the Williams River which are regulated by an in-stream weir at Seaham; • Rainfall and freshwater surface runoff from the localised catchment; • Tidal incursion of seawater; and • Natural recharge from Tomago and Stockton Sandbeds. Mixing of these water sources is important to maintain both the salinity profile and the water quality within the estuary. Salinity within the estuary ranges from 32.25 to 33.99 parts per thousand (ppt) during average

	freshwater input events (50%ile) and tidal influences. Shortland Wetlands are essentially isolated from the Hunter Estuary by bunding of the wetlands within the site and the Ironbark Creek Floodgates, which regulates tidal flow into the wetlands via Ironbark Creek. The Shortland Wetlands are an important storage of rainfall and stormwater, which in turn provide both habitat and nutrient recycling ecosystem services (DEWHA 2002).
Energy and nutrient dynamics	Estuarine wetlands, such as the Hunter Estuary Ramsar, act as sinks for nutrients by filtering runoff and thereby reducing the amount of nutrients entering downstream areas. The process improves water quality and reduces the risk of eutrophication and algal blooms. Nutrient cycling is undertaken both by the vegetation that fringes wetlands e.g. mangroves and saltmarsh, but also by key animals within the system, primarily microbes and macroinvertebrates which transfer nutrients in and out of the sediments. Nutrients can be exchanged up and down the estuary via water and animal movement.
Processes that maintain animal and plant populations	Estuaries have several very important physical habitat values, including: **Maintaining a distinct salinity gradient** is critical for many flora and fauna species that inhabit the estuary. e.g. saltmarsh can tolerate hypersaline conditions in areas that are not regularly inundated by tidal flow, but will experience rapid dieback if freshwater incursions are too frequent or long in duration. Furthermore, many fish species (including commercially important species) require different salinity levels to spawn. **Water column tidal movement** allows fish and crustaceans to access high tide feeding areas, some fish species move up- or down-stream to breed and spawn, water flow between wetland pools during high flow events such as floods or king tides allows aquatic animals to access new habitats. **Sub- and inter-tidal vegetation** provides physical protection for small and juvenile fish, nursery areas for fish and crustacean larvae (e.g. prawns), mangroves provide shade for water and sediments which buffers temperatures and blocks ultra-violet radiation. **Sediments (submerged and periodically exposed mudflats)** provide habitat for macroinvertebrates and feeding areas for shorebirds and fish.

Species interactions	Estuaries support key food web interactions. Carbon tends to move from high intertidal zones out into the estuary through a series of predator-prey interactions. Abundant macroinvertebrate populations are the base of healthy food webs within estuarine ecosystems, since both fish and shorebirds feed heavily on such organisms. Microbes play an important role in recycling nutrients and making them available to macroinvertebrates e.g. crabs rely heavily on diatom films formed on mudflats. Estuaries are important areas for exchange of carbon between freshwater and marine ecosystems. Carbon can be lost from estuaries due to export offshore and departure of migratory species (fish and birds).

3.11.2 Ecosystem benefits and services

Benefits and services are defined in accordance with the Millennium Ecosystem Assessment definition of ecosystem services as 'the benefits that people receive from ecosystems' (Ramsar Convention 2005 A) and include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits.

Coastal wetlands such as estuaries, marshes and mangroves deliver many services, with the key services of the Hunter Estuary Ramsar summarised and described in Table 3. A weighted valuation of these services is also provided in Table 3, based on a qualitative valuation. The rationale to developing the weighted value of a given service is as follows:

- Low importance – Hunter Estuary Wetland does not provide a crucial proportion of the service;
- Moderate Importance – Hunter Estuary Wetland is important for the local provision of the service; the service may be available elsewhere but not to the same extent;
- High Importance – Hunter Estuary Wetland is crucial for the delivery of the service.

Quantitative information on the importance of these services is largely lacking; general assumptions only can be made about the importance of services based on general knowledge from estuarine wetlands. Some of the necessary information has been derived from an understanding of the key ecological processes (described above) that along with the biophysical components of the wetland form the basis of many of the services.

Table 3: Ecosystem services provided from the Hunter Estuary Wetland.

Service	Description	Importance
Food	Fishery, prawn in industry, estuary mangroves and beaches	Moderate
Climate regulation	Regulation of greenhouse gases, temperature, precipitation, and other climatic processes; chemical composition of the atmosphere	Low to Moderate
Pollution control retention,	With the history of industrial land use in the Hunter Estuary Ramsar, the recovery, removal and detoxification of contaminants, excess nutrients and pollutants	High
Hydrological regulation	Hazards flood control; storm protection	High
Erosion protection	Retention of soils and sediments from up stream	High
Recreational opportunities	Tourism and recreational activities	High
Educational opportunities	Formal and informal education and training	High
Aesthetic	Appreciation of natural features	Moderate
Biodiversity habitats	Resident or transient species, including the Migratory waders and other biodiversity provided in Section 4.7.	High
Soil formation	Sediment retention and accumulation of organic matter	High
Nutrient cycling storage	Recycling, processing, and acquisition of nutrients	High
Biological resistance of species	Regulating interactions between	High

invasions; regulation	different trophic levels; preserving functional diversity and interactions	

3.11.3 Conceptual Wetland Model

A conceptual model of the Hunter Estuary Wetland (Figure 11) has been developed based on the general format provided by DEWHA (2008) and the information presented above. The model is presented in the form of a flow diagram that shows the links between the climate and geomorphology and the biota and key ecological processes. In addition the ecological components and processes and ecosystem services that comprise the ecological character of the wetland are marked. Given the information sources available the model is generalised and used to represent the broad links only. While the detail and complexity of the inter-relationships within the wetland are not depicted an idea of these can be gained by reference to Figure 10 showing some of the processes within the wetland.

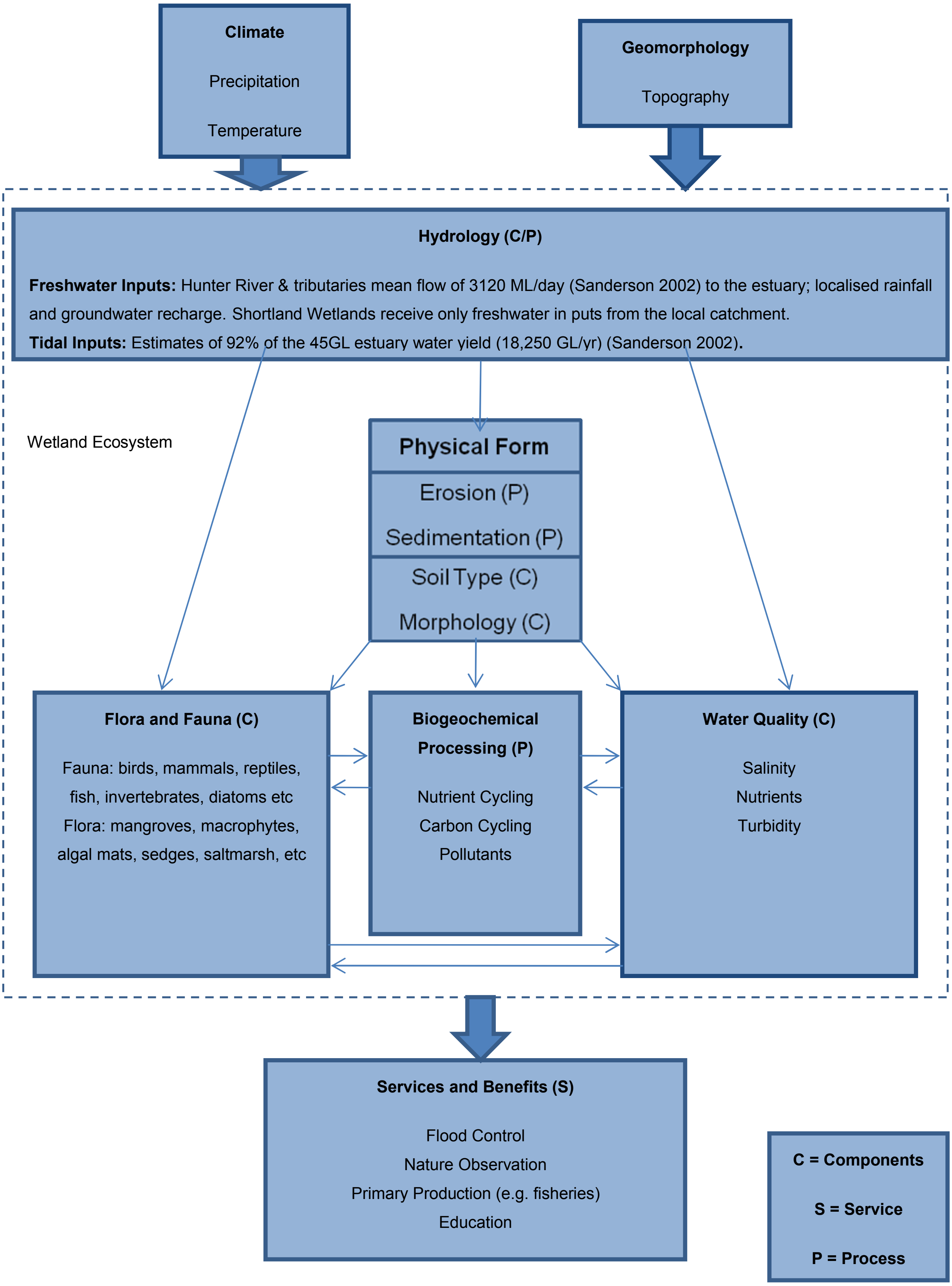


Figure 11: Conceptual model of the ecological character of the Hunter Estuary Wetland (adapted from DEWHA 2008).

3.11.4 Identification of Threats to Ecological Character

By way of identifying and ranking the potential threats to the Hunter Estuary Ramsar site, Table 4 below sets a framework for identifying the level of threat based on a matrix of consequence versus the likelihood of the threat eventuating. Table 5 contains a list of the threats that have been identified for the Hunter Estuary Wetland and ranks the level of threat based on Table 4.

Table 4: Framework for identifying the level of threat to the Hunter Estuary Wetland.

CONSEQUENCE			LIKELIHOOD		
LEVEL	DESCRIPTOR	DESCRIPTION	LEVEL	DESCRIPTOR	DESCRIPTION
1	Insignificant	No loss of native species, minimal loss of habitat	A	Almost Certain	The impact is expected to occur in most circumstances
2	Minor	Minor loss of native species or their habitat	B	Likely	The impact will probably occur in most circumstances
3	Severe	Moderate loss of native species and their habitat	C	Moderate	The impact could occur at some time
4	Major	Extensive loss of native species and their habitat, serious environmental damage	D	Unlikely	The impact could occur at some time but is not expected
5	Catastrophic	Local extinctions, huge loss of native species and their habitat, major environmental damage with detrimental effect	E	Rare	The impact occurs only in exceptional circumstances

MATRIX	CONSEQUENCE				
LIKELIHOOD	1	2	3	4	5
A	H	H	E	E	E
B	M	H	H	E	E
C	L	M	H	E	E
D	L	L	M	H	E
E	L	L	M	H	H

LEGEND	THREAT
E	Extreme
H	High
M	Moderate
L	Low

Table 5: Threats to the Ecological Character of the Hunter Estuary Wetland.

Potential Threat	Potential Cause	Outcome/ Consequence	Potential Consequence for Ramsar	Kooragang Nature Reserve	Shortland Wetland
Changed Hydrological Regime	• Upstream regulation • Change in land use within catchment • Large development in catchment	• Reduced freshwater input • Reduced water quality • Altered sediment load • Increased input of pollutants	• Reduced foraging habitat such as mudflats Reduced habitat for aquatic organisms • Change in saltmarsh/ mangrove distribution • Decrease in biodiversity	M	M
Biochemical Changes	• Point and diffuse sources of nutrients and pollutants • Tidal and freshwater hydrological regime changes	• Input of pollutants & sediments • Altered salinity, nutrient regime	• Altered salt intrusion, particularly during drought periods • Cumulative alteration to extents of habitat (i.e. salt marsh/mangroves, impacts on flora and fauna • Reduction in biodiversity due to unsuitable conditions • Reduction in forage resource/biodiversity	M	M
Urban/ Industrial Development	New developments in catchment such as: • Industry • Housing • Roads & Infrastructure	• Increased input of pollutants and sediments • Reduction in water quality • Changes to hydrology	• Loss of aquatic habitat • Sedimentation of foraging areas • Loss of biodiversity	L	L
Floods & Storms	• Severe weather events including el Niño & la Niña • Erratic weather due to climate change	• Physical damage to flora and to habitat components such as beaches • Increased sediments and pollutants from the catchment • Reforming/shaping of wetlands	• Loss of habitat • Loss of biodiversity • Potential for habitat creation where sediments are deposited	M	M
Offsite Threats to Biodiversity	• Development in other regions & countries	• Loss of offsite breeding habitat of migratory species	• Decline in migratory species • Reduction in significance of wetland • Reduction in passive recreation such as bird watching	H	H
Climate change and associated sea level rise	• Enhanced greenhouse effects	• Rise in sea level • More severe weather events • Altered temperature trends • Changed sediment transportation	• Loss of habitat for terrestrial biodiversity • Increase distribution and abundance of environmental weeds due to altered range • Altered habitat for native fauna • Change in saltmarsh/ mangrove distribution • Loss of biodiversity	E	E

There are two main perceived threats on the Hunter Estuary Wetlands resulting from the proposed Tillegra Dam project, these being:

- Hydrological changes
- Biochemical changes.

The perceived threats to the Kooragang Nature Reserve portion of the Ramsar site are of particular concern; primarily due to a relatively uninhibited hydrological link between Tillegra Dam and the Williams River. There is considered to be no increase in the level of threat to the Shortland Wetlands portion of the Ramsar site, due to the inhibited hydrological link with the Williams River caused by the operation of the Ironbark Creek Floodgates bunding.

In order to assess the magnitude of these threats and the level of impact that would result from Tillegra Dam, BMT WBM have undertaken hydrological, salinity and nutrient budget modelling of 19 different scenarios that factor in 25%ile, 50%ile, 75%ile, 90%ile flows and sea level rise for different phases of Tillegra Dam construction and operation and different proposed alterations to Seaham Weir. Section 4 provides the modelling methods and results, and an assessment of the magnitude of impacts that would result from the proposed Tillegra Dam is provided in Section 5.

From a management perspective the conceptual models used to depict the ecological processes in an estuary could also be used to consider the likely impacts of specific drivers of change. Examples are shown in Figure 12 although these are not specific to the Hunter Estuary Wetland.

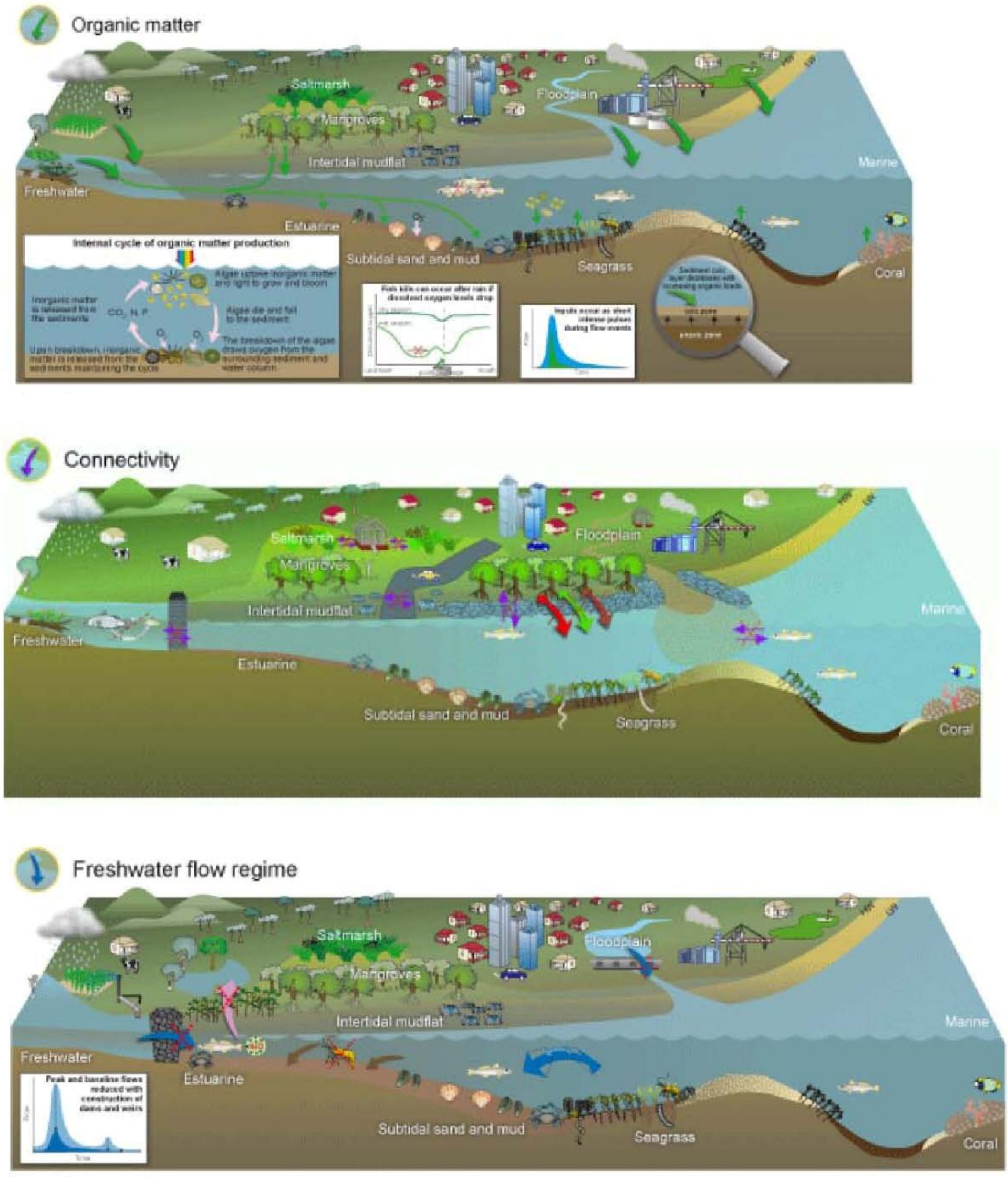


Figure 12: Examples of conceptual models of estuarine wetlands used to illustrate the interrelationships within the wetland as a consequence of changes to the freshwater flow, connectivity and organic matter cycles.

An explanation of the symbols used in the models is available at
http://www.ozcoasts.org.au/conceptual_mods/introduction.jsp

3.11.5 Setting the Limits of Acceptable Change for the Hunter Estuary Ramsar Wetland

The Shortland Wetland ECD has been used in developing the Limits of Acceptable Change (LAC) for this portion of the Hunter Estuary Wetland. However, the lack of an ECD for the Kooragang Nature Reserve presented some constraints when determining the LAC, as the information on which limits could be agreed was on the whole not available. As such it may be difficult to determine specific LACs given the dynamic nature of wetlands and the availability of sufficient scientific information on wetland responses to change. As a consequence, the LACs presented in Table 6 have been set at a conservative level using those outlined in the Shortland Wetland ECD as a guide. The term “significant” refers to a change or an impact which is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the environment which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts (DEWHA 2006).

Table 6: Limits of Acceptable Change for the Hunter Estuary Wetland.

Critical Ecological Components and Processes	Kooragang Nature Reserve		Shortland Wetland	
	Baseline Condition and range of Natural Variation where known	**Limits of Acceptable Change**	**Baseline Condition and range of Natural Variation where known**	**Limits of Acceptable Change**
Number of waterbird species recorded in Ramsar site annually.	Over 160 species of bird have been recorded on Kooragang (NPWS 1998), including 60 water bird species (Herbert 2007)	A reduction in the total number of waterbird species over a ten year period to less than 95% would be unacceptable	Around 67 waterbird species have been recorded in Shortland Wetlands. Half of these (33 spp.) are listed as commonly seen, the others as occasionally or rarely seen (Biosis 2005). Migratory shorebirds, including Latham's Snipe, normally occur every year (Biosis 2005)	A reduction in the total number of waterbird species at Shortland Wetlands over a ten year period to less than 63 (95%) would be unacceptable (Biosis 2005) Occurrence of migratory shorebirds in less than nine of every ten years or the occurrence of less than four species of migratory shorebirds at Shortland Wetlands would be unacceptable (Biosis 2005)
Number of waterbird species recorded roosting in Ramsar site annually.	30 species of water birds have been recorded roosting within the Kooragang NR Ramsar (Herbert 2007)	A reduction in the total number of waterbird species over a ten year period to less than 95% would be unacceptable	Over 1,000 Australian White Ibis often roost at the site during the year and they are joined by up to 7,000 of Straw-necked Ibis in autumn-winter principal predator of agricultural pests). Numbers of all roosting species may be higher during extended or severe inland drought (Biosis 2005)	Roosting by less than 1,000 ibises on at least one occasion in each year would be unacceptable (Biosis 2005)
Number of water birds recorded breeding in the Ramsar	Ten water bird species have been recorded or are considered at least potentially likely to breed within the Kooragang NR Ramsar (Herbert 2007)	A reduction in the total number of waterbird species over a ten year period to less than 95% would be unacceptable	An average of 400 nests/pairs breeding per year (extremes values: 203 and 855). These averages comprised 32 nests of Great Egret, 23 of Intermediate Egret, six of Little Egret and 339 of Cattle Egret. Analysis of all 19 years of data reveals larger averages: 575 in total; 50, 65, 15 and 445 by species (Biosis 2005).	Reduction in the average number of breeding egret pairs (nests) over any ten year period to less than 380 (the 95% level) would be unacceptable

Species observed in numbers exceeding 1% of flyway population (notable species)	The large number of Chestnut Teal present in the estuary, often more than 1% of the global population. Between 2-5% of the East Asian Australasian flyway population of Eastern Curlew.	The loss of or significant change (i.e. hydrological, biochemical) to wader habitats would be unacceptable	Not relevant to Shortland Wetlands	Not relevant to Shortland Wetlands
Other notable species	A free ranging Green and Golden Bell Frog population occurs on the edge of the Ramsar Grey-headed Flying-fox have been recorded foraging within the Ramsar and a known roost of 500+ individuals occurs at Fullerton Cove (Eby 2001)	The loss or modification to Green and Golden Bell Frog habitat and Grey-headed Flying-fox roost habitat would be unacceptable.	The Australasian Bittern was recorded in 1998, 1999 and possibly also during 1992-7. It is reasonable to conclude that it occurs in at least two of every ten years (Biosis 2003) Green and Golden Bell Frogs are being reared in captivity and will be released in the near future when circumstances are appropriate (Biosis 2003). Reintroduced Magpie Geese, roost and breed (at least a few families with dependent young occur) each year in Shortland Wetlands	Occurrence of Australasian Bittern in less than two of every 15 years would be unacceptable There is no free-roaming population of Green and Golden Bell Frog at present and this variable cannot be defined further (Biosis 2003) Failure of Magpie Geese to continue occurring at Shortland Wetlands may not be undesirable provided they have instead occupied other sites in the region.
Native fish species	The Hunter estuary contains about 15 species of commercially important fish, crustacean and molluscs. Major components being mullet, jewfish, prawn and oyster fisheries which together provide about 8% of the NSW annual catch. Amateur fishing is also a popular pursuit in the estuary.	The loss of or significant change to fish habitats would be unacceptable	Information not currently available	
Macroinvertebrates	Aquatic invertebrates such as worms, gastropods, molluscs and crustaceans are extremely abundant in Fullerton Cove (Herbert 2007; NPWS 1998). There is limited information on macro invertebrate diversity.	Significant loss of, modification to, and biochemical alterations to estuarine habitats would be unacceptable	At least 12 families of macroinvertebrates comprising at least 24 taxa, are known to occur in BHP Pond in Shortland Wetlands complex, based on substantial, consistent sampling effort over many years (Biosis 2005).	A reduction in total number of macroinvertebrate taxa at Shortland Wetlands over a ten year period to less than 22 (95%) would be unacceptable. Loss of certain key indicators of diversity would also be unacceptable (details need to be developed)

Mangrove community	1477 ha of mangroves occur within the Kooragang NR Ramsar, based on DPI 200	Significant loss of, modification to, hydrological and biochemical changes to mangrove communities would be unacceptable	Not relevant to Shortland Wetlands	
Saltmarsh	400ha of saltmarsh occurs within the Kooragang NR Ramsar, based on DPI 2007	Significant loss of, modification to, hydrological and biochemical changes to Saltmarsh communities would be unacceptable	Not relevant to Shortland Wetlands	
Freshwater wetlands	Figures on the extent of freshwater wetland are not available.	Significant loss of, modification to, hydrological and biochemical changes to Saltmarsh communities would be unacceptable	Shortland Wetlands provide a diverse combination of wetland habitats including habitats of varied inundation permanence, and at least eight wetland vegetation communities A substantial stand of Melaleuca Swamp Forest, dominated by *M. quinquenervia* but including several other *Melaleuca* species, normally occurs in Shortland Wetlands; a smaller and contiguous area of similar swamp forest (Middleton Swamp) lies outside the Ramsar boundary (Biosis 2003). A substantial area of healthy *Phragmites/Typha* community is normally present in Shortland Wetlands (Biosis 2003).	Further reduction in the number and health of *Melaleuca* trees in the Melaleuca Swamp Forest would be unacceptable (Biosis 2003). Loss of any wetland vegetation communities from Shortland Wetlands would be unacceptable to the wetland managers (Biosis 2003). Any significant loss of bittern habitat would be unacceptable (Biosis 2003).

Mud Flats and other wetland bird foraging habitat	The exact extent of mud flat habitat has not been calculated; however, it is estimated that up to 60ha of mud flat occurs within Kooragang NR Ramsar	Significant loss of, modification to, hydrological and biochemical changes to Saltmarsh communities would be unacceptable	The exact extent of mud flat habitat has not been calculated. Muddy or shallow edges tend to appear seasonally (mainly summer) each year around some of the ponds at Shortland Wetlands. Mudflats offer suitable habitat for Lathams Snipe (Biosis 2003)	Availability of habitat for Latham's Snipe or other migratory shorebirds at Shortland Wetlands in less than nine of every ten years would be unacceptable (Biosis 2003).
Tidal inputs, seawater discharge – hydraulic input	The Kooragang NR wetland is subject to predominantly tidal hydrological inputs. The exact volume of tidal inputs varies with tidal phases and is not currently available. Estimates of 92% of the 45GL estuary water yield (18,250 GL/yr) (Sanderson et. al. 2002)	Significant changes, outside of the natural limit of variation, to tidal recharge would be unacceptable.	There are no tidal inputs into Shortland Wetlands, due to the Ironbark Creek Floodgates and wetland bunding	Not relevant to Shortland Wetlands
Freshwater inputs and inundation	Freshwater recharge into the Kooragang NR occurs from the Hunter River and associated tributaries, including the Williams River which is regulated by Seaham Weir before entering the Estuary. Mean freshwater flow of the Hunter, Paterson and Williams rivers over the last 25 years as 3,120 ML/day (Sanderson et. al. and Redden 2001). Of this the Williams contributes approximately 1078ML/day. Some recharge from the Tomago and Stockton Sandbeds occurs.	Significant changes, outside of the natural limit of variation, to freshwater recharge would be unacceptable	The swamp forest is inundated most of the time, becoming shallower in the hotter, drier months and in a few years (at most, one in ten) the water dries out. Several decades ago, the swamp forest dried out more frequently, perhaps in most years (Biosis 2005) Substantial inundation of the *Phragmites/Typha* community in Shortland Wetlands normally occurs in most years for a period of at least several months	Detailed quantitative limits cannot be specified at present. Despite a better understanding of the hydrology of this wetland resulting from the 2008 hydrology study, long term inundation data are needed to form the basis of quantitative limits. An interim target would be for this wetland to be dry for approximately three consecutive months of each calendar year (Biosis 2005). Long term inundation data are needed to form the basis of quantitative limits.

Water Quality General	The concentration of heavy industry and shipping along the South Arm and on the southern parts of Kooragang Island has led to a reduction in water quality compared to that in the North Arm. Fishing was banned in the South Arm at one time due to public health concerns.	Quantitative limits have been discussed below. Significant reductions in water quality within the Kooragang NR would be unacceptable.	BHP Pond is a eutrophic freshwater pond, although the level of phosphorus, as recorded between April 2007 and April 2008, is generally not high enough to initiate a eutrophication 'collapse' (Winning 2008). However, the high nutrient levels do promote blooms of algae, azolla and duckweeds in some summers.	Detailed quantitative limits cannot be specified at present due to the limited duration of the available dataset. Phosphorus levels (reactive phosphorus) should be no higher than the 2007/2008 average and to aim for a reduction in the level of phosphorus (Biosis 2005).
Phosphorous	Tidal Input: 0.025mg/L (80% of total) River flow input: Hunter = 0.05mg/L (5.4% of total) Paterson = 0.06 mg/L (2.9% of total) Williams = 0.08mg/L (3.3% of total)	Significant reductions in water quality within the Kooragang NR would be unacceptable.	Total Phosphorous ranges from 0.62Mg/L to 3.66Mg/L within the seven ponds (BMT WBM 2008)	Excess nutrients within the Shortland Wetlands is an issue of concern.
Nitrogen	Tidal Input: 0.25mg/L (75% of total) River flow input: Hunter = 1.1mg/L (11.5% of total) Paterson = 0.87mg/L (2.1% of total) Williams = 0.74mg/L (3.8% of total)	Significant reductions in water quality within the Kooragang NR would be unacceptable.	Total Nitrogen ranges from 4.6Mg/L to11.5 Mg/L within the seven ponds (BMT WBM 2008).	Excess nutrients within the Shortland Wetlands is an issue of concern (Biosis 2005)
Carbon	Tidal Input: 2mg/L (79% of total) River flow input: Hunter = Approximately 7.9% of total Paterson = Approximately 2.5% of total Williams = Approximately 3% of total	Significant reductions in water quality within the Kooragang NR would be unacceptable.	Information not available.	Significant reductions in water quality within the Kooragang NR would be unacceptable

Turbidity	Readings between 8-30NTU encountered during normal conditions. During flood events between 300 and 600NTU (Sanderson et al. 2002).	Significant changes outside of the range of natural variability would be regarded as unacceptable	Turbidity within the Shortland Wetland ponds is variable depending on weather conditions and range from 1.15NTU to 435NTU (BMT WBM 2008).	Significant changes outside of the range of natural variability would be regarded as unacceptable
Salinity	Currently, salinity levels vary by up to 14ppt over a tidal cycle. High tide salinity levels vary by up to 5.5ppt and low tide salinity varies by up to 13ppt between high and low flow events.	Significant changes outside of the range of natural variability would be regarded as unacceptable	Salinity within the ponds of the Shortland Wetlands vary depending on conditions and pond location, but range from 1.05ppt to 0.28ppt (BMT WBM 2008).	The Shortland Wetlands are freshwater wetlands and significant increases in salinity levels would be unacceptable.
Pests and Weeds	Major weeds within Kooragang NR include: Bitou bush (Chrysanthemoides monilifera); Alligator weed (Alternanthera philoxeroides); Water hyacinth (Eichornia crassipes). Several other weeds also occur (refer to NPWS 1998)	A significant increase in weeds would be unacceptable	Alligator Weed, a declared noxious weed in NSW, has at times choked out parts of the wetland ponds	Substantial infestations are unacceptable

4 Hydrological Modelling Overview

4.1 Tuflow Flood Inundation Modelling

The objective of the flood modelling was to investigate the potential impact of a modified flood regime (as a result of Tillegra Dam operation) on wetland inundation. This was undertaken utilising detailed hydrodynamic modelling of flood conditions to simulate changes in the inundation frequency in the study area at various flood stage levels (i.e. 5-year to 100-year Average Recurrence Interval [ARI]).

The following key activities have been undertaken to achieve the objectives of flood inundation modelling:

- Establish design flood flows for pre- and post-Tillegra Dam conditions;
- Simulate flood conditions for a range of design event magnitudes for both existing conditions and the revised flood regime for post-Tillegra Dam conditions; and
- Undertake comparative analyses of simulated flood conditions to assess flood levels and extents under the new flood regime conditions compared with the base case (existing condition) flood results.

The key output of the flooding assessment is the derivation of flood frequency curves of peak flood water level for key locations within the Ramsar wetlands for the existing and future scenarios. These will identify the relative impact of the changed flood conditions on peak flood levels and provide a basis for assessment of ecological impacts associated with changed flood inundation regimes.

4.1.1 Model description

The flooding analysis has been undertaken using the TUFLOW 2-dimensional hydraulic model of the Lower Hunter developed by BMT WBM. This model has been developed for the NSW Roads and Traffic Authority (RTA) in undertaking a flood impact assessment of a proposed extension of the F3 Freeway to Heatherbrae. (We wish to thank the RTA for granting permission to utilise the existing model in the current study.)

TUFLOW was developed in-house at BMT WBM and has been used extensively for over fifteen years on a commercial basis by BMT WBM for Local and State Governments. TUFLOW is Australia's leading flood modelling system, and has reached international recognition through selection for the major Thames Embayments Inundation Study (London), the 2012 London Olympics Flood Risk Assessment, extensive use elsewhere in the UK, and integration into the ISIS and XP-Software 1D systems.

The 2D model has distinct advantages over 1D and quasi-2D models in applying the full 2D unsteady flow equations. This approach is necessary to model the complex interaction between rivers, creeks and floodplains and converging and diverging of flows through structures. The river and floodplain topography is defined using a high resolution DEM for greater accuracy in predicting flows and water levels and the interaction of in-channel and floodplain areas.

The TUFLOW model of the Lower Hunter River extends between Green Rocks and the Newcastle Harbour Entrance, incorporating the Williams River from downstream of Seaham Weir. This model was developed using topographic and bathymetric survey data available for the river and floodplain, and calibrated to the February 1990 flood event.

The Hunter River forms a confluence with the Williams River within the model area, and depending on the magnitude of a flood event, the combined river flows can exceed the in-bank channel capacity, overtopping levees and causing widespread floodplain inundation in areas such as Raymond Terrace, Millers Forest and Woodberry.

In the lower model area, particularly downstream of Hexham Bridge including the Kooragang Nature Reserve, the tidal influence is significant. The combination of tidal and fluvial flows in major flooding events results in significant inundation of the lower floodplain.

4.1.2 Flood frequency analysis

In order to undertake a comparative analysis of design flood conditions for pre- and post-Tillegra scenarios, design flows for a range of flood magnitudes were established using flood frequency analysis techniques on annual flow series data provided by Hunter Water Corporation (HWC). HWC use a custom built water supply system simulation model to represent the behaviour of its supply system. This model was used to provide estimated daily outflow from Seaham Weir for pre- and post-Tillegra conditions utilising historic rainfall and streamflow data from 1931 to 2008.

From the daily flow model data provided by HWC, an annual peak flow series (77 years of data) was extracted for pre- and post-Tillegra conditions. Table 7 shows the annual peak flow series with ranking order used for the flood frequency analysis.

Gumbel (Generalised Extreme Value Type I) distributions were fitted to the annual flow series data using Gringorten plotting position. The fitted flood frequency distributions for pre and post Tillegra conditions using the daily timestep HWC data are shown in Figure 13 and Figure 14 respectively.

A comparison of the fitted flood frequency distributions for pre and post Tillegra conditions is shown in Figure 15. The figure clearly demonstrates the predicted shift in the distribution resulting from construction of the dam. For a given design flood frequency, the post Tillegra conditions show a decrease in peak flow in the Williams River at Seaham compared with existing conditions. This reduction in peak discharge reflects the flow capture by available storage and additional attenuation of inflows to the storage as simulated by the HWC model.

Accordingly, the design peak discharges for given recurrence intervals based on the flood frequency analysis is reduced for the post Tillegra condition. A summary of the pre and post Tillegra design peak flows at Seaham Weir for a range of design flood frequencies is given in Table 7. In general it is found that the design peak flood discharge for the Williams River at Seaham is reduced by approximately 20% for the post Tillegra condition, in comparison to existing conditions.

Table 7: Annual peak flow series from HWC data at Seaham Weir.

Pre Tillegra Annual Peak Flow (ML/day)						Post Tillegra Annual Peak Flow (ML/day)					
Rank	Year	Q	Rank	Year	Q	Rank	Year	Q	Rank	Year	Q
1	1946	157594	40	1934	30758	1	1946	133920	40	1934	26870
2	1990	142646	41	2005	29808	2	1990	125971	41	1953	24883
3	1971	139709	42	1953	28685	3	1971	118454	42	1964	24278
4	1978	121046	43	1964	25834	4	2001	88560	43	1933	24019
5	1954	108518	44	1939	24883	5	1978	87610	44	1991	22205
6	2001	98150	45	1981	23674	6	1956	82771	45	1981	21427
7	1963	95299	46	1991	23242	7	2007	70589	46	1939	21168
8	1956	91584	47	1959	22637	8	1951	68083	47	1959	19958
9	1967	89856	48	1932	22291	9	1955	65578	48	1932	19872
10	1955	85363	49	2003	21946	10	1987	65578	49	1937	14083
11	1951	78451	50	1970	19354	11	1954	62726	50	1970	13306
12	1968	78106	51	1992	16762	12	1949	61517	51	1960	12442
13	1957	76550	52	1937	15984	13	1963	60307	52	2002	11837
14	1972	73613	53	1936	15898	14	1968	59702	53	1961	11750
15	2007	72835	54	1961	15638	15	1962	59702	54	2003	11578
16	1949	70243	55	1982	14515	16	1967	59011	55	1936	11491
17	1931	70070	56	1943	13824	17	1952	57110	56	1992	11059
18	1987	67219	57	1941	13738	18	1931	56678	57	1938	9936
19	1969	65664	58	1986	13306	19	1950	53741	58	1973	9850
20	1945	64800	59	1960	13306	20	2000	52704	59	1943	9158
21	1962	63936	60	1938	12701	21	1972	52013	60	1982	8899
22	1942	62122	61	2002	12096	22	1969	45360	61	1997	8813
23	2000	60912	62	1973	10973	23	1977	44150	62	1986	6739
24	1952	59962	63	1947	10022	24	1976	42163	63	1996	5443
25	1977	59789	64	1997	9331	25	1974	38707	64	1948	5357
26	1950	58752	65	1993	8899	26	1945	35165	65	1983	4147
27	1988	45446	66	1996	7430	27	1988	34819	66	1935	3456
28	1999	45187	67	1948	6998	28	1999	34560	67	1993	2765
29	1976	43286	68	1944	6307	29	1985	34560	68	1947	2506
30	1995	43027	69	1983	5443	30	1957	33869	69	2006	1037
31	1984	41731	70	2006	5443	31	1998	33782	70	1944	605
32	2004	41299	71	1935	5098	32	1975	33782	71	1940	173
33	1974	40522	72	1966	2592	33	1989	33005	72	1941	173
34	1998	36634	73	1994	1642	34	1984	32832	73	1958	173
35	1985	36115	74	1958	1382	35	2004	32659	74	1965	173
36	1975	35856	75	1940	1210	36	1942	31104	75	1966	173
37	1979	34301	76	1965	1037	37	1995	30240	76	1980	173
38	1989	33869	77	1980	173	38	1979	29894	77	1994	173
39	1933	32918				39	2005	28944			

Table 8: Comparison of pre- and post-Tillegra flood flows at Seaham Weir

Return Period (years)	Pre-Tillegra Flow (ML/day)	Post-Tillegra Flow (ML/day)	Flow Ratio (post/pre)
2	36029	28166	0.78
5	68342	54864	0.80
10	89683	72576	0.81
20	110246	89510	0.81
50	136771	111456	0.82
100	156730	127958	0.82
200	176515	144374	0.82

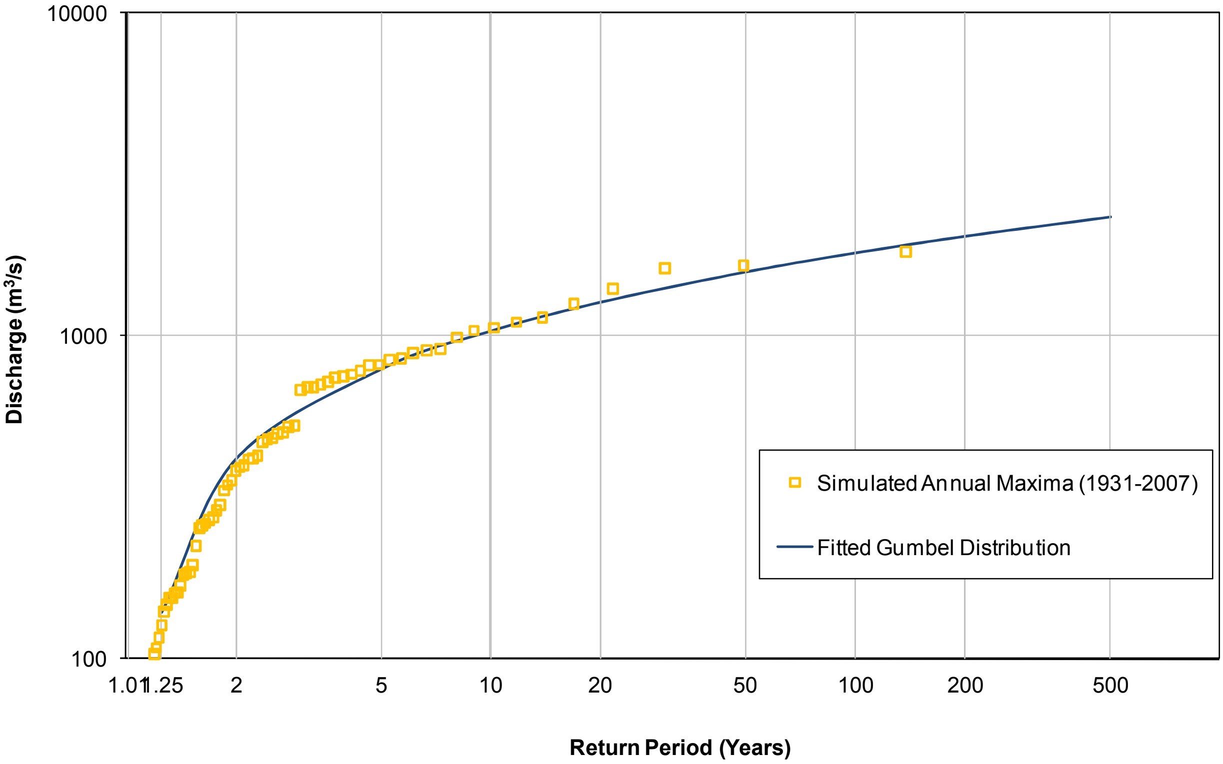


Figure 13: Pre Tillegra Flood Frequency Distribution for the Williams River at Seaham Weir.

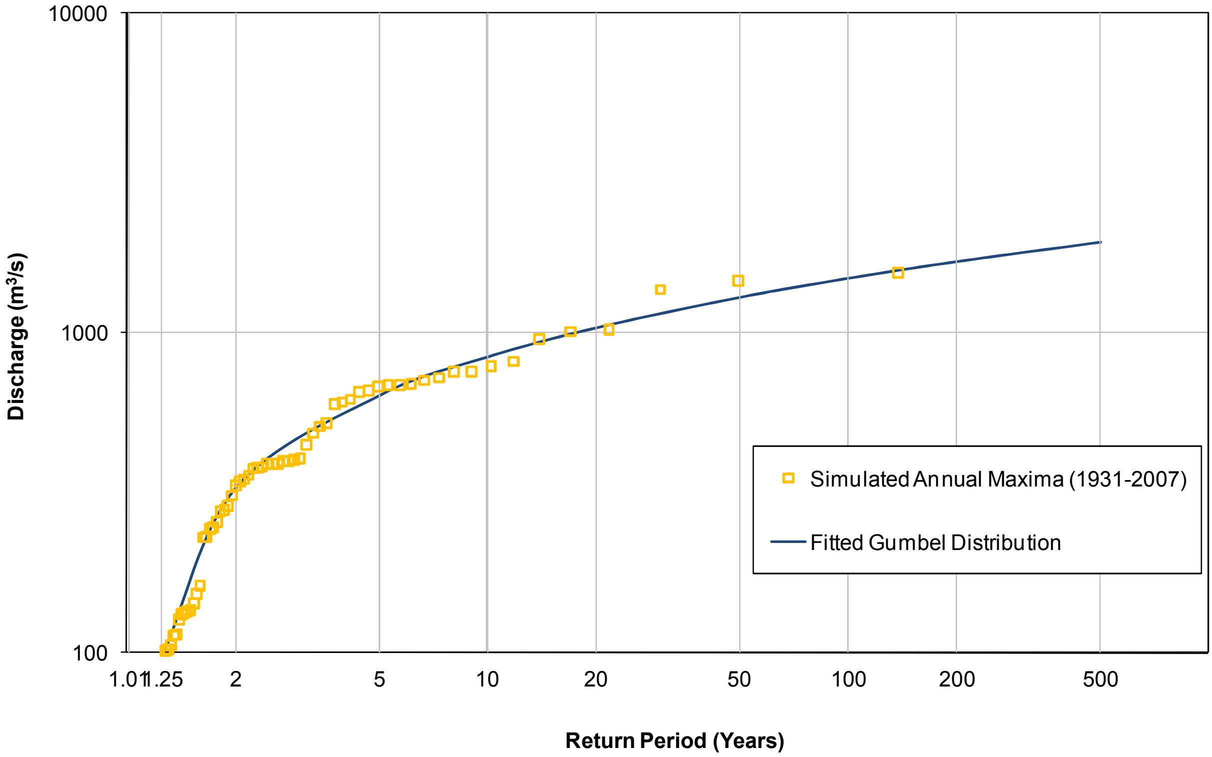


Figure 14: Post Tillegra Flood Frequency Distribution for the Williams River at Seaham Weir.

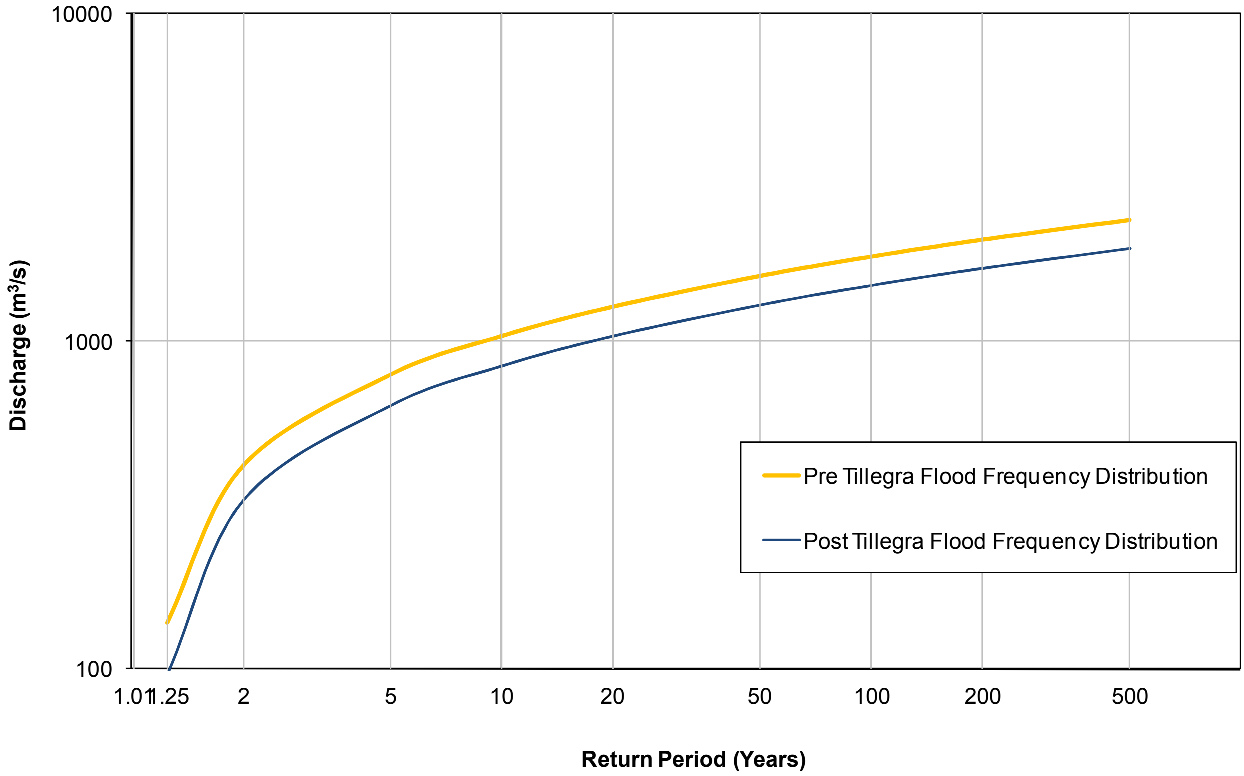


Figure 15: Changes to flood frequency distribution for Williams River at Seaham Weir.

4.1.3 Design flows

The design flood flows derived from the frequency analysis of the HWC daily timestep model data (i.e. average daily flow) does not match the Williams River design flood flows in the existing Lower Hunter River TUFLOW model. For example, the 100-year return period Williams River flow (downstream of Seaham Weir) in the existing TUFLOW model is 3060 m^3/s. This is considerably larger than the daily flow of 156730 ML/day as shown in Table 9 from the frequency analysis of the HWC data, which corresponds to an average daily flow of 1814 m^3/s.

The design Williams River flood flows in the existing TUFLOW model have been derived from flood frequency analysis of annual peak flows at the Glen Martin gauge, routed through the Williams River hydrodynamic model to Seaham.

The HWC daily time-step model, whilst utilising data from the Glen Martin gauge, has been calibrated to lower flow regimes, and not specifically focused on large flood events. Accordingly, the model does not provide a good representation of the most extreme flood events. In addition, the mean daily flow calculated from the model is likely to underestimate the peak flow for given flood event due to the daily time-step applied.

Notwithstanding these limitations in matching actual peak flows, the daily time-step model is expected to provide a reasonable representation of the relative impact of the Tillegra Dam on peak flood flows. As shown in Table 9, a flow factor defined as the ratio of post Tillegra flow to pre Tillegra flow has been determined for a range of design flood magnitudes. A relatively constant factor of the order of 0.8 has been determined across the range of design events considered.

It is noted that the existing Lower Hunter Flood Study design flows for the Williams River provides a better representation of the flow contribution to the Hunter River than the HWC model. However, the ratio of the relative flow for pre- and post-Tillegra conditions derived from the HWC model has been applied to the existing design flows for the Williams River to represent the relative impact of the dam construction on flood discharges.

The design flows adopted in the TUFLOW model are summarised in Figure 15. The relative contributions of the Hunter River and Williams River flows for existing conditions are shown, with a factored Williams River input to the reflect the relative impact for post Tillegra conditions.

Table 9: Adopted design flows in TUFLOW Flood Model.

Return Period (years)	Hunter River Flow (m^3/s)	Pre Tillegra Williams River Flow (m^3/s)	Post Tillegra Williams River Flow (m^3/s)
5	1100	400	320
10	1950	610	500
20	3300	730	600
100	6100	3060	2480

The estimated flood hydrograph (extracted from the TUFLOW flood model) at Hexham during the 5-year, 10-year, 20-year and 100-year ARI under pre and post Tillegra conditions is presented in Figures 16 to 19.

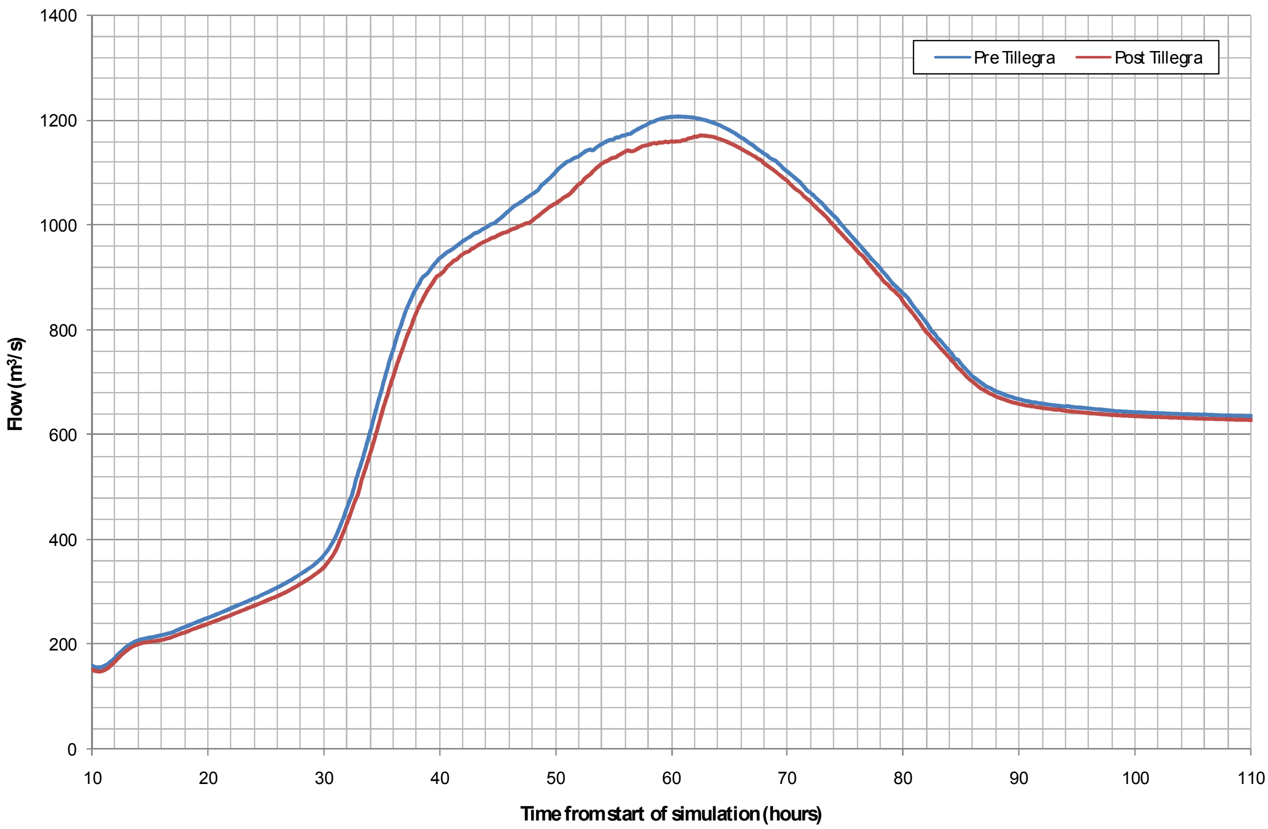


Figure 16: Flood Hydrographs at Hexham (5-year ARI)

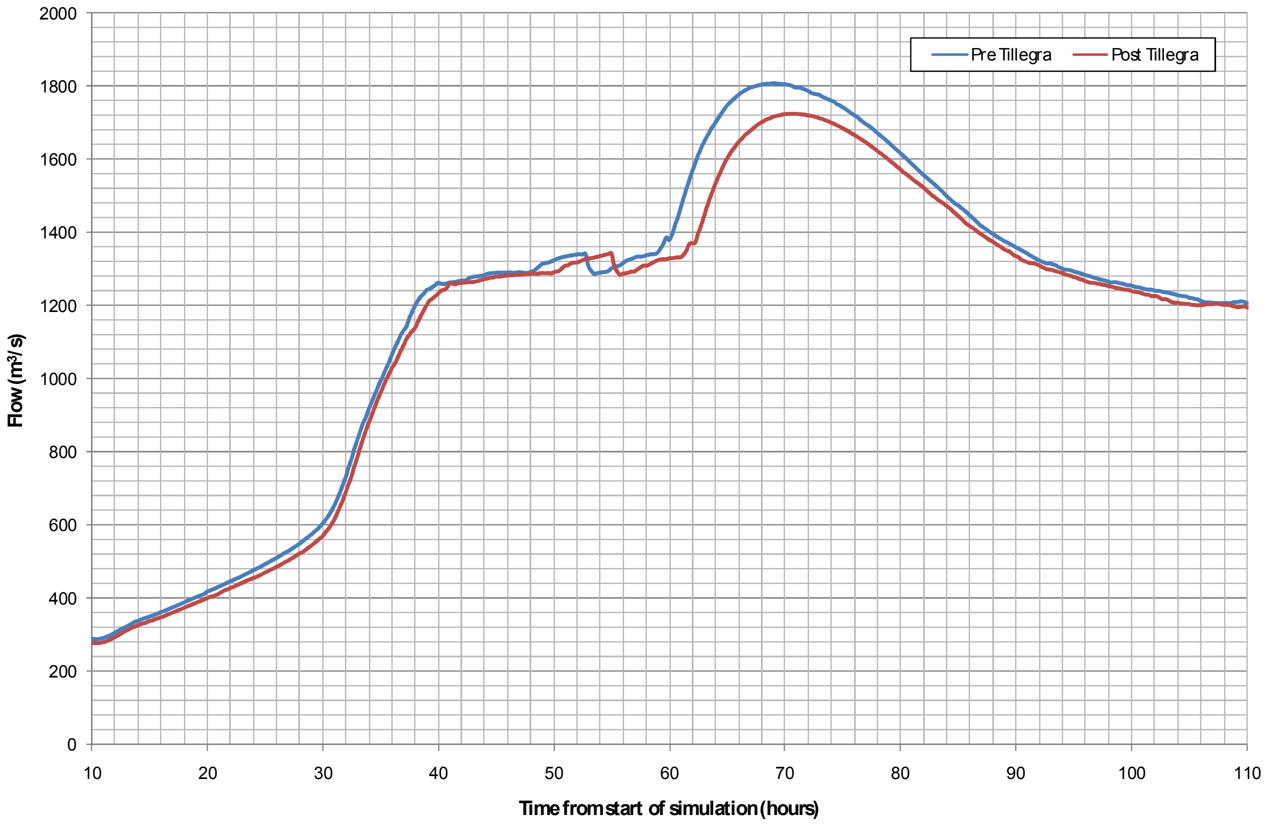


Figure 17: Flood hydrographs at Hexham (10-year ARI).

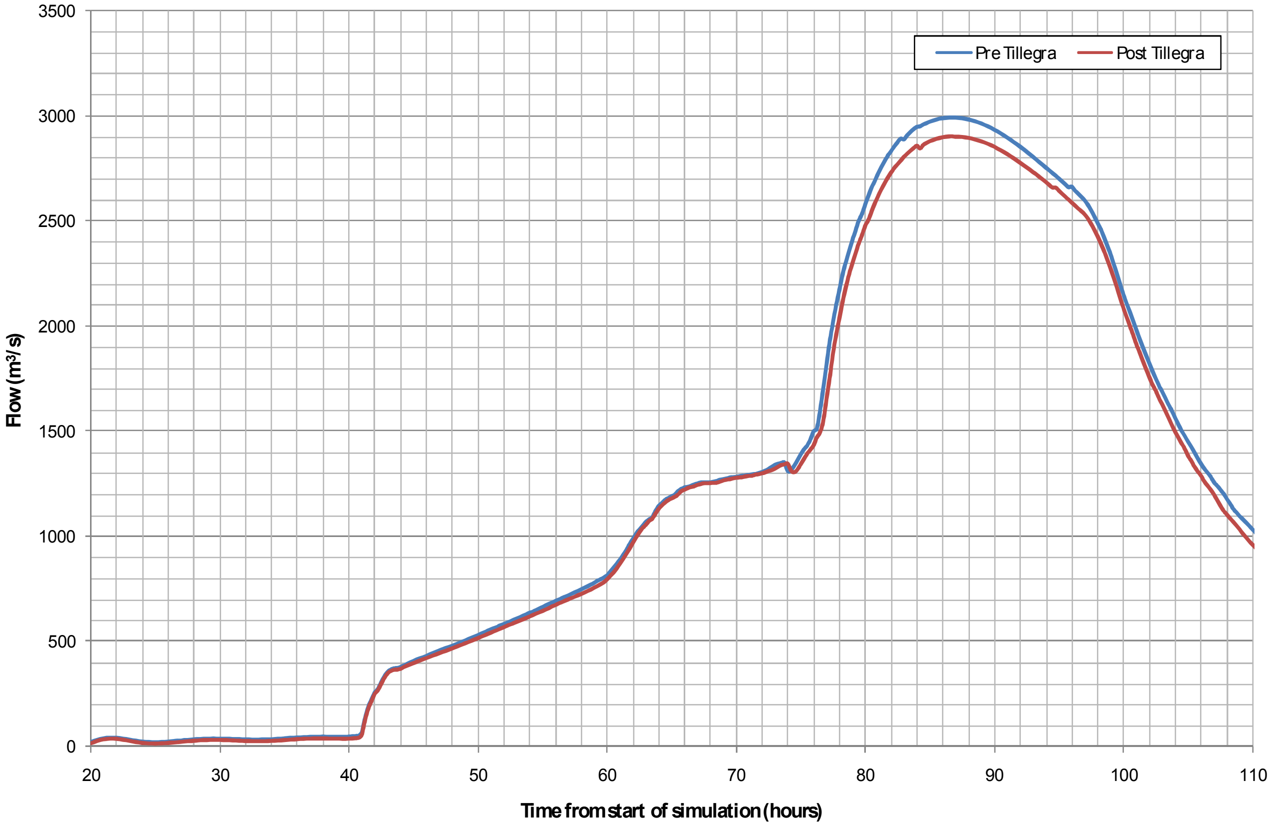


Figure 18: Flood hydrographs at Hexham (20-year ARI).

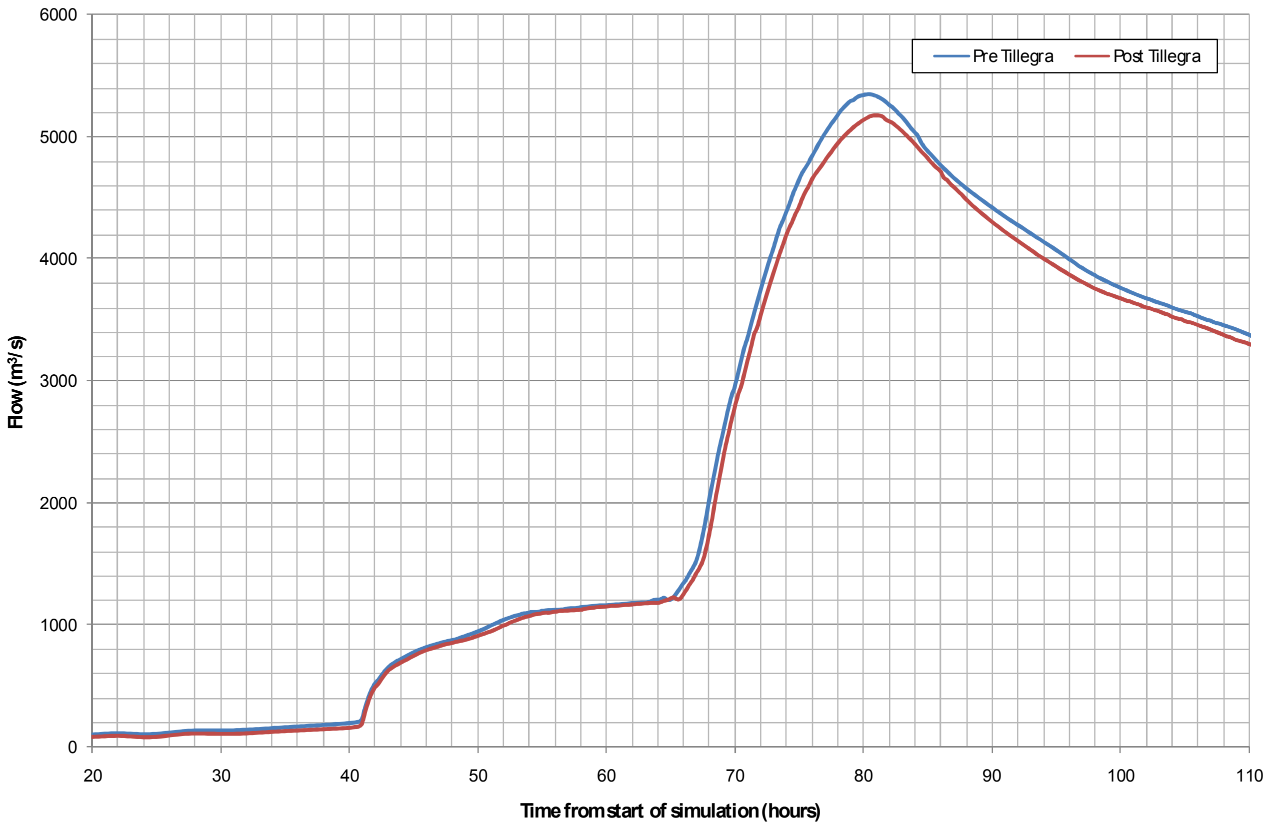


Figure 19: Flood hydrographs at Hexham (100-year ARI).

4.1.4 Flood modelling results

Design flood simulations utilising the existing Lower Hunter River TUFLOW model were undertaken to simulate the relative impact of the Tillegra Dam in accordance with the modified flow regimes as summarised in Table 9.

A long section of peak flood water levels along the Hunter River for pre- and post-Tillegra conditions is shown below in Figure 20. The longitudinal profile used to extract flood results between Newcastle Harbour and Green Rocks is presented in Figure 21.

The longitudinal profiles illustrate the minor reduction in peak flood water levels for the post Tillegra conditions. It is evident from the profiles that the impact of the changed flow regime as a result of the Tillegra Dam dissipates with distance downstream, towards the lower reaches, including the Hunter Estuary Wetlands area. The lessened impact at the lower reaches is due to the attenuation of the flood wave as it progresses through the Lower Hunter system. Accordingly, the relative change in peak flow in the Hunter River at Fullerton Cove is notably less than the relative change at Raymond Terrace.

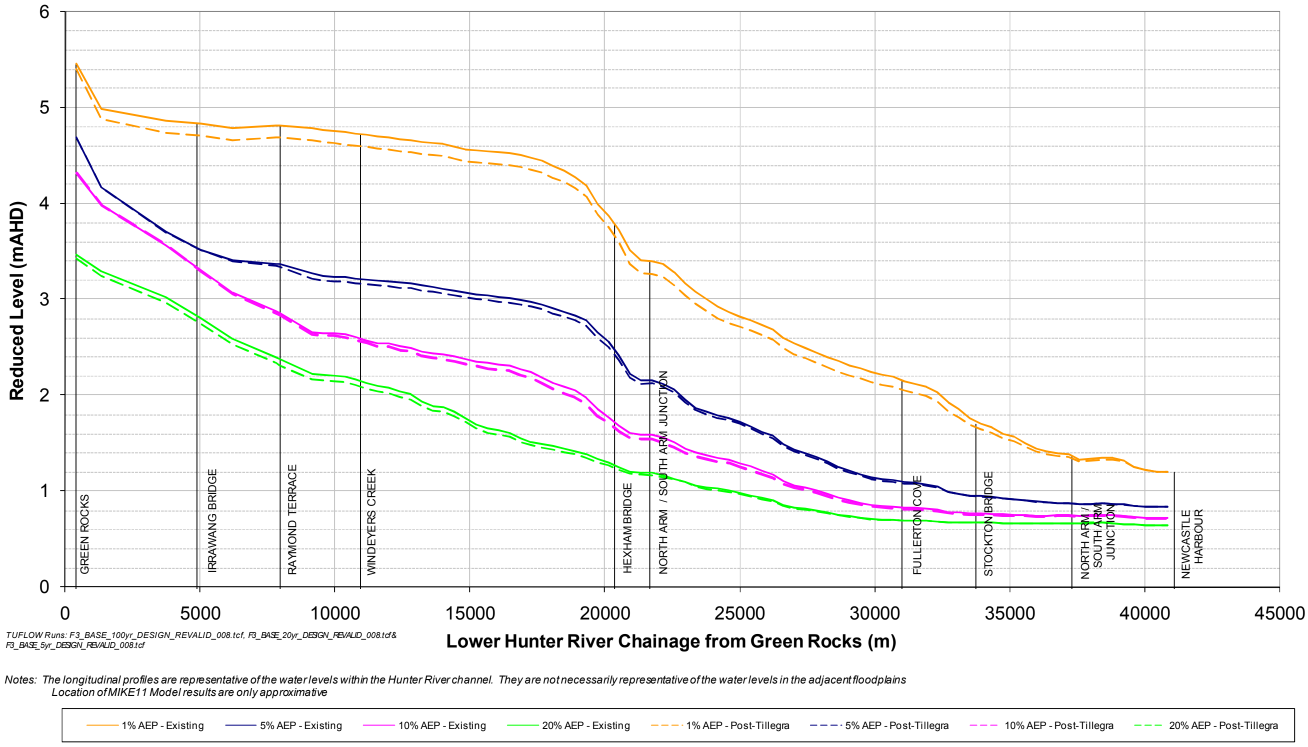
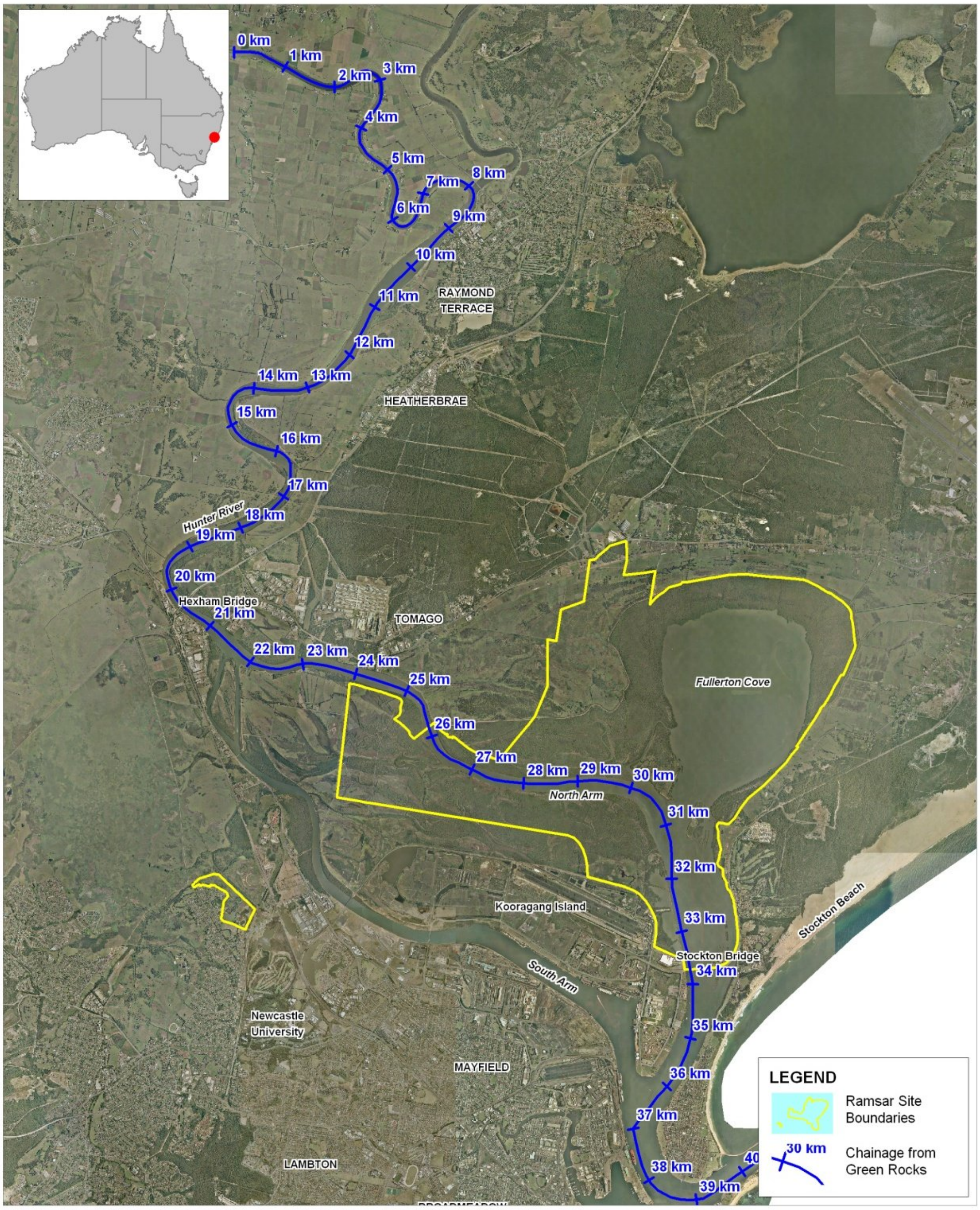


Figure 20: Longitudinal profile of Hunter River peak flood water level.



Title:

Longsection Profile Along Hunter River North Arm

Figure: 21

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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0 1.25 2.5km
Approx. Scale

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The baseline (existing conditions) flood inundation extents in the Lower Hunter for the range of design events simulated is shown in Figure 22 to Figure 25. The mapping illustrates the increase in flood inundation areas by floodwaters with increasing design flood magnitude.

The flood inundation extents for the post Tillegra conditions during the adopted design flow conditions are similar to those shown in the figures below. Changes in peak water levels from the existing conditions are relatively small (<0.1 m) such that whilst depths locally may have changed by a small amount, the broader inundation extents remain largely unchanged. To demonstrate these small differences in the predicted peak flood level, contours of the relative change in flood depth are provided on the flood inundation maps. As an example, a contour interval of '-10' shown in Figure 22 would signify a 10 mm decrease in predicted peak flood levels between pre- and post-Tillegra Dam conditions.

A summary of peak flood levels at a number of reporting locations (shown in the flood inundation maps) for the 5-year, 10-year, 20-year and 100-year ARI under pre- and post-Tillegra Dam conditions are provided in Table 10.

Table 10: Summary of peak flood level at reporting Locations.

Reporting Location	Peak Flood Level (Pre Tillegra) m AHD				Peak Flood Level (Post Tillegra) m AHD			
	5-year ARI	10-year ARI	20-year Ari	100-year ARI	5-year ARI	10-year ARI	20-year Ari	100-year ARI
1				1.782				1.719
2	0.681	0.774	0.980	1.876	0.681	0.769	0.972	1.791
3			0.972	1.828			0.965	1.749
4	0.707	0.837	1.114	2.174	0.704	0.827	1.101	2.071
5	0.709	0.842	1.128	2.213	0.706	0.831	1.114	2.108
6	0.650	0.772	1.037	2.238	0.647	0.762	1.024	2.131
7	0.709	0.842	1.133	2.241	0.706	0.832	1.118	2.133
8	0.709	0.842	1.133	2.241	0.706	0.832	1.118	2.134
9	0.709	0.842	1.135	2.253	0.706	0.832	1.121	2.145
10	0.790	1.023	1.333	2.398	0.781	1.000	1.316	2.292
11	0.785	0.977	1.318	2.406	0.777	0.957	1.300	2.300
12	0.866	1.112	1.504	2.605	0.854	1.084	1.482	2.498
13	0.927	1.207	1.624	2.735	0.912	1.175	1.601	2.627
14	0.945	1.272	1.736	2.913	0.928	1.234	1.711	2.788
15	0.943	1.263	1.717	2.884	0.926	1.226	1.692	2.766
16	0.923	1.223	1.657	2.802	0.906	1.190	1.633	2.690
17	0.905	1.183	1.595	2.717	0.889	1.152	1.573	2.609
18	0.897	1.176	1.591	2.720	0.881	1.145	1.568	2.610
19	0.920	1.230	1.667	2.851	0.901	1.197	1.644	2.735
20	0.921	1.235	1.678	2.881	0.902	1.202	1.653	2.761
21	0.959	1.283	1.713	3.211	0.941	1.245	1.695	3.092
22	0.822	1.041	1.407	2.499	0.813	1.018	1.388	2.393
23	0.827	1.047	1.411	2.501	0.818	1.023	1.392	2.395
24	0.750	0.917	1.235	2.327	0.744	0.901	1.218	2.220
25	0.706	0.836	1.117	2.198	0.703	0.826	1.103	2.094
26	0.706	0.840	1.124	2.191	0.703	0.829	1.110	2.088
27	0.756	0.922	1.212	2.268	0.750	0.907	1.197	2.166
28		0.858	1.154	2.181		0.845	1.141	2.080
29		0.858	1.153	2.190		0.845	1.139	2.087
30		0.851	1.139	2.137		0.838	1.127	2.035
31	0.696	0.815	1.069	2.086	0.693	0.807	1.057	1.987

Note: Blank cells in the above table indicate floodwaters do not inundate these reporting locations at the corresponding average recurrence interval flood.

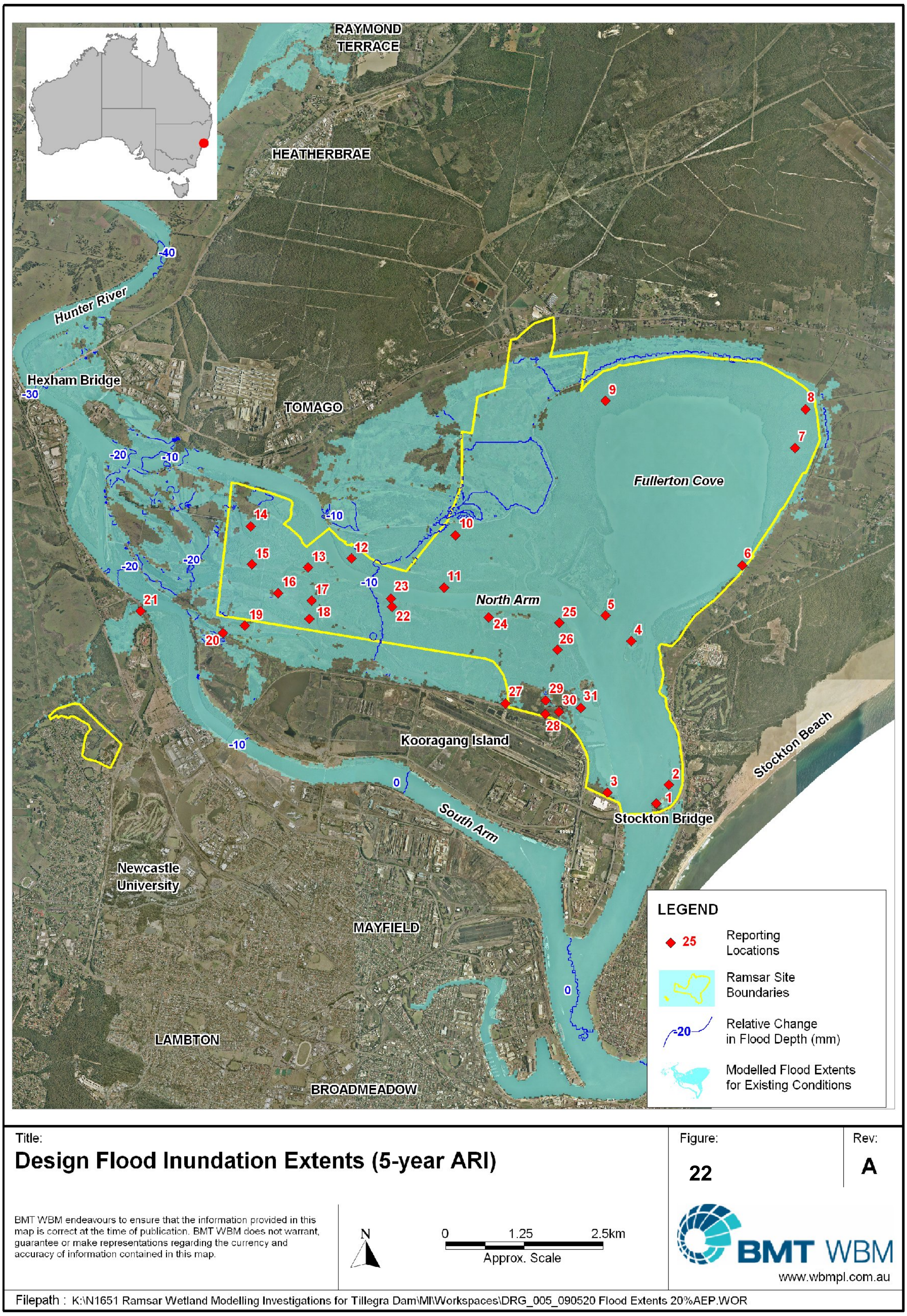
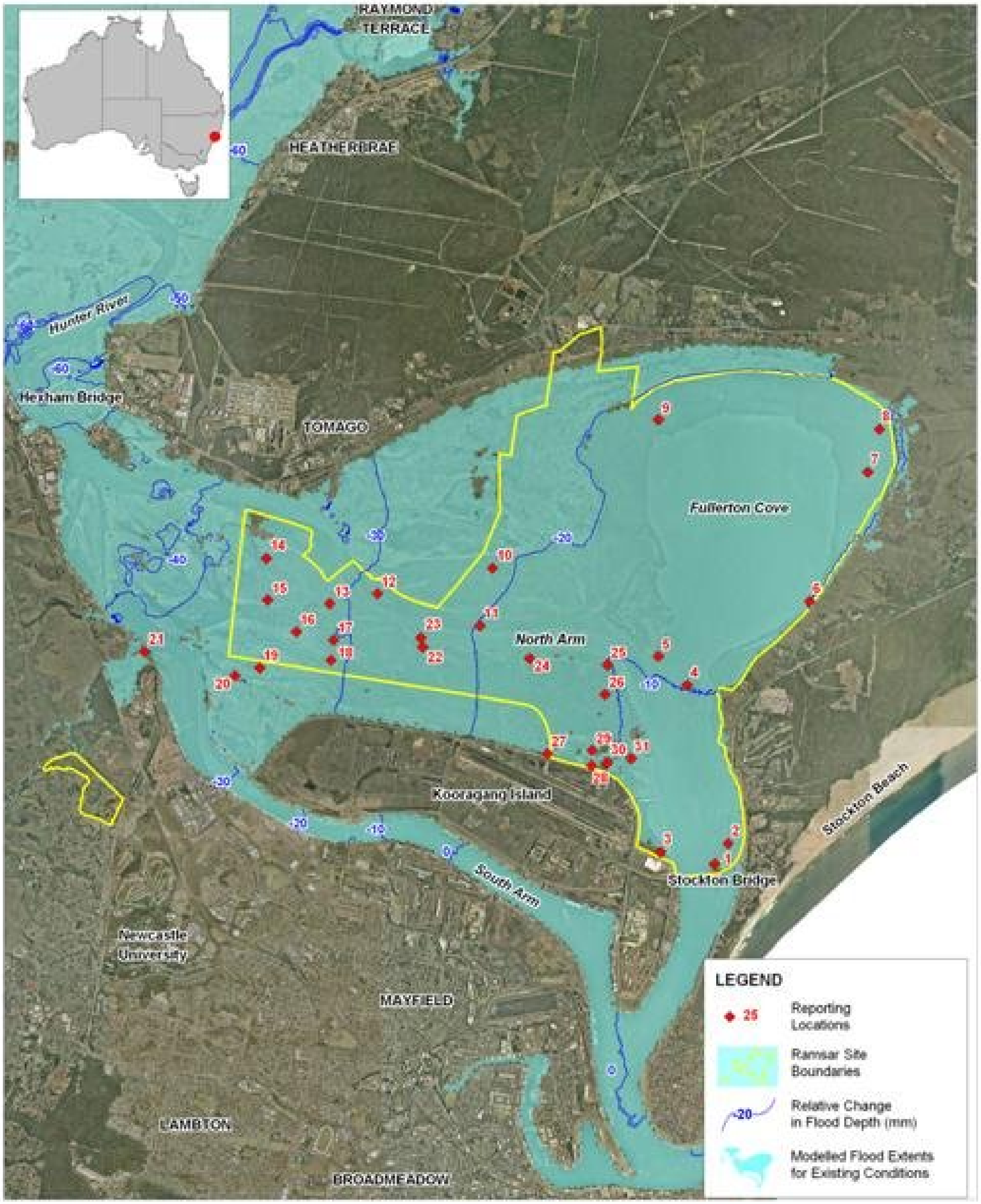


Figure 22: Design flood inundation extents (5-year ARI).

Figure



Title:
Design Flood Inundation Extents (10-year ARI)

Figure: 23

Rev: A

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0 1.25 2.5km
Approx. Scale

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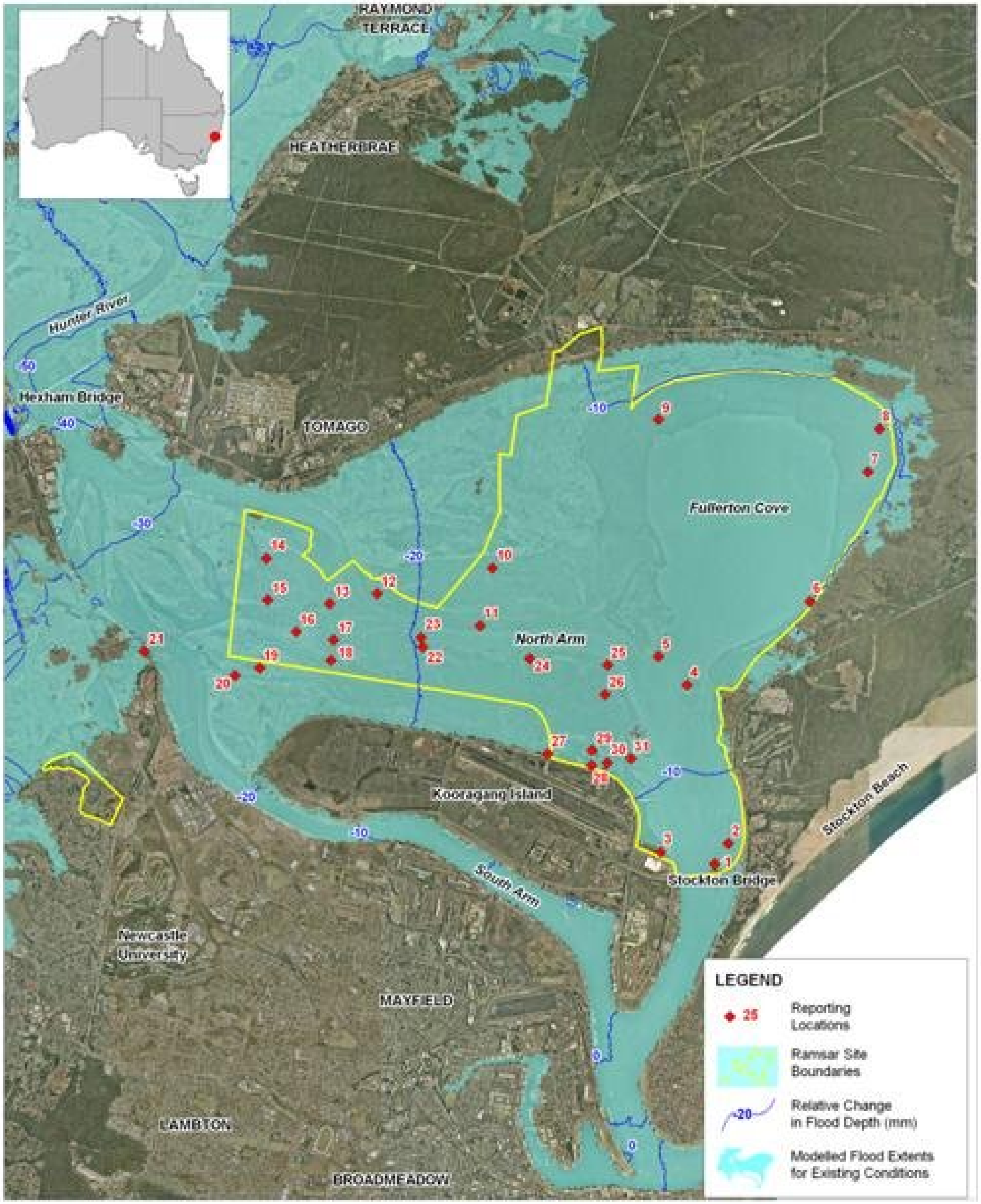
Figu



Title:
Design Flood Inundation Extents (20-year ARI)

Figure: 24

Rev: A

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BMT WBM
www.wbmpl.com.au

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Figure 25: Design flood inundation extents (100-year ARI).

4.2 Elcom Sensitivity Modelling

4.2.1 Overview

Sensitivity testing using the Estuary, Lake and Coastal Ocean Model software (ELCOM) was undertaken to investigate sensitivity of the Ramsar wetlands to changes in the dry-weather (base flow) regime at Seaham Weir. The ELCOM model was previously developed by BMT WBM on behalf of Hunter Water Corporation for the purpose of assessing impacts of the proposed Kooragang Recycled Water Plant. This model was established in 2008. A summary of the ELCOM model development and calibration is provided in Appendix B.

Nineteen modelling scenarios were used to investigate the sensitivity of water levels and salinity within the study area to changes in dry weather base flow conditions and sea level rise predictions. Model results include predictions of water level and salinity concentration at a number of locations within the Ramsar wetlands as well as long section profiles between Newcastle Harbour and Seaham Weir via both the South Arm and North Arm of the Hunter River.

A WaterCAST catchment model previously developed by BMT WBM was also used to estimate the volume of runoff entering the lower estuary from local sub-catchments surrounding the study area. Daily runoff volumes from a number of key sub-catchments have been utilised as inputs to the ELCOM hydrodynamic model to account for the additional 'freshwater' inputs to the system.

4.2.2 Model description and selection

Estuary Lake and Coastal Ocean Model (ELCOM)

The Estuary, Lake and Coastal Ocean Model (ELCOM) was developed at the Centre for Water Research at the University of Western Australia (CWR) and is a three dimensional hydrodynamic model capable of predicting the velocity, salinity and temperature distribution in natural water bodies.

The governing equations and fundamental models used for the three dimensional transport and surface thermodynamics are the unsteady Reynolds – Averaged Navier Stokes (RANS) and scalar transport equations using the Boussinesq approximation and neglecting the non-hydrostatic pressure terms (Hodges and Dallimore 2007). The free surface evolution is governed by an evolution equation developed by vertically integrating the continuity equation applied to the Reynolds–averaged kinematic boundary condition terms (Hodges and Dallimore 2007).

ELCOM uses an Arakawa-C grid where velocities are defined on the cell faces with a free surface height. Scalar concentrations are defined at the cell centres and a mixing model is incorporated to each vertical layer to provide vertical turbulent transport (Hodges and Dallimore 2007).

A background review of the estuarine processes operating within the lower Hunter River estuary demonstrates a number of three dimensional characteristics within the hydrodynamics. In particular the differences during dry (tide dominated) and wet (flood dominated) periods, can result in the lower sections of the estuary being either well mixed or stratified at a given time, and this directly impacts on the potential advection and dispersion of pollutants within and from the estuary.

WaterCAST

The 'WaterCAST' catchment model has been developed by the CRC for Catchment Hydrology, and is an upgrade of the earlier EMSS model. WaterCAST is considered the benchmark catchment runoff model in Australia and was designed to continuously simulate the hydrologic behaviour of catchments over a range of spatial scales utilising actual rainfall records. The primary feature of WaterCAST is the ability to select alternative models for each of the component processes occurring in the system. The main model structure is referred to as a 'node-link', where sub-catchment inputs feed water and material fluxes into nodes, which are then routed along links. Sub-catchment processes are modelled as a combination of up to three processes including runoff generation, constituent generation and filtering. Processes occurring along flow links include routing and in-stream processing. Spatial data of elevation, land use, climate, geology and soils are often used within the sub-catchment-node-link structure.

A WaterCAST catchment model was used to estimate volumetric (i.e. flow) inputs to the lower estuary from local sub-catchments surrounding the study area. Daily runoff volumes from a number of key sub-catchments have been utilised as inputs to the ELCOM hydrodynamic model (Appendix B) to account for the additional 'freshwater' inputs to the system. Estimates of the 25%ile, 50%ile, 75%ile and 90%ile daily flow (to match flow inputs from the Williams and Hunter Rivers) were obtained from modelled flow records for the period 1931 to 2007.

The WaterCAST model covers the parts of the Hunter River catchment downstream of Oakhampton to Newcastle Harbour (i.e. Pacific Ocean), extends up the Paterson River to Gostwyck and up the Williams River to Glen Martin. A Digital Elevation Model (DEM) with a grid resolution of 25m was used to derive sub-catchments draining to key inflow locations. The DEM was pre-processed to fill and remove erroneous data allowing for the subsequent automated catchment delineation available in WaterCAST.

Sub-catchments were initially derived using a stream threshold of 1km2 for all areas within the DEM draining to Newcastle Harbour entrance. Sub-catchments within the upper reaches of the Hunter River Catchment, Paterson River Catchment and Williams River Catchment were combined to simplify the model network particularly for areas where flow inputs were not required by the ELCOM model. The extent of the WaterCAST catchment model is shown in Figure 26.

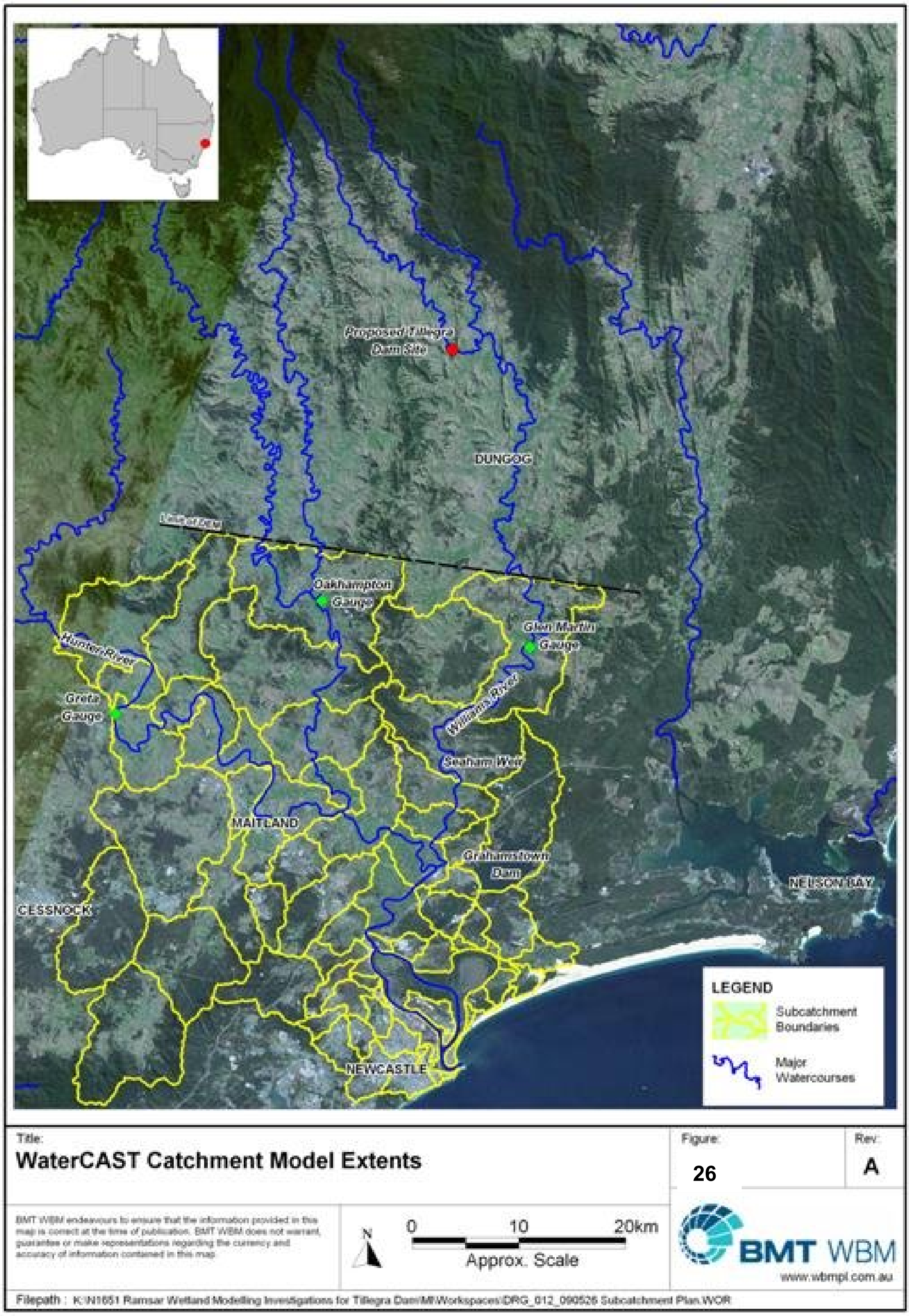


Figure 26: WaterCAST catchment model extents.

4.2.3 Summary of model calibration

The calibration and verification of hydrodynamics and salinity summarised above was undertaken during the initial development of the model (refer Appendix B). As discussed, the purpose of the model was for investigation within the Lower Estuary between Hexham and Newcastle Harbour. The model is considered to reflect hydrodynamic conditions (i.e. water level and flow) for the lower reaches of the estuary. The ELCOM model also responds to and recovers well from major freshwater inflows from the Hunter, Paterson and Williams Rivers which is evident at a number of monitoring locations close to, or within the study area for this project.

4.2.4 Derivation of sensitivity scenarios

HWC source model

HWC use a custom built water supply system simulation model to represent the behaviour of its supply system. The model provides a means to assess what yield can be provided for a given set of performance criteria and to assess the impact of alternative operating scenarios on storage levels and river flows. The model simulates demand, inflows and outflows from storages (dams and aquifers), transfers and source supply selection for either historical climate sequences or stochastically generated replicates. The model explicitly represents Chichester Reservoir, the Williams River and Grahamstown Reservoir at a daily timestep and Tomago Sandbed and Anna Bay Sandbed at a monthly timestep, and computes water balances for each. The model can also represent various potential upgrade options including Tillegra dam at a daily timestep. The operating rules determine the source to be utilised to meet a set level of demand, with selection being influenced by relative storage in each source. The model can be used to investigate a wide range of scenarios including different operating rules, climate scenarios, augmentation options and performance criteria.

Inflows to the dams have been estimated using a combination of historic records and a rainfall runoff model which was calibrated using stream flow gauging stations located on the Chichester and Williams Rivers which monitor flows upstream of Chichester Dam, Tillegra Dam and Seaham Weir. The rainfall runoff model was applied to extend the stream flow sequences using data from daily rainfall stations. The stream flow sequence for Glen Martin was extended to 1898 giving 110 years of historical stream flow records.

Data from the HWC source model was provided in Excel to facilitate the simulation of the various pre and post Tillegra Dam scenarios to assess the impact of Tillegra Dam operations on the flow of water out of the Williams River into the Hunter estuary. This model provided estimates of daily outflow from Seaham Weir for each scenario for the historic rainfall and streamflow sequence between 1931 and 2008.

ELCOM scenarios

ELCOM is a complex three-dimensional model and as such is not suitable for long-term continuous simulations, as it utilises a very small timestep (i.e. 30 seconds) which is required for solving hydrodynamic and scalar transport processes. However, it is possible to use the existing ELCOM model for simulations of much shorter durations (i.e. 2 weeks or less) to assess changes of salinity in response to a particular magnitude and duration of river inflow.

The sensitivity scenarios assessed using ELCOM aimed to include potential variations in the flow rates from the Williams River and the Hunter River. For the Williams River flows, scenarios have been derived that cover the inclusion of Tillegra Dam (during both the initial fill-up phase and during design operation), and a number of options for modification of the flow/release rules at Seaham Weir (including the upgrade of the fishway). Consideration has also been given to the relative impacts of climate change with regards to sea level rise only.

Flows for the Williams River (at Seaham Weir) were provided by HWC for pre and post Tillegra Dam conditions, and a number of possible flow release options as a result of an upgrade of the fishway and weir gate operation. Flow-frequency curves of daily flow volumes past Seaham Weir provided by HWC are shown in Figure 27 for a number of potential weir operation scenarios. The modelled outputs represent the flow passing Seaham Weir on a daily interval, however, it is recognised that existing and future flow rules for Seaham Weir result in a combination of base flow (through the fishway) and pulsed releases through the gates.

The sensitivity modelling undertaken aims to investigate impacts on Ramsar wetlands in the Lower Hunter Estuary using daily averaged flows derived from flow-frequency curves presented in Figure 15. The model was run for 2 weeks under constant inflow conditions and a typical tide at the ocean boundary. It is considered that daily averaged flows at Seaham Weir would be sufficient for comparative assessment purposes. Average daily inflows for a range of typical flow conditions (i.e. 'low', 'medium', 'medium to high' and 'high') were assigned at the model boundary on the Williams River downstream of Seaham Weir. For this assessment, the following percentiles have been adopted to represent the typical flow conditions:

- 'low flow' defined as 25%ile average daily flow;
- 'medium flow' defined as 50%ile average daily flow;
- 'medium to high flow' defined as 75%ile average daily flow; and
- 'high flow' defined as 90%ile daily flow.

Major river inflows for the Hunter River and Paterson River were sourced from PINNENA stream gauging records at Site Number 210064 (Greta) and 210079 (Gostwyck) respectively. Inflows to the model from the Hunter River and Paterson River were determined as the 25%ile and 50%ile daily averaged flow based on available gauging records between December 1968 and February 2006. Sensitivity runs with 50%ile and 75%ile flow conditions at Seaham Weir were coupled with equivalent 50%ile flows from the Hunter River and Paterson River. All low flow scenarios were assigned 25%ile flows at the major inflow boundaries to the model.

Lateral inflows to the estuary downstream of the major river inflow boundaries have been incorporated at a number of key locations corresponding to freshwater inflows from adjacent local sub-catchment areas (e.g. urban areas drained by Styx Creek and Cottage Creek catchments). The existing WaterCAST model for catchment runoff was used to determine the 25%ile, 50%ile, 75%ile and 90%ile flow conditions from the lateral inflow sources. A summary of the core ELCOM sensitivity scenarios investigated is provided in Table 11 and described below.

Table 11: Core ELCOM sensitivity scenarios.

Scenario	Seaham Weir Flow		
	25%ile	50%ile	75%ile
Existing system, current demand, historic streamflow	Same as Scenario 1	Scenario 1	Scenario 6
Plus Tillegra at future demand (120GL/yr): Existing gates and fishway	Same as Scenario 1	Same as Scenario 1	Same as Scenario 1
Plus Tillegra at future demand (120GL/yr): Existing gates and fishway with fill-up phase	same as Scenario 12	Scenario 2	Scenario 7
Plus Tillegra: Transparent to 20MLD at Seaham	same as Scenario 16	Scenario 3	same as Scenario 3
Plus Tillegra: Transparent to 20MLD + 30% Translucent to 100MLD at Seaham	same as Scenario 3	Scenario 5	Scenario 9
Plus Tillegra: Transparent to 20MLD + 70% Translucent to 100MLD at Seaham	same as Scenario 3	Scenario 4	Scenario 8
Plus Tillegra: Transparent to 20MLD + 30% Translucent to 2400MLD at Seaham	same as Scenario 3	same as Scenario 5	Scenario 10
Plus Tillegra: Transparent to 20MLD + 70% Translucent to 5500MLD at Seaham	same as Scenario 3	same as Scenario 4	similar to Scenario 6

Note: MLD = Megalitres per day

The sensitivity modelling included ten (10) core scenarios that focused on percentile flows of 50% and 75% at Seaham Weir under pre and post Tillegra Dam flow conditions. With regards to the derivation of modelling scenarios, the adoption of a 75%ile flow and 50%ile flow at Seaham Weir was coupled with a median flow in the Hunter River and Paterson River. In terms of 'upgrade scenarios' the priority was to examine upgraded flows past Seaham at 20 ML/day (green line), the transparent to 20 ML/day and 70% translucent to 100 ML/day (red line) and the 20 ML/day transparent and 30% translucent to 100 ML/day (black line) (refer Figure 27)

In some cases the flow specified at the 50%ile and at the 75%ile are the same between more than one options. Table 11 shows that the ten ELCOM scenarios cover flow conditions for the 25%ile, 50%ile and 75%ile for a total of eight (8) potential scenarios. In determining the core model scenarios outlined above, the 'upgrade' scenarios were prioritised in accordance with guidance provided by HWC.

Within a number of scenarios listed above, transparent and translucent rule-based environmental flows have been assessed. The rationale of applying 'transparency' and 'translucency' is to reproduce natural flow regimes as much as is possible within the operational constraints of a weir or other similar structure. The concept of 'transparency' and 'translucency' are used in combination to create environmental flow regimes that aim to protect low flows, protect or restore a portion of higher flows (e.g. fresh events), and maintain or mimic natural flow variability. Low flows are passed transparently (up to a limit), and are therefore fully protected. All remaining (higher) flows are passed translucently, which protects a portion of these higher flows.

Broadly speaking, the total amount of water available to the environment downstream of a Dam is made up of both ‘active’ and ‘passive’ environmental water. Active environmental water includes licensed environmental flows and is rule-based. The rule specifies the minimum amount of water that must be provided to the environment downstream of the dam. The rule comprises ‘transparent’ and ‘translucent’ flow components.

In addition to the licensed (active) environmental water, there are other passive environmental water components, which include surplus water remaining after inflow water has been allocated to any extractions and the licensed environmental flow. Typically, active environmental water is delivered through controlled releases from outlets in the dam wall or in this case controlled releases from Seaham Weir and passive environmental water is delivered through spills over the dam wall etc.

The concept of transparent and translucent flows can be explained using the analogy of light passing through a material such as glass. ‘Transparent’ flows are those that pass through a Dam or other similar structure as if it were see-through, or invisible just like transparent (clear) glass. A transparently-operated structure enables all inflows up to a particular flow threshold to pass through unmodified. Inflows below a defined threshold flow value are defined as ‘transparent’ and cannot be stored or extracted (i.e. these flows must be passed through as if the structure was not there at all). ‘Translucent’ flows include those where some (not all) can pass through the structure, which is typically expressed as a percentage. As an example, 20% translucency means that 80% of the inflow is not allowed to pass through the nominated structure.

In the scenarios above, a number of potential flow release options at Seaham Weir have been considered as part of the sensitivity modelling using ELCOM. The flow release rules incorporate both transparent and translucent flows which are explained further using the following as an example:

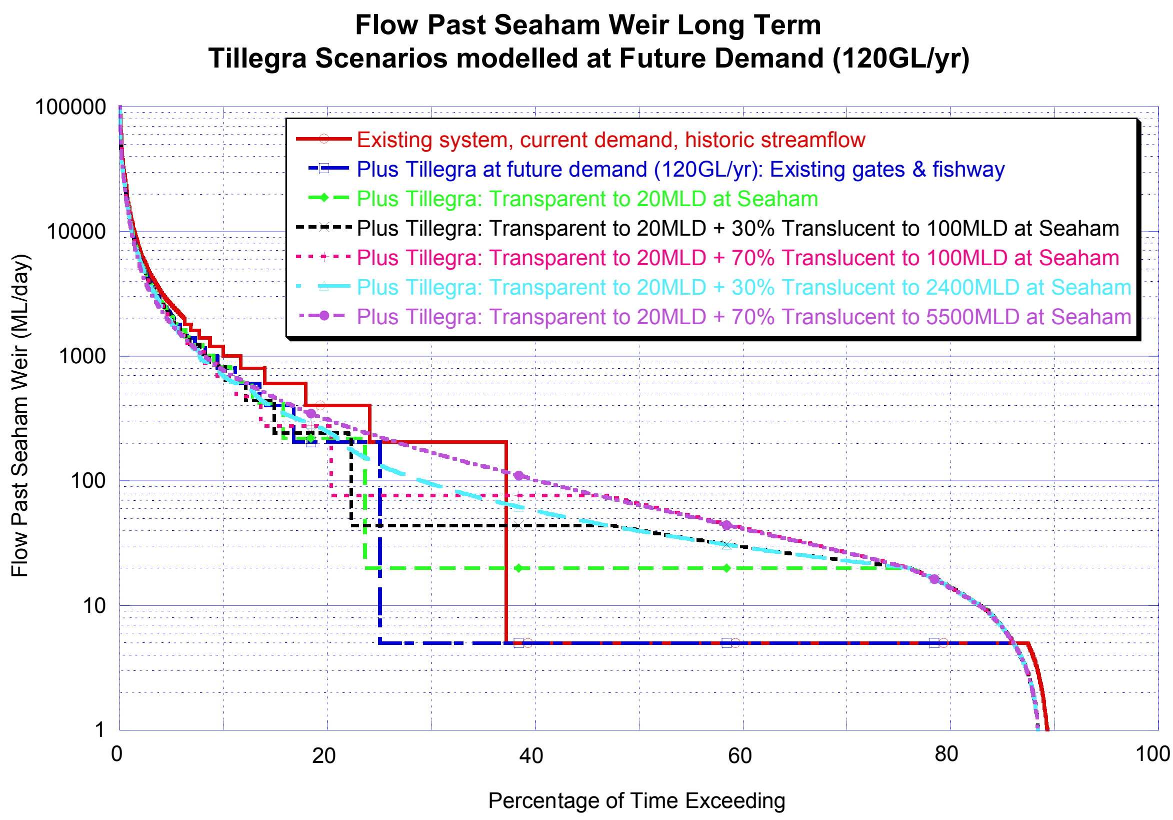
Plus Tillegra: Transparent to 20 MLD + 30% Translucent to 100MLD at Seaham

The above potential flow release option at Seaham Weir can be explained as follows:

- Transparent to 20MLD indicates that all flows up to 20ML/day are ‘transparent’ and must be passed through Seaham Weir unmodified (i.e. flows between 0ML/day and 20ML/day cannot be stored or extracted);

- 30% Translucent to 100MLD indicates that flows between 20ML/day and 100ML/day are ‘translucent’ and may be modified as part of the flow release option. In this example a translucency of 30% has been defined, which means 30% of incoming flows within this range are passed through the weir;

- For flows above 100MLD at Seaham Weir, there is no flow release rule in place which means that flows are 100% translucent (i.e. all flows above 100ML/day are transparent) subject to weir operation limitations and any licensed water extraction.



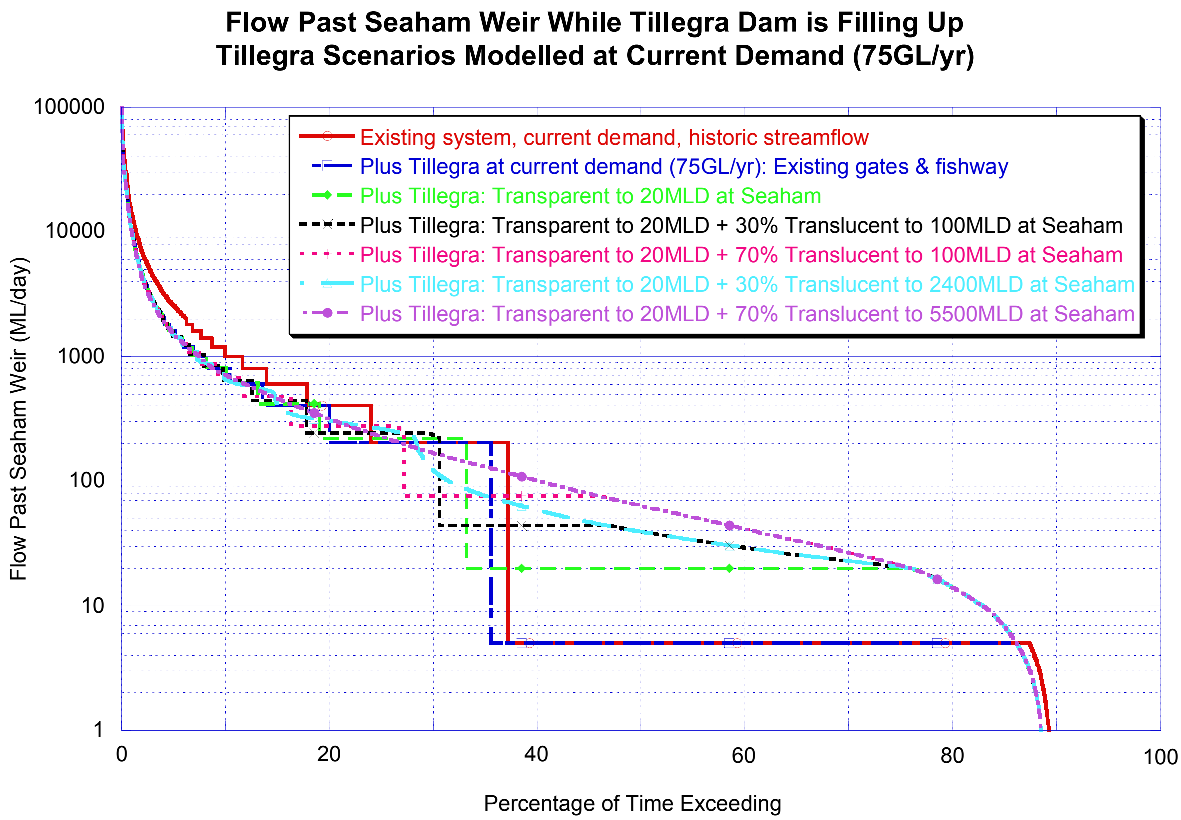


Figure 27: Flow frequency curves for flow release options at Seaham Weir

In addition to the core ELCOM sensitivity scenarios outlined above, six (6) additional model runs were included in the investigations covering pre Tillegra Dam, post Tillegra Dam and post Tillegra Dam with a fill-up phase under the 25%ile (low flow) and 90%ile (high flow) conditions at Seaham Weir. Low flow conditions (i.e. 25%ile flows) at Seaham Weir were coupled with representative low flow conditions in the Hunter River and Paterson River. High flow conditions at Seaham Weir (i.e. 90%ile flows) were coupled with median flow conditions in the Hunter River and Paterson River.

A summary of the additional ELCOM scenarios are presented in Table 12.

Table 12: Additional ELCOM scenarios.

Scenario	**Seaham Weir Flow**	
	25%ile	**90%ile**
Existing system, current demand, historic streamflow	Scenario 11	Scenario 13
Plus Tillegra at future demand (120GL/yr): Existing gates & fishway	Scenario 16	Scenario 14
Plus Tillegra at future demand (120GL/yr): Existing gates & fishway with fill-up phase	Scenario 12	Scenario 15
Climate Change Scenarios	**50%ile Flow**	**SLR Adjustment***
Plus Tillegra: Transparent to 20MLD at Seaham	Scenario 17	+0.18m
Plus Tillegra: Transparent to 20MLD at Seaham	Scenario 18	+0.55m
Plus Tillegra: Transparent to 20MLD at Seaham	Scenario 19	+0.91m

* Sea level rise adjustment above current mean seal level

As shown in Table 12, the additional six runs cover the low flow (i.e. 25%ile) and high flow (i.e. 90%ile) conditions. Three climate change (sea level rise) scenarios were included in the investigations to demonstrate relative changes to water level and salinity within the study area as a result of increases to the mean sea level based on projections for the year 2020, 2050 and 2100 outlined by IPCC (2007). Sea level rise (SLR) scenarios were configured for the future dam scenario with an upgraded weir and fishway (i.e. Plus Tillegra: Transparent to 20MLD at Seaham). Median flow conditions were adopted for inflows at Seaham Weir, Hunter River and the Paterson River. Sea level rise adjustments to the mean tide were included by shifting the tidal boundary upwards in accordance with values presented in Table 12.

The ELCOM model scenarios outlined above have been summarised on Figure 28 to demonstrate the coverage of sensitivity runs adopted for the investigations. A description of the nineteen model scenarios is presented in Table 13.

Table 13: Summary of ELCOM sensitivity scenarios.

Scenarios		Daily Flow at Seham Weir (ML/day)	Description
Tillegra Dam Sensitivity Scenarios	1	5	Median flow conditions for the Hunter River, Paterson River and Williams River. Existing configuration and flow release conditions at Seaham Weir. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam not included.
	2	220	Median flow conditions for the Hunter River and Paterson River. 75%ile flow conditions for Williams River. Flow release option at Seaham Weir is transparent to 20MLD. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam is under fill-up phase conditions.
	3	20	Median flow conditions for the Hunter River, Paterson River and Williams River. Flow release option at Seaham Weir is transparent to 20MLD. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam is operational.
	4	66	Median flow conditions for the Hunter River, Paterson River and Williams River. Flow release option at Seaham Weir is Transparent to 20MLD and 70% Translucent to 100MLD. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam is operational.
	5	40	Median flow conditions for the Hunter River, Paterson River and Williams River. Flow release option at Seaham Weir is Transparent to 20MLD and 30% Translucent to 100MLD. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam is operational.
	6	205	Median flow conditions for the Hunter River and Paterson River. 75%ile flow conditions for Williams River. Existing configuration and flow release conditions at Seaham Weir. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam not included.
	7	276	Median flow conditions for the Hunter River and Paterson River. 75%ile flow conditions for Williams River. Flow release option at Seaham Weir is Transparent to 20MLD and 70% Translucent to 100MLD. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam is under fill-up phase conditions.
	8	76	Median flow conditions for the Hunter River and Paterson River. 75%ile flow conditions for Williams River. Flow release option at Seaham Weir is Transparent to 20MLD and 70% Translucent to 100MLD. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam is operational.
	9	44	Median flow conditions for the Hunter River and Paterson River. 75%ile flow conditions for Williams River. Flow release option at Seaham Weir is Transparent to 20MLD and 30% Translucent to 100MLD. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam is operational.
	10	134	Median flow conditions for the Hunter River and Paterson River. 75%ile flow conditions for Williams River. Flow release option at Seaham Weir is Transparent to 20MLD and 30% Translucent to 2400MLD. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam is operational.
	11	5	25%ile flow conditions for the Hunter River, Paterson River and Williams River. Existing configuration and flow release conditions at Seaham Weir. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam not included.
	12	644	Median flow conditions for the Hunter River and Paterson River. 90%ile flow conditions for Williams River. Flow release option at Seaham Weir is Transparent to 20MLD and 30% Translucent to 100MLD. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam is under fill-up phase conditions.
	13	1005	Median flow conditions for the Hunter River, Paterson River. 90%ile flow conditions for Williams River. Existing configuration and flow release conditions at Seaham Weir. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam not included.
	14	805	Median flow conditions for the Hunter River, Paterson River. 90%ile flow conditions for Williams River. Existing configuration and flow release conditions at Seaham Weir. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam is operational.
	15	657	Median flow conditions for the Hunter River and Paterson River. 90%ile flow conditions for Williams River. Flow release option at Seaham Weir is Transparent to 20MLD and 30% Translucent to 2400MLD. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam is under fill-up phase conditions.
	16	20	25%ile flow conditions for the Hunter River, Paterson River and Williams River. Flow release option at Seaham Weir is Transparent to 20MLD. Mean tide with range of 1.4m adopted at ocean boundary. Tillegra Dam not included.
SLR Sensitivity Scenarios	17	20	Sea level rise scenario. Median flow conditions for the Hunter River, Paterson River and Williams River. Flow release option at Seaham weir is transparent to 20MLD. Mean tidal boundary shifted up by 0.18m in accordance with projected SLR conditions for 2020. Tillegra Dam is operational.
	18	20	Sea level rise scenario. Median flow conditions for the Hunter River, Paterson River and Williams River. Flow release option at Seaham weir is transparent to 20MLD. Mean tidal boundary shifted up by 0.55m in accordance with projected SLR conditions for 2050. Tillegra Dam is operational.
	19	20	Sea level rise scenario. Median flow conditions for the Hunter River, Paterson River and Williams River. Flow release option at Seaham weir is transparent to 20MLD. Mean tidal boundary shifted up by 0.91m in accordance with projected SLR conditions for 2100. Tillegra Dam is operational.

4.2.5 ELCOM Results

The following results are derived from hydrodynamic and salinity modelling undertaken using the calibrated ELCOM model. A total of 19 model scenarios have been simulated using ELCOM to investigate the sensitivity of water level and salinity at the study area to changes in flow at Seaham Weir. Additional ELCOM results are presented in Appendix B, which include long section profiles of water level and salinity along the North Arm and South Arm of the Hunter River.

As mentioned previously, the sensitivity scenarios aim to include potential variations in the flow rates from the Williams River and the Hunter River, and have been derived with the inclusion of Tillegra Dam (during both the initial fill-up phase and during design operation), and a number of options for modification of the flow/release rules at Seaham Weir (including the upgrade of the fishway). The results of the ELCOM modelling also include consideration of relative impacts of climate change with regards to sea level rise.

The modelling undertaken includes results of water levels and salinity concentrations for a range of flow conditions corresponding to the 25%ile, 50%ile, 75%ile and 90%ile daily flows assigned at the model boundary on the Williams River downstream of Seaham Weir. In the following modelling results, runoff has been included from a number of inflow locations including Ironbark Creek, Tomago, Cottage Creek / Styx Creek, Purgatory Creek, Fullerton Cove, and the Fourteen Foot Drain (Williamtown). However, since all model scenarios incorporate the same initial conditions and inflow conditions for the Hunter River and Paterson River, the difference predicted for each scenario relative to the base scenario can therefore be attributed to changes to the volume entering the estuary from the Williams River at Seaham Weir.

The results presented in the following sections include summary tables of long section profiles (average water level and salinity concentration) simulated over the last tidal cycle of each model scenario. Plots of the long section profiles for water level and salinity concentration between the entrance to Newcastle Harbour and Seaham Weir via the North Arm and South Arm of the Hunter River are presented in Appendix B.

Water levels

The average water level (obtained from output at hourly intervals) simulated along the North Arm and South Arm of the Hunter River over the last tidal cycle is shown in Table 14 and Table 15 respectively. Columns shaded grey correspond to the base case scenario for each of the percentile flow categories assessed with relative differences (unshaded) shown for each of the proposed condition scenarios.

The results show minor differences (typically less than 5 mm) in water level along the South Arm and North Arm of the Hunter River as a result of changes in flow at Seaham Weir. The greatest difference in water level are estimated under 90%ile flow conditions at Seaham Weir coupled with median flow conditions in the Hunter River and Paterson River. Differences in the average water level are greatest immediately downstream of Seaham Weir (approximately 20 mm). In the vicinity of the study area between Hexham and Newcastle Harbour the difference in water level is between 6 mm and 13 mm. Overall, differences in water levels are least in the vicinity of the tidal boundary which is a key driver of water levels (hydrodynamics) especially during low flow conditions.

Table 14: Hunter River North Arm long section profile impacts (water level).

Distance Upstream from Ocean (m)	25%ile Flow Conditions		50%ile Flow Conditions				75%ile Flow Conditions						90%ile Flow Conditions			
	Scenario 11	Scenario 16	Scenario 1	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 2	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 13	Scenario 12	Scenario 14	Scenario 15
	mAHD	Δm	mAHD	Δm	Δm	Δm	mAHD	Δm	Δm	Δm	Δm	Δm	mAHD	Δm	Δm	Δm
0	-0.0600	-0.0058	-0.0658	0.0000	0.0000	0.0000	-0.0657	-0.0001	0.0000	-0.0658	0.0000	-0.0658	-0.0598	-0.0002	-0.0002	-0.0058
1032	-0.0631	-0.0059	-0.0690	-0.0003	-0.0002	0.0001	-0.0688	-0.0002	-0.0031	-0.0688	-0.0031	-0.0692	-0.0613	-0.0003	-0.0001	-0.0070
1946	-0.0548	-0.0058	-0.0602	-0.0005	-0.0002	-0.0001	-0.0601	-0.0002	0.0057	-0.0603	0.0055	-0.0606	-0.0508	-0.0010	-0.0007	-0.0083
2667	-0.0542	-0.0061	-0.0601	-0.0005	-0.0002	0.0001	-0.0602	-0.0002	0.0055	-0.0597	0.0057	-0.0606	-0.0505	-0.0011	-0.0006	-0.0081
3538	-0.0512	-0.0057	-0.0568	-0.0004	0.0000	0.0003	-0.0562	-0.0003	0.0094	-0.0562	0.0092	-0.0569	-0.0476	-0.0010	-0.0006	-0.0079
4354	-0.0534	-0.0060	-0.0595	-0.0005	-0.0005	0.0002	-0.0597	0.0000	0.0060	-0.0592	0.0064	-0.0603	-0.0509	-0.0007	-0.0008	-0.0084
5366	-0.0465	-0.0066	-0.0535	-0.0004	-0.0002	0.0004	-0.0533	-0.0003	0.0121	-0.0532	0.0123	-0.0539	-0.0452	-0.0006	-0.0007	-0.0085
6288	-0.0420	-0.0064	-0.0487	0.0000	-0.0002	0.0006	-0.0484	0.0002	0.0171	-0.0482	0.0170	-0.0490	-0.0407	-0.0010	-0.0007	-0.0082
7571	-0.0451	-0.0077	-0.0530	-0.0001	-0.0002	0.0009	-0.0526	-0.0001	0.0132	-0.0529	0.0132	-0.0532	-0.0440	-0.0012	-0.0008	-0.0088
8824	-0.0283	-0.0098	-0.0369	-0.0008	-0.0005	-0.0002	-0.0375	0.0003	0.0283	-0.0369	0.0285	-0.0376	-0.0274	-0.0012	-0.0009	-0.0100
9922	-0.0141	-0.0076	-0.0217	-0.0001	-0.0003	0.0004	-0.0213	0.0003	0.0445	-0.0214	0.0440	-0.0219	-0.0118	-0.0011	-0.0011	-0.0083
11104	-0.0058	-0.0070	-0.0133	0.0001	-0.0002	0.0008	-0.0128	0.0006	0.0535	-0.0133	0.0527	-0.0134	-0.0029	-0.0011	-0.0009	-0.0083
12504	-0.0042	-0.0073	-0.0112	0.0001	-0.0001	0.0008	-0.0107	0.0007	0.0558	-0.0115	0.0547	-0.0112	-0.0013	-0.0010	-0.0005	-0.0085
13795	-0.0015	-0.0073	-0.0076	0.0000	0.0003	0.0009	-0.0068	0.0007	0.0597	-0.0077	0.0584	-0.0072	0.0047	-0.0024	-0.0010	-0.0096
14949	0.0133	-0.0076	0.0077	-0.0002	0.0005	0.0008	0.0093	0.0007	0.0009	-0.0013	-0.0012	-0.0007	0.0248	-0.0041	-0.0017	-0.0109
16464	0.0280	-0.0076	0.0226	-0.0001	0.0007	0.0008	0.0246	0.0004	0.0005	-0.0012	-0.0013	-0.0009	0.0402	-0.0040	-0.0019	-0.0114
17904	0.0359	-0.0068	0.0319	0.0003	0.0012	0.0011	0.0349	0.0003	0.0008	-0.0018	-0.0022	-0.0012	0.0525	-0.0044	-0.0024	-0.0117
19285	0.0379	-0.0065	0.0343	0.0005	0.0013	0.0012	0.0377	0.0002	0.0008	-0.0021	-0.0025	-0.0015	0.0562	-0.0048	-0.0027	-0.0119
20322	0.0458	-0.0058	0.0441	0.0006	0.0015	0.0014	0.0482	0.0002	0.0011	-0.0025	-0.0031	-0.0018	0.0688	-0.0058	-0.0032	-0.0128
21196	0.0541	-0.0059	0.0532	0.0007	0.0016	0.0014	0.0578	0.0003	0.0012	-0.0027	-0.0035	-0.0019	0.0788	-0.0057	-0.0030	-0.0127
22841	0.0644	-0.0060	0.0639	0.0007	0.0017	0.0015	0.0687	0.0003	0.0014	-0.0029	-0.0037	-0.0019	0.0908	-0.0060	-0.0032	-0.0133
23854	0.0762	-0.0056	0.0772	0.0007	0.0018	0.0015	0.0822	0.0005	0.0015	-0.0030	-0.0040	-0.0020	0.1053	-0.0068	-0.0037	-0.0137
25020	0.0782	-0.0051	0.0802	0.0007	0.0019	0.0015	0.0857	0.0006	0.0018	-0.0033	-0.0043	-0.0020	0.1106	-0.0078	-0.0043	-0.0142
25787	0.0852	-0.0047	0.0885	0.0008	0.0020	0.0017	0.0944	0.0007	0.0019	-0.0036	-0.0046	-0.0021	0.1195	-0.0084	-0.0048	-0.0143
27282	0.0894	-0.0045	0.0926	0.0007	0.0021	0.0017	0.0987	0.0008	0.0023	-0.0037	-0.0048	-0.0023	0.1253	-0.0087	-0.0050	-0.0143
28386	0.0923	-0.0043	0.0950	0.0007	0.0018	0.0016	0.1004	0.0008	0.0023	-0.0033	-0.0042	-0.0021	0.1295	-0.0095	-0.0055	-0.0149
29550	0.0930	-0.0040	0.0960	0.0007	0.0019	0.0016	0.1015	0.0009	0.0024	-0.0035	-0.0044	-0.0022	0.1319	-0.0101	-0.0060	-0.0153
31105	0.0984	-0.0039	0.1027	0.0007	0.0023	0.0019	0.1094	0.0010	0.0028	-0.0042	-0.0052	-0.0026	0.1426	-0.0114	-0.0068	-0.0167
31877	0.1035	-0.0042	0.1079	0.0007	0.0024	0.0019	0.1148	0.0011	0.0030	-0.0043	-0.0054	-0.0026	0.1501	-0.0121	-0.0072	-0.0176
39877	0.1103	-0.0051	0.1133	0.0008	0.0030	0.0023	0.1222	0.0011	0.0035	-0.0057	-0.0070	-0.0034	0.1644	-0.0146	-0.0085	-0.0211
47077	0.1125	-0.0050	0.1147	0.0012	0.0038	0.0028	0.1257	0.0011	0.0036	-0.0065	-0.0084	-0.0039	0.1668	-0.0145	-0.0086	-0.0208

Table 15: Hunter River South Arm Long Section Profile Impacts (Water Level)

Distance Upstream from Ocean (m)	25%ile Flow Conditions		50%ile Flow Conditions				75%ile Flow Conditions						90%ile Flow Conditions			
	Scenario 11	Scenario 16	Scenario 1	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 2	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 13	Scenario 12	Scenario 14	Scenario 15
	mAHD	Δm	mAHD	Δm	Δm	Δm	mAHD	Δm	Δm	Δm	Δm	Δm	mAHD	Δm	Δm	Δm
0	-0.0600	-0.0058	-0.0658	0.0000	0.0000	0.0000	-0.0657	-0.0001	0.0000	-0.0001	-0.0001	-0.0001	-0.0598	-0.0002	-0.0002	-0.0058
1032	-0.0631	-0.0059	-0.0690	-0.0003	-0.0002	0.0001	-0.0688	-0.0002	0.0001	0.0000	-0.0001	-0.0004	-0.0613	-0.0003	-0.0001	-0.0070
1946	-0.0548	-0.0058	-0.0602	-0.0005	-0.0002	-0.0001	-0.0601	-0.0002	0.0002	-0.0002	-0.0002	-0.0005	-0.0508	-0.0010	-0.0007	-0.0083
2667	-0.0542	-0.0061	-0.0601	-0.0005	-0.0002	0.0001	-0.0602	-0.0002	0.0000	0.0004	0.0001	-0.0004	-0.0505	-0.0011	-0.0006	-0.0081
3538	-0.0512	-0.0057	-0.0568	-0.0004	0.0000	0.0003	-0.0562	-0.0003	0.0000	0.0000	-0.0004	-0.0007	-0.0476	-0.0010	-0.0006	-0.0079
4382	-0.0478	-0.0060	-0.0543	-0.0006	-0.0003	0.0001	-0.0544	-0.0003	-0.0004	0.0005	0.0002	-0.0006	-0.0466	-0.0003	-0.0004	-0.0075
5320	-0.0461	-0.0065	-0.0529	-0.0005	-0.0003	0.0002	-0.0529	-0.0004	-0.0006	0.0005	0.0003	-0.0006	-0.0448	-0.0006	-0.0007	-0.0083
6163	-0.0461	-0.0066	-0.0531	-0.0006	-0.0003	0.0002	-0.0531	-0.0005	-0.0006	0.0004	0.0002	-0.0006	-0.0450	-0.0004	-0.0006	-0.0083
7295	-0.0474	-0.0060	-0.0537	-0.0004	-0.0002	0.0000	-0.0534	-0.0007	-0.0007	0.0002	0.0000	-0.0008	-0.0447	-0.0006	-0.0007	-0.0084
8278	-0.0486	-0.0053	-0.0548	0.0000	0.0002	0.0006	-0.0538	-0.0009	-0.0005	0.0000	-0.0004	-0.0011	-0.0436	-0.0010	-0.0009	-0.0091
9202	-0.0419	-0.0051	-0.0478	0.0003	0.0004	0.0007	-0.0465	-0.0008	-0.0003	-0.0004	-0.0007	-0.0010	-0.0356	-0.0016	-0.0010	-0.0096
10127	-0.0454	-0.0054	-0.0513	0.0005	0.0006	0.0007	-0.0500	-0.0007	-0.0002	-0.0005	-0.0008	-0.0007	-0.0387	-0.0018	-0.0008	-0.0100
11044	-0.0290	-0.0056	-0.0339	0.0004	0.0008	0.0004	-0.0326	-0.0001	0.0004	-0.0008	-0.0010	-0.0005	-0.0206	-0.0024	-0.0013	-0.0091
11882	-0.0135	-0.0062	-0.0179	0.0004	0.0008	0.0003	-0.0163	0.0003	0.0007	-0.0011	-0.0015	-0.0005	-0.0021	-0.0032	-0.0020	-0.0098
12671	-0.0090	-0.0065	-0.0134	0.0005	0.0009	0.0003	-0.0117	0.0003	0.0008	-0.0012	-0.0016	-0.0005	0.0036	-0.0034	-0.0022	-0.0106
13409	-0.0034	-0.0072	-0.0082	0.0005	0.0009	0.0004	-0.0062	0.0004	0.0009	-0.0013	-0.0018	-0.0007	0.0101	-0.0036	-0.0023	-0.0112
14263	0.0044	-0.0081	-0.0009	0.0004	0.0009	0.0005	0.0012	0.0003	0.0009	-0.0014	-0.0020	-0.0008	0.0186	-0.0040	-0.0026	-0.0120
15182	0.0331	-0.0080	0.0282	0.0005	0.0011	0.0009	0.0309	0.0003	0.0008	-0.0018	-0.0025	-0.0012	0.0500	-0.0048	-0.0028	-0.0134
16251	0.0366	-0.0066	0.0329	0.0006	0.0011	0.0011	0.0358	0.0003	0.0010	-0.0019	-0.0022	-0.0013	0.0542	-0.0048	-0.0027	-0.0125
17182	0.0379	-0.0064	0.0344	0.0005	0.0012	0.0012	0.0377	0.0002	0.0008	-0.0021	-0.0025	-0.0015	0.0562	-0.0048	-0.0027	-0.0119
18561	0.0514	-0.0059	0.0501	0.0007	0.0016	0.0014	0.0545	0.0002	0.0011	-0.0027	-0.0034	-0.0019	0.0752	-0.0056	-0.0030	-0.0127
19601	0.0564	-0.0060	0.0554	0.0007	0.0016	0.0014	0.0600	0.0003	0.0012	-0.0027	-0.0035	-0.0019	0.0810	-0.0058	-0.0032	-0.0130
20771	0.0639	-0.0060	0.0633	0.0007	0.0017	0.0014	0.0680	0.0003	0.0013	-0.0028	-0.0037	-0.0019	0.0898	-0.0059	-0.0031	-0.0132
21796	0.0733	-0.0056	0.0742	0.0007	0.0018	0.0015	0.0794	0.0005	0.0016	-0.0031	-0.0040	-0.0020	0.1028	-0.0070	-0.0038	-0.0138
22944	0.0794	-0.0050	0.0815	0.0007	0.0019	0.0015	0.0871	0.0006	0.0018	-0.0034	-0.0044	-0.0021	0.1123	-0.0080	-0.0044	-0.0143
23881	0.0872	-0.0047	0.0904	0.0008	0.0021	0.0017	0.0966	0.0007	0.0019	-0.0037	-0.0048	-0.0022	0.1217	-0.0083	-0.0048	-0.0143
25157	0.0910	-0.0044	0.0942	0.0007	0.0020	0.0017	0.1002	0.0009	0.0025	-0.0038	-0.0048	-0.0023	0.1294	-0.0092	-0.0053	-0.0148
26603	0.0916	-0.0042	0.0943	0.0007	0.0018	0.0016	0.0996	0.0008	0.0023	-0.0033	-0.0042	-0.0021	0.1293	-0.0097	-0.0057	-0.0151
27954	0.0968	-0.0040	0.1004	0.0007	0.0021	0.0018	0.1066	0.0010	0.0026	-0.0039	-0.0049	-0.0024	0.1383	-0.0106	-0.0063	-0.0159
29419	0.1031	-0.0041	0.1078	0.0007	0.0025	0.0020	0.1149	0.0011	0.0030	-0.0044	-0.0055	-0.0026	0.1497	-0.0120	-0.0072	-0.0175
35821	0.1078	-0.0052	0.1111	0.0007	0.0029	0.0022	0.1196	0.0011	0.0033	-0.0054	-0.0066	-0.0032	0.1610	-0.0144	-0.0084	-0.0209
44821	0.1125	-0.0050	0.1147	0.0012	0.0038	0.0028	0.1257	0.0011	0.0036	-0.0066	-0.0084	-0.0039	0.1669	-0.0145	-0.0086	-0.0208

The results of the SLR scenarios (Figure 28) show much greater differences in water level near the study area as a consequence of an increase in the mean ocean tide level. The water level profiles below correspond to a mean tide with range of 1.4 metres that has been adjusted in accordance with projected increases of 0.18 m (Scenario 17), 0.55 m (Scenario 18) and 0.91 m (Scenario 19).

These results although not directly comparable to the other sixteen model scenarios demonstrate the impact that SLR could potentially be much greater than any change to flow conditions as a consequence of dam construction and / or upgrade to Seaham Weir. The Ramsar site as previously mentioned is influenced by tides on a daily basis given its proximity to the ocean. As such the sensitivity scenarios undertaken using ELCOM show that parts of the study area (situated between 10 km and 20 km from the ocean) would be significantly inundated during high tide and its influence would extend some 25 km to 30 km upstream.

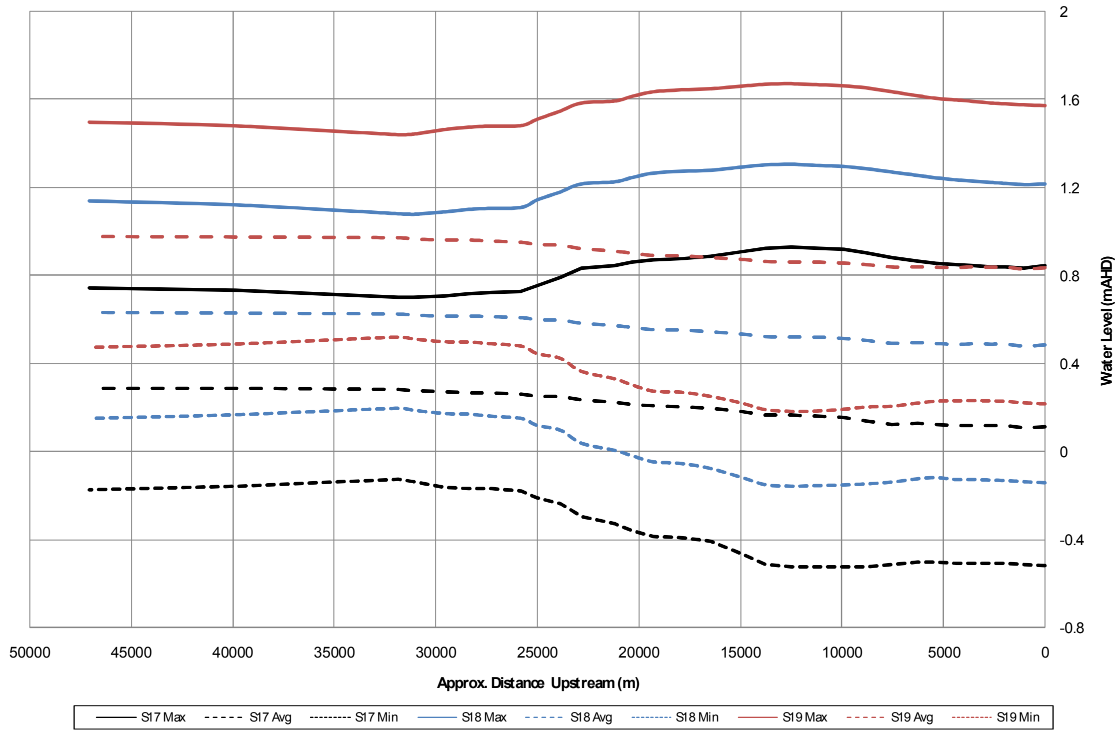


Figure 28: Hunter River North Arm water level profile (SLR conditions).

4.2.6 Salinity

The average salinity concentration (obtained from output at hourly intervals) simulated along the North Arm and South Arm of the Hunter River over the last tidal cycle is shown in Table 16 and Table 17 respectively. Columns shaded grey correspond to the base case scenario for each of the percentile flow categories assessed with relative differences (unshaded) shown for each of the proposed condition scenarios.

The results show relatively minor differences (typically less than 0.5 ppt) in salinity as a result of changes in flow at Seaham Weir along the South Arm and North Arm of the Hunter River. The greatest difference in salinity are estimated under 90%ile flow conditions at Seaham Weir coupled with median flow conditions in the Hunter River and Paterson River. Differences in the average salinity concentration are greatest (approximately 3 ppt) near the upstream extents of the Ramsar site (approximately 20 km upstream of the ocean boundary). In the vicinity of the study area between Hexham and Newcastle Harbour the difference in salinity is typically less than 0.5 ppt under 25%ile flow conditions, 1 ppt under 50%ile flow conditions, 2 ppt under 75%ile flow conditions and 3 ppt under 90%ile flow conditions. Figure 29 below shows the salinity profiles along the Hunter River North Arm under 50%ile flow conditions.

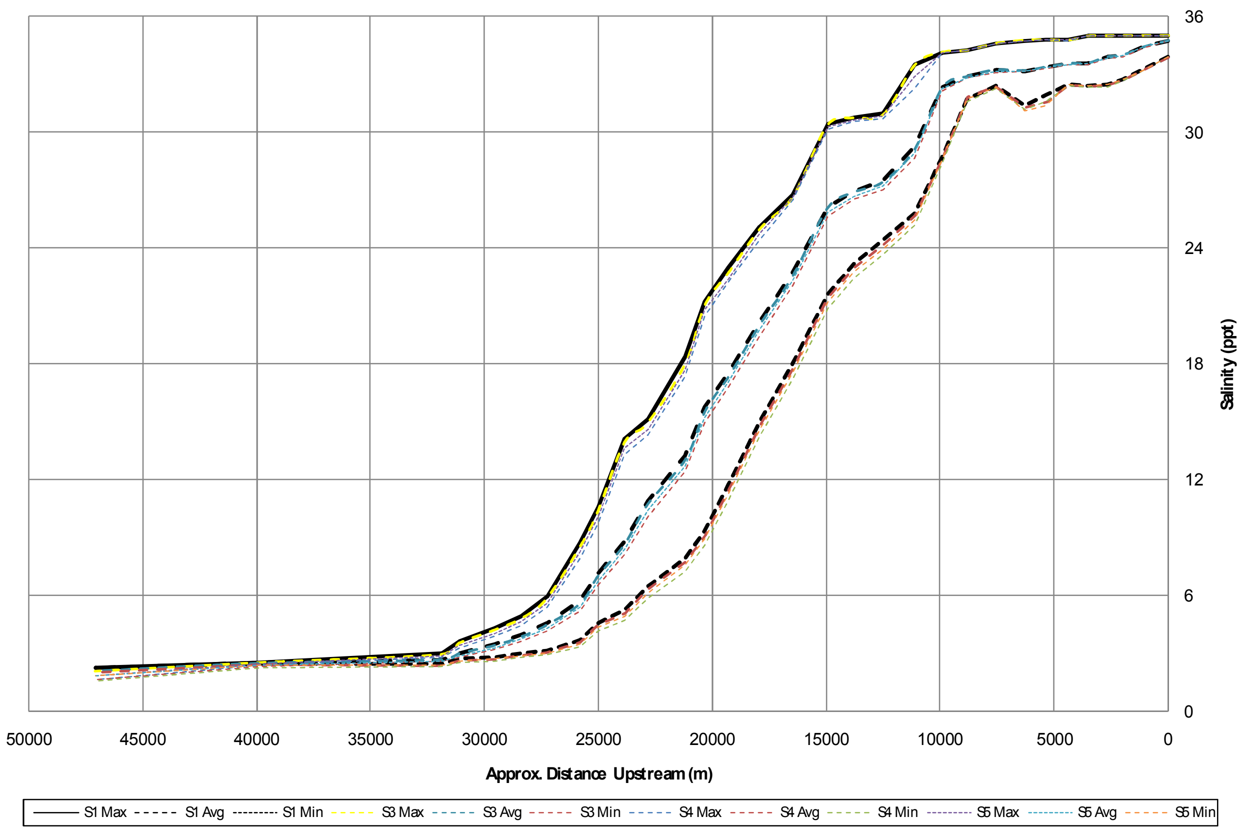


Figure 29: Hunter River North Arm salinity profile (50 percentile flow conditions).

Additional flow condition profiles can be found in Appendix E.

The salinity profiles below (Figure 30) correspond to a mean tide with range of 1.4 metres that has been adjusted in accordance with projected increases of 0.18 m (Scenario 17), 0.55 m (Scenario 18) and 0.91 m (Scenario 19). The results of the SLR scenarios (refer Figure 28) show that the concentration of salinity in the vicinity of the study area (situated between 10 km and 20 km from the ocean boundary) could increase by around 3 ppt or 4 ppt as a consequence of greater tidal inundation within the lower estuary caused by an increase of 0.73 metres (i.e. difference between Scenario 19 and Scenario 17).

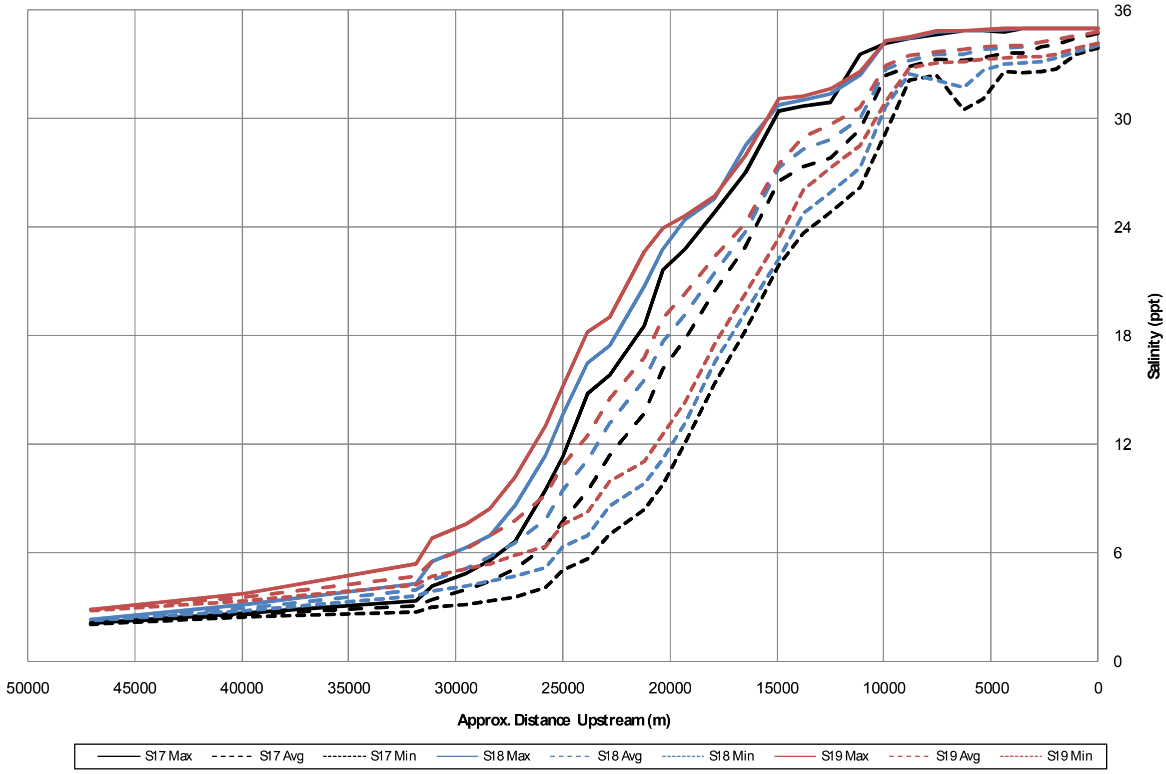


Figure 30: Hunter River North Arm salinity profile (SLR conditions).

Table 16: Hunter River North Arm long section profile (Salinity).

Distance Upstream from Ocean (m)	25%ile Flow Conditions		50%ile Flow Conditions				75%ile Flow Conditions						90%ile Flow Conditions			
	Scenario 11	Scenario 16	Scenario 1	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 2	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 13	Scenario 12	Scenario 14	Scenario 15
	ppt	Δ ppt	ppt	Δ ppt	Δ ppt	Δ ppt	ppt	Δ ppt	Δ ppt	Δ ppt	Δ ppt	Δ ppt	ppt	Δ ppt	Δ ppt	Δ ppt
0	34.803	-0.005	34.739	-0.002	-0.005	-0.004	34.693	0.000	-0.020	0.043	0.040	0.020	34.139	0.319	0.198	0.341
1032	34.587	0.002	34.436	-0.012	-0.015	-0.004	34.285	-0.027	-0.064	0.118	0.136	0.073	33.381	0.467	0.261	0.458
1946	34.306	-0.023	33.981	0.023	-0.092	-0.014	33.739	-0.046	-0.097	0.202	0.244	0.104	32.425	0.656	0.327	0.613
2667	34.154	-0.013	33.913	-0.018	-0.059	-0.035	33.703	-0.021	-0.106	0.146	0.177	0.063	32.383	0.727	0.483	0.554
3538	33.955	-0.018	33.596	-0.030	-0.076	-0.034	33.354	-0.028	-0.120	0.162	0.212	0.088	32.016	0.644	0.332	0.610
4354	33.870	-0.028	33.553	-0.007	-0.079	-0.023	33.320	-0.023	-0.114	0.158	0.187	0.082	32.123	0.579	0.321	0.524
5366	33.699	0.005	33.381	-0.014	-0.077	-0.042	33.112	-0.045	-0.124	0.188	0.195	0.089	31.726	0.656	0.320	0.612
6288	33.553	0.074	33.185	-0.006	-0.051	-0.004	32.933	-0.030	-0.123	0.210	0.211	0.108	31.499	0.690	0.328	0.623
7571	33.611	0.010	33.218	-0.008	-0.127	-0.037	32.873	-0.035	-0.167	0.233	0.266	0.117	30.999	0.933	0.488	0.846
8824	33.406	-0.026	32.880	0.001	-0.068	-0.029	32.526	-0.048	-0.228	0.223	0.253	0.118	30.089	1.020	0.546	1.115
9922	32.964	0.000	32.342	-0.052	-0.203	-0.089	31.792	-0.041	-0.291	0.326	0.454	0.166	28.013	1.878	0.994	1.812
11104	31.377	-0.140	29.283	-0.134	-0.649	-0.316	27.007	-0.113	-0.770	1.446	1.944	0.626	20.846	2.540	1.369	2.410
12504	29.632	-0.132	27.526	-0.110	-0.485	-0.277	26.022	-0.093	-0.530	0.950	1.178	0.512	20.847	2.212	1.129	2.022
13795	29.167	-0.105	26.970	-0.098	-0.455	-0.253	25.536	-0.103	-0.523	0.901	1.140	0.484	20.204	2.277	1.195	2.127
14949	28.541	-0.123	26.150	-0.099	-0.493	-0.273	24.502	-0.145	-0.671	1.058	1.327	0.570	17.943	2.813	1.523	2.550
16464	26.071	-0.209	22.724	-0.156	-0.693	-0.400	20.548	-0.180	-0.884	1.359	1.743	0.722	12.555	3.141	1.663	3.085
17904	23.978	-0.254	20.218	-0.178	-0.773	-0.458	17.724	-0.188	-0.886	1.561	2.003	0.827	9.731	3.125	1.638	3.001
19285	21.599	-0.321	17.573	-0.240	-0.806	-0.508	14.972	-0.152	-0.852	1.615	2.095	0.899	7.109	3.051	1.539	2.791
20322	19.766	-0.288	15.736	-0.207	-0.815	-0.487	13.227	-0.194	-0.873	1.557	1.982	0.819	5.879	2.782	1.434	2.593
21196	17.157	-0.167	13.220	-0.207	-0.816	-0.491	10.714	-0.183	-0.834	1.560	1.979	0.818	3.870	2.444	1.238	2.349
22841	14.756	-0.217	10.893	-0.194	-0.773	-0.464	8.542	-0.164	-0.770	1.456	1.849	0.766	2.533	2.079	1.045	1.973
23854	12.549	-0.239	8.810	-0.177	-0.705	-0.424	6.674	-0.147	-0.688	1.324	1.676	0.694	1.659	1.634	0.815	1.561
25020	10.669	-0.211	7.143	-0.163	-0.635	-0.382	5.225	-0.131	-0.595	1.186	1.498	0.622	1.236	1.216	0.600	1.168
25787	8.964	-0.262	5.719	-0.141	-0.551	-0.332	4.133	-0.102	-0.465	0.953	1.219	0.493	1.056	0.962	0.483	0.919
27282	7.299	-0.174	4.555	-0.114	-0.435	-0.261	3.319	-0.080	-0.349	0.738	0.947	0.380	0.929	0.796	0.407	0.758
28386	6.329	-0.146	3.933	-0.090	-0.348	-0.205	2.926	-0.065	-0.275	0.602	0.778	0.323	0.866	0.760	0.389	0.726
29550	5.630	-0.150	3.473	-0.080	-0.309	-0.185	2.602	-0.049	-0.214	0.511	0.665	0.260	0.788	0.717	0.360	0.685
31105	4.740	-0.092	3.032	-0.055	-0.220	-0.132	2.411	-0.037	-0.164	0.365	0.472	0.187	0.751	0.690	0.341	0.658
31877	4.025	-0.087	2.690	-0.038	-0.144	-0.085	2.254	-0.033	-0.155	0.267	0.339	0.145	0.498	0.656	0.286	0.618
39877	2.644	-0.056	2.507	-0.039	-0.173	-0.094	1.783	-0.066	-0.305	0.518	0.619	0.301	0.004	0.245	0.036	0.217
47077	2.251	-0.192	2.252	-0.193	-0.632	-0.405	0.787	-0.067	-0.292	0.755	1.021	0.375	0.000	0.001	0.000	0.000

Table 17: Hunter River South Arm long section profile (Salinity)

Distance Upstream from Ocean (m)	25%ile Flow Conditions		50%ile Flow Conditions				75%ile Flow Conditions						90%ile Flow Conditions			
	Scenario 11	Scenario 16	Scenario 1	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 2	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 13	Scenario 12	Scenario 14	Scenario 15
	ppt	Δ ppt	ppt	Δ ppt	Δ ppt	Δ ppt	ppt	Δ ppt	Δ ppt	Δ ppt	Δ ppt	Δ ppt	ppt	Δ ppt	Δ ppt	Δ ppt
0	34.803	-0.005	34.739	-0.002	-0.005	-0.004	34.693	0.000	-0.020	0.043	0.040	0.020	34.139	0.319	0.198	0.341
1032	34.587	0.002	34.436	-0.012	-0.015	-0.004	34.285	-0.027	-0.064	0.118	0.136	0.073	33.381	0.467	0.261	0.458
1946	34.306	-0.023	33.981	0.023	-0.092	-0.014	33.739	-0.046	-0.097	0.202	0.244	0.104	32.425	0.656	0.327	0.613
2667	34.154	-0.013	33.913	-0.018	-0.059	-0.035	33.703	-0.021	-0.106	0.146	0.177	0.063	32.383	0.727	0.483	0.554
3538	33.955	-0.018	33.596	-0.030	-0.076	-0.034	33.354	-0.028	-0.120	0.162	0.212	0.088	32.016	0.644	0.332	0.610
4382	33.738	0.005	33.437	-0.010	-0.060	-0.020	33.217	-0.022	-0.090	0.163	0.195	0.090	31.762	0.812	0.514	0.691
5320	33.786	0.022	33.530	-0.046	-0.115	-0.073	33.260	-0.019	-0.087	0.177	0.196	0.093	31.913	0.707	0.416	0.666
6163	33.843	0.009	33.559	-0.017	-0.070	-0.029	33.300	-0.008	-0.084	0.210	0.221	0.096	31.671	0.921	0.512	0.866
7295	33.876	-0.039	33.480	-0.022	-0.098	-0.043	33.150	-0.043	-0.142	0.260	0.287	0.135	30.888	1.213	0.711	1.221
8278	33.735	-0.014	33.204	-0.046	-0.161	-0.091	32.715	-0.060	-0.204	0.331	0.401	0.183	29.823	1.481	0.854	1.418
9202	33.430	-0.058	32.670	-0.061	-0.214	-0.126	32.021	-0.081	-0.274	0.426	0.526	0.240	28.444	1.747	0.993	1.671
10127	33.158	-0.074	32.237	-0.076	-0.251	-0.153	31.491	-0.090	-0.307	0.479	0.604	0.271	27.606	1.900	1.069	1.763
11044	32.832	-0.089	31.754	-0.085	-0.287	-0.177	30.895	-0.102	-0.346	0.546	0.694	0.311	26.615	2.055	1.149	1.922
11882	32.327	-0.123	30.971	-0.102	-0.358	-0.224	29.890	-0.122	-0.428	0.685	0.867	0.389	24.805	2.416	1.337	2.232
12671	31.614	-0.183	29.920	-0.127	-0.424	-0.267	28.661	-0.141	-0.493	0.783	1.006	0.447	22.489	2.947	1.641	2.788
13409	30.648	-0.207	28.536	-0.152	-0.522	-0.331	26.996	-0.170	-0.590	0.950	1.219	0.528	20.463	3.031	1.678	2.771
14263	29.767	-0.244	27.274	-0.165	-0.614	-0.372	25.441	-0.186	-0.716	1.142	1.467	0.614	18.162	3.258	1.769	2.985
15182	27.308	-0.202	24.156	-0.211	-0.777	-0.458	21.854	-0.224	-0.874	1.429	1.811	0.764	13.516	3.459	1.871	3.271
16251	25.531	-0.204	21.917	-0.194	-0.788	-0.460	19.372	-0.222	-0.936	1.633	2.032	0.836	11.012	3.346	1.761	3.248
17182	21.757	-0.390	17.489	-0.211	-0.768	-0.461	14.870	-0.138	-0.836	1.656	2.094	0.876	7.092	2.868	1.519	2.681
18561	19.252	-0.326	15.130	-0.209	-0.831	-0.494	12.531	-0.184	-0.860	1.623	2.057	0.857	5.415	2.618	1.317	2.464
19601	16.100	-0.227	12.147	-0.199	-0.794	-0.475	9.715	-0.177	-0.804	1.514	1.919	0.789	3.335	2.325	1.181	2.165
20771	14.794	-0.221	10.930	-0.195	-0.775	-0.463	8.584	-0.165	-0.766	1.451	1.844	0.763	2.563	2.105	1.061	1.994
21796	12.464	-0.248	8.727	-0.178	-0.706	-0.423	6.596	-0.147	-0.686	1.321	1.673	0.694	1.634	1.602	0.799	1.527
22944	10.540	-0.236	7.017	-0.161	-0.632	-0.378	5.109	-0.131	-0.591	1.182	1.492	0.615	1.206	1.187	0.584	1.125
23881	8.473	-0.246	5.379	-0.132	-0.518	-0.310	3.867	-0.095	-0.431	0.913	1.167	0.467	1.018	0.902	0.462	0.864
25157	7.065	-0.175	4.411	-0.107	-0.416	-0.248	3.206	-0.077	-0.331	0.726	0.929	0.372	0.925	0.794	0.408	0.757
26603	6.010	-0.152	3.730	-0.088	-0.338	-0.202	2.768	-0.057	-0.247	0.569	0.738	0.293	0.828	0.739	0.375	0.705
27954	5.307	-0.136	3.314	-0.073	-0.278	-0.166	2.533	-0.044	-0.194	0.457	0.596	0.233	0.774	0.708	0.353	0.674
29419	4.099	-0.083	2.717	-0.038	-0.148	-0.088	2.271	-0.033	-0.155	0.273	0.347	0.145	0.525	0.670	0.296	0.633
35821	2.982	-0.070	2.592	-0.036	-0.151	-0.085	1.992	-0.057	-0.274	0.421	0.505	0.249	0.019	0.389	0.085	0.354
44821	2.261	-0.194	2.262	-0.195	-0.644	-0.415	0.779	-0.068	-0.289	0.761	1.029	0.376	0.000	0.001	0.000	0.001

4.3 Complementary Data Analysis

4.3.1 LiDAR Data Analysis

Overview

An analysis of LiDAR (Light Detection and Ranging, i.e. Remote Sensed Ground Survey) data provided by HWC was undertaken to gain a greater understanding of the sensitivity of wetland areas to possible changes in river water level. Using LiDAR data available for the study area, a ground level frequency distribution was prepared for the Kooragang Nature Reserve, which incorporates Kooragang Island, the Hunter River North Arm and Fullerton Cove. A separate analysis was undertaken to assess the Shortland Wetlands given that these wetland areas are not directly connected to the Hunter River Estuary.

In addition to the analysis of LiDAR data available for the wider study area, separate assessments were also undertaken to assess the frequency of ground levels within broad vegetation types categorised as being areas of mangrove, saltmarsh or other terrestrial vegetation.

The LiDAR data analysis provides a frequency histogram of ground levels highlighting the extents that may be considered susceptible to inundation from changes to river water levels in the Lower Hunter River Estuary. The analysis also includes cumulative percentage inundation curves to demonstrate the proportion of the study area(s) likely to be inundated for various water surface elevations.

LiDAR data

The Light Detection and Ranging (LiDAR) data provided by HWC was collected by Fugro Spatial Solutions Pty. Ltd. in January 2007. The resolution of the raw data is approximately one elevation point per square metre. The raw elevation data provided was processed to filter (i.e. remove) any non-ground data points and verified using ground-surveyed GPS control points. The verification found that 67% of the data was within +/- 0.01m and 95% within +/- 0.20m elevation. The product of the post-processing undertaken by Fugro was a ground digital elevation model (DEM), supplied in a 2m resolution ASCII grid format. The accuracy of this data is specified as being +/-150 mm Root Mean Square Error (RMSE) in the vertical plane and +/-600 mm RMSE in the horizontal plane.

In addition to the HWC LiDAR data source, hydrosurvey data was used to define elevations of the Hunter River channels and Fullerton Cove situated within the Ramsar Site boundary. These data were provided by Newcastle Ports Corporation (NPC) to Newcastle City Council (NCC) for the Hunter Estuary Processes Study (MHL, 2003) and have been used for a variety of studies in the lower Hunter.

These two elevation data sources were combined to produce a composite DEM of the study region. Small gaps that remained in the DEM were filled using a gap-filling algorithm, before being filtered using a multi-direction Lee filter, to remove any localised noise typically found in remote-sensed data sources. Despite the application of vegetation removing algorithms by Fugro in the production of the ground only DEM, some evidence of remnant vegetation is present within the LiDAR DEM data, which is small, localised and overcome to some extent by the utilisation of the Lee filter. However, dense areas of phragmities (or common reed) are not removed by the Fugro filtering algorithms. The lack of true ground elevation returns and low vegetation height make effective filtering of these areas extremely difficult. A few such areas exist within the study area such as within the northern portion of the Shortland Wetlands. The elevations in these areas were mostly interpolated from the surrounding ground elevations where possible. As such, the resulting accuracy of the ground surface DEM in these areas is considered to be less than that in the remaining areas covered by the DEM.

Individual DEMs covering the Kooragang and Shortland Wetland Ramsar sites were clipped from the composite DEM using the Ramsar site boundary polygons provided by Eco Logical Australia. A frequency analysis of ground elevations at 0.1 metre intervals was performed for each DEM. For the Shortland wetlands DEM, areas of standing water were digitised from aerial imagery and removed from the DEM analysis to remove any 'artificial' data resulting from the data capture methods. These areas contain a large number of grid cells with similar elevation values and are not representative of the true ground topography (i.e. water surface of ponds have been detected by LiDAR as a flat surface). The DEM for the Kooragang wetlands was resampled to a 10 m resolution to enable a more efficient frequency analysis.

The DEMs used for the frequency analysis are shown in Figure 31 and Figure 32.

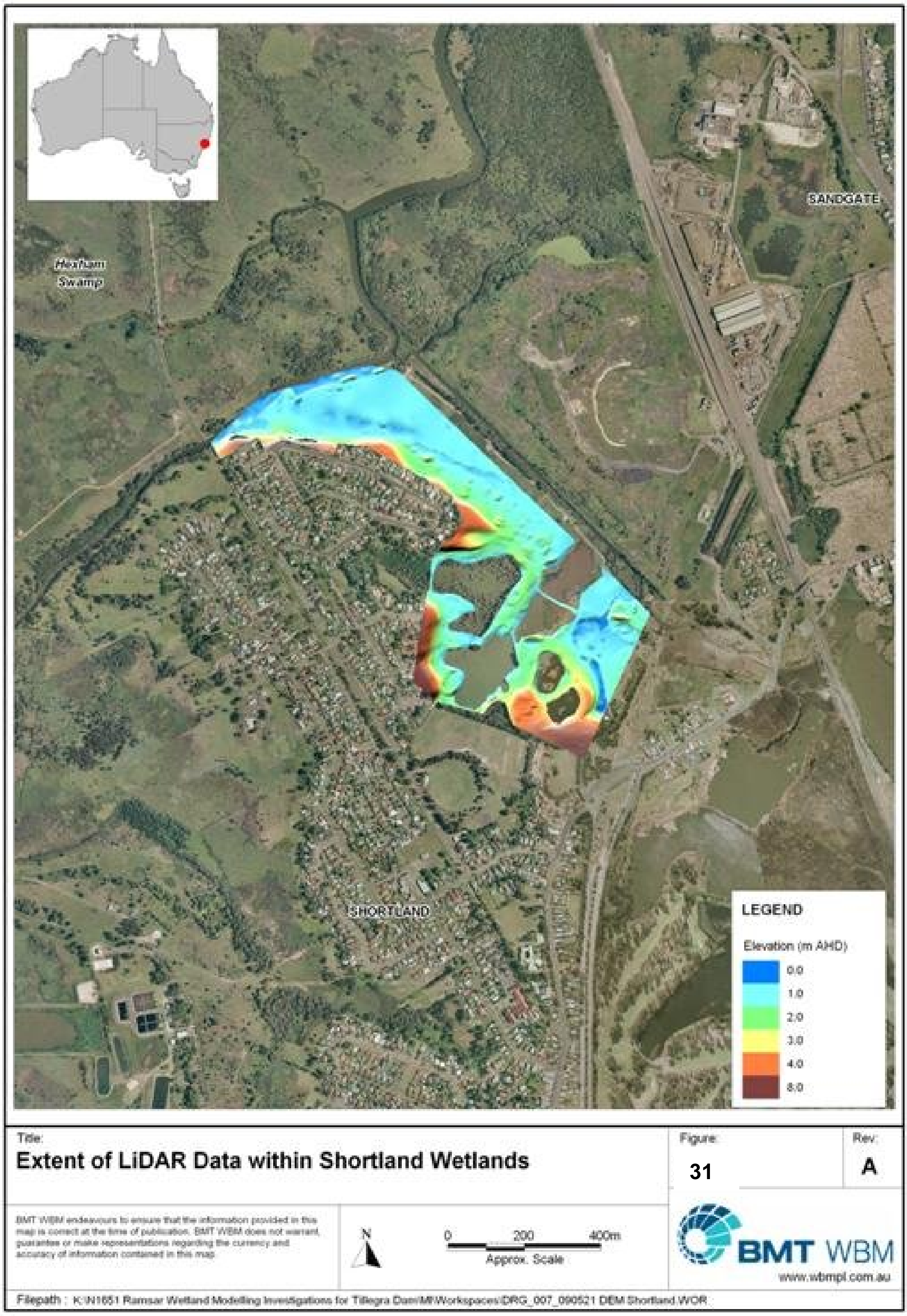


Figure 31: Extent of LiDAR data within the Shortland Wetlands.

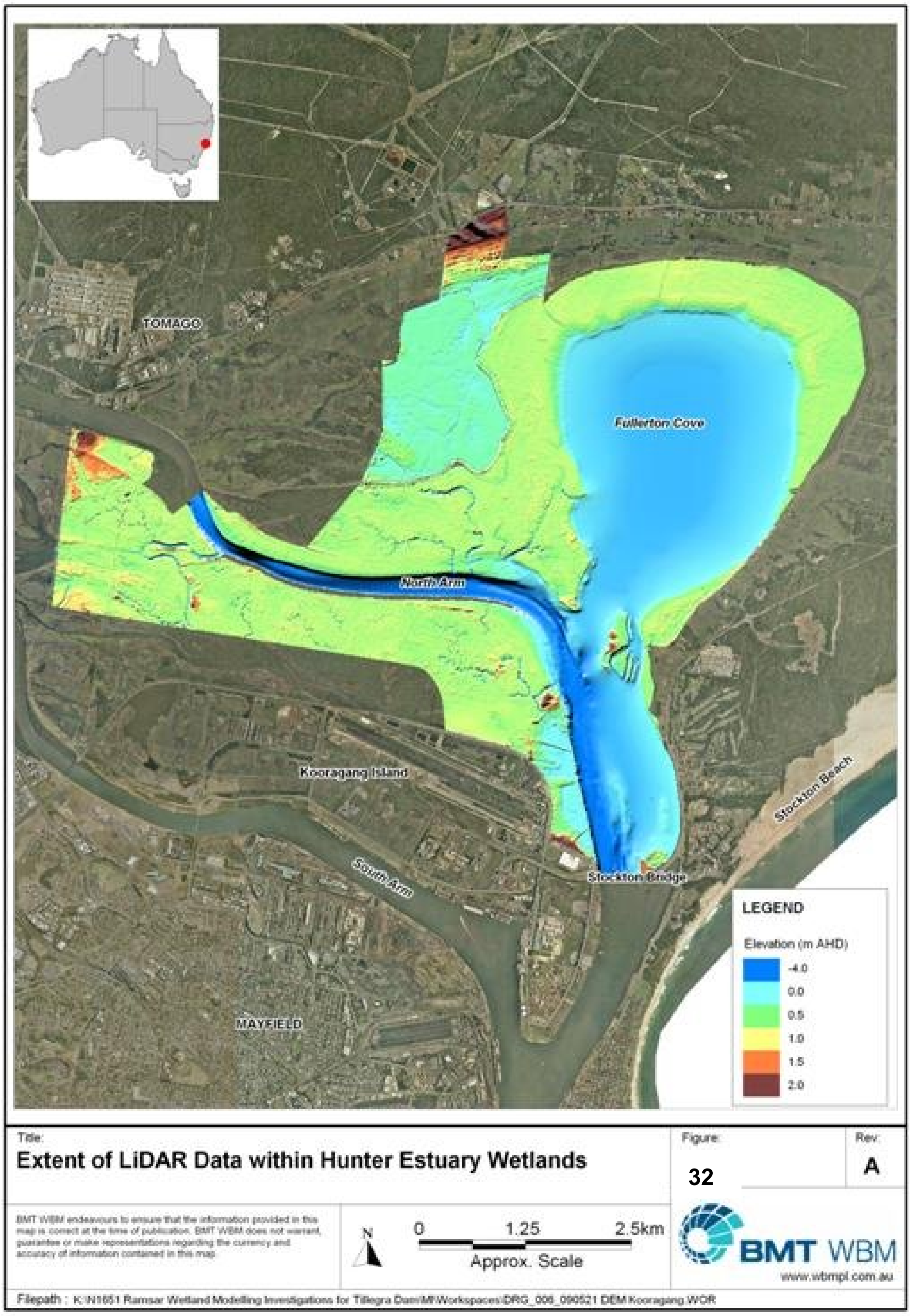


Figure 32: Extent of LiDAR data within the Kooragang Nature Reserve.

Ground level frequency distribution

An analysis of LiDAR data was undertaken for the main Ramsar site which includes Kooragang Island, Hunter River North Arm and Fullerton Cove. A separate analysis was considered necessary for the Shortland Wetlands for the reason that the site is disconnected from the remainder of the Ramsar site both geographically and hydrologically. Ironbark Creek drains along the north-west boundary of the site towards the south arm of the Hunter River near the Pacific Highway (Maitland Road). Floodgates, constructed in the 1970s, (refer Figure 33) are located at the downstream end of Ironbark Creek, a short distance upstream of Maitland Road. The floodgates comprise eight individual gates each 2 metres by 2 metres. The floodgates significantly attenuate tidal flow between the South Arm of the Hunter River and Ironbark Creek at the present time (only one floodgate is open, and even then, by just 30 cm). Opening of the floodgates to restore tidal flows in Ironbark Creek and tidal inundation of Hexham Swamp is the main objective of the Hexham Swamp Rehabilitation Project (HSRP), which is currently being implemented by the Hunter-Central Rivers Catchment Management Authority. Given the small tidal range upstream of the floodgates, there is presently no tidal connection between Ironbark Creek and the waterbodies at Shortland. Indeed, one-way flap-gates have been constructed at the outlets of the wetlands at Shortland to prevent tidal backwater inundation by high tides once the Ironbark Creek floodgates are opened as part of the HSRP. The presence of artificial controls (i.e. Ironbark Creek floodgates), drainage bunds and flap gates downstream of the Shortland Wetlands are considered to be substantial impediments to any changes in water level experienced within the study area and for these reasons it has been assessed separately to the remainder of the Ramsar site.

The results of the LiDAR analyses are shown below in Figure 34 and Figure 35 as frequency distributions for a range of levels with intervals of 0.1 metres. As mentioned previously, the results of the LiDAR analysis for the Hunter Estuary Wetland shown in Figure 34 have been obtained from a composite DEM of LiDAR and hydrosurvey data available within the study area.

Figure 33: Ironbark Creek Floodgates

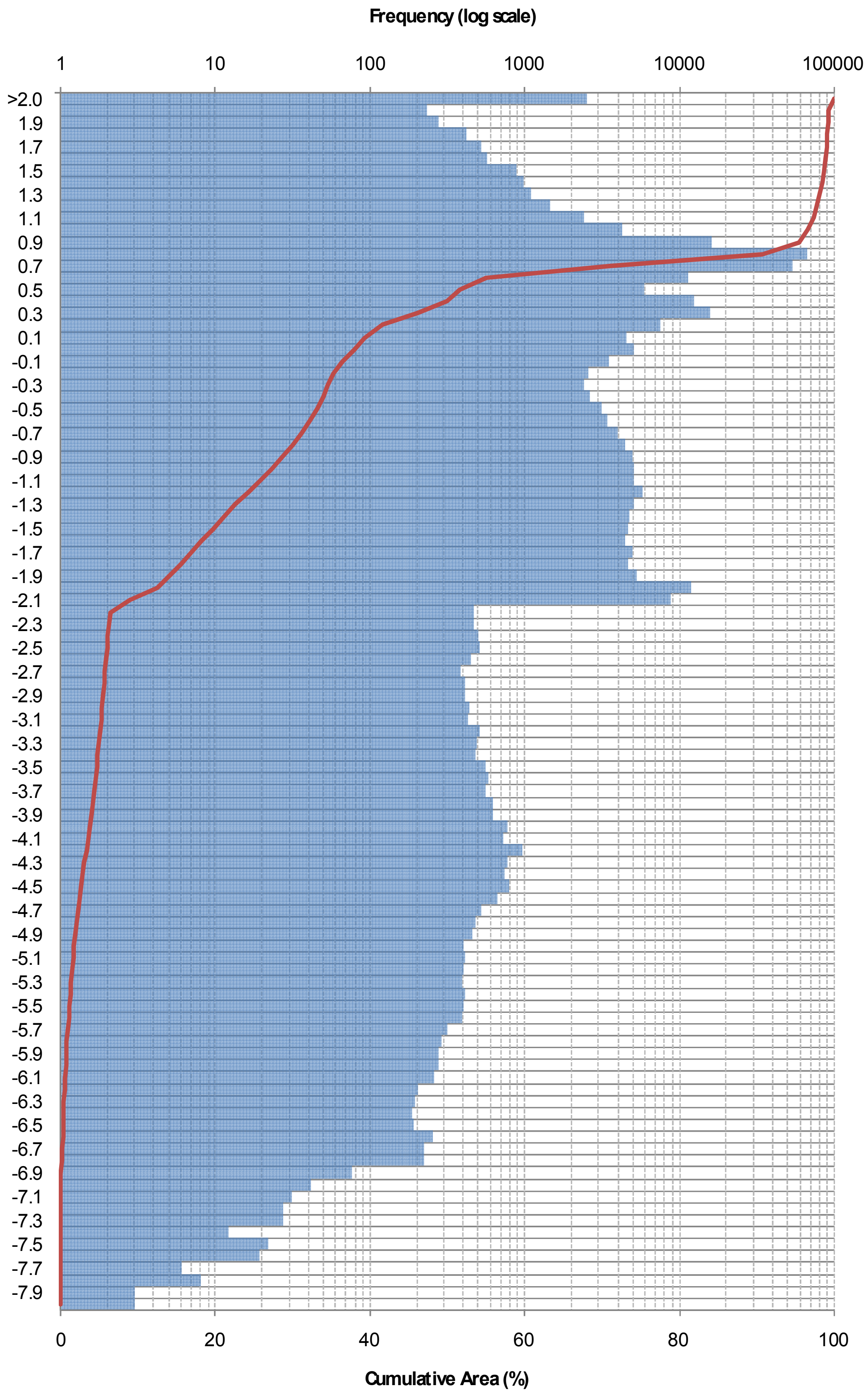


Figure 34: Ground Level Frequency Distribution for Kooragang NR (subject to accuracy of LiDAR data)

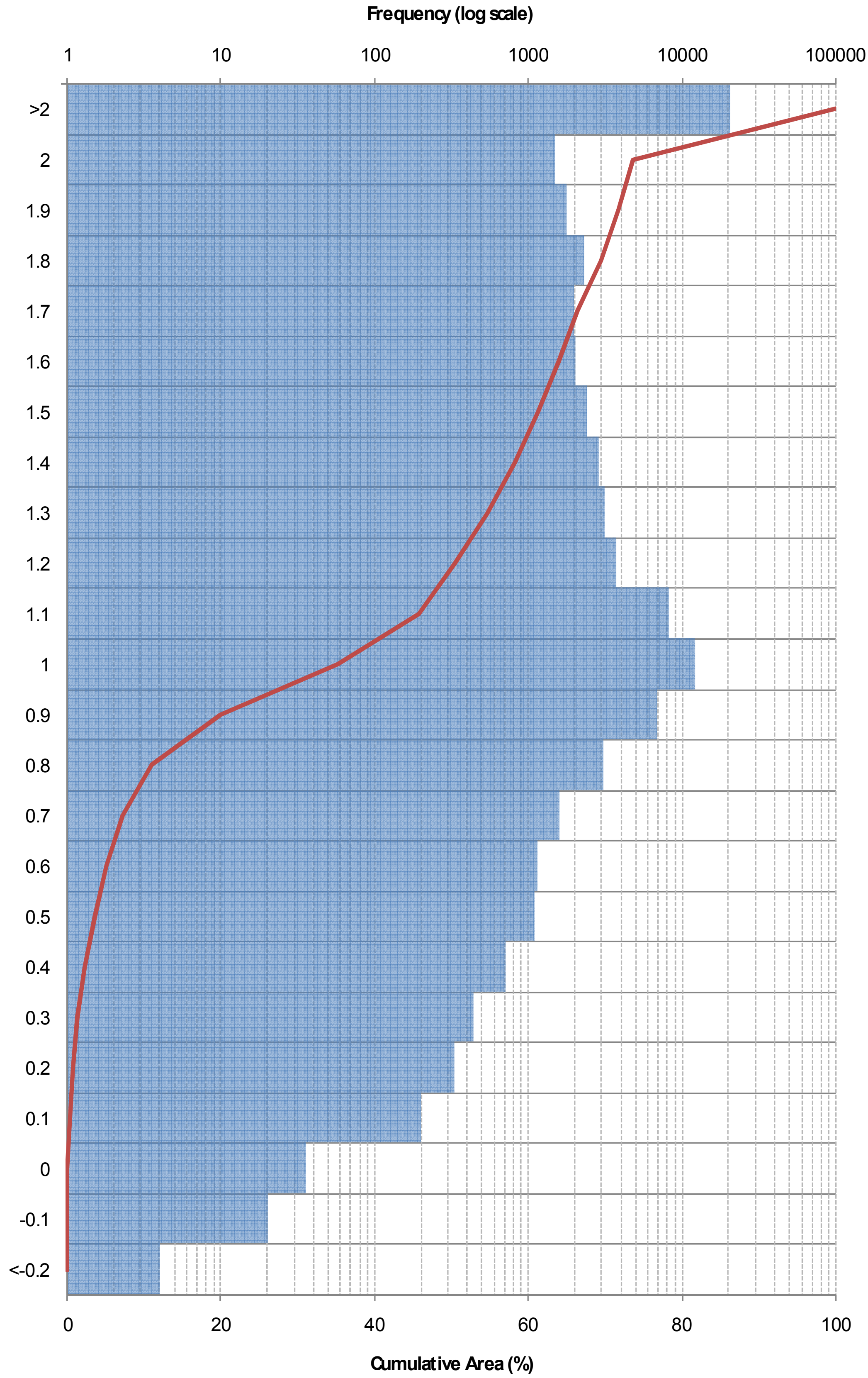


Figure 35: Ground Level Frequency Distribution for Shortland Wetland (subject to accuracy of LiDAR data)

The LiDAR analysis undertaken for the Kooragang Nature Reserve (Figure 34) incorporates both waterway areas (i.e. Hunter River North Arm and Fullerton Cove) and the wetland / saltmarsh complex covering an area of some 3350 ha. Ground surface and channel bed levels within this area range between +2 m AHD and -8 m AHD.

Waterways situated within the Ramsar site boundary are continuously inundated with tidal waters confined to deep narrow river sections (e.g. navigation channels) and across broad relatively shallow storage areas (i.e. Fullerton Cove) with levels between -2.2 m AHD and -8 m AHD. These waterway areas, although very deep in many areas, correspond to approximately 2% of the total site area.

For levels above -2.2 m AHD, the percentage of cumulative area increases significantly (to approximately 6%) as a result of a greater frequency of ground levels between -2.1 mAHD and -1.9mAHD. It is apparent from the results that a greater proportion of the study area includes level between -1.9 m AHD and 0.1 m AHD, which increases the percentage cumulative area from 6% to approximately 38%.

A similar relationship is observed for levels up to 0.6 m AHD where the percentage cumulative area reaches approximately 50%, which can be attributed to the increased frequency of ground levels between 0.3 m AHD and 0.5 m AHD. Parts of the study site within these ranges would correspond to a significant portion of the inter-tidal zone (i.e. the area between high tide and low tide) which is exposed to air at low tide and submerged at high tide. Vegetation within this zone would include mangroves fringing waterway areas and low-lying saltmarsh areas.

The most significant increase in the percentage cumulative area (up to 88%) is apparent for levels between 0.6 mAHD and 1.0 mAHD, which typically include more elevated saltmarsh areas within Kooragang Island and higher relief areas surrounding Fullerton Cove. Ground levels between 1.0 mAHD and >2.0 mAHD account for the remaining site area (approximately 12%), which are likely to correspond to drainage bunds, levees, roads or other elevated surfaces.

The LiDAR analysis undertaken for the Shortland Wetlands (Figure 35) include higher relief areas compared to the remainder of the Hunter Estuary Wetlands (ie Kooragang NR) and cover an area of some 31 ha. The results of the frequency distribution indicate that ground levels range between -0.2 mAHD and >2.0 mAHD with a small portion of the site (approximately 2%) being below 0.65 mAHD. The greatest frequency of ground levels situated between 0.9 mAHD to 1.1 mAHD and above 2.0 mAHD. Overall, the results show that approximately 50% (of the site area) is defined by levels of less than approximately 1.3 mAHD, approximately 17% by levels between 1.3 mAHD and 2.0 mAHD and approximately 33% by levels greater than 2.0 mAHD.

4.3.2 Tidal Data Analysis

Overview

Tidal data analysis for Newcastle Harbour was undertaken to assess the frequency of sea level rise conditions at Ramsar Wetlands. Tidal records obtained from Manly Hydraulic Laboratory (MHL) at Stockton Bridge and Hexham Bridge was used to derive percentage exceedance plots of water level to determine the frequency of inundation at the wetlands (based on tidal levels plus any storm surge conditions). Tidal planes determined by MHL (2003b) are presented for the water level gauges near the upstream (i.e. Hexham Bridge) and downstream (i.e. Stockton Bridge) extents of the study area. Maps showing the likely extents of inundation within the study area as a result of Sea Level Rise projections are also provided.

In addition to exceedance plots of tidal data at Hexham Bridge and Stockton Bridge, supplementary information relating to tidal water levels and tidal flushing in the vicinity of the study area is provided in the following sections.

Tidal water levels

The tidal limit along the Hunter River is located at Oakhampton (64 km from the ocean), along the Paterson River it is between Paterson and Gostwyck (between 70 km and 75 km from the ocean) and in the Williams River it is at Seaham Weir (46 km from the ocean) (MHL, 2003a).

Tidal range

The conveyance of tides upstream is dependent on the water level in the channel and the channel dimensions. As a consequence of dredging in the 1950's and 1980's, the water levels and tidal ranges within the Hunter River have changed. An analysis of tidal data from 1955 and 2000 showed that the spring tide range has increased in upstream reaches (MHL 2003a).

Moving upstream there is a gradual reduction in the mean tidal range along the Hunter River, with a range of approximately 1.0 m at the entrance and 0.4 m at Belmore Bridge, Maitland (MHL 2003a). Along the Paterson River there is a slight amplification of the mean tidal range (0.7 m at Dunmore) (MHL 2003a), while on the Williams River there is a slight amplification of the tidal range (0.91 m recorded at Raymond Terrace, increasing to 0.96 m at Seaham) (MHL 2003a). Along the Williams River, the weir at Seaham acts as a reflective barrier and the tides are therefore expected to act like a standing (or stationary) wave. Standing waves are produced when a wave is confined within boundaries such as an upstream structure or control (e.g. weir). As a consequence the tides in the Williams River are weaker (by a factor of 0.3), when compared to the Hunter River.

Tidal phase

Tidal lags also vary within the three rivers. Along the Hunter River at Bolwarra the low tides lag 8.8 to 6.3 hrs after the entrance tide and the high lags 3.8 hrs. Along the Paterson River at the Paterson Railway Bridge the low tides are 6.1 to 5.3 hrs after the entrance tide and the high tide lags by 4.3 hrs, and along the Williams River at Seaham Weir the low tides are 3.3 to 2.5 hrs after the entrance tide and the high tide is 1.8 hrs after (MHL 1995). In the lower estuary the tidal excursion is around 10 km during spring tides (MHL 1995).

Tidal velocities

Maximum tidal velocities decrease upstream with values of around 1.0 ms^{-1} near the entrance during the ebb tide to around 0.5ms^{-1} at Morpeth (48 km upstream) (MHL 2003a). During the flood tide the maximum velocities are similar, at around 0.9 ms^{-1} near the entrance.

Low frequency oscillations

Low frequency oscillations in tidal level of about 3 to 10 days period with amplitudes of 0.1 m have been recorded within the estuary (MHL 2003a).

Tidal flushing

The ELCOM hydrodynamic model has previously been used to investigate the potential for ocean exchange and flushing, by assessing e-folding flushing times. The e-folding time corresponds to the time taken for average tidal conditions to reduce the concentration of a conservative constituent inside the lower estuary from a value of 1.0 to a value of 0.368 (1/e) under the forcing of clean ocean water (concentration of 0.0) and the physical processes of advection and dispersion. Generally, areas close the ocean will have a very short flushing time (indicative of the time it takes for water particles at these locations to be advected out of the estuary system), while areas near the tidal limits of the estuary have long flushing times (and are much more influenced by freshwater inflows to the estuary).

The results from the hydrodynamic model indicate that the lower estuary has a very short flushing time, in the order of 1-5 days, suggesting that the daily tidal motions are quite effective at flushing the waters of the lower estuary. Moving further upstream to Hexham the flushing time doubles to around 10 or 11 days.

Given that tidal flushing within the study area is largely dominated by tidal processes, it is likely that small changes to inflows at Seaham Weir (over a sustained period) would not influence tidal flushing in the vicinity of the study area.

Results

Water level data measured by MHL (15-minute intervals) at Hexham Bridge and Stockton Bridge were reviewed to determine the overall quality of the datasets used for the subsequent tidal analysis. A summary of the properties of the two datasets used for the analysis is presented in Table 18.

Table 18: Properties of water level datasets at Hexham and Stockton.

Station	Start Date	End Date	Percentage Complete (%)	Minimum Water Level (mAHD)	Maximum Water Level (mAHD)
Stockton	11/12/1984	30/06/2008	91.7	-1.10	1.34
Hexham	12/06/1985	30/06/2008	92.4	-1.13	1.66

Data used for the analysis was reviewed with any erroneous values (i.e. null values) removed from the dataset. The final time series of water levels at Stockton Bridge and Hexham Bridge used for the analysis is shown in Figure 36 and Figure 37 respectively. Data gaps evident in the plots below are greatest in the years 1986 and 1987 with less missing data for years following 1990. Overall, the data used for the analyses are considered representative of water levels experienced at the two sites, incorporating daily tidal variations, storm surge and river rise during periods of high river flow.

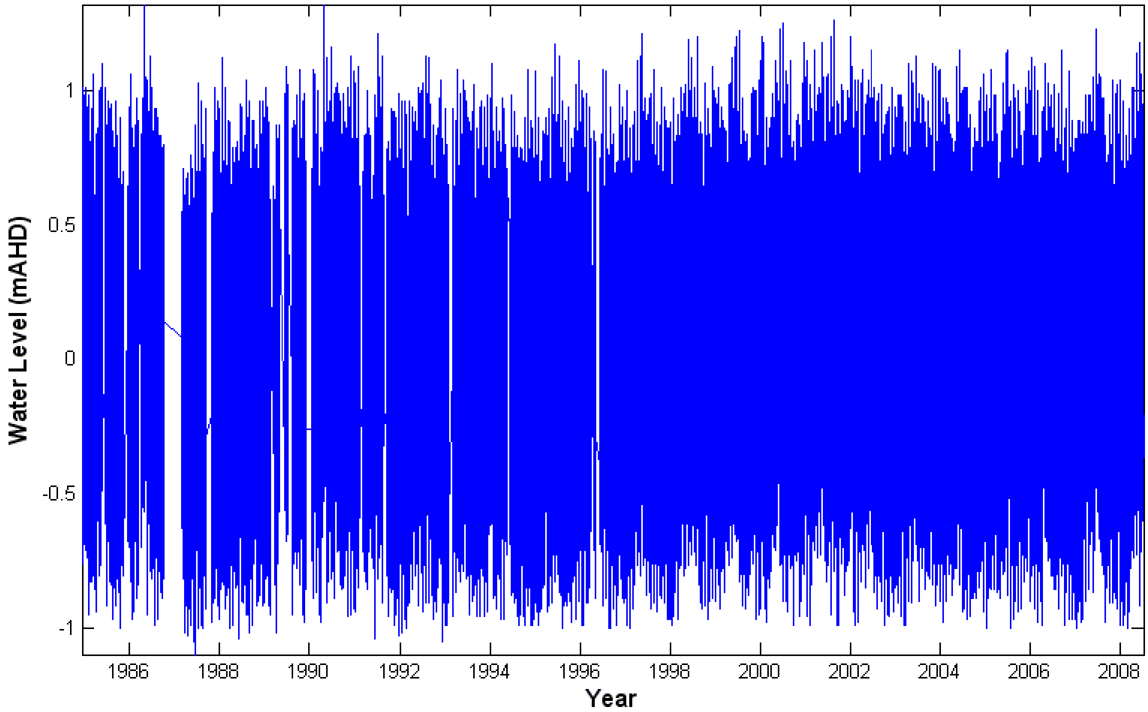


Figure 36: Water level data at Stockton Bridge (1984 – 2008).

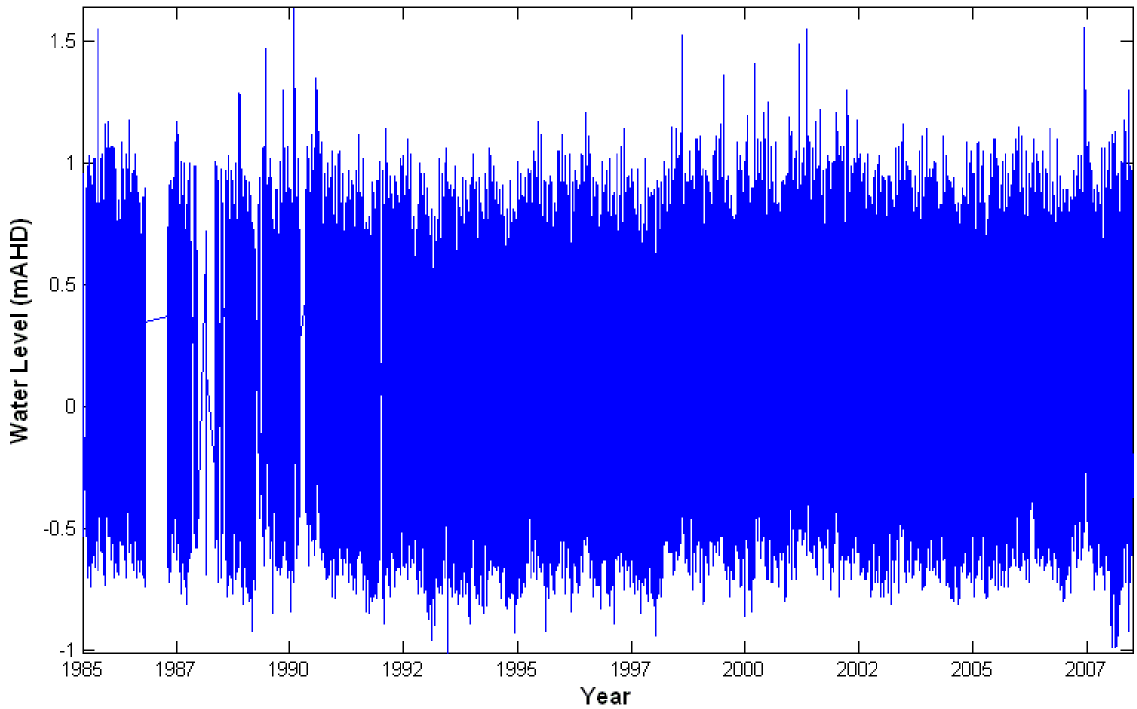


Figure 37: Water level data at Hexham Bridge (1985 – 2008).

These two data sets were analysed to determine the frequency distribution and percentage exceedance of tidal water levels at intervals of 0.1 metres. Frequency histograms of water level data measured at Hexham Bridge and Stockton Bridge are shown in Figure 38.

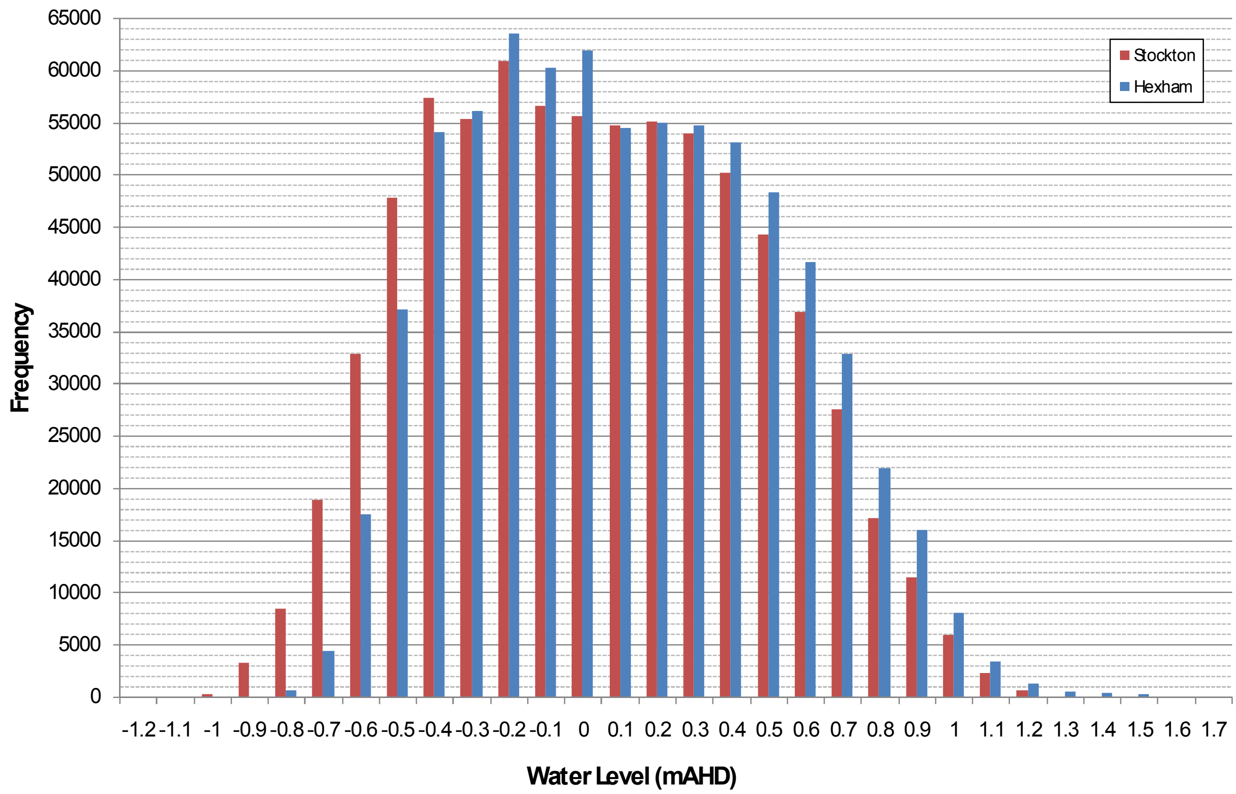


Figure 38: Frequency histogram of water levels.

The frequency histogram of water levels measured at Stockton Bridge shows that the majority of water levels are between -0.7 mAHD and 0.8 mAHD. The highest and lowest water levels recorded within the available gauging period were 1.34 mAHD (25 April 1986) and -1.10 mAHD (12 June 1987) respectively.

The frequency histogram of water levels measured at Hexham Bridge shows a similar distribution with an apparent shift towards higher water levels, when compared to Stockton Bridge. A slightly greater range of water levels, particularly above 1.3 mAHD were also recorded at Hexham. The histogram shows a majority of data lying between -0.6 mAHD and 0.9 mAHD with a maximum water level of 1.66 mAHD recorded in February 1990 during a major flood event in the Hunter River. The minimum water level of -1.13 mAHD recorded at Hexham Bridge occurred on the 16 June 1993.

The higher water levels correspond to freshwater inputs during major flooding events resulting in water levels higher than expected under tidal conditions alone and for this reason values above 1.3 mAHD have been ignored within the subsequent analysis. Water levels measured below this level are considered representative of conditions outside of major floods in the Hunter River, which correspond to the ‘natural’ influences from ocean tides.

Percentage exceedance curves derived from water level data measured at Stockton Bridge and Hexham Bridge shown in Figure 39.

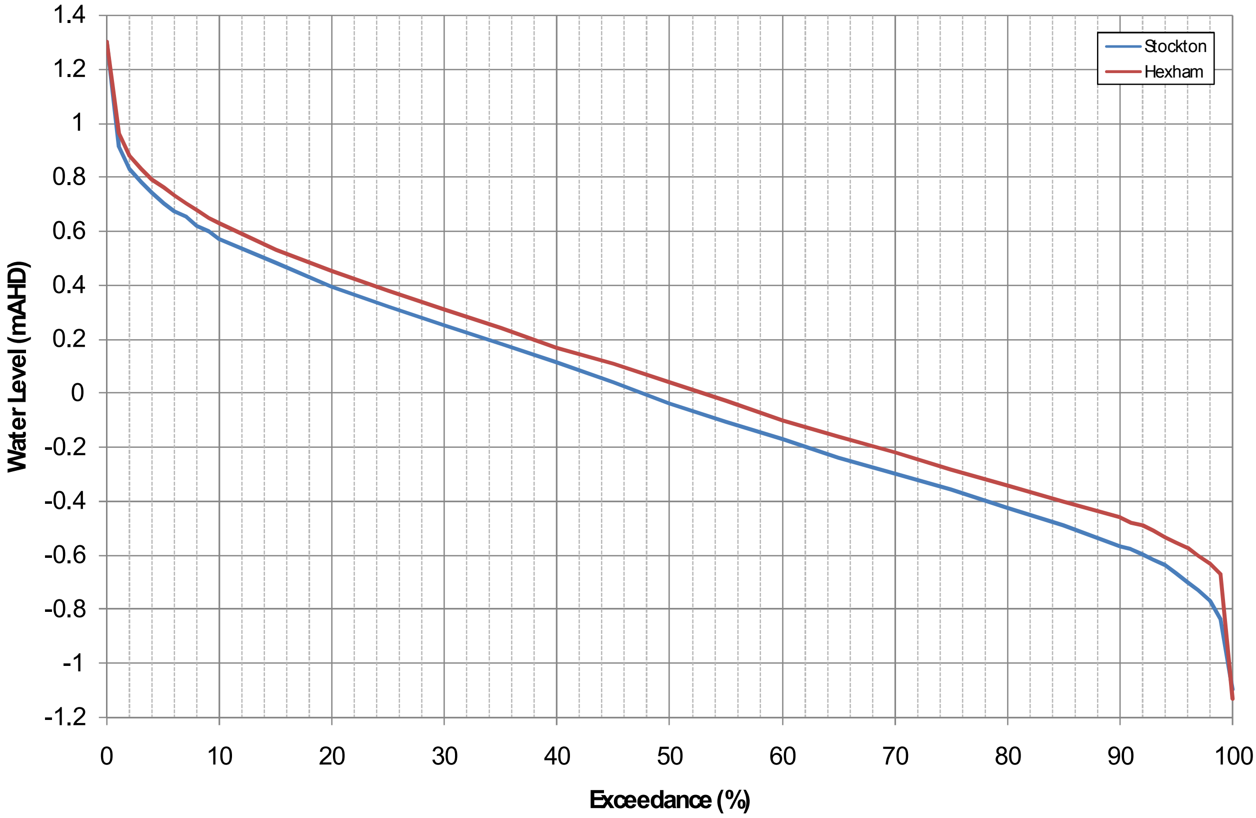


Figure 39: Percentage Exceedance Curves of Water Levels

Using the curves shown in Figure 39, an approximation of percentage exceedance for tidal planes (refer Table) calculated for the period July 1990 to June 2000 (inclusive) for Stockton Bridge and Hexham Bridge was undertaken and is presented below in Table 19. The results show that the percentage exceedance of tidal planes at Hexham Bridge and Stockton Bridge are for the most part identical with the greatest difference apparent for the MHWS and MHW planes.

Table 19: Percentage exceedance of water levels.

Tidal Plane	Stockton		Hexham	
	Water Level (mAHD)	Exceedance (%)	Water Level (mAHD)	Exceedance (%)
HHWSS	0.997	0.8	0.992	0.9
MHWS	0.634	7.5	0.643	9
MHW	0.508	13	0.539	15
MHWN	0.382	21	0.436	21
MSL	-0.021	49	0.043	50
MLWN	-0.424	80	-0.349	81
MLW	-0.551	89	-0.453	89
MLWS	-0.677	95	-0.556	96
ISLW	-0.936	>99	-0.806	>99

Using the results of the ground level frequency distribution prepared for the Hunter Estuary Wetland (excluding Shortland Wetlands), an estimate of the percentage of the Ramsar Site below key tidal planes was undertaken. To simplify the analysis, a single representative water level was approximated for tidal planes within the study area. Tidal planes for Stockton Bridge are considered to better represent the study area given its proximity to a majority of the study area, and for this reason were given a greater overall weighting (i.e. 75%) than values for tidal planes at Hexham Bridge (i.e. 25%). The approximate percentage of site area below each of the averaged tidal planes is summarised in Table 20.

Table 20: Percentage of Hunter Estuary Wetland below representative tidal planes.

Tidal Plane	Water Level (mAHD)	Percentage of Site Area Below
HHWSS	1.00	97
MHWS	0.64	61
MHW	0.52	52
MHWN	0.40	50
MSL	0.00	38

MLWN	-0.23	35
MLW	-0.53	33
MLWS	-0.65	32
ISLW	-0.90	29

Tidal Extent Mapping

During the analysis of LiDAR data, it was apparent that the vegetation types within the study area (broadly defined as an assemblage of mangrove, saltmarsh, wetland and other terrestrial vegetation) are commonly found and adapt to areas that provide the necessary conditions to satisfy ecological requirements of each particular species in that community. For example, in NSW saltmarsh communities typically occur between the MHW and HHWSS and they are generally only inundated on the highest tides, rather than every tidal cycle. Overall, saltmarsh distribution is not well understood and controlling factors are often site specific. Elevation, tidal frequency, soil condition and inter-specific competition between saltmarsh species and mangroves are all influential in determining saltmarsh distribution (DECC 2008). In NSW, the dominant mangrove species is *Avicennia marina* (Grey Mangrove). In open estuaries in south eastern Australia, the distributional limits of this species are generally between MHW and MSL. Usually there is very limited open space between the mangrove-saltmarsh boundary (DECC 2008).

The analysis of LiDAR data provides an indication of the overall distribution of ground levels within the study area. A map of the tidal extents for the MHW and HHWSS have been prepared and compared to aerial photography (refer Figure 40). This mapping exercise has been used to provide further insight into the distribution of these vegetation types as a function of key tidal planes which are known to have an important role their ecological function and distribution. The mapping shows the distribution of mangrove and saltmarsh complex within areas inundated by these key tidal planes. In general, areas of mangrove establish in areas corresponding to MHW or lower and saltmarsh in areas of higher relief (i.e. above MHW) that are inundated by less frequently by HHWSS.

Approximate inundation extents have also been prepared to demonstrate the sensitivity of the Ramsar site to inundation from high tide predicted for sea level rise scenarios. The extents presented in Figure 41 show the estimated maximum extent of inundation for increases to the MHW (i.e. 0.53 mAHD) based on projections for the year 2020 (i.e. 0.71 mAHD), 2050 (i.e. 1.08m AHD) and 2100 (i.e. 1.44 mAHD). The approximate extents shown are for comparative purposes only to highlight the significant inundation that could potentially arise for changes to downstream tidal conditions.

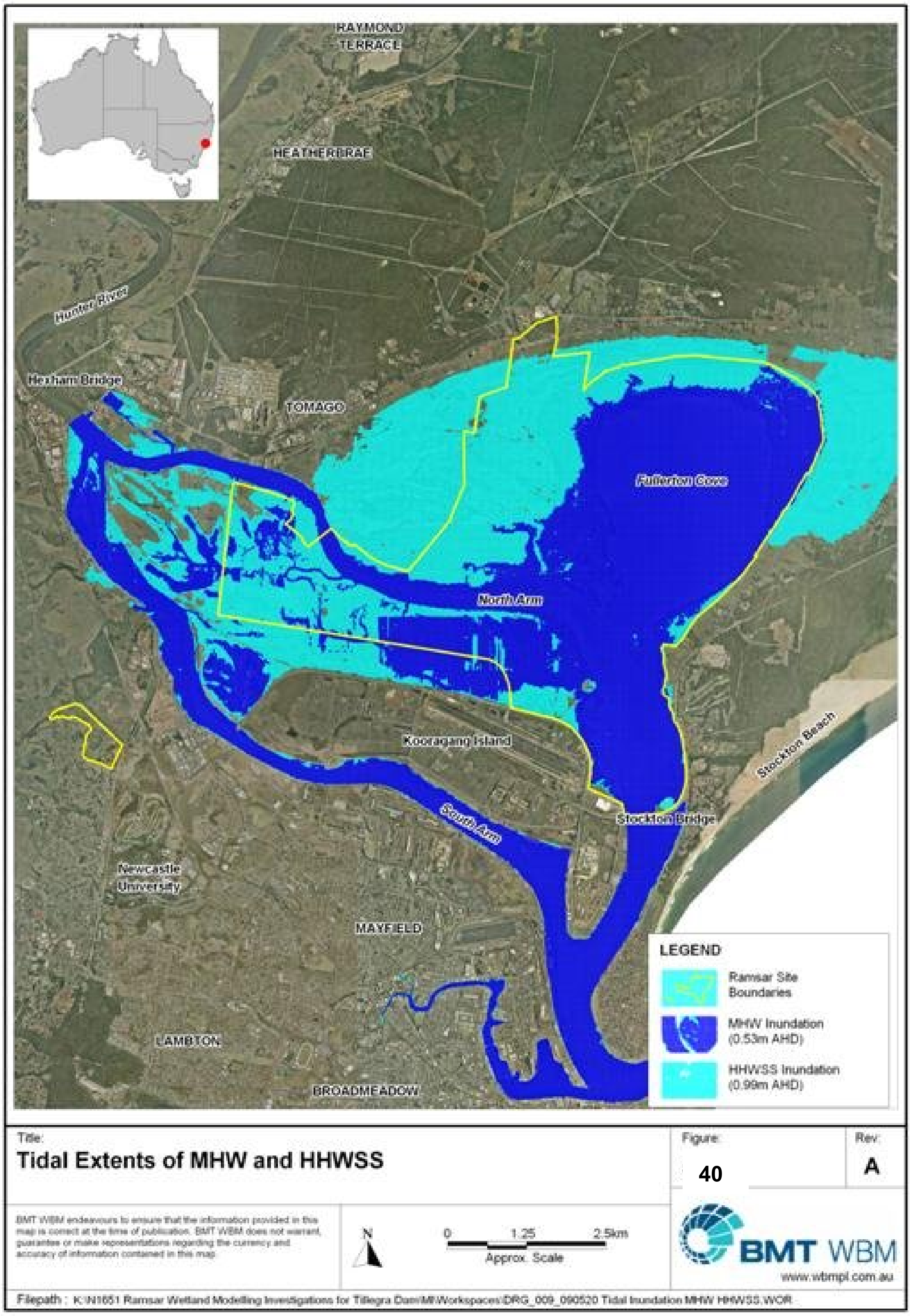


Figure 40: Tidal extents of MHW and HHWSS.

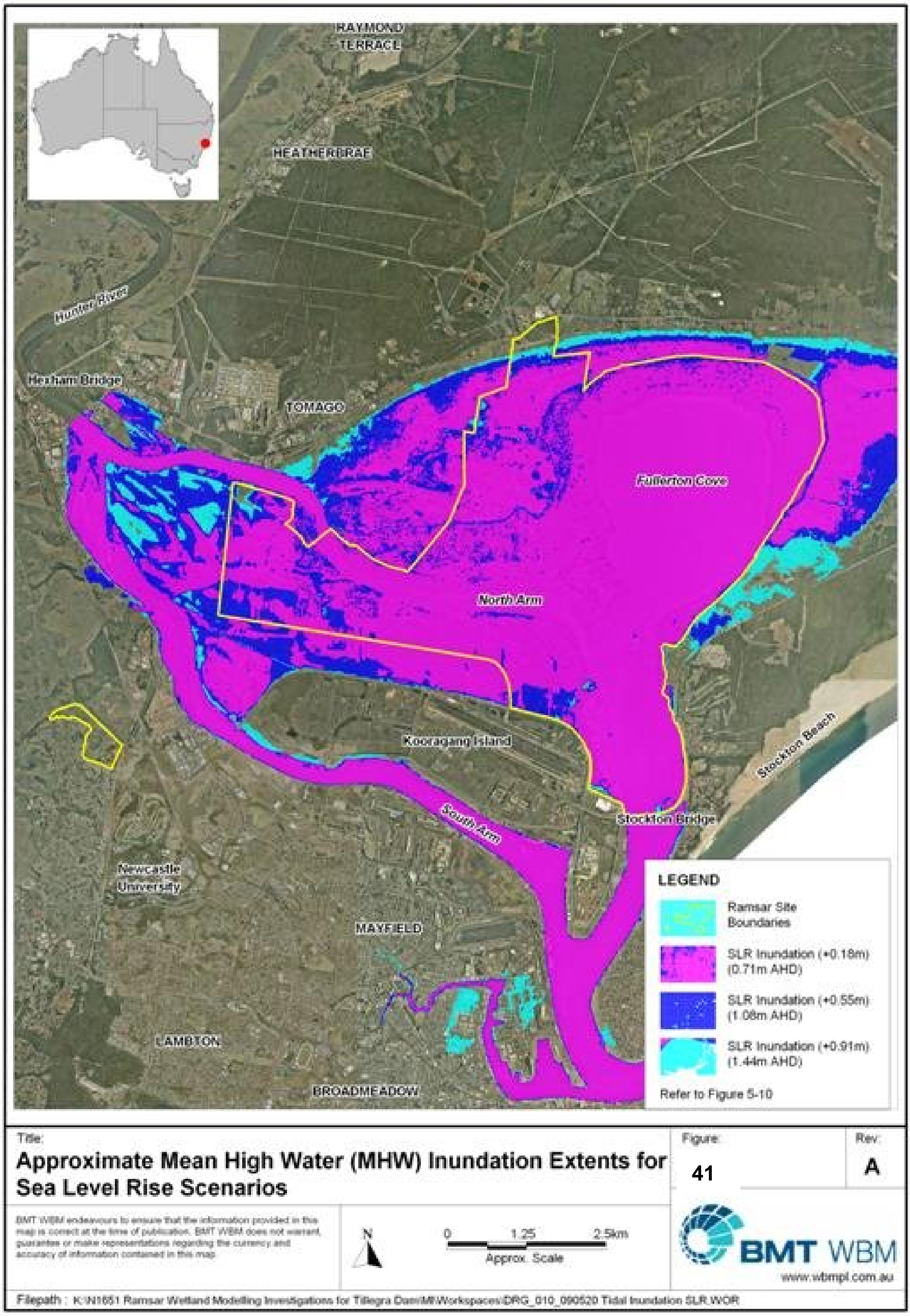


Figure 41: Approximate Inundation Extents for Sea Level Rise Scenarios

4.3.3 Average annual budget inputs

Tides

Flows

One of the most significant contributions to the water budget is tides. A water budget prepared by MHL (2003b) notes that contribution to the water budget from the tidal prism is estimated to be ±18,250 GL/yr. The tidal contribution at the mouth is some ten times greater than the freshwater inputs from upstream river and catchment flows. A value of 18,250 GL/yr was therefore adopted for the analysis.

Nutrients

The concentration of TN and TP for ocean water was based on water quality measurements of ocean water (Haines 2006). Concentrations of 0.25mg/L for TN and 0.025mg/L for TP were adopted for the average annual nutrient budget, which are considered representative of 'clean' ocean waters.

The typical concentration of total organic carbon (TOC) in ocean water has been estimated using the Redfield ratio. The Redfield ratio is the ratio of carbon, nitrogen and phosphorus in phytoplankton. The ratio of the atomic mass of carbon, nitrogen and phosphorus was assumed to be 42:7:1. For preliminary estimation of TOC inputs from tides, the concentration of TOC was estimated based on an average of the C:N and C:P ratios using TN and TP concentrations assumed above. The TOC concentration for ocean (tidal) waters was therefore assumed to be 1.3 mg/L.

River inflows

Flows

Another significant input to the water budget includes freshwater inflows from the Hunter River, Paterson River and Williams River. Sanderson and Redden (2001) determined the mean freshwater flow of the Hunter, Paterson and Williams rivers over the last 25 years as 3,120 ML/day, while MHL (2003) estimate the total catchment runoff to be approximately 1,800 GL/yr (before extractions and storages). Other estimates of total runoff have also been made by ANRA (1,900 GL/yr) and DWE (1,650 - 2,400 GL/yr) based on a range of modelling techniques. DWE has estimated catchment runoff from the Patterson and Williams Rivers to be 287 GL/yr and 392 GL/yr (before extraction and storage). A proportionally higher runoff occurs from these catchments (as well as the Allen River) relative to their sizes given the higher average rainfall occurring within the Barrington Tops ranges, which are located within these catchments.

For the purpose this comparative assessment, inputs from each of the individual river systems were estimated to further demonstrate their relative contributions. Stream gauging data available for the Hunter River at Greta and Paterson River at Gostwyck (ie just upstream of the tidal limits) were used to estimate average annual flows based on more than 25 years of data (~1970s to present). Freshwater inputs from the Hunter River and Paterson River to the estuary were estimated to be approximately 613 GL/yr and 202 GL/yr, respectively.

Stream gauging in the Williams River is not so straightforward, due to the operation of Seaham Weir. The average annual freshwater inflow from the Williams River was therefore estimated using modelled data provided by HWC (refer Section 5.2). Based on the HWC data, which considers stream gauging at Glen Martin and offtakes from the Seaham Weir pool, the average annual flow passing Seaham Weir under existing (without Tillegra Dam) and proposed (with Tillegra Dam) conditions was estimated to be approximately 276 GL/yr and 215 GL/yr, respectively.

Additional catchment inputs to the Hunter, Paterson and Williams Rivers, downstream of their respective tidal limits, are included within the local catchment runoff estimates, as discussed further in Section 5.3.3, and have been determined through catchment modelling.

Nutrients

The primary source of water quality data available for the study area is the Hunter River Estuary Water Quality Data (HREWQ) Review and Analysis undertaken by Sanderson and Redden (2001). This source of data includes water quality measurements made by HWC, the EPA (now Department of Environment and Climate Change) and Maitland City Council within the upper and lower reaches of the Hunter River Estuary over the last 25 years. Water quality data collected by these authorities have been compiled into a database to facilitate holistic analysis of water quality in conjunction with measurements of river flow. The analysis undertaken highlights interesting patterns of nutrients and biota within the estuary and also quantifies changes in the nutrient status during the last 25 years (Sanderson and Redden, 2001). Water quality data available within the accompanying database was reviewed to determine the average concentrations of TN and TP in flows from the Hunter River and Paterson River.

Water quality data collected by HWC at weekly intervals within Seaham Weir Pool were available for the period 1987 to 2007. Water quality data collected included measurement of TN and TP concentrations within the Williams River immediately upstream of Seaham Weir. It has been assumed that monitoring undertaken at the weir pool over this period is representative of average surface water conditions entering the system via Seaham Weir under existing conditions. The concentration of TN and TP assumed from a review of these data was 0.74 mg/L and 0.08 mg/L respectively (i.e. TN:TP ratio of approximately 9.25).

Water quality and hydrologic investigations of the proposed Tillegra Dam have been undertaken as part of the EIS prepared by Aurecon (previously Connell Wagner). As part of these investigations, an assessment of expected nutrient concentrations in the proposed storage was undertaken (refer Table 5.4 of accompanying EIS), which estimates the total phosphorus concentration in Tillegra Dam to be about half the inflow concentration or 0.034 mg/L. The expected total nitrogen concentration in Tillegra Dam was estimated by Aurecon using an average TN:TP ratio of 7.06 resulting in an expected outflow concentration of 0.24 mg/L.

For comparison purposes, the concentration of TP at Seaham Weir was estimated to establish whether future (with Tillegra Dam) conditions would have a significant impact on the nutrient budget. A flow-based estimate of TP and TN concentration at Seaham Weir was made using the following assumptions:

- Relationship between the concentration of TP at Seaham Weir and outlet of Tillegra Dam catchment would remain the same under post Dam conditions (i.e. assumes contribution of TP concentration from other catchment areas upstream of Seaham Weir would not change);
- Estimate of TP concentration is based on an assumption that a decrease at the outlet of the Tillegra Dam catchment would correspond to a proportionate reduction at Seaham Weir as a function of flow contributions (i.e. rate of decay and transformation processes between various phosphorus and nitrogen species would not change significantly);
- TN concentration based on assumed TN:TP ratio of 9.25 derived from historical measurements of TN and TP concentration at Seaham Weir under existing (Tillegra Dam) conditions.

Fortnightly water quality monitoring data collected by HWC (2007) at Boags Hill (located at mouth of Balickera Canal on the Seaham Weir Pool) between 2005 and 2007 indicates the median concentration of TOC is approximately 5.4mg/L. It is worth noting that the maximum and minimum concentration of TOC measured at Boags Hill was 10.3 mg/L and 3.7 mg/L respectively. In the absence of any additional data for the Hunter River and Paterson River it has been assumed that the concentration of TOC would be of a similar magnitude to that measured in the Williams River (i.e. between 3 mg/L and 10 mg/L). The concentration of TOC for river inflows from the Hunter River and Paterson River has been assumed to be approximately 4 mg/L using the Redfield ratio.

Local catchment runoff

Flows

In addition to freshwater inputs from river inflows, an estimate of the average annual volume of runoff from local subcatchments was undertaken using the WaterCAST catchment model. The estimates include areas downstream of Greta, Gostwyck and Seaham Weir that contribute runoff to the Hunter River Estuary. The model was used to simulate daily rainfall-runoff processes using synthetic SILO rainfall data available for the period 1900 to 2007. The average annual runoff volume from local catchments over this 108 year period was estimated to be approximately 368 GL/yr.

Nutrients

The WaterCAST catchment model also enables the specification of constituents, which can be modelled as a component of the sub-catchment processes. The model simulates constituents including Total Suspended Solids (TSS), Total Nitrogen (TN) and Total Phosphorus (TP).

The Event Mean Concentration / Dry Weather Concentration (EMC/DWC) constituent model was adopted for the generation of constituents within the WaterCAST catchment model. EMC/DWC model parameters required for TSS, TN and TP were adopted from a review and gap analysis of stormwater flow and quality undertaken by Fletcher et al. (2004). A summary of the EMC and DWC values adopted for each land use category is summarised in Table 21.

Table 21: EMC / DWC constituent model parameters.

Land use	EMC (mg/L)			DWC (mg/L)		
	TSS	TN	TP	TSS	TN	TP
Bushland	40	0.9	0.08	6	0.3	0.03
Rural	90	2	0.22	14	0.9	0.06
Urban / Industrial	140	2	0.25	16	1.3	0.14

Using outputs from the catchment model, the combined catchment-averaged concentration of TN and TP from the local catchment areas was estimated to be approximately 1 mg/L and 0.1 mg/L respectively.

The concentration of TOC from catchments is dependent upon land use types (e.g. urban, bushland, rural etc) which contribute differing concentrations of TOC under dry weather and wet weather (event) conditions. Fletcher et al. (2004) provide wet weather summary statistics of TOC concentrations for residential and other high residential land use types which have median concentrations of 19 mg/L and 30 mg/L. In the absence of any further information, average annual EMCs for catchment runoff has been adopted as 10 mg/L. This value is higher than average river concentrations but is considered justified based on the higher proportion of urban development within the lower catchment.

Licensed discharges

Flows

Licensed discharges from Wastewater Treatment Works (WWTW) have also been incorporated into the water and nutrient budget. Effluent discharges from the Morpeth WWTW enter the system via an outfall located near the Hunter River and Paterson River confluence. Discharges from the Raymond Terrace and Shortland WWTW enter the Hunter River via Windeyers Creek and Ironbark Creek respectively. The average annual discharge volume from the Shortland, Raymond Terrace and Morpeth WWTW was estimated to be approximately 7.6 GL using data provided by HWC.

Nutrients

The concentration of TN and TP assumed for the analysis are based on median values within effluent from the Morpeth WWTW, which are expected to be approximately 7 mg/L and 1 mg/L respectively (Patterson Britton & Partners 2007).

The primary form of carbon in treated wastewater effluent is organic carbon. The concentration of TOC in treated effluent following secondary and tertiary treatment is typically 14 mg/L and 7 mg/L respectively (Metcalf and Eddy 2007). A conservative assumption of a TOC concentration of 14 mg/L (i.e. secondary treatment only) was assumed for the carbon budget.

Rainfall and evaporation

Flows

Estimates of the average annual rainfall and evaporation volume were also included in the water and nutrient budget. The average annual rainfall volume was estimated using the long-term estimate of annual rainfall at Williamtown RAAF (1128 mm at BoM Station 061078) during the period 1942 to 2009 (inclusive) and an assumed study area of 3350 ha. Similarly, the average annual evaporation volume was estimated using an average annual areal potential evapotranspiration (PET) of 1401 mm estimated from PET grids supplied by the Bureau of Meteorology.

The average annual rainfall and evaporation volume was estimated to be approximately 37.8 GL and 46.9 GL.

Nutrients

Typical concentrations of TN and TP in rainfall have been assumed to be 0.4 mg/L and 0.030 mg/L based on results presented by Drapper (2001).

The concentration of TOC is likely to be influenced by local atmospheric conditions and would vary accordingly. Approximate values for TOC are expected to be less than 1mg/L. Given the volume input from direct rainfall is small compared to the other major sources it is considered acceptable to ignore rainwater TOC loads from the carbon budget.

4.3.4 Results

The results of the water and nutrient budget for the ‘without Tillegra Dam’ scenario are presented in Figure 42. The values derived from the analysis represent the proportion of average annual volume and load of TN and TP for a number of key sources discussed in Section 6.2. The analysis has been undertaken to determine relative contributions of the volume of water (both freshwater and ocean tides) and nutrient loads (TN and TP). Within such an analysis, it is considered more informative to assess the relative contribution of key sources defined within the system given that the interactions of many source-sink processes occur over much smaller timeframes (i.e. no individual sink has been identified to show any accumulation of losses from the system).

The results show that the largest contribution of the water budget comes from tides (approximately 92% of total volume). The next largest input to the system is the combined river inflows from the Hunter River, Paterson River and Williams River. Of these three river inflows, the Hunter River provides the greatest proportion of volume (3.1% of total volume or 56% of combined river inflows) and the Paterson River the least (1% of total volume or 19% of the combined river inflows). Other freshwater inflows entering the system are supplied by the Williams River (1.4% of total volume or 25% of the combined river inflows) and local catchment runoff (1.9% of total volume). The remaining components of the water budget include minor contributions from licensed discharges (0.04% of total volume) and direct rainfall (0.19% of total volume). Evaporative losses are estimated to represent approximately 0.24% of the total water budget.

Nutrient loads estimated for the key sources show that tides are again estimated to contribute the greatest TN and TP loads. Although the assumed concentration of TN and TP are lower than all other sources (0.25 mg/L and 0.025 mg/L), the very large proportion of TN and TP loads (approximately 75% and 80% of total loads respectively) are due to the very large volume of water entering the system from tides (assumed to be 18,250 GL/year). It is worth noting that although tides contribute to more than 90% of the water budget, their contribution within the nutrient budget is somewhat less, which is a consequence of the higher concentration of TN and TP for other key sources (e.g. Hunter River flows and catchment runoff). The greatest contribution of TN and TP from freshwater sources is via flows from Hunter River (approximately 11.5% and 5.4% of total load respectively) and local catchments (6.5% and 6.8% of total load respectively). The higher contribution of TN from the Hunter River and local catchments on an average annual basis is a consequence of the higher average concentration of TN (assumed to be approximately 1.1 mg/L) and the larger volume of freshwater, as detailed above. Inputs from the Paterson River and Williams River flows are estimated to contribute similar TN loads (2.9% and 3.3% of total load respectively) although notably less than the Hunter River and local catchment inputs, which is a reflection of the lower concentration of TN adopted (0.87 mg/L and 0.74 mg/L respectively) and freshwater volume input. Similarly, TP loads are estimated to be less from the Paterson River and Williams River (2.1% and 3.8% respectively). It is worth noting the concentration of TP adopted for freshwater sources are similar especially for the Hunter River, Paterson River and Williams River flows (0.05 mg/L, 0.06 and 0.08 mg/L respectively) and as such the TP load from these rivers is less overall when compared to that estimated for TN. Of the three major river inflows, the Hunter River has the lowest concentration of TP which, when coupled with a larger proportion of the total freshwater volume results in only a slightly smaller contribution to overall TP load.

Significantly smaller contributions of TN and TP are associated with licensed discharges and rainfall (typically less than 1% of total TN and TP loads) when assessed on an average annual basis. Although the concentration of TN and TP for licensed discharges (assumed to be 7 mg/L and 1 mg/L) is much higher than any other source included in the analysis, the overall average annual volume generated is negligible (less than 8 GL/year) when compared to volumes generated by major river inflows and tides which are orders of magnitude greater. This results in much smaller contributions to overall TN and TP loads from licensed discharges.

Consideration of the proposed Tillegra Dam has been included in the analysis by adjusting the average annual flow and concentration of TP and TN entering the estuary at Seaham Weir. As discussed in Section 6.2.2, an estimate of the average annual TP and TN concentration was made using an assumed reduction of TP and TN at the outlet of the Tillegra Dam catchment, which has been used to infer a proportionate reduction at Seaham Weir based on changes to mean annual runoff. The net effect of these assumed changes to flow and concentration within the system are minimal when compared to other major sources (i.e. tides). The estimated reductions at the Hunter Wetlands Ramsar site, resulting from the construction of Tillegra Dam are:

- Flow Volume: Reduction of 0.3%;
- Phosphorus: Reduction of 1.3%; and
- Nitrogen: Reduction of 1.1%.

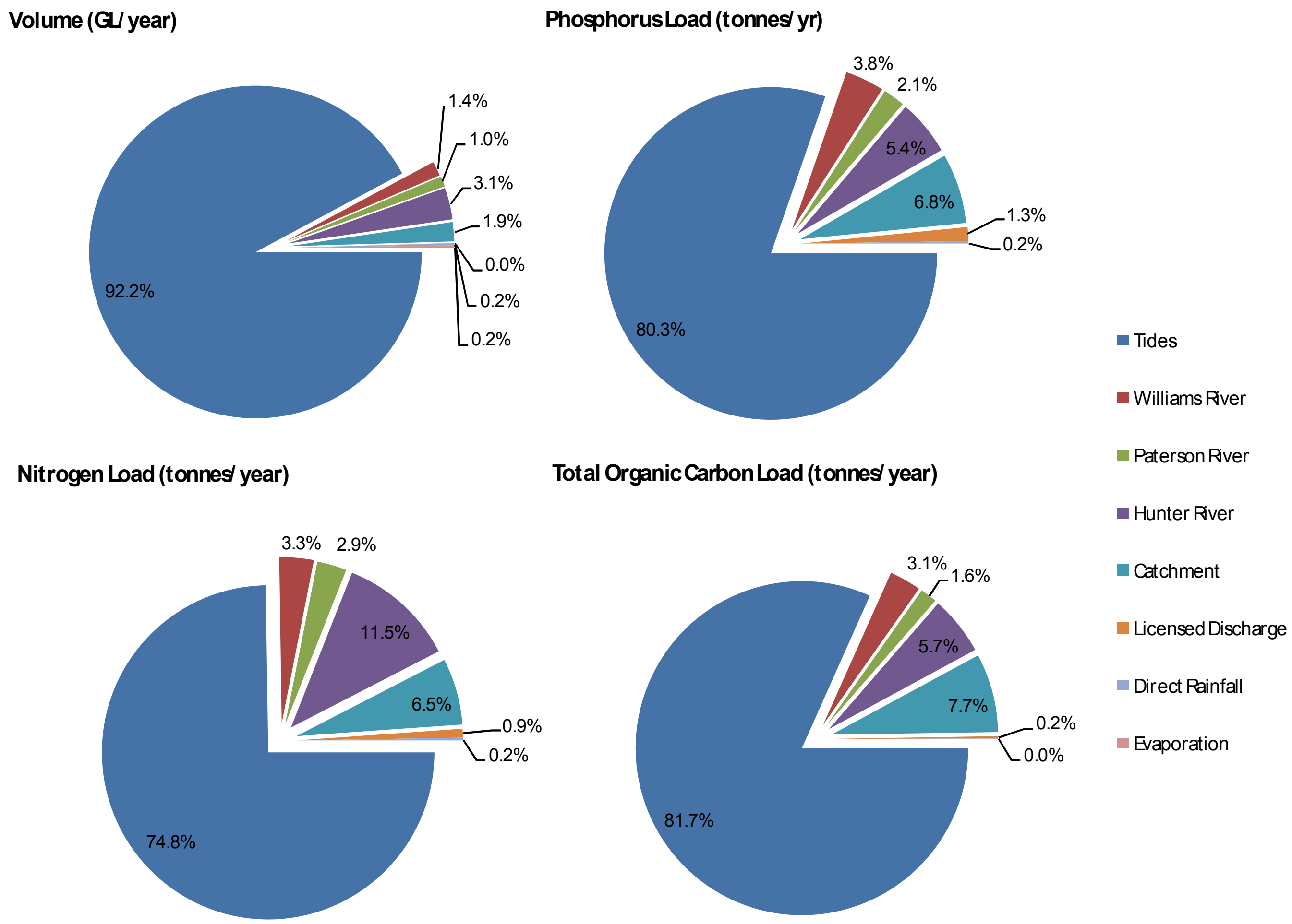


Figure 42: Water and nutrient budget (without Tillegra Dam)

The results show of the key sources included in the assessment, tides are estimated to contribute the greatest TOC loads. Although the assumed concentration of TOC is lower than all other sources (i.e. 1.3mg/L), the very large proportion of TOC loads (approximately 82% total load) are due to the very large volume of water entering the system from tides (assumed to be 18,250 GL/year). The greatest contribution of TOC from freshwater sources is via flows from catchment runoff (approximately 7.7% of total load) and the Hunter River (approximately 5.7% of total load). The higher contribution of TOC from the Hunter River and local catchments on an average annual basis is a consequence of the higher average concentration of TOC and the larger volume of freshwater, as detailed above. Inputs from the Paterson River and Williams River flows are estimated to contribute smaller TOC loads (1.6% and 3.1% of total load respectively) than the Hunter River and local catchment inputs, which is a reflection of the lower concentration of TOC adopted and freshwater volume input.

In the absence of any substantial data sources to determine concentration inputs to the carbon budget it is considered that the relative volume inputs would have the greatest influence on average annual loads of carbon to the system. The results of the water and nutrient budget illustrate the relatively small contribution of loads from the Williams River catchment. Flow inputs from the Williams River are less than 1.5% of the total volume of inputs considered by the budget and consequently, changes to the concentration of TOC as a result of Tillegra Dam are not expected to result in considerable changes within the Lower Hunter River Estuary in the vicinity of the study area. That is to say, the relative contribution (and potential change thereof) from the Tillegra Dam catchment to long-term cumulative water quality conditions within the study area is considered negligible when assessed in combination with much greater contributions such as tides, the Hunter and Paterson River catchment and local catchment runoff. As mentioned previously, tides play an important role in flushing of the lower estuary in which the study area is located and is considered to play a more dominant role in the expected water quality conditions during average annual conditions.

It is difficult to determine the reduction (if any) to the concentration of TOC as a result of the Tillegra Dam. However, based on an estimated average annual flow volume reduction of 0.3% from the Williams River alone, the percentage reduction of the TOC load into the system from the sources included in the assessment would be approximately 0.7% (i.e. a reduction from 3.1% [pre Tillegra] to 2.4% [post Tillegra]).

5 Impacts of Tillegra Dam on the Hunter Estuary Wetland

5.1 Overview

The proposed Tillegra Dam site is located approximately 100 km upstream of the Hunter Estuary Ramsar site. Given this large distance, there will be no direct impact of the dam on the estuary, since no dam infrastructure will be built/operated in or near the Ramsar. Therefore, all impacts will be indirect and associated with changes in the hydrological regime resulting from the on-going operation of the dam. These hydrological and the associated chemical changes have been highlighted above as the two perceived threats on the Hunter Estuary Wetland likely to result from the proposed Tillegra Dam project.

Consequently, this impact assessment has been based on changes in the hydrological regime and chemistry of the entire Hunter Estuary predicted by the modelling undertaken by BMT WBM. It should be noted that the impact assessment is focused heavily on the Kooragang Nature Reserve, as it is the part of the Ramsar site likely to be affected by the proposed dam. There is no perceived increase in the level of threat to the Shortland Wetlands, since they are geographically and hydrologically isolated from the Williams River and not directly linked to the Hunter Estuary. All limitations or information deficiencies encountered during this investigation have been addressed along with a justification of how these deficiencies were managed.

The potential impacts from the dam need to be considered in context of other factors impacting the estuary and that may contribute to cumulative effects. These include:

- tidal and oceanic influences;
- climate change and sea level rise; and
- activities in the wider catchment area.

The modelling indicates there will be minimal hydrodynamic changes to the Hunter Estuary Wetlands and the estuary in general. This is particularly evident when the predicted changes are evaluated in the context of daily tidal fluctuations and predicted impacts from climate change and sea level rise.

The Hunter estuary and associated wetland environments are a highly dynamic environment, dominated by tidal influences (modelling suggests that over 90% of the flow into the estuary is from ocean tides) that drive fluctuations in key parameters e.g. water level and salinity. Therefore most of the plants and animals living within the Kooragang Nature Reserve are well adapted to these fluctuations and have broad environmental tolerances. Given the broad environmental tolerances of most estuarine species, it is unlikely that the small changes in hydrology and water quality caused by the construction and operation of Tillegra Dam as predicted by the hydrodynamic models will have a significant impact on the flora and fauna of the Kooragang Nature Reserve and the Hunter Estuary Wetlands.

Hydrological changes are predicted to create small differences in end values e.g. tidal height or maximum salinity. Key ecosystem processes are unlikely to be altered, water will not be cut-off from any area of the estuary and the majority of nutrients entering the estuary will continue to be sourced from the ocean or cycled within the estuary itself. Given that these key ecosystem processes will be largely unaffected by the dam, it is very unlikely that an overall change in the ecological character of the Hunter Estuary Wetlands will occur as a result of Tillegra Dam.

It should be noted that the ecological character of the Hunter Estuary Wetlands may change naturally over time, and particularly as a consequence of climate change and sea level rise. Therefore, it will be very difficult to separate potential impacts from the operation of Tillegra Dam from changes caused by other factors.

5.2 Impact Guidelines for Matters of National Environmental Significance

The supplementary DGRs issued for the Tillegra Dam proposal require an assessment of the impacts that the action will have on the ecological character of the Hunter Estuary Wetlands in relation to the EPBC Act Policy Statement 1.1 Significant Impact Guidelines for Matters of National Environmental Significance (2006) for Wetlands of International Importance. Under these guidelines, an action will have a significant impact on the ecological character of a declared Ramsar wetland if there is a real chance or possibility that the action will result in:

- Areas of the wetland being destroyed or substantially modified;
- A substantial and measurable change in the hydrological regime of the wetland, for example, a substantial change to the volume, timing, duration and frequency of ground and surface water flows to and within the wetland;
- The habitat or lifecycle of native species, including invertebrate fauna and fish species, dependent upon the wetland being seriously affected;
- A substantial and measurable change in the water quality of the wetland – for example, a substantial change in the level of salinity, pollutants, or nutrients in the wetland, or water temperature which may adversely impact on biodiversity, ecological integrity, social amenity or human health or;
- An invasive species that is harmful to the ecological character of the wetland being established (or an existing invasive species being spread) in the wetland.

The proposed Tillegra Dam is highly unlikely to result in any of the above scenarios occurring, and thus the dam is not likely to alter the ecological character of the Hunter Estuary Wetlands. The potential impacts of Tillegra Dam are discussed below, with respect to each of the relevant matters outlined in the Significant Impact Guidelines.

5.2.1 Areas of the wetland being destroyed or substantially modified

No areas of the Hunter Estuary Wetlands will be destroyed or substantially modified. The proposed Tillegra Dam is to be located 100 km upstream from the wetland and therefore there will be no direct impacts of the dam structure on the wetland. The only way in which any areas of the Hunter Estuary Ramsar Wetland could be destroyed or modified by Tillegra Dam is through changes to the flow regimes of water entering the estuary. Based on the modelling undertaken for this assessment, the predicted changes in flow regime are minor. Therefore, no area of the Ramsar wetland will be destroyed or substantially modified by direct construction and operation of Tillegra Dam.

5.2.2 Substantial and measurable change in the hydrological regime of the wetland

Extensive modelling of potential changes to the hydrological regime of the Hunter Estuary Wetlands and the broader estuary were been undertaken for this assessment by BMT WBM. These are summarised in the following sections and in Tables 23 and 24; however, no substantial or measurable changes are predicted. Changes across each of the 19 modelled scenarios indicate that changes in inundation height are predicted to be in the magnitude of 1-2 cm, salinity at 1-3 ppt and nutrients less than 2%. Despite the limitations of the models used, these predicted changes are several orders of magnitude less than the large fluctuations in all of these parameters experienced over a tidal cycle.

Nutrient budget

The average annual nutrient budget indicates that 92% of the water entering the Hunter Estuary Ramsar Wetland site comes from ocean tides. Proportionally less of the total nutrient load enters the estuary via the ocean (75% of the total nitrogen and 80% of the total phosphorus loads). This difference is due to the elevated levels of nutrients flowing into the estuary via freshwater sources (rivers and catchment runoff). The effects of Tillegra Dam on the total nutrient budget for the entire estuary were analysed with the following results predicted:

- Flow volume reduced by 0.3%
- Total phosphorus reduced by 1.3%
- Total nitrogen reduced by 1.1%
- Carbon reduced by 0.7%

Sediments

Based on the catchment area (21,545 km^2), land use, topography and rainfall, the Australian Natural Resources website lists Total Suspended Sediment supplied to the whole of the Hunter River catchment basin as 2,950,924 tonnes per year (ANR 2002).

Of this, estimates of 1 million tonnes of Total Suspended Sediment enters the Hunter Estuary, 100,000 tonnes of this is accumulated within the estuary channels, such as the Ramsar (typical rate of 2.3 mm/yr), 414,000 tonnes is accumulated within Newcastle Harbour, and is dredged (and then dumped offshore), and 500,000 tonnes is transported out of the river and deposited on the offshore continental shelf (Manly Hydraulics 2003).

Gipple and Anderson (2008) reports that Tillegra Dam will trap sediment. The trapping efficiency of the dam will reduce the mean annual suspended load at Thalabar Bridge and Mill Dam Falls, just upstream of Seaham Weir, from 66.41 kt/yr to 18.01 kt/yr. This is a suspended load reduction of 48.4kt/yr. This reduction in TSS represents a 1.64 % per annum reduction in the total sediment available in the Hunter Estuary. Given that Seaham Weir currently acts as a sediment trap for TSS flowing down the Williams River during low flow periods, this minor percentage reduction will only be relevant during high flow events, during which time TSS are typically in surplus within the estuary. Furthermore, the draft Hunter Estuary Management Plan (BMTWBM 2007) highlights the importance of reducing sediment loads from catchments, an outcome that Tillegra Dam could potentially improve.

Inundation levels

The results of the inundation modelling vary depending on the dam-weir configuration used and the flow regime. However, the following results are applicable for both sites within the main channel and within the mangrove communities:

- Low water mark is predicted to be within ±1 cm of current levels.
- High water mark is predicted to be within -1.2 cm to +1 cm of current levels.

To put these values into context, the current daily tidal range under average tidal condition is between 0.1 m – 2 m depending on location in the estuary. Furthermore, the difference in water level (at the same point in the tide) between high and low flow events is up to 4 cm of current levels depending on the location in the estuary.

Salinity levels

Again, the results of the salinity modelling vary depending on the dam-weir configuration used and the flow regime. However, the results can be summarized in the following manner:

Table 22: Mangrove community sites

Flow regime	Predicted change in maximum salinity (i.e. on high tide) (ppt)	Predicted change in minimum salinity (i.e. on low tide) (ppt)
Low to moderate flow (25^{th}-75^{th} percentile)	-0.2 to +0.3	-0.7 to 1.7
High flow (90^{th} percentile)	0.1 to 3.1	0.3 to 5.3

Table 23: Main channel sites

Flow regime	Predicted change in maximum salinity (i.e. on high tide) (ppt)	Predicted change in minimum salinity (i.e. on low tide) (ppt)
Low to median flow (25^{th}-50^{th} percentile)	-0.2 to 1.2	-0.6 to 1.5
Moderate to high flow (75^{th}-90^{th} percentile)	-3.4 to 2.5	-3.4 to 2.3

Currently, salinity levels vary by up to 14 ppt over a tidal cycle. High tide salinity levels vary by up to 5.5 ppt and low tide salinity varies by up to 13 ppt between high and low flow events. These values are not predicted to change markedly under any of the modelled scenarios (generally by approximately ±1ppt).

5.2.3 The habitat or lifecycle of native species dependent upon the wetland

The Hunter Estuary Wetland is an important site for many native species including birds, fish and sensitive vegetation communities e.g. mangroves and saltmarsh. Given that Tillegra Dam is located 100 km upstream of the wetland, there will be no direct impacts of the dam structure on native species or vegetation communities within the wetland. The only way in which any species/communities could be affected by Tillegra Dam is through changes to the hydrological regime, and associated changes to habitat or interference with key life cycle stages. Modelling has predicted minor alterations in nutrient and salinity regimes and water inundation levels. The potential impacts of these key factors are discussed for the flora and fauna of the Hunter Estuary Wetlands below.

Nutrients

Hydrological modelling indicates that the vast majority of nutrients entering the Hunter River Estuary come from tidal sources. Additionally, significant nutrient cycling will occur within the estuary itself.

The modelling indicates that Tillegra Dam will result in a small decrease in the amount of nutrients entering the estuary, due to the trapping of sediments and nutrients within the dam. There is no evidence to suggest that the Hunter River Estuary is a nutrient limited ecosystem and there are significant nutrient inputs into the catchment from surrounding land uses. Therefore, decreases in nutrient inputs of approximately 1% are unlikely to have an impact on the estuarine ecosystem. Sufficient nutrients will still be available within the estuary to drive key ecosystem processes and primary production. Impacts further up the food chain are therefore not anticipated.

Inundation levels

Based on the modelling undertaken for this assessment, the predicted changes in flow regime are minor. Small differences in the inundation height (i.e. several centimetres at most) will not substantially change the habitat areas available for most flora and fauna of the estuary. The Hunter River Estuary is a tidal dominated system and therefore a highly dynamic environment with metre scale daily variations in inundation. Species using the estuary are well adapted to these large tidally driven fluctuations in the available habitat (e.g. mudflats which are exposed only on low tide). Therefore, they are extremely unlikely to be impacted by the centimetre scale variations in inundation height associated with Tillegra Dam.

It should be noted that there are some significant areas of saltmarsh within the Hunter Estuary Ramsar Wetlands. Saltmarsh is a highly sensitive vegetation community that is currently in decline along the NSW coast (DECC 2009). This ecosystem is most at risk from changes to inundation levels, as it occupies a narrow band between the mean high tide and the king or maximum tide height. Saltmarsh are generally only inundated on the highest tides, rather than every tidal cycle. Furthermore, saltmarsh are highly susceptible to changes in an additional range of parameters including elevation, tidal frequency, soil condition and inter-specific competition (saltmarsh and mangrove species). Sea level rise is also a major concern for saltmarsh.

Saltmarsh communities are high salinity communities that exist in sea water salinities or even higher concentrations. These communities generally lie between high tide and spring tide levels that aren't prone to frequent freshwater inundation. Changes in estuarine water level predicted by the modelling suggest that changes in estuarine hydrology due to Tillegra Dam will have minimal or no effect of the tidal cycles and amplitudes, therefore the dam is likely to have no impact on saltmarsh communities.

Salinity

The salinity modelling indicates that Tillegra Dam may result in up to a ~3 ppt change in salinity levels within the Hunter Estuary Ramsar Wetlands and the Estuary itself and that this may be a salinity increase or decrease depending on the scenario examined. It should be noted that this level of change is only predicted under high flow events, while for the majority of flow levels, salinity changes of <1 ppt are predicted. The magnitude of this change is very small when it is considered that salinity fluctuates by up to 14 ppt (or by 50%) over the course of a tidal cycle. No areas that are currently freshwater will be inundated with saline water and conversely no marine/brackish areas will revert to freshwater systems. Therefore the impacts of minor alterations to salinity regimes are unlikely in an estuarine system where the plants and animals have naturally high tolerances to salinity fluctuations.

5.2.4 A substantial and measurable change in the water quality of the wetland

Modelling results show that the Hunter Estuary is dominated by oceanic influences with approximately 92% of the water entering the estuary coming from ocean tides. Given that Tillegra Dam will not impact on the ocean, it is unlikely that there will be any substantial or measurable change in the water quality of the Hunter Estuary Ramsar Wetlands. It is worth noting that the modelling results predict a very slight decrease in nutrients entering the estuary (<1.3%), which may be seen as an overall positive impact on water quality.

Similarly, sediment contributions to the Hunter Estuary are likely to be marginally reduced as a result of Tillegra Dam. This reduction in Total Suspended Sediment represents a 1.64% per annum reduction in the total sediment available in the Hunter River catchment and represents 48.4 kt/yr of the Hunter Estuary Total Suspended Sediment budget. Given that Seaham Weir currently acts as a sediment trap for TSS flowing down the Williams River during low flow periods, this minor percentage reduction will only be relevant during high flow events, during which time Total Suspended Sediment are typically in surplus within the estuary. Furthermore, the draft Hunter Estuary Management Plan (BMTWBM 2007) highlights the importance of reducing sediment loads from catchments, an outcome that Tillegra Dam could potentially improve. Therefore, the reductions in sediment entering the estuary that would result from the proposed Tillegra Dam are not considered likely to cause substantial and measurable changes to water quality.

5.2.5 An invasive species that is harmful to the ecological character of the wetland being established

Construction and operation of Tillegra Dam will not connect the Hunter Estuary Wetlands to any new waterways. Consequently, the dam does not present an invasion pathway for aquatic pests to enter the estuary.

Currently, several pest species are found within the Ramsar site in particular aquatic weed species such as Alligator weed. Tillegra Dam will not change conditions to the extent that these pest species will be affected and therefore no new infestations or expansion of current infestations are likely to results from the building and operation of Tillegra Dam.

5.3 Limits to Acceptable Change

Limits of acceptable change (LACs) have been outlined for the Kooragang Nature Reserve and Shortland Wetland. Tillegra Dam is unlikely to impact significantly on any of the critical ecological components and processes in these wetlands. Very minor changes are anticipated for the physical processes of the estuary including freshwater and nutrient inputs, water inundation levels and sediment loads. However, all changes are well within the LACs determined.

There will be no direct impacts on the flora and fauna of the Hunter Estuary Wetlands site associated with the Tillegra Dam proposal. Very minor indirect impacts may result from the changes to hydrological parameters. However, these changes will also be well within the natural levels of variation seen within the highly dynamic estuarine environment and therefore are considered to be within the LAC.

5.4 Cumulative Impacts

The consideration of cumulative impacts is difficult to quantify for the Hunter Estuary Wetlands due to the dynamic nature of the wetlands and influences from sources that are external to the wetland (e.g. climate change, other proposed developments, impacts on migratory bird breeding habitat in other nations). However, given the modelling undertaken as part of this study demonstrates the limited extent of change that would result from the proposed Tillegra Dam, it is considered highly unlikely that the proposal will substantially contribute to any cumulative impacts or changes to the Hunter Estuary Wetlands.

5.5 Worst Case Scenario

All Tillegra Dam flow scenarios (including Tillegra Dam fill-up, construction and operation) would have limited impact on the flows received at the Hunter Estuary and Hunter Estuary Wetland due to the overriding control of flows at Seaham Weir. The modelling results further show that all Seaham Weir scenarios examined as part of the impact assessment for the wetland had unique flow, water level, salinity, nutrient transport, and sediment transport characteristics. The complexity of the outcomes can not be under-estimated, but as the modelling results ultimately showed only minor deviations in baseline water quality and hydrological parameters, limited impact for all scenarios was predicted. Accordingly, there is no worse case scenario in relation to the dam. Rather the modelling conducted for the dam provides an opportunity to further examine the existing scenario currently in operation for the weir. Keeping in mind that the weir is an effective mechanism for ameliorating flow impacts from the dam on the wetlands the modelling provides the opportunity to examine whether modifications to the existing scenario for the weir would be warranted to improve environmental outcomes within the estuary.

The importance of Seaham Weir in the management of the Hunter Estuary Wetland can not be under-estimated. The weir had been in place since 1967 and has been a major influence on the flow regime reaching the estuary from the Williams River. The impact assessment presented in this report is based around the presence of the weir with some thought given as to how this may be operated or adjusted in future years. Such adjustments could be undertaken to address wider environmental outcomes whilst meeting the important water management objectives associated with the weir.

5.6 Seaham Weir Flow Regimes

As discussed in Section 4.2.4 and shown in Figure 23, a number of potential flow regimes at Seaham Weir have been identified, including:

- Existing system
- Transparent flows to 20 ML/day
- Transparent flows to 20 ML/day +30% translucent to 100 ML/day at Seaham
- Transparent flows to 20 ML/day +70% translucent to 100 ML/day at Seaham
- Transparent flows to 20 ML/day +30% translucent to 2400 ML/day at Seaham
- Transparent flows to 20 ML/day +70% translucent to 5500 ML/day at Seaham

The modelling results presented in this report show that each of the above Seaham Weir flow regimes has minimal impact on the flows received further downstream at the Hunter Estuary Ramsar site.

Design limitations of the existing Seaham Weir gate structure prevent low and moderate releases being made from the weir with a high degree of finesse. High flows can be passed through the existing gates at a rate of approximately 3000 ML/day and floods are able to overtop the weir. However, due to the large size of the gates, low to moderate flow releases can only be made in a blocked release. A blocked release is one which results from the temporary opening of the gates and a large quantity of water being released in a gushing flow, rather than a smaller opening being made resulting in a longer, more consistent, natural and controlled release. The gates can only be fully opened or fully closed. Partial opening of the gates with any degree of control is beyond the technological capacity of the structure.

Currently, an average low to moderate release lasts for an hour and 20 minutes with a total flow of 170 ML (pers comm. E. Doeleman 2009). As these short blocked flow releases do not simulate natural river flows they are unlikely to have significant environmental benefits. The cost of modifying the weir and the gates to allow releases that better simulate natural river flows is understood to cost of many millions of dollars (based on discussions with Hunter Water). Such work would involve the retrofitting of flap or radial gates, bypass pipes or some other engineered solution to pass more water in a controlled manner. An investment of many of millions of dollars would need to be balanced against the anticipated environmental outcomes. Changes to the riverine hydrology from the release of low flows may improve environmental conditions directly below the weir but, given the modelling results presented in this report, may be of limited benefit to the Hunter Estuary Wetland, or indeed, the wider estuary.

In this regard, the higher order translucent flow regimes listed above and as modelled, were found to provide little difference in their impact on the ecological character of the Hunter Estuary Wetland. However, translucent flow releases of these magnitudes would significantly impact on the yield of town water extracted at Seaham Weir.

While significant changes to the operation of Seaham Weir to enable a more natural low flow regime to occur is a difficult issue to reconcile with the town water supply requirements it is recognised that more natural flows across the weir would be desirable in order to ensure connectivity between the estuary and the river. The importance of connectivity between rivers and estuary environments for migrating aquatic biota seeking to complete their life cycles has long been recognised, but not always realised, despite attempts to establish “fishways” to accommodate migrating organisms. The weir has an existing fishway, but it is an older submerged orifice design which is now widely accepted to be sub-optimal. A new fishway with an improved design would improve the existing environmental conditions in the vicinity of the weir, and further, would also improve the connectivity between the upper Williams River and the Hunter Estuary Wetlands during very low flow conditions. An upgraded fishway could potentially also be used to provide additional transparent flows across the weir to 20 ML/day.

On this basis, with a recognised need to improve system connectivity whilst acknowledging that significant changes could affect the existing town water supply at great cost to the local community, the preferred Seaham Weir configuration was considered to be “Transparent flows to 20 ML/day” without translucent flows. This position was also reached with the recognition that the release of additional water within moderate flow classes would not necessarily result in significant positive changes to the downstream characteristics of the estuary. It is further mentioned that the operation of any flow regime will in the future need to consider the implications of anticipated sea level rises as a consequence of global climate change. Under this scenario the above outlined preferred configuration for the weir should be seen as a measure to restore a more beneficial flow regime to the wetland within a climate change scenario with its own uncertainties but inevitable impacts on the estuary as a whole.

6 Information Gaps and Project Limitations

The following provides a list of the information gaps and limitations that were encountered during this study and the implications of these factors in evaluating and assessing the impacts of the proposed Tillegra Dam on the Hunter Estuary Wetlands.

6.1 Ecological Character Description for Kooragang NR

Whilst the information fact sheet on the Hunter Estuary Wetlands - Shortland Wetlands and Kooragang Nature Reserve – and the Ecological Character Description for the Shortland Wetlands have been prepared as similar detailed description was not available for the Kooragang Nature Reserve. However, a rigorous information and literature review from a variety of sources, including the current legal document for Ecological Character Description the Hunter Estuary Ramsar Information Sheet, allowed for the presentation of the ecological character of this wetland.

By way of reducing the implications of this limitation, threats and the limits of acceptable change for the Kooragang Nature Reserve were presented in a conservative manner. Given the marginal modelled changes that would result from the proposed Tillegra Dam, these changes are within the LAC presented herein.

6.2 Limitations of the hydrological, Salinity and Nutrient Budget Models

This assessment has been undertaken primarily using numerical modelling. Whilst the modelling has undergone a rigorous calibration and validation process (Appendix B), care should still be exercised in interpreting the results. There are likely to be other factors influencing hydraulics and water quality within the Hunter Estuary (both locally and more broadly) that are not included in the numerical analysis. As such, actual values generated by the model should be considered to have a maximum potential error of +/- ~10%. The assessment of potential Tillegra Dam impacts is, however, essentially based on comparisons between different modelling scenarios. All other factors being equal, the modelling results actually highlight differences between these scenarios (and thus the potential impacts of the dam) to a much higher degree of accuracy.

The degree of accuracy of all assessments presented in this report is further limited by the degree of accuracy of the source data used for the assessments.

7 Recommendations

Given the limited degree of likely change to the Ramsar wetlands that would result from the proposed Tillegra Dam in all river flow scenarios, recommendations have focused on providing direction on improvements to the management of Seaham Weir. Low and moderate Williams River flows received at the Hunter Estuary Wetlands are largely controlled by operations at Seaham Weir. This existing situation will continue to occur with or without the proposed Tillegra Dam. Consequently, Tillegra Dam will have limited impact on these flows received at the Ramsar site, due to the existing management rules governing the operation of the weir, as well as design limitations within the existing gate structure on the weir that precludes alternate operational rules being adopted.

Improved flow connectivity between the upper Williams River and the Hunter Estuary Wetlands could however occur if the Seaham Weir fishway was upgraded. A new vertical slot fishway with the capacity to allow additional transparent flows across the weir to 20ML/day is recommended. This would result in improvements to the ecological health of the river system. Specifically such an upgrade would facilitate the movement of aquatic biota between the river and the estuary as well as improve flow conditions immediately below the weir, contributing to improvements to the overall health of the estuary and therefore, the Ramsar estuary wetlands further downstream.

Monitoring of water levels, water quality and ecological characteristics downstream of the weir would enable the measurement of Seaham Weir upgrade benefits as well as providing additional baseline data that would provide the foundation to the ongoing and adaptive management of Seaham weir. Monitoring of improvements made to the weir is therefore recommended both immediately downstream of the weir, as well as extending past the confluence of the Williams and Hunter River’s at Raymond Terrace.

Such monitoring would also support or complement existing monitoring programs being undertaken by the managers of the Ramsar wetland and would also contribute to the holistic management of the estuary. HWC should make information available from its monitoring program available to other natural resource managers including the Department of Environment and Climate Change, the Hunter Central Rivers Catchment Management Authority, the Department of Primary Industries, The Hunter Wetlands Centre, the Kooragang Wetland Rehabilitation Project and the Commonwealth Department of Environment, Heritage, Water and the Arts.

Monitoring of water levels, water quality and biota to confirm whether the upgraded fishway and improved connectivity within the low flow regime had contributed to improved environmental health below the weir would also assist Ramsar wetland managers with a direct interest in the estuary further downstream. Such information could be combined with wider data sources to continue to refine projections for nutrients, sediment and carbon budgets within the estuary.

No recommendations are made in relation to managing the proposed dams’ impacts on high flows. High flows including floods will be suppressed by the dam along the length of the Williams River, however, at the estuary, including the Hunter Estuary Ramsar Sites, flood modelling in this study has shown that differences in the volume of water reaching the sites, affecting the extent and scope of flooding is marginal at best. Hence no corrective action is warranted.

Whilst flow changes from the proposed dam are masked by the intervening influence of the existing Seaham Weir, as well as being subsumed by larger dominant flows from the Hunter River, integrated management of the Williams River system is essential for maintaining the environmental health of the overall river system. This includes the Hunter Estuary Ramsar Site. Hunter Water Corporation has noted that as part of its response to managing potential riverine impacts below the proposed dam, that an aquatic offsets package for the Williams River would be formulated. Such a package may include a small grants scheme to fund environmental improvement works along the river. As a consequence, it is recommended that any such scheme be extended to allow the sponsorship of any beneficial environmental works of merit along the entire river system, including within the broader estuary and the specific Hunter Estuary Ramsar sites.

8 Conclusion

The Tillegra Dam project has been identified by the Department of Environment, Water, Heritage and Arts (DEWHA) as a Controlled Action under the *Commonwealth Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act). The controlling provision is Wetlands of International Importance, namely the Hunter Estuary Wetlands Ramsar site, and the action is subject to the assessment and approval process under the EPBC Act. In line with the Commonwealth and NSW State Government bilateral agreement, supplementary Director Generals Requirements (DGRs) have been prepared, subsequent to the initial DGRs for Tillegra Dam as part of the *Environmental Planning and Assessment Act 1979* (EP&A Act) approvals process. This report has been prepared to address the supplementary DGRs as they apply to the Hunter Estuary Wetland Ramsar site

The ecological character of the Hunter Estuary Ramsar Wetland, including the condition, values, threats and limits of acceptable change were prepared in line with the DEWHA Ecological Character Description Framework (DEWHA 2008). This has included emphasis of information on the Hunter Estuary Wetland Information Sheet (DEWHA 2002), the current standing legal document on ecological character for the wetland, and supplementary information from recent literature and studies for the Ramsar site. The Hunter Estuary Wetlands is composed of two discrete sites, the Shortland Wetlands and Kooragang Nature Reserve. An ecological character description has been previously prepared for the Shortland Wetlands site (Biosis 2005), though not in accordance with the updated procedure (DEWHA 2008). An Ecological Character Description was not available for the Kooragang Nature Reserve and subsequently, assumptions made in this document present a conservative case. The Kooragang Nature Reserve Ecological Character Description should be updated once a final ecological characterisation has been prepared. In an assessment of the perceived threats to the Ramsar site and the potential impacts associated with Tillegra Dam, the Kooragang Nature Reserve site was considered to be most susceptible to impacts. This is due to hydrological links between the dam site and the wetland, conversely, a lack of hydrological connectivity between the dam site and Shortland Wetlands.

Hydro-dynamic modelling of flood flows and low to moderate in-channel flows and mass balance modelling of nutrients and sediment under pre-Tillegra and post-Tillegra conditions was undertaken. A total of 19 different scenarios (incorporating different Tillegra Dam and Seaham Weir configurations) were simulated throughout sites in the Hunter Estuary and the Hunter Estuary Ramsar Wetland areas. The modelled data suggest that the impacts of Tillegra Dam on the hydrological function and sediment/nutrient budgets will be minor and well below any significant ecological thresholds. The data indicate that changes in inundation height are predicted to be in the magnitude of 0.01-0.02 m, salinity at 1-3 ppt and nutrients less than 2%. These predicted changes are several orders of magnitude less than the large fluctuations in all of these parameters experienced over a daily tidal cycle.

Given the limit degree of likely change to the Hunter Estuary Wetlands that would result from the proposed Tillegra Dam in all scenarios, recommendations have focused on providing direction on the preferred scenario (i.e. dam and Seaham Weir configurations) and ongoing monitoring to report on any changes in the ecological character of the Ramsar. Much of this monitoring is either already being undertaken by current Ramsar wetland managers (i.e. the Shortland Wetland Centre or DECC) or may well be incorporated into the Ecological Character Description for the wetlands.

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Appendix A: Supplementary Director General Requirements

Supplementary Director-General's Requirements

Section 75F(3) of the *Environmental Planning and Assessment Act 1979*

The Tillegra Dam proposal (reference: 07_0156, EPBC 2008/4551) has been determined to be a controlled action under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The controlling provision is Wetlands of International Importance (sections 16 and 17B of the EPBC Act) and the action is subject to the assessment and approval process under the EPBC Act.

It is the ecological character of the Hunter Estuary Wetlands Ramsar sites (ie Shortland Wetlands and Kooragang NR) that is protected under Sections 16 and 17B of the EPBC Act. The ecological character is the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time. The phrase 'at a given point in time' refers to Resolution VI.1 paragraph 2.1 of the Ramsar Convention, which states that 'It is essential that the ecological character of a site be described by the Contracting Party concerned at the time of designation for the Ramsar List, by completion of the Information Sheet on Ramsar Wetlands'.

Further information on the ecological character of listed Ramsar Wetlands, including ecological character descriptions, can be obtained from the Australian Wetlands Database using the following links:

http://www.environment.gov.au/water/publications/environmental/wetlands/database/index.html

http://www.environment.gov.au/water/environmental/wetlands/ramsar/implementation-guidance.html

Under the provisions of the bilateral agreement between New South Wales and the Commonwealth, the environmental impacts of the controlled action will be assessed under Part 3A of the *Environmental Planning & Assessment Act 1979*.

To enable the assessment of controlled actions under the EPBC Act, the Director-General's requirements issued for the project on 8 January 2008 are supplemented with the following additional requirements.

The Environmental Assessment must include:

- a description of the action and an assessment of the relevant impacts[1] that the action has, will have or is likely to have on the ecological character of the Hunter Estuary Wetlands Ramsar site in relation to the *EPBC Act Policy Statement 1.1 Significant Impact Guidelines Matter of National Environmental Significance (May 2006)*;
- a description of the environmental values, including the ecological character of the Hunter Estuary Wetlands Ramsar site;
- a description of the relevant impacts should include direct, indirect, cumulative and facilitative impacts on the quality, quantity and hydrological flow regimes of surface and groundwater flow. These impacts should be described for the construction and operation phases of the proposed action;
- a description of the seasonal dynamics of the Williams River in the context of flows into the Hunter River Estuary, including volume, timing, duration, and frequency, and the associated maintenance of ecological character of the Ramsar site including a consideration of (and justification for) the worst case scenario;
- a description of the relevant water planning and allocation frameworks for the Williams River, such as the draft Water Sharing Plan, and in this context a description of the proposed release strategy and assessment of the potential impacts on the ecological character of the Hunter Estuary Wetlands Ramsar site;
- description of the data and modelling used to develop the scenarios and proposed release strategy, including the assumptions, sensitivities and the degree of confidence in the predictions;
- a description of feasible mitigation measures, changes to the proposed action or procedures, which have been proposed by the proponent or suggested in public submissions, and which are intended to prevent or minimise relevant impacts;
- to the extent practicable, a description of any feasible alternatives to the proposed action that have been identified through the assessment, and their likely impact;
- sufficient information about the proposed action and its relevant impacts to allow an informed decision whether or not to approve the controlled action under the EPBC Act; and
- information to address the matters outlined in Schedule 4 of the Commonwealth *Environment Protection and Biodiversity Conservation Regulations 2000*.

The description and assessment of these issues in the Environmental Assessment must be integrated as far as is practicable with the description and assessment of the other impacts of the proposal including but not limited to impacts on the ecology, hydrology, fluvial geomorphology, geology and socio-economic values.

Footnote: Some of the elements listed above are addressed within the Tillegra Dam Environmental Assessment Report developed by Aurecon.

[1] The term “relevant impact” is defined in section 82 of the EPBC Act.

Appendix B: BMT WBM Technical Report Appendices

Appendix B -1 Supplementary Background Information

Site History

The Port of Newcastle is one of Australia's largest tonnage ports and accommodates over 3000 shipping movements per year. During the early development of the region, many wetland areas were altered or reclaimed. For example, around Kooragang Island there were formerly up to 21 individual islands whereas now there are just 6 (Ecology Lab, 2001).

At the entrance and Port area, Newcastle Port Corporation (NPC) maintains a depth of around -14 to -16m AHD for shipping purposes (MHL, 2003). Upstream in the South Arm, the depth quickly decreases to around -4m AHD, while near the upstream junction of the South and North Arms the depth is approximately -1m AHD. In the North Arm the typically depths vary between -7m to -9m AHD near the outside of bends and approximately -5m AHD in the remainder of the channel. In Fullerton Cove, the maximum depths are around -2m AHD (MHL 2003).

Flow behaviour in the river been modified significantly through clearing of the natural forested catchment (MHL, 2003). Further modifications to flow include approximately 200 floodgates in and around the Hunter Estuary, including many in the grazing areas north of Hexham and around Fullerton Cove (MHL 2003). There are approximately 59 culverts in the waterways of the Hunter Estuary and these occur predominantly in the lower estuary on Kooragang Island, around Fullerton Cove and around Newcastle (MHL 2003). Levees also occur extensively in the upper estuary north of Hexham and around Fullerton Cove, which modify overbank and flood flow behaviour (MHL 2003).

Climate and Hydrology

Temperatures across the catchment can vary. In the lower estuary, temperatures are generally mild to warm, with a mean summer maximum of 25oC (winter 17oC) and a mean summer minimum of 19oC (winter 9oC) (MHL, 2003). Evaporation is higher inland, ranging from 750mm to 1000mm per annum in the north east of the catchment, to 1250mm to 1500mm per annum in the west (MHL, 2003).

Summer winds in the Hunter region are predominantly from the east and north-east, with westerly winds dominating in winter (MHL, 2003). Strong easterly winds occur occasionally in the lower Hunter region as a result of deep barometric depressions. Strong winds may also be the result of local storms.

The mean annual rainfall at Newcastle is 1145mm/yr, decreasing inland to 950mm/yr at Hexham (MHL, 2003).

The large catchment of 22,000 km2 (DWE, 2008) produces an average annual runoff of 1,800 GL, or about 12.5% of the total catchment rainfall. Groundwater flow is relatively small compared to surface flows, and has been calculated at approx. 0.5 GL/day or 183 GL per annum entering the waterway.

Flood Hydrodynamics

The addition of flood control structures along the Hunter River has diverted extreme floodwaters away from the main Hunter River channel to overbank flood channels and storage areas, resulting in the reduction in flood water levels and flood flows downstream. Ocean water levels, influenced by storm surge and the tide, have an effect on flood levels up to Green Rocks (PBP, 1996a). In higher frequency low discharge floods the flow is contained within the rivers banks and levees. As flood severity increases, floodwaters overtop the natural and man-made levees and flow across the floodplain. During a high magnitude flood, over half of the total flow upstream of Maitland is directed into the Oakhampton and Bolwarra floodways, with the remainder contained within the river (PWD, 1980). At Green Rocks, the Hunter River has cut a channel into the floodplain exposing a rock intrusion that along with the natural topography causes a constriction to flow and a ‘backing up’ of floodwaters. When the floodwaters reach the upstream end of Kooragang Island, 75% of the flow continues down the North Arm, and 25% down the South Arm. During large flood events, freshwater inflows can flush the majority of the estuary of salt water, except at depth in the dredged areas, where saline waters become trapped.

There are a number of floodgates along the estuarine limits of the Hunter River. These are located on smaller tributaries branching off from the river on Purgatory Creek, Ironbark Creek and Wallis Creek. The floodgates on Wallis Creek are currently kept partially open (MHL, 2003), while as of December 2008, one (out of eight) of the floodgates on Ironbark Creek has been reopened to allow tidal flows to return to the former estuarine wetlands during non-flood times.

Wetlands / Mangroves

The lower reaches of the estuary typically consist of muddy sediments lined with mangroves. The Hunter Estuary wetlands (ie Shortland Wetland and Kooragang NR) are recognised as being of international significance under the Ramsar Convention on Wetlands as well as state significant wetlands, as defined by State Environmental Planning Policy No.14 (SEPP 14) (NSW Dept. of Planning).

Water Quality

The water quality of the lower estuary is typically dominated by high loads of suspended solids, due to the strong tidal currents (causing re-suspension of fine bed sediments), the small wetland areas (which would otherwise act as sinks for particulate matter) and the relatively large river flow (providing a source) (Sanderson & Redden, 2001). In many estuarine systems, the phytoplankton (as represented by chlorophyll a) growth rates can be dependent on nutrient loading, however in the Hunter River the high suspended solids levels appears to have a limiting effect on phytoplankton growth and a mitigating effect on the high nutrient levels (Sanderson & Redden, 2001). This is confirmed by low average chlorophyll a levels within the lower, saline, section of the estuary, which are documented as being within ANZECC guidelines (Sanderson & Redden, 2001). High average turbidity levels within the estuary are also considered to be the main factor for the absence of estuarine macrophytes (seagrasses).

Salinity

The salinity of the lower Hunter River can fluctuate from brackish to saline, depending on the degree of inflows, rainfall and runoff. Surface waters as far downstream as Newcastle can become fresh after extensive rain, while during dry conditions, brackish water can extend upstream of Morpeth (Ecology Lab, 2001). The position of the 10ppt, 15ppt, 20ppt, and 30ppt vertically averaged salinity is dependent on the degree of river inflow and can be approximated using equations calculated by Sanderson and Redden (2001).

Turbidity

After heavy rainfall the estuary is subject to river inflows and local runoff from surrounding land; and the water may become quite brown and turbid (Ecology Lab, 2001). Levels of turbidity and non-filterable residue are both highest in the winter months when the salinity is lowest. This is attributed to the source of the waters with higher levels of turbidity found in rivers compared to the ocean (MHL, 1995).

Turbidity is generally higher in the upper estuary than the lower estuary, with mean turbidity levels of 15 NTU and maximum values of 260 NTU. The EPA interim guidelines (1999) suggest the concentration should be less than 5 NTU for the protection of aquatic ecosystems.

Dissolved oxygen

Dissolved Oxygen profiles indicate a slight increase downstream but generally show that the estuary is well oxygenated throughout. During wet weather/flood events, the lower estuary exhibits a decline in dissolved oxygen (DO), with a slow recovery time of DO after the flood events (Sanderson & Redden, 2001).

Nutrients and microfauna

- Dissolved Inorganic Nitrogen (DIN) tends to increase towards the mouth before the dilution effect of sea water near the mouth dominates (up to 10km from the mouth) (Sanderson and Redden, 2001).

- Chlorophyll-a indicates high concentrations in the upstream reaches and decreases towards the mouth, which could be explained by a number of processes including a spatial shift from freshwater species upstream to saltwater species downstream, coupled with the effects of dilution in the lower reaches. Chlorophyll-a shows a clear peak in February – March in the lower estuary, while phytoplankton counts show a small peak at this time with a later peak in September.

- Zooplankton counts are high from April to June, and in October – November, showing a lag response to the peaks in chlorophyll-a / phytoplankton.

- Two species of toxic dinoflagellates have been found in the Hunter River; Alexandrium catenella and Alexandrium minutum. These are introduced species and no blooms have been recorded to date (The Ecology Lab, 2001).

Interactions between Hydrodynamics and Water Quality

Sanderson and Redden (2001) have summarised the interaction between the hydrodynamics and water quality within the Hunter River, as discussed below, and presented in Figure B .

Stage 1 – Flood Events

- The estuary is flushed fresh to the mouth. Floodwaters, sediment and nutrients discharge directly to the adjacent coastal waters and spill over the lower floodplain and backwater areas. During the flood, turbidity at the mouth is very high (~180 NTU) compared to normal (1-10 NTU).

- During sufficiently large events, the mouth may stay fresh for a number of days, and significant scouring of the channel may occur.

- If even just a small part of the salinity gradient remains within the mouth of the estuarine basin there may be significant flocculation of fine particles, deposition and processing of material within the estuary.

• The scouring of particulate organic carbon (POC) during the larger floods may result in the estuary being net autotrophic.

Stage 2 – Estuarine Recovery

• As the estuary recovers from floods it progresses from a highly stratified salt wedge to a partially mixed system with a well developed two layered circulation and finally back to a vertically homogeneous system.

• Immediately following floods some of the sediment from the sediment laden upper layer probably flocculates and settles through the halocline at slack water where it is caught in the lower layer, transported landward, and deposited near the salt/freshwater interface.

• DO is reduced due to the breakdown of organic material mobilised by the floodwaters, including NH4 production by ammonification processes.

• The amount of material trapped will depend on the flushing timescale.

• Early in the recovery stage material passes through relatively conservatively due to short flushing times, but the processing of material increases with an increase in flushing time.

• The location of the fresh/salt water interface dictates where the maximum deposition occurs in the estuary. During this stage nutrients are typically very high due to diffuse runoff from the catchment. However, phytoplankton growth is not generally stimulated due to light limitation and/or rapid flushing.

Stages 3 and 4 – Medium flow and extended dry periods

• Vertically homogeneous system due to low freshwater inflow and strong tidal mixing.

• Point source inputs upstream are retained within the system due to very long flushing times.

• The highest phytoplankton biomass probably occurs during the dry periods due to lower turbidity and slow flushing, however, the resultant rapid uptake of nutrients may result in phytoplankton growth being nutrient limited.

• Medium flows can provide diffuse sources of nutrients which in turn stimulate phytoplankton growth. Because of the high turbidity, however, the phytoplankton growth is likely to be light limited with short periods of nitrogen limitation.

• Small diffuse loading events are likely to support primary productivity when the benthic supply of nitrogen is exhausted.

• During extended dry periods the point sources contribute largely to the nutrient loading. There may also be some N and P loading from the ocean during these periods. The nutrient loading thus limits phytoplankton growth the most during stage 4.

Appendix B-2 ELCOM Development

As mentioned previously, an existing ELCOM model of the Hunter River Estuary has been prepared by BMT WBM. A summary of the model configuration, model assumptions, data sources and calibration / verification results is provided in the following sections.

Upstream from Raymond Terrace

There are two major rivers extending from the main tributary of the Hunter River. These include the Paterson River and the Williams River.

The ELCOM model incorporates hydro survey data for the Paterson River, which extends approximately 4km upstream from Woodville, (approximately 7.5km downstream from Paterson). An additional 15km of river were required to extend the model to the tidal limit along the Paterson tributary. The extension of the model over these last 15km has been approximated based on the available depths of the river to this point.

Hydrosurvey data exists along the full tidal extents of the Williams River, to Seaham Weir, with the Weir acting as an upstream boundary. A deep weir pool exists upstream of Seaham Weir.

Along the Hunter River, hydro survey data exists from the harbour entrance to Oakhampton. A further ~2km of river was required to extend the model to the tidal limit along the Hunter River, which has been estimated from depths surveyed along the river immediately downstream from this location.

Lower Estuary and Mangrove Regions

Throughout the lower estuary there are extensive sections of mangroves and wetlands, covering approximately 17km2. The majority of this area lies within the upper tidal range and as such is required for inclusion in the hydrodynamic model to allow adequate simulation of the tidal volume and exchange characteristics within the estuary.

Limited work has been undertaken to date on the inclusion of mangroves in three dimensional hydrodynamic models. Previous field research has found that mangrove trees have a significant impact on flow structure by increasing the drag force and causing blockage to flow (Wu et al 2001). Due to the large frictional resistance there is most likely to be a horizontal gradient in water elevation from the mangroves to the main river channel. These processes, whilst arresting flow in the vegetated areas, may also affect the peak tidal currents within the main channel of the river, by producing a double peak. Flood currents can attain two maxima in velocity, before and after mangrove bank inundation. The current acceleration after the mangrove inundation is explained by a sudden expansion of the tidal prism (Lessa 1996). As a result mangrove regions may result in the trapping of low velocity water along the sides of the estuary.

Within an estuarine hydrodynamic model it is not efficient to model mangrove forests at a scale that defines each tree. As a consequence the concept applied to simulate the increased friction to flow through mangroves is via the application of an artificially high bottom drag coefficient (3D models) or a roughness coefficient (2D models).

Bathymetry

The bathymetry developed for the hydrodynamic model consists of a finite grid structure. In order to adequately capture the detail required from the river, a ‘plaid’ grid has been applied with a varying size of 200 to 30m in the x direction (north - south) and a constant 40m in the y direction (east - west). The upstream section of the model, from Raymond Terrace, has been numerically ‘straightened’ to reduce computational time. Natural channels differ from a ‘straightened’ channel in three important ways:

- the depth may vary irregularly;
- the channel is likely to curve; and
- there may be large sidewall irregularities such as groins or points of land.

None of these factors are considered to have much influence on the rate of vertical mixing, since the scale of vertical motions is limited by the local depth (Fischer et al 1979). Straightening of riverine type bathymetry has been undertaken before with success (Romero et al 2004) and allows greater resolution within the area of interest, whilst removing unnecessary numerical drag within the model computations.

A number of data sources have been utilised in the development of the model bathymetry for the Hunter River. The sources and associated data sets are outlined as follows:

- Newcastle Port Corporation (NPC) – Hydro surveys of the lower estuary;

- Department of Commerce (DoC) – River transects upstream from Green Rocks, extending along the Paterson and the Hunter River. The data was sourced from hard copy transects which were manually entered and converted from Newcastle Sewerage datum;

- Roads and Traffic Authority (RTA) – Hydro surveys between Heatherbrae to Raymond Terrace; and

- DECC/ Department of Natural Resources (DNR) – River transects along the Williams River and Paterson Rivers

Boundary Conditions

The downstream boundary condition is driven by the water level in the ocean, which is a function of the tides, storm surge and mean sea level changes. In order to simulate representative conditions for the sensitivity scenarios, a mean tide with tidal range of 1.4 metres and period of 12 hours was applied to the open boundary at the entrance to Newcastle Harbour.

At the upstream boundaries of the model there are two major river inflows, namely the Hunter River (at Greta) and the Paterson River (at Gostwyck). The upstream boundary of the Williams River is governed by the presence of Seaham Weir. Inflows to the model at the tidal extents of the Hunter River and Paterson River were assigned average percentile flow values determined from daily stream gauge records for these two rivers. Inflows to the model at the tidal extent of the Williams River were assigned flow percentile values determined from modelling undertaken by HWC (refer Section 4.4).

Throughout the catchment there are a number of smaller inflows from creeks, rivers, tributaries and general runoff from the catchment. To quantify these inputs, the WaterCAST catchment model has been used (refer Section 4.2.2) to estimate catchment runoff volumes. Again, flow percentile values were estimated from the catchment model and included within the ELCOM sensitivity scenarios (refer Section 4.4).

Appendix B-3 ELCOM CALIBRATION AND VERIFICATION

Model Calibration

The ELCOM model has previously been calibrated by BMT WBM to field data collected by Manly Hydraulics Laboratory (MHL) undertaken for the Hunter River in October 1995. This study consisted of measured flow velocities and discharge volumes through nine transects along the Hunter River and water levels at 25 sites. The model calibration focused on the lower estuary only.

The hydrodynamic processes occurring with the Lower Hunter River Estuary are believed to be dominated by different characteristics during wet and dry periods. In order to allow greater confidence in the hydrodynamic model, a wet weather period was chosen for independent verification of model performance.

Annual rainfall measurements obtained from Williamtown RAAF (BoM Station 061078) illustrated that the year 1998 was a wetter than average year, and during April-May of that year, there were major inflows from both the Hunter River (at Greta) and the Paterson River (at Gostwyck). This period was subsequently adopted as the verification period. Water level data was available from a number of locations within the lower estuary for this period, however, no flow records were available.

The results of the calibration previously undertaken by BMT WBM were evaluated using a predictive skill parameter as first presented by Wilmott (1981), and defined as follows:

$$Skill = 1 - \frac{\sum \left| X_{\mathrm{mod}\,el} - X_{obs} \right|^2}{\sum \left(\left| X_{\mathrm{mod}\,el} - \overline{X}_{obs} \right| + \left| X_{obs} - \overline{X}_{obs} \right| \right)^2}$$

(Equation 1)

Where *X* is the variable being compared with a time mean . Perfect agreement between the model results and the observed (measured) data will yield a skill of 1, and complete disagreement yields a skill of zero. This method was used to assess model results for both water level and flow.

Within the following sections, an acceptable result has been defined as > 0.7, a good fit as > 0.8 and an excellent fit as >0.9.

Water levels

The modelled water levels at Stockton Bridge and at Hexham Bridge agree well with the measured data (refer Table D-1). The water levels also show a slight amplification in tidal range towards Hexham Bridge, but not to the extent of the measured data. Overall, the modelled water levels are typically within 0.15m of the measured water levels at the two locations, with a skill of 0.99 at Stockton Bridge and 0.96 at Hexham Bridge. The water levels further upstream were found not to correlate as well with a skill parameter of 0.88 in both the Williams River at Raymond Terrace and at Green Rocks further upstream on the Hunter River. These sites are located upstream and past the expected extent of influence for this project. If the focus of the model were to change to upstream areas, then re-assessment of the calibration for water levels at upstream sites may be required.

Table D-1 Skill parameters for water level calibration

	Stockton Bridge	**Hexham Bridge**	**Williams River, Raymond Terrace**	**Green Rocks, Hunter River**
Skill Parameter	0.99	0.96	0.88	0.88

Potential reasons for the mismatch in water levels moving upstream may be due to the following:

- Modifications to the lower estuary have included dredging of the river bed since 1845, and as such there will be variations in the bathymetry that cannot be accounted for. In the current project the bathymetry information is dated 2005 and the measured field data is dated 1995 (i.e. a ten year difference). A previous comparison has been undertaken on water levels from 1955 and 2000 to understand the changes the dredging may have had on the hydrodynamics of the river system, and the results showed an increase in tidal range over this time due to the deepening of the river bathymetry from dredging (MHL, 2003a).

• The Hunter River is an equilibrium type estuary, where the tidal amplitude is retained upstream. The river is smooth and sinuous and the banks are almost parallel, resulting in the tide acting as a progressive wave with approximate equality between flood and ebb tides (Dyer, 1997). Changes to the tidal prism, depth and width and convergence along the estuary may cause the tidal wave to be compressed laterally and in the absence of friction, result in increases to the tide amplitude upstream. To achieve no loss in volume and water level, due to friction, has been difficult to simulate in the model due to the grid configuration and resulting computational time. As a consequence, some friction losses have been accepted in the upstream reaches, which are considered negligible to the downstream focus of this project.

Flows

The modelled and measured flow results agreed well at Stockton and the North Arm, with similarities of 0.97 for both (refer Table D-2). In the South Arm, the magnitude of the flow is much smaller and the modelled results did not match observed data with the same level of skill.

Table D-2 Skill parameters for the flow calibration

	Stockton	**North Arm**	**South Arm**	**Raymond Terrace, Hunter River**	**Raymond Terrace, Williams River**
Skill Parameter	0.97	0.97	0.90	0.71	0.85

The modelled results show a lag in the flow timing, leaving the South Arm, although the magnitudes appear to correlate quite well and the overall similarity is still high at 0.90. The lag in flows may be due to the presence of mangroves which affect the timing of overbank flow and influence the in-channel flow characteristics especially when the in-channel flow is quite small. This is not seen in the North Arm, even though there are large expanses of mangroves, and this is most likely due to the larger magnitude of in-channel flow as opposed to overbank flows.

The next closest ADCP transect (from the calibration data set) is located much further upstream at the confluence of the Hunter and Williams Rivers at Raymond Terrace. At both of these sites the skill parameter for flow is reduced to 0.71 and 0.84 respectively. The reduction in flow is largely due to the grid structure within the model producing numerical drag. The grid cannot be modified any further in this region due to computational run-time restraints.

Due to the focus of this project being on the lower estuary, it has been assumed that the level of error upstream is not significant for this project. The results have been included to highlight difficulties in the upstream sections of the model, in case the model is to be used for a purpose other than assessment of the lower estuary hydrodynamics.

Further errors can be introduced within the measured flow data. The ADCP profiling range is limited at the top, bottom and sides of the channel which result in shadow zones where no data is available (MHL 1995a). As a result the total error in discharge calculations when using the ADCP data is considered to be in the order of +/- 5% (PW 1994a). The error associated with ADCP increases with distance upstream, because the affected shadow zones comprise a larger proportion of these smaller river cross sections.

Model Verification

The period April – May 1998 was adopted for model verification. Verification of the ELCOM model was undertaken based on water levels only due to the absence of flow data for the period. The verification period was chosen due to the higher (freshwater) flows that occurred during the time.

Model results for the verification period (refer Table D-3) showed that the water levels at Stockton and Hexham Bridge correlated well with measured data in magnitude and timing, with similarities of 0.97 and 0.98 respectively. Evidence of large inflows from upstream river reaches are present in both the measured and the modelled water levels, suggesting the model captures the volume of water correctly as it travels down the river.

The water levels at Seaham Weir and Raymond Terrace on the Williams River produced slightly weaker correlations with a similarity level of 0.92.

Table D-3 Skill parameters for water level verification

	Stockton Bridge	**Hexham Bridge**	**Williams River, Raymond Terrace**	**Seaham Weir, Williams River**
Skill Parameter	0.97	0.98	0.92	0.92

Salinity

The ELCOM model was also calibrated for salinity during the period 23 April to 20 May 1998 (inclusive). The results of the calibration included time series of salinity over a 28 day period at seven (7) monitoring sites within the Lower Hunter River Estuary downstream of Tourle Street Bridge (refer Figure D-1).

The time and depth of salinity measurements available within the calibration period were not available. The variability in the magnitude / concentration of salinity throughout the day can be significant especially for sites influenced by incoming tides. Given the temporal uncertainty of the measured data, all measurements were assumed to be collected during the middle of the day and plotted at 12pm (noon).

Long section profiles were also prepared to assist with interpretation of the calibration results. The minimum, maximum and average value of modelled data at regular intervals along the Hunter River (via the South Arm) between Maitland and Newcastle Harbour was prepared to highlight the range of values predicted throughout the day.

To assist with interpretation of the long section profiles, times series of major river inflows and local catchment runoff are presented at the top of each figure. Daily hydrographs of major river inflows correspond to river gauging from the Hunter River at Oakhampton, Paterson River at Gostwyck and Williams River at Glen Martin. A hydrograph of minor inflows is also presented showing the contribution of catchment runoff to the river estuary during rainfall events occurring during April and May 1998. Rainfall data presented on each figure corresponds to synthetic daily rainfall data (SILO) near the study area at Shortland.

Salinity concentrations modelled at the seven calibration sites (refer Figure D-1) agree well with measured data collected during the calibration period. The results indicate that the ELCOM model responded well to major river inflows (i.e. 1 May to 12 May and 17 May to 20 May) from the Hunter River, Paterson River and Williams River. The magnitude and timing of changes in salinity concentrations modelled during these two large river inflow events match measured data values well. Overall, salinity concentrations simulated are considered representative of measured responses during periods of high river flows.

The results also indicated the model responds well to local catchment runoff entering the river estuary during smaller rainfall events. As an example, salinity concentrations simulated at Site 27 (near Hannell Street Bridge) compared well with spot measurements of salinity collected in the area.

Salinity concentrations at this location recover from initial values of less than 6ppt to values in the range of 27ppt to 30ppt (indicative of a well mixed estuarine environment). On May 1, a rapid decrease in salinity was predicted in response to catchment runoff from the upstream Styx Creek Catchment which maintains salinity concentrations at values less than 1ppt until 5 May (refer to Figure D-1). Following inputs from the upstream catchment during this rainfall period, salinity concentrations increase in response to flushing of more saline ocean waters. On the 7 May, salinity concentrations are predicted to again decrease slightly due to freshwater river inflows reaching the lower estuary following major discharges from the Hunter, Paterson and Williams Rivers. Over the following 8 days, the concentration of salinity continues to increase until a rapid decrease occurs in response to a second major river inflow and local catchment runoff.

Long section profiles of salinity concentrations at 5 day intervals are presented in Figure D-2. The results showed adjustment of the longitudinal salinity profile over the first 5 days as the system begins to equilibrate in response to tidal intrusions and freshwater inflows from the ocean and river inflow boundaries respectively. The longitudinal salinity profile for the 3 May showed evidence of some freshwater river inflows entering the upper reaches of the estuary which begin to alter the salinity profile in this area. During periods of significant freshwater inflow from the Hunter River, Paterson River and Williams River, the ability of tidal intrusions to propagate upstream is reduced. As freshwater inflows are conveyed downstream, the influence of downstream tidal intrusions is further dampened which is evident by the salinity profile modelled on the 8 May. The longitudinal salinity profile five days later shows some recovery in the lower estuary following major freshwater inputs with salinity concentrations in the range of 24ppt to 35ppt. Salinity profiles on the 18 May and 20 May show the influence of a second larger freshwater event which peaks on the 20 May. Salinity concentrations for May 20 reach a maximum of approximately 10ppt at the ocean boundary with an average salinity concentration of 5ppt for the day. Salinity data collected on this day falls within the range of salinity concentrations predicted within the lower estuary.

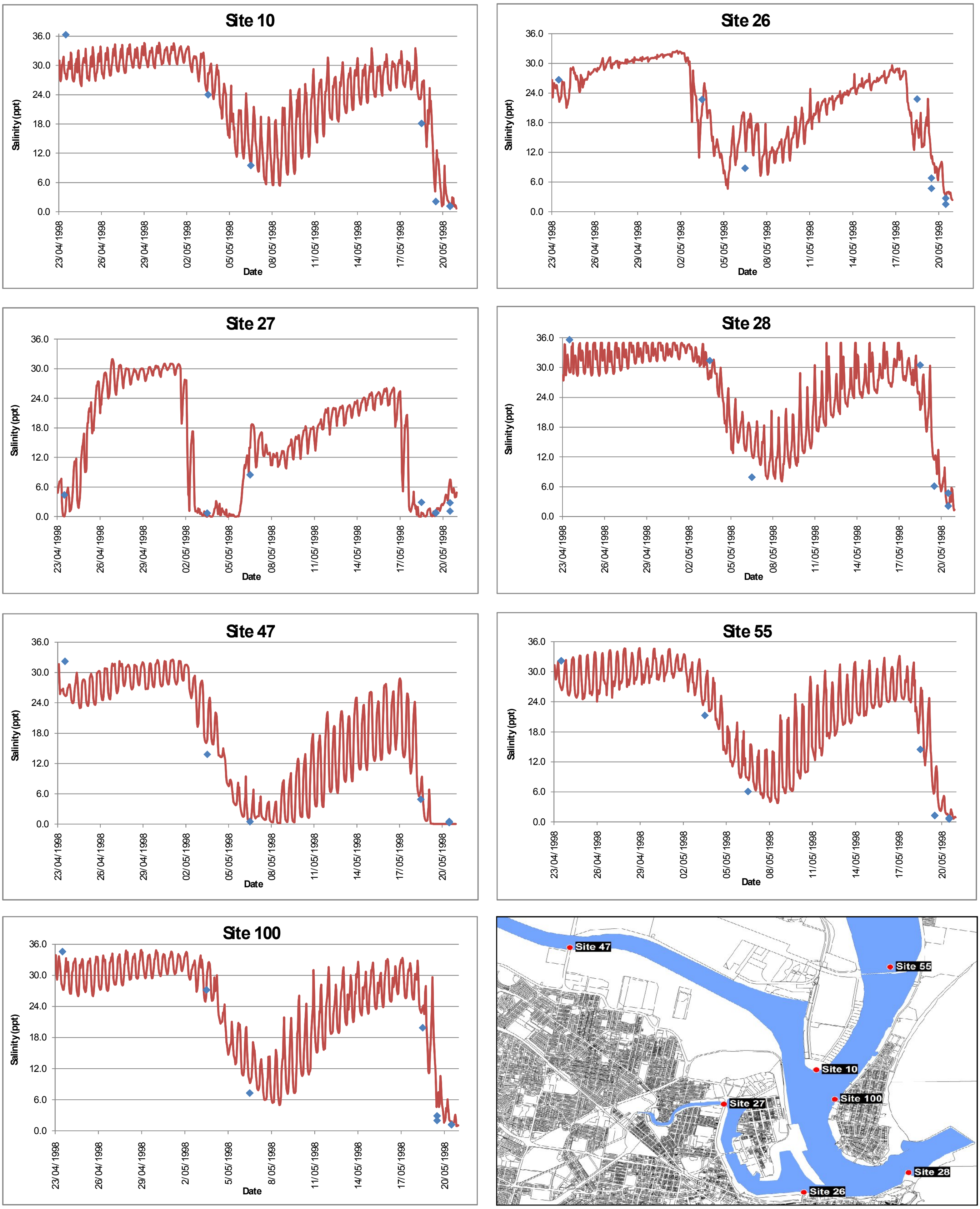

Figure D-1 Salinity Concentrations at Calibration Sites

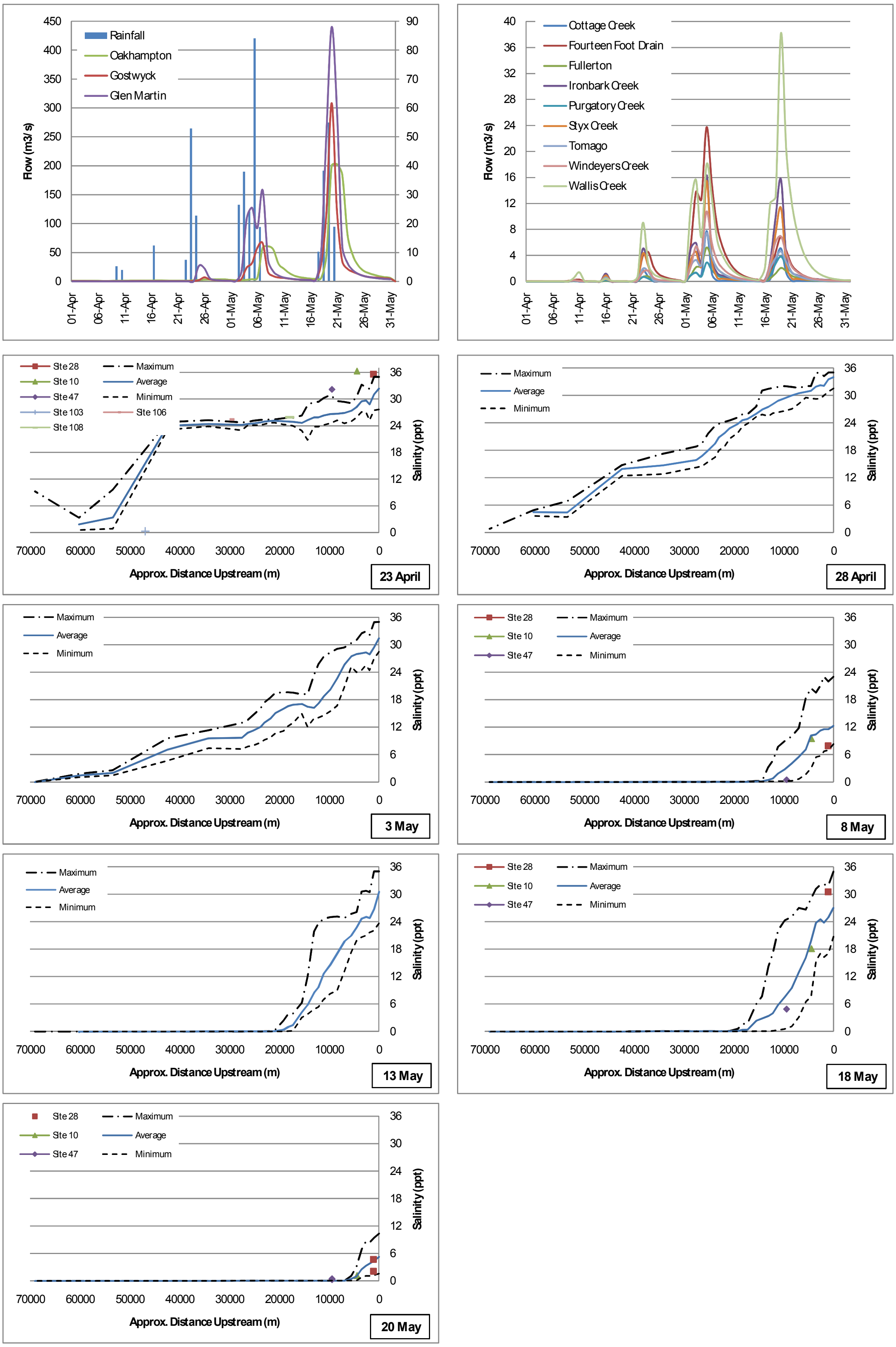

Figure D-2 Long section profile of salinity concentrations

Appendix B- 4 ADDITIONAL ELCOM MODELLING RESULTS

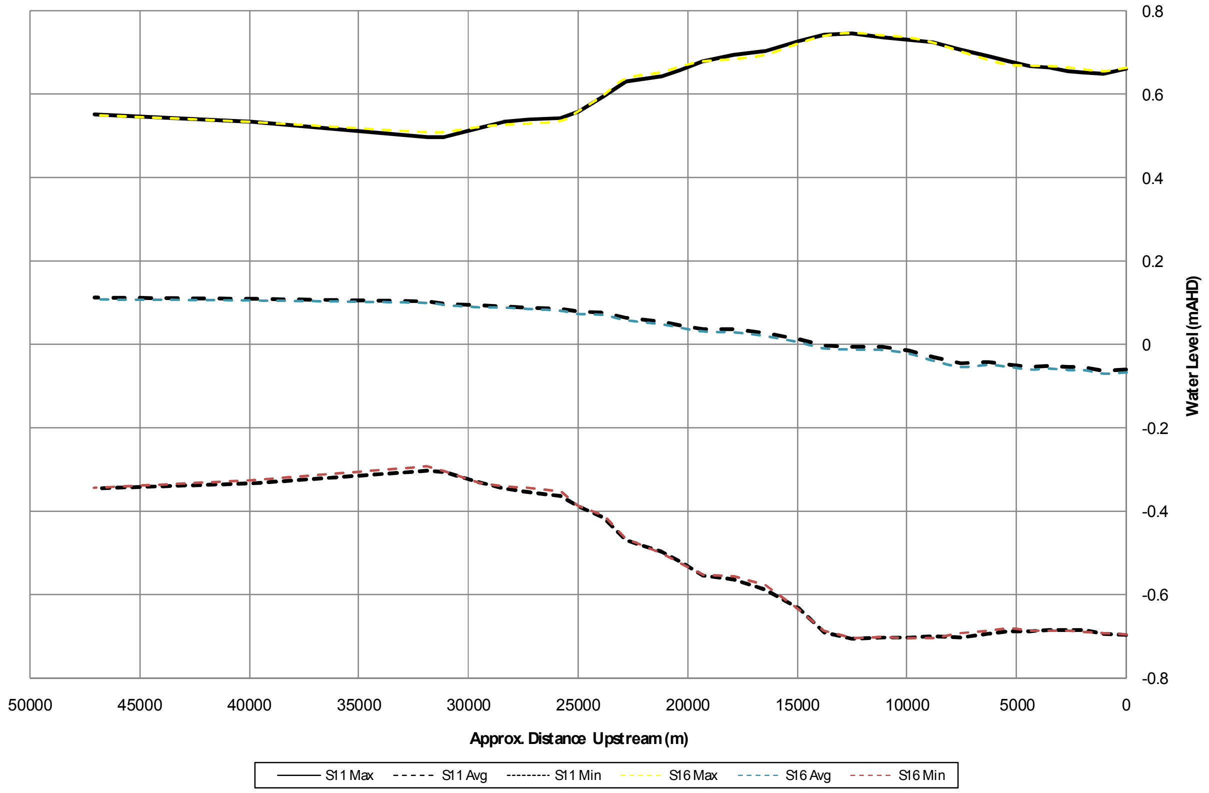

Figure E 1 Water level profile along North Arm (25%ile flow conditions)

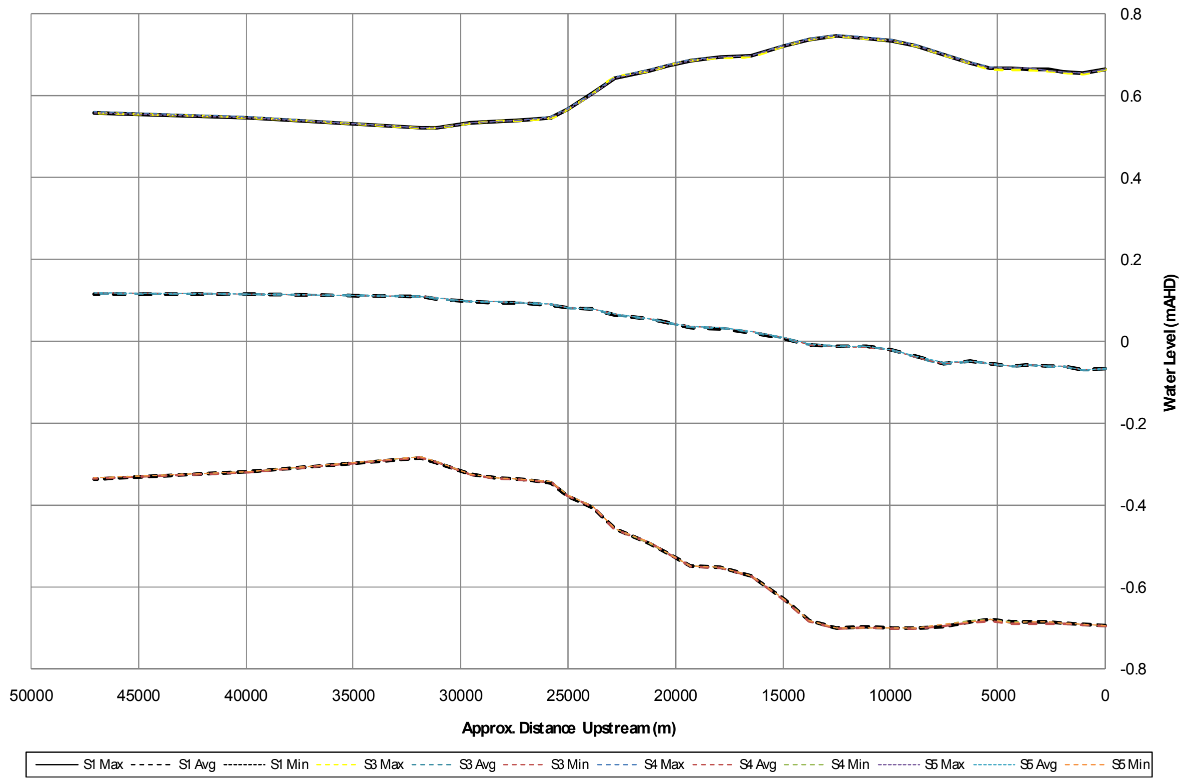

Figure E 2 Water level profile Along North Arm (50%ile flow conditions)

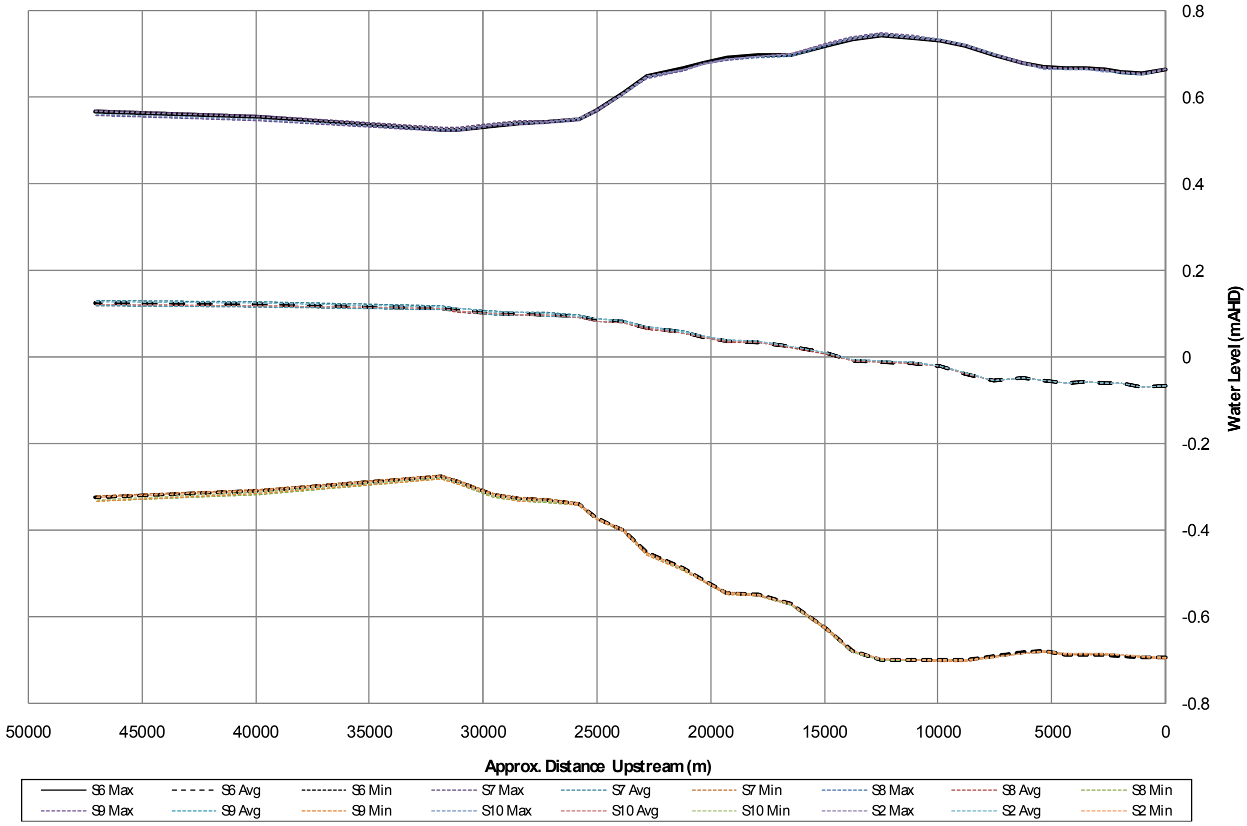

Figure E 3 Water level profile along North Arm (75%ile flow conditions)

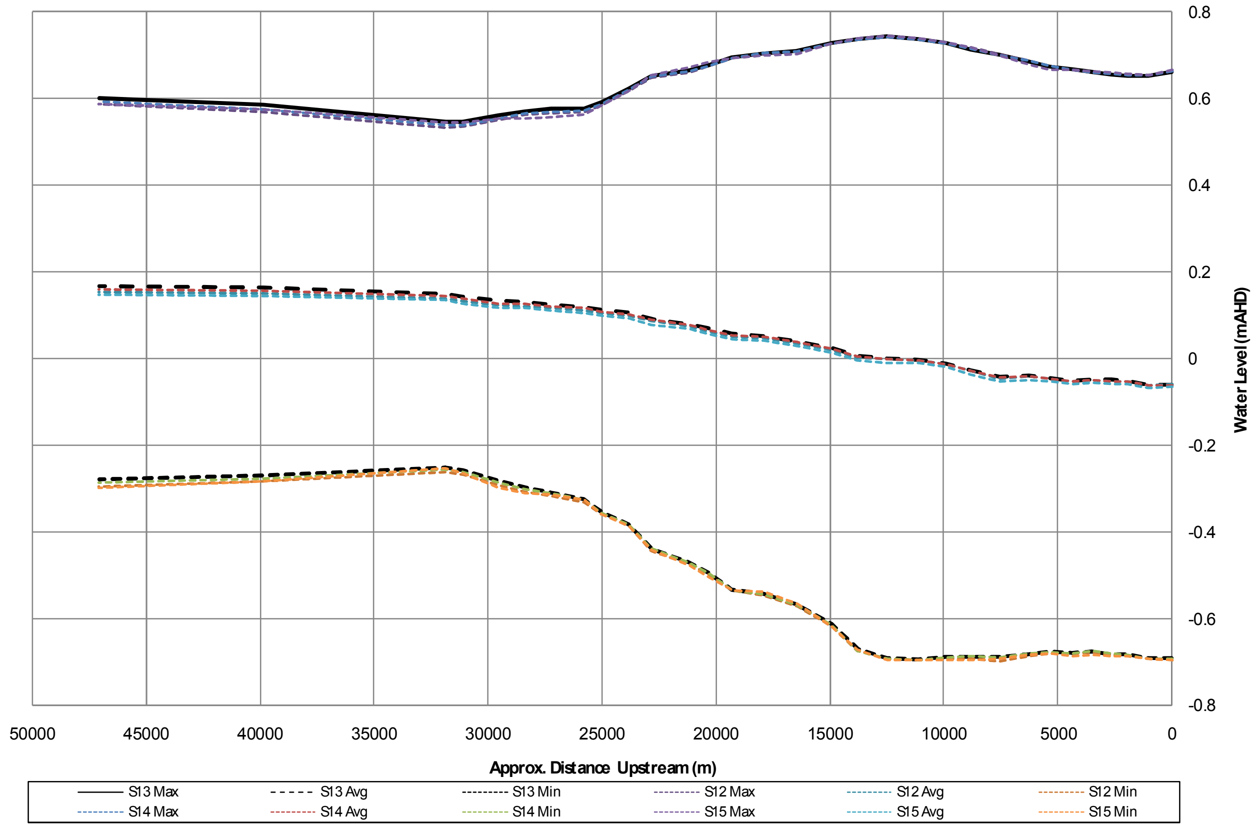

Figure E 4 Water level profile along North Arm (90%ile flow conditions)

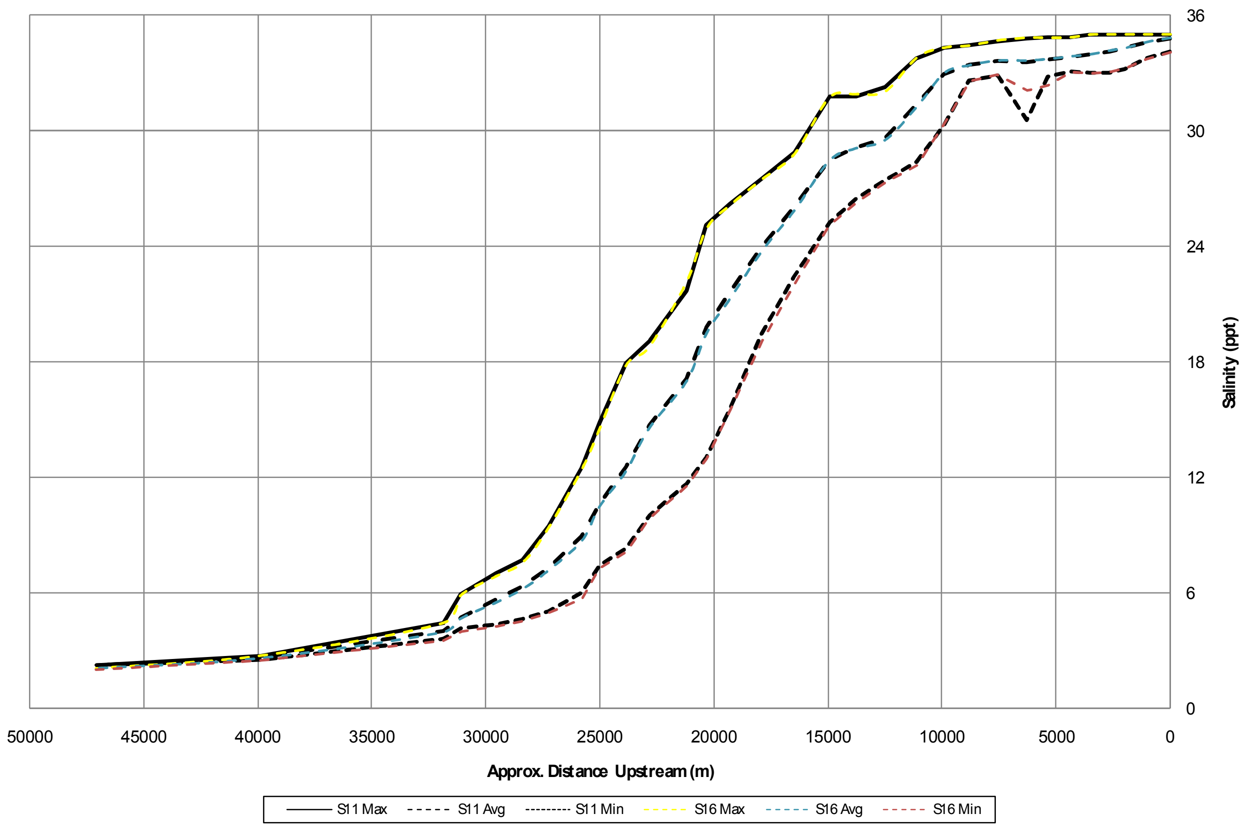

Figure E 5 Salinity profile along North Arm (25%ile flow conditions)

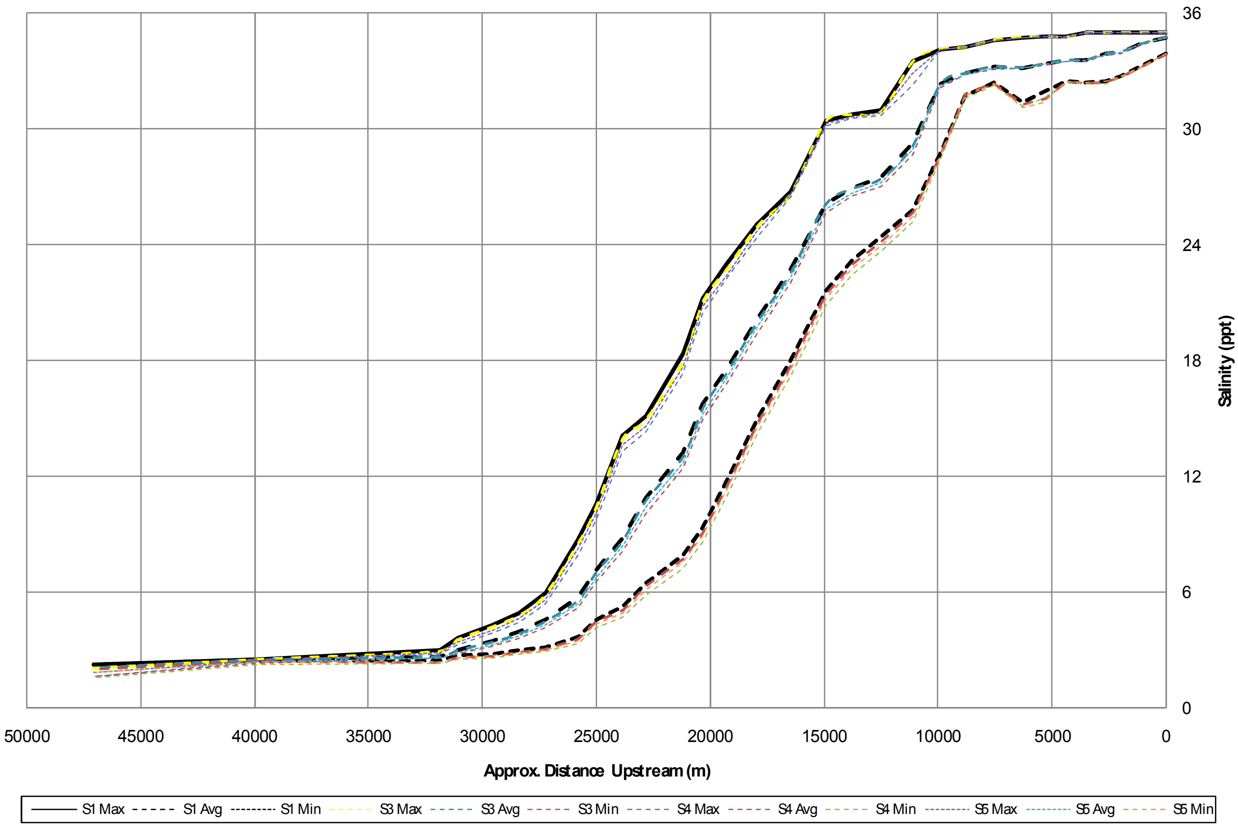

Figure E 6 Salinity profile along North Arm (50%ile flow conditions)

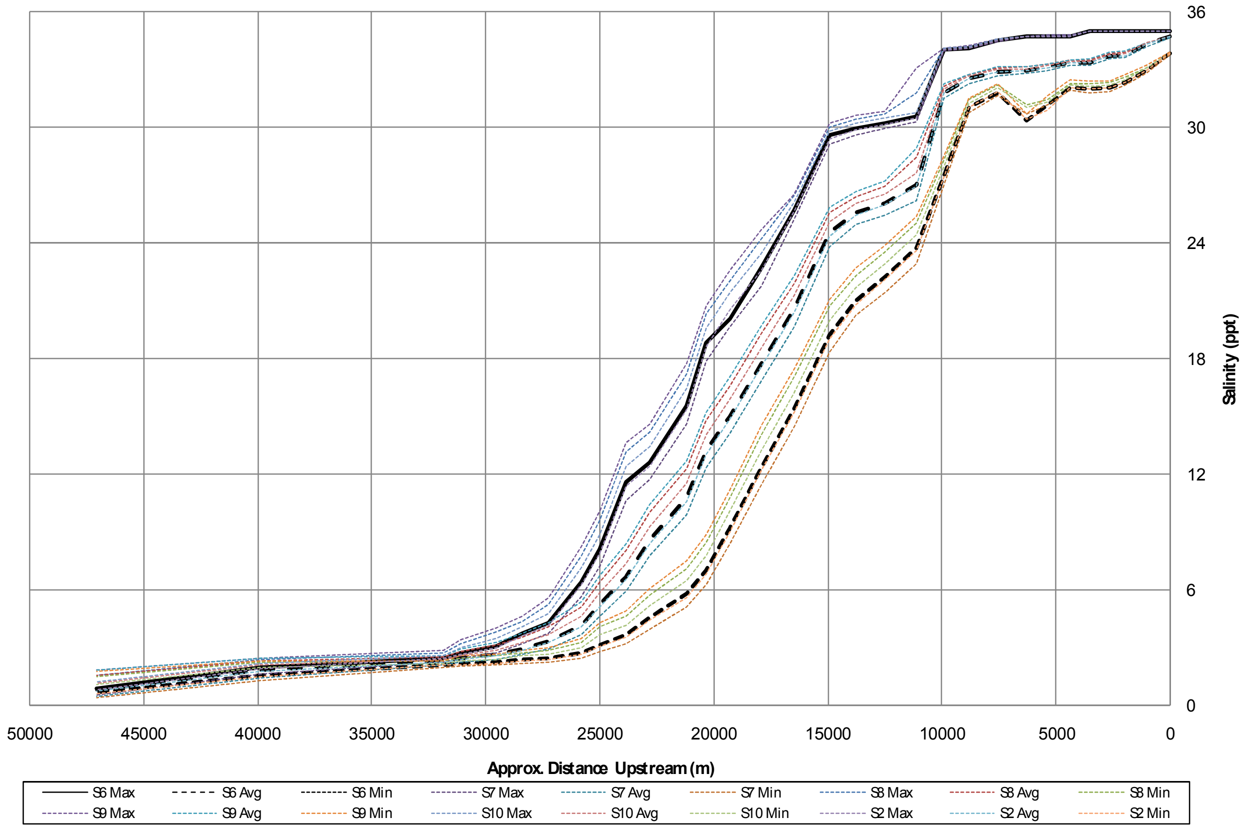

Figure E 7 Salinity profile along North Arm (75%ile flow conditions)

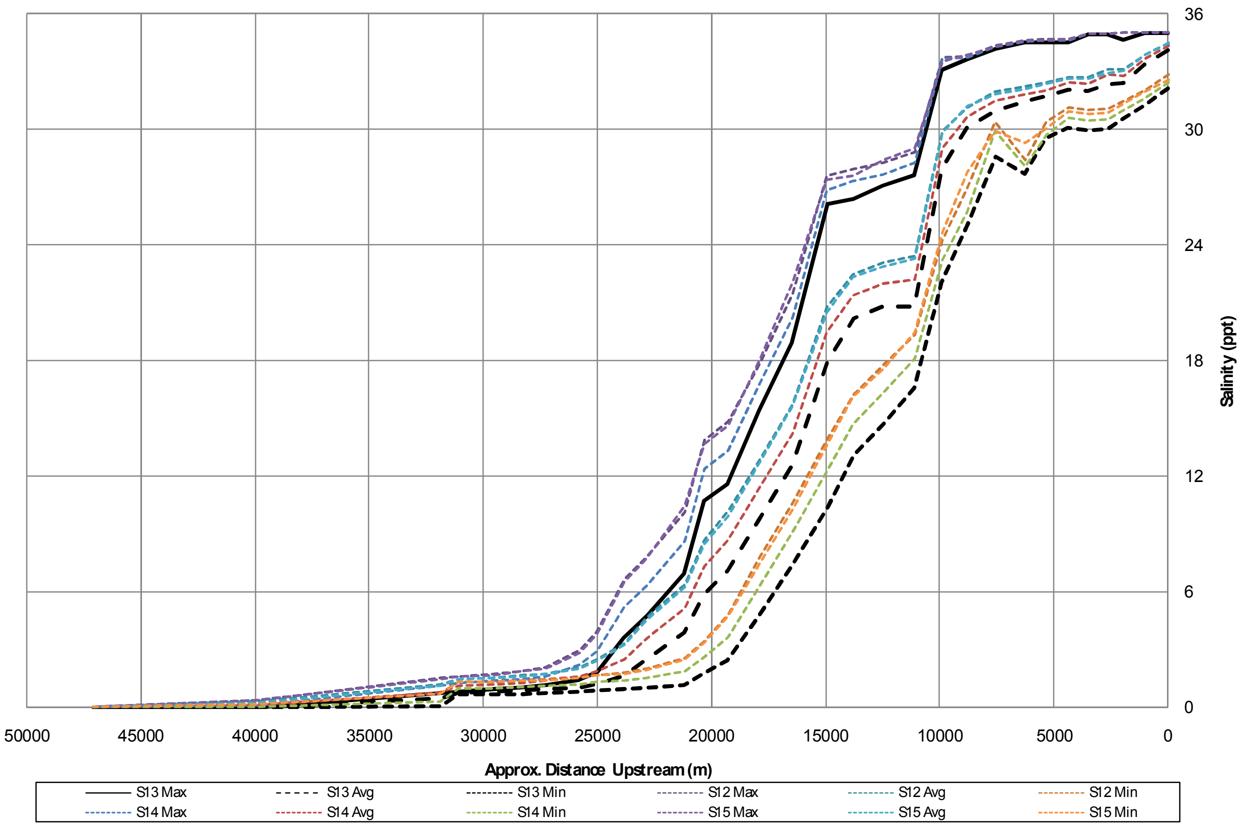

Figure E 8 Salinity profile along North Arm (90%ile flow conditions)

Appendix B-5: SUMMARY OF TIDAL PLANE AMPLITUDES

Tidal Plane	Acronym	Location	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	Mean ± SD
Higher Solstice High Water Spring	HHWSS	Stockton	1019	987	976	974	964	973	990	1008	1045	1029	997 ± 27
		Hexham	999	961	938	952	953	988	998	980	1085	1063	992 ± 48
Mean Higher Water Spring	MHWS	Stockton	658	625	609	613	599	610	628	648	681	669	634 ± 28
		Hexham	651	614	584	602	602	636	650	637	736	717	643 ± 49
Mean High Water	MHW	Stockton	530	497	483	489	473	484	502	522	556	543	508 ± 28
		Hexham	645	507	480	499	502	532	546	535	634	611	539 ± 49
Mean High Water Neap	MHWN	Stockton	402	369	357	364	347	357	377	396	432	416	382 ± 28
		Hexham	441	401	376	397	402	428	442	433	532	505	436 ± 49
Mean Sea Level	MSL	Stockton	1	-36	-47	-41	-62	-45	-24	-11	33	18	-21 ±31
		Hexham	55	19	-16	0	9	32	46	41	137	110	43 ± 48
Mean Low Water Neap	MLWN	Stockton	-400	-440	-450	-445	-471	-448	-424	-418	-366	-379	-424 ± 34
		Hexham	-322	-362	-407	-397	-383	-365	-350	-352	-258	-285	-349 ± 47
Mean Low Water	MLW	Stockton	-528	-568	-576	-570	-597	-574	-550	-545	-491	-506	-551 ± 34
		Hexham	-437	-469	-511	-500	-483	-469	-454	-453	-360	-390	-453 ± 47
Mean Low	MLWS	Stockton	-656	-696	-703	-695	-723	-701	-675	-671	-615	-633	-677 ± 34

Water Spring		Hexham	-542	-576	-615	-602	-583	-573	-558	-555	-463	-496	-556 ± 47
Indian Spring Low Water	ISLW	Stockton	-914	-955	-965	-953	-984	-960	-934	-928	-875	-889	-936 ± 35
		Hexham	-790	-823	-868	-853	-834	-824	-807	-800	-712	-744	-806 ± 48

Appendix C: Hunter Estuary Ramsar Information Fact Sheet

Information Sheet on Ramsar Wetlands (RIS)

http://www.environment.gov.au/cgi-bin/wetlands/report.pl?smode=RAMSAR&ramsar_refcodelist=24

Categories approved by Recommendation 4.7 of the Conference of Contracting Parties.

To save this report to your computer, use File/Save as, and use a .TXT file extension.

Hunter Estuary Wetlands - 24

1. Form compiled by:	The Wetlands Centre Ltd, PO Box 292, Wallsend NSW 2287, Phone: 02 4055 8673, Fax: 02 4950 0497, Contacts: Christine Prietto and Helen Aitchison. NSW National Parks and Wildlife Service, PO Box 1967, Hurstville NSW 2220, Phone: 02 9585 6692, Fax: 02 9585 6495, Contact: Penny Brett. NSW National Parks and Wildlife Service, Hunter Coast Area, Locked Bag 99, Nelson Bay NSW 2315, Phone: 02 4984 8200, Fax: 02 4981 5913, Contact: Mick Murphy.
2. Sheet last modified:	October 2002.
3. Country:	Australia
4. Name of Ramsar site:	Hunter Estuary Wetlands
5. Map of site included?	a) hard copy: b) digital (electronic) format:
6. Geographical coordinates:	Kooragang: Latitude: 32 degrees 51' S; Longitude: 151 degrees 46' E. Shortland: Latitude: 32 degrees 53' S; Longitude: 151 degrees 41' E.
7. General Location:	The Hunter Estuary Wetlands Ramsar site comprises Kooragang Nature Reserve (designated to the Ramsar list in 1984) and Shortland Wetlands. Although the sites are not contiguous they have significant linkages. Kooragang Nature Reserve is located in the estuary of the Hunter River, approximately 7km north of Newcastle on the coast of New South Wales. Shortland Wetlands are located in the Ironbark Creek Catchment in the suburb of Shortland, 12km northwest of Newcastle and 2.5 km from Kooragang Nature Reserve. The Ironbark Creek Catchment, which also includes Hexham Swamp, is a sub-catchment of the Hunter Estuary. The two sites are linked hydrologically and by a wildlife

corridor consisting of Ironbark Creek, the Hunter River and Ash Island (NPWS 1998). The sites are complementary as together they provide a representative range of wetland types found in coastal estuaries within the Sydney Basin biogeographic region. They provide habitat for a great diversity of flora and fauna species that are common to both sites and are highly used by numerous waterbird species for feeding and roosting. The population of Newcastle in 2000 was over 140,000.

8. Elevation: 0-10m ASL.

9. Area: Kooragang - 2,926 hectares; Shortland - 45 hectares.

10. Overview: The Hunter Estuary Wetlands Ramsar site comprises Kooragang Nature Reserve (designated to the Ramsar list in 1984) and Shortland Wetlands. The boundary of Shortland Wetlands is 2.5 km from Kooragang Nature Reserve and is connected to it by a wildlife corridor consisting of Ironbark Creek, the Hunter River and Ash Island. Kooragang Nature Reserve lies in the estuarine section of the Hunter River. The Reserve and surrounding areas have become known as one of the most important bird study areas in New South Wales. The area is extremely important as both a feeding and roosting site for a large seasonal population of Palaearctic shorebirds and as a waylay site for transient migrants. The site also supports a significant number of birds that over-winter. Shortland Wetlands is a small but unique complex of wetland types surrounded by urban development along three boundaries. Previously degraded, this urban wetland has been restored with the key objectives of wetland conservation, education and community involvement. The site provides habitat for a diverse range of wetland species, including waterbirds at a critical stage of their lifecycles and threatened species.

11. Ramsar Criteria: 1, 3, 4, 6,

12. Justification of criteria under point 11: Criterion 1: Shortland Wetlands is unique in that it has, within its 45ha site, a combination of high conservation value near-natural wetlands (Melaleuca Swamp Forest, freshwater reed marsh, coastal estuarine mangrove-lined creek) and high conservation value artificial wetlands (constructed freshwater lagoons, coastal estuarine Casuarina-lined channel, model farm dam). It is the only complex of this type found within the Sydney Basin biogeographic region. The Melaleuca Swamp Forest in particular represents a wetland type that, although once very widespread, is poorly represented in the Sydney Basin biogeographic region. Criterion 3: Kooragang Nature Reserve is ecologically diverse and represents a significant genetic pool for wetland species in the Sydney Basin biogeographic region. Winning (1996) identified 112 species of vascular plants at Kooragang Island (Appendix 4) which form many distinct habitat types (see Category 16). The Mangrove and Saltmarsh areas are particularly good examples of these plant communities. The most significant wetland plant community at Shortland Wetlands is the Melaleuca Swamp Forest, dominated by Broad-leaved Paperbark (Melaleuca quinquenervia). The Swamp Forest is remnant of a plant community that was once very wide spread in this area and is now poorly represented in the Sydney Basin biogeographic region. The Hunter Estuary Wetlands are also important for maintaining a high diversity of birds within the biogeographic region with over 250 species recorded (Appendix 1). Criterion 4: Kooragang Nature Reserve is widely recognised for its importance in the conservation of migratory birds (Geering 1995; NPWS 1998). At least 38

	species of migratory birds recorded at Kooragang and 21 species of migratory birds at Shortland Wetlands are presently listed under International treaties including the Japan-Australia and China-Australia Migratory Bird Agreements (JAMBA and CAMBA) (Appendix 1). In 2000, 4,800 migratory shorebirds were recorded in the Hunter Estuary (Straw 2000). Kooragang Nature Reserve regularly supports 15 species of migratory shorebird. Shortland Wetlands regularly provides habitat for at least seven species of migratory shorebird, particularly when muddy margins of the ponds become exposed (Appendix 1). Kooragang and Shortland Wetlands also support a large number of species at a critical seasonal stage of their breeding cycle. Twenty-four of the 28 bird species recorded breeding at Shortland also occur at Kooragang (see Appendix 2). The site provides refuge for a number of species during periods of critical inland drought. These species include Freckled Duck (Stictonetta naevosa); Pink-eared Duck (Malacorhynchus membranaceus); Australian Pelican (Pelecanus conspicillatus); and Glossy Ibis (Plegadis falcinellus) (Albrecht and Maddock 1985). The site is also important for local resident ducks, herons and other waterbirds, with up to 2000 ducks recorded at Shortland Wetlands during dry periods (Winning 1989). Criterion 6: Kooragang Nature Reserve regularly supports between 2% and 5% of the East Asian-Australasian Flyway population of Eastern Curlew (Numenius madagascariensis), with counts ranging from 320 to 900 birds between 1989 and 2000 (Straw 2000). The 1% population threshold for this species is 210 individuals (Rose and Scott 1997).
13a. Biogeographic region:	
13b. Biogeographic regionalisation scheme:	Environment Australia 2000. Revision of the Interim Biogeographic Regionalisation of Australia (IBRA) and the Development of Version 5.1. - Summary Report. Department of Environment and Heritage, Canberra.
14. Physical Features:	Kooragang Nature Reserve: Kooragang Nature Reserve comprises Kooragang Island and Fullerton Cove, two areas that lie in the estuarine section of the Hunter River. Kooragang Island originally consisted of several smaller islands or bars (NPWS 1998). Attempts to control deposition and siltation of the Newcastle port area resulted in the artificial filling of channels and the construction of training walls (NPWS 1998). Fullerton Cove is a large, shallow embayment north of Kooragang Island. It has a maximum depth of two to three metres at its centre and at low tide large areas of mudflats are exposed. The lower Hunter River is a barrier estuary formed by the deposition of sediments in swamps and flats lying between the inner and outer coastal barrier sands (NPWS 1998). The sediments on Kooragang Island and adjacent estuarine areas comprise black silty and highly saturated soft clays to a depth of about 2m which are underlain by a light grey and silty sand (NPWS 1998). Salinities may vary from 70% in evaporative salt marsh areas to 8% behind levees where the soil is generally more fertile and regularly flooded by fresh water (NPWS 1998). Most soils of Kooragang Island are only slightly acidic, although small areas of sandy clays supporting brackish swamps can reach significantly low pH and create the potential for acid sulphates to occur, should they be permanently dried out or drained (NPWS 1998). The tidal variation for Kooragang Island is 0.1m to 2m. Average annual rainfall at Williamtown (nearest gauging station) is 1088 mm. The mean temperature ranges from 22.7 degrees C to 12.2 degrees C. Shortland

Wetlands: Shortland Wetlands is a restored and remnant wetland bounded on the south by the suburb of Shortland, on the east by a major arterial road, on the north by an old landfill site and on the west by Ironbark Creek and Hexham Swamp. There are strong ecological links between Hexham Swamp, Shortland Wetlands and the western end of Kooragang Nature Reserve (NPWS 1998). Shortland Wetlands is situated on Quaternary estuarine/lacustrine sediments including silts and clays (Matthei 1995). The site consists of seven discreet but interconnected ponds and a freshwater channel. Four of these ponds are natural and three are man-made. The man-made ponds have been constructed on old landfill sites that were subsequently used as sporting fields. Water flows from adjacent urban areas into the wetlands and is controlled by various methods. It flows from south-east to north-west through the ponds and exits the site into Ironbark Creek. The average size of the ponds is 14 sq. m and each pond varies in depth from 0.4m to 1m (Bischof and Brown 1996). Most ponds are permanent, with varying water levels, although the Reed Marsh dries bi-annually. Water may be pumped into ponds from a nearby channel but this is rarely done. There is no tidal variation. The catchment area is not known but includes the urban suburbs of Shortland, Waratah West and Warabrook. Water quality is consistent with natural, freshwater ponds. Abiotic measurements indicate that pH is generally between 6.2 and 7.9. Water temperature varies seasonally between 14 degrees C and 24 degrees C and turbidity is usually less than 10ntu. Salinity is less than 1% (Grace and Francesconi 1997). The water flowing from Shortland Wetlands enters Ironbark Creek and subsequently the Hunter River. At peak flood times Shortland Wetlands becomes a storage area for approximately 42,000 cu. m of water (Sinlaparommard 1999).

15. Catchment Area:

16. Hydrological Values:

Kooragang Nature Reserve: Kooragang Island originally consisted of seven islands that were mostly separated by narrow mangrove lined channels. One of the larger channels was Moscheto Creek which linked the north and south arms of the river. In the 1950s the islands were reclaimed and as a result the hydrological regime of what became 'Kooragang Island' and the Hunter Estuary was modified (NPWS 1998). Restrictions in tidal, normal and flood river flows have resulted from the reclamation. Flows through the south arm of the Hunter River have increased. Moscheto was occluded at its southern end by an industrial railway to become tidal via the north arm only (NPWS 1998). In 1970 a levee bank was built around Fullerton Cove in an effort to ameliorate flooding in low-lying areas of Newcastle, downstream of Kooragang Island (NPWS 1998). Drains were installed to reclaim the significant wetland areas behind the levees for agriculture. This levee provides some protection to agricultural lands during minor floods but the levee is overtopped in major floods (NPWS 1998). Shortland Wetlands: Shortland Wetlands are a natural drainage depression, a remnant of extensive tidal and floodplain wetlands that once extended east of Ironbark Creek. Changes in the natural flow regime have been caused by the construction of floodgates on Ironbark Creek and a drainage canal from Sandgate Road to Ironbark Creek, the establishment of a garbage dump, the construction of a power transmission line and associated access roads and development as a sporting complex (Winning 1989). These actions restricted the entry of saline tidal water, changing the wetlands from a brackish to fresh water regime (Winning 1989). All of these actions pre-date the establishment of Shortland Wetlands as a Wetlands Centre. Water flowing into Shortland Wetlands today is generated by local rainfall and run-off from nearby suburbs. Stormwater pipes and culverts collect stormwater from lands and suburbs to the south, east and north and deliver water to the Wetlands (NCC 2000). Shortland Wetlands delivers water to Ironbark Creek or to a constructed channel via a series of drainage points along Ironbark Marsh and on the northern boundary of the site. However, the flow occurs only after periods of heavy rain or when Ironbark Marsh is at full capacity (Sinlaparommard 1999). Shortland Wetlands is valuable for the storage of rainfall and stormwater which provide habitat for significant wetland fauna and flora species. The Wetlands enable the recycling of nutrients that enter the site in stormwater or through the activity of nesting birds.

17. Wetland Type: D, E, F, G, H, 2, J, K, Ss, Ts, Xf, I

18. Ecological Features: Kooragang Nature Reserve: Kooragang Nature Reserve is ecologically diverse and represents a significant genetic pool for wetland species in the Sydney Basin bioregion. Habitat types mapped within the site (Briggs, Dames and Moore, Outhred and Buckney in NPWS 1998) include: Mangrove forests dominated by Grey Mangrove (Avicennia marina) and some River Mangrove (Aegiceras corniculatum); Saltmarsh dominated by Samphire (Sarcocornia sp.) and Saltwater Couch (Sporobolus virginicus). The saltmarsh community to the west of Fullerton Cove was once the largest in the region (Moss 1983). The present levee bank and drains have led to it being replaced with drier pasture grasses such as Paspalum (Paspalum vaginatum), Buffalo, Kikuyu (Pennisetum clandestinum) and Couch (Cynodon sp.); Saline and freshwater pastures are dominated by Couch and other agricultural grasses, sedges and introduced weeds; Swamp Forests consisting of Swamp She-oak (Casuarina glauca) and Paperbarks (Melaleuca spp.) that are now limited; Rainforest communities exist in remnants on Kooragang Island. Isolated individual Fig trees (Ficus spp.) and Cabbage Tree Palms (Livistona australis) occur; Brackish swamps and standing open water containing Sedges (Scirpus spp.) and other aquatic species; and Other important habitats include standing open water, mudflats, sandy beaches and rock retaining walls. Shortland Wetlands: Shortland Wetlands were originally part of the estuarine wetlands of lower Ironbark Creek, with saltmarsh and mangroves extending well into the present site. Today the site represents a remnant wetland that maintains its ecological connections to fresh, brackish and saline wetlands elsewhere in the estuary through its connection to Ironbark Creek. Although the floodgates on Ironbark Creek are still in place, their management is to be modified in the near future, allowing increased tidal flows into the creek system. This may enhance the brackish wetland values on the site. The main habitats and vegetation types on the site include restored semi-permanent/seasonal freshwater ponds and marshes, natural semi-permanent/seasonal brackish ponds and marshes, freshwater swamp forests and a coastal estuarine creek. Variations in water levels in the ponds result in a significant range of vegetation succession across the site annually, contributing to biodiversity values, especially in macro-invertebrate populations. Over 150 flora species occur on the site (Appendix 4) within 22 vegetation communities (Beretta 1998). Floral communities include: Closed Commersonia Forest, Closed

Mangrove Forest, Open Planted Rainforest, Casuarina Forest, Open Melaleuca Swamp Forest, Open Woodland, Wet Heath, Banksia Shrubland, Acacia Shrubland, Water Couch Wet Meadow, Closed Typha Rushland, Closed Phragmites Reed Swamp, Juncus Rushland and several large remnant Eucalypts. The site contains a high diversity of original and rehabilitated plant communities and has undergone a committed landscaping effort (see Category 17). Since 1996 over 32,000 trees have been planted on the site into four zones: Visitor Centre Zone (native Australian plants); Constructed Wetlands (plants native to the local region); Natural Wetlands (plants native to the site); and Rainforest Zone (a rehabilitated rainforest). These plantings have significantly changed the landscape, enhancing natural processes on the site. The distribution and abundance of these plant communities create a stable and complex ecosystem that contributes to hydrologic processes, soil stabilisation and fauna diversity. The reedy margins provide breeding and feeding areas for waterfowl and vegetation in shallow pool margins provides foraging sites for shorebirds.

19. Noteworthy Flora:

Kooragang Nature Reserve: A list of flora species compiled by Winning (1996) identified 112 species of vascular plants at Kooragang Island (Appendix 4) which form many distinct habitat types (see Category 16). The Mangrove and Saltmarsh areas are particularly good examples of these plant communities. The estuarine herb Zannechellia palustris has been recorded immediately adjacent to the western end of the Reserve. This herb is only found in the Newcastle/Lake Macquarie area and along Ironbark Creek. The rainforest vine Cynanchum elegans is listed as Endangered under both State (TSC Act) and Commonwealth (EPBC Act) legislation. It occurs adjacent to the western boundary of the Reserve and has only been recorded in 40 other sites in NSW (NPWS 1998). Shortland Wetlands: The most significant wetland plant community at Shortland Wetlands is the Melaleuca Swamp Forest, dominated by Broad-leaved Paperbark (Melaleuca quinquenervia). The Swamp Forest is remnant of a plant community that was once very wide spread in this area and is now poorly represented in the Sydney Basin bioregion. Shortland Wetlands is significant for a range of plant communities that have been successfully re-introduced to the site, including: Open Rainforest developed around remnant rainforest species dominated by Turpentine (Syncarpia glomulifera), Lilly Pilly (Acmena smithii), Scentless Rosewood (Synoum glandulosum), Cheese Tree (Glochidion ferdinandi) and Bleeding Heart (Omalanthus populifolius); Open Eucalypt woodland dominated by Swamp Mahogany (Eucalyptus robusta), Red Bloodwood (Eucalyptus gummifera) and Grey Gum (Eucalyptus punctata); Melaleuca Shrubland dominated by Ball Honeymyrtle (Melaleuca nodosa), Swamp Paperbark (Melaleuca ericifolia), Prickly-leaved Paperbark (Melaleuca styphelioides), and Swamp Millet (Isachne globosa); Acacia Shrubland dominated by Sydney Golden Wattle (Acacia longifolia); Wet Heath dominated by Callistemon citrinus, Banksia robur and Christmas Bells (Blandfordia grandiflora); and Casuarina Forest dominated by Swamp Oak (Casuarina glauca).

20. Noteworthy Fauna:

The Hunter River Estuary is renowned for its birdlife. Over 250 species of birds have been recorded across the Hunter Estuary Wetlands site (Appendix 1). The occurrence of migratory waterbirds is of particular importance. In 2000, 4,800 migratory shorebirds were recorded in the Estuary (Straw 2000). At least 45 migratory species presently listed under the Japan-Australia Migratory Bird

Agreement (JAMBA) and/or the China-Australia Migratory Bird Agreement (CAMBA) have been recorded at the site including 38 species at Kooragang and 21 species at Shortland, with 14 of these species common to both areas (Appendix 1). The Estuary has supported more than one percent of the Australian populations of sixteen migratory wading species (Smith 1991) and based on this criterion has been ranked as the fifth most important site for shorebirds in Australia (Watkins 1993). It has also been recognised as the most important area for shorebirds in NSW (Smith 1991). The site provides habitat for numerous threatened species listed under the NSW Threatened Species Conservation Act 1995 (TSC Act) (see Appendix 1). The Green and Golden Bell Frog (Litoria aurea) is also listed as vulnerable nationally under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). A project is currently underway to re-introduce the Bell Frog to Shortland Wetlands. The Australasian Bittern (Botaurus poiciloptilus) is also listed as vulnerable globally (IUCN 2000) and the Red Goshawk (Erythrotriorchis radiatus) is vulnerable nationally (EPBC Act). Threatened species (under the TSC Act) include Black-necked Storks (Ephippiorhynchus asiaticus), Australasian Bittern, Comb-crested Jacana (Irediparra gallinacea) and Magpie Geese (Anseranas semipalmata). Black-necked Storks regularly use the site during their nomadic movements throughout the lower Hunter region. Australasian Bittern occur as a small, probably breeding population, but are rarely seen because of their secretive nature. Comb-crested Jacana is a rare species within the lower Hunter region. It has been reported at Kooragang Island and is a rare visitor to Shortland Wetlands. In 1987, the Wetlands Centre initiated a re-introduction of the locally extinct Magpie Goose and now supports a breeding population of more than 100 Geese. The Centre is one of four centres hosting a Freckled Duck captive-breeding program. A total of seven mammal species have been recorded at Shortland Wetlands with only two of these being native. Several species of frogs, tortoise, skinks and snakes have been recorded at the site, all of which are common to the region (Appendix 3). Records for these species are currently not available for Kooragang. The Hunter Estuary contains about 15 species of commercially important fish, crustacea and molluscs. The industry has been estimated at around a half a million dollars annually with major components being mullet, jewfish, prawn and oyster fisheries which together provide about 8% of the NSW annual catch (NPWS 1998). Pond life at Shortland Wetlands is abundant. Six species of fish have been recorded (see Appendix 3). A wide diversity of macro-invertebrates is present including many sensitive insect larvae. Macro-invertebrate surveys routinely record molluscs, bloodworms, caddisfly larvae, gastropods, beetles, bugs, water fleas, seed shrimps, copepods and nymph forms of dragonfly, damselfly, stonefly and mayfly (Bischof and Brown 1996).

21. Social and Cultural Values:

Kooragang Nature Reserve: Kooragang Nature Reserve and the surrounding areas have become known as one of the most important bird study areas in New South Wales. The Reserve is used for both research and recreational birdwatching. Limited recreational fishing is also undertaken within the Reserve. The Worimi and Awabakal Aboriginal tribes were the earliest inhabitants of the lower Hunter Estuary (NPWS 1998). There are numerous middens and campsites scattered throughout the lower Hunter but they occur particularly along the riverbanks and within the dunes along Stockton Bight. The nearest Aboriginal sites outside the Reserve come from the dunes and coastal forests between Fullerton Cove and Stockton Bight where many and varied sites are known to occur (NPWS 1998). There are a few European historic sites within Kooragang Nature Reserve. These include concrete footings of an old munitions store on Sandy Island, a timber bridge, a mature Moreton Bay Fig associated with early farming and a half submerged timber drogher. Shortland Wetlands: Historically the site now occupied by Shortland Wetlands would have been well-used by Aboriginal people as a food and materials source due to their productive and dynamic nature. The present site was occupied by the Pambalong people, a smaller tribe of the Awabakal People (Sokoloff 1974). Shortland Wetlands contains a significant archaeological site that is believed to have been a factory site for the production of stone tools (Bangent 1990; Winning 1989). Shortland Wetlands have retained their importance in the fabric of the local community since a community campaign to save and restore the wetlands. In 1984 the actions of the local conservation group gained support for the restoration of the degraded wetlands and the development of Shortland Wetlands Centre. This was a very ambitious project at that time. Now trading as The Wetlands Centre Australia, the Centre continues to attract strong community support and involvement. The Wetlands Centre promotes wetland conservation and wise use through communication and education, passive recreation and community involvement and acts as a focal point for community-based environmental interest groups that represent valuable partnerships. The Hunter Bird Observers Club, Australian Plant Society and the Society for Frogs and Reptiles contribute expertise and resources to the sustainable management of the site. The successful restoration of Shortland Wetlands has been supported by the investment of many thousands of volunteer man-hours and valuable partnerships with relevant interest groups such as those mentioned above.

22. Land tenure/ownership: Kooragang Nature Reserve: The site is Crown Land dedicated as a Nature Reserve under the NSW National Parks and Wildlife Act 1974. Surrounding lands are a mixture of Freehold and other public authority managed lands. Shortland Wetlands: The site is owned by Shortland Wetlands Centre, Ltd, trading as The Wetlands Centre Australia, a company limited by guarantee and owned by its (600) members. It operates as a not-for-profit conservation organisation and is managed by a volunteer Board of Directors. Land ownership in the surrounding area includes residential landholders, Newcastle City Council, Hunter Water Corporation, NSW Roads and Traffic Authority, Hunter Catchment Management Trust and NSW National Parks and Wildlife Service.

23. Current land use: Kooragang Nature Reserve: The site is permanently dedicated as a Nature Reserve and is used as a nature conservation area. A substantial amount of ornithological, wetlands ecology and fisheries research together with bird watching is undertaken within the Reserve. Surrounding areas are privately owned and used for heavy industry and pastoral activities. Two areas adjoining Kooragang Nature Reserve are being rehabilitated (known as the Kooragang Wetland Rehabilitation Project) and are used for conservation purposes. Shortland Wetlands: The Shortland Wetlands site is used for wetland conservation, education and passive recreation. From 1984 the aim was to develop a wetland centre based on Slimbridge in the United Kingdom, to complement the restoration project. This project has matured alongside the restoration work. The site is well established as an education and eco-tourism destination. Providing public access for education purposes requires on-going management to assure that ecological values are not threatened. The immediate surrounding area includes residential, water delivery infrastructure, a sports ground, roads, former local government landfill site, market gardens, railway line, a cemetery, as well as significant conservation areas adjacent to the site. It is important to note that approximately one-third of the Newcastle Local Government Area is classified as wetland. However, Newcastle also has an industrial economic base, including coal imports, a working port and small, medium and heavy manufacturing.

24. Factors adversely affecting ecological character (past, present, potential):

Past/present: Kooragang Nature Reserve: Introduced animals are a moderate threat to the Reserve. Domestic dogs (Canis familiaris), foxes (Vulpes vulpes) and cats (Felis cattus) affect bird populations through direct disturbance and predation. Black Rat (Rattus rattus), Brown Rat (Rattus norvegicus) and House Mouse (Mus musculus) compete with native species in the area. Rats are also known to take both waterfowl eggs and their hatchlings as food. There are limited numbers of hares and rabbits in the Reserve, however they are a minor threat due to lack of suitable habitat. Introduced weeds are a moderate threat to the Reserve. Four weeds are established within the Reserve and include Bitou bush (Chrysanthemoides monilifera), Alligator Weed (Alternanthera philoxeroides), Water hyacinth (Eichornia crassipes) and Pampas Grass (Cortaderia selloana). Sharp Rush (Juncus acutus) occurs in part of the Reserve but is considered a minor threat. The lower catchment of the Hunter River is highly industrialised and urbanised. The mouth of the River has been developed as one of Australia's most important ports. Further industrial expansion adjacent to the Reserve is proposed and potential impacts on the Ramsar values are currently being assessed. Land development continues near the Reserve and upstream along the Hunter River and this could accelerate soil erosion and water pollution in the vicinity of the Reserve. Soil erosion and water pollution are considered moderate threats. Air pollution from nearby aluminium and steel industries is a minor threat. Oil spills are considered a major threat but to date none have occurred within the Reserve. Shortland Wetlands: In 1971, floodgates were installed in Ironbark Creek. The purpose of this installation was to mediate flood control for surrounding areas. The Hunter Catchment Management Trust is proposing to open the floodgates in an attempt to re-introduce natural water flows and a tidal influence. Modelling suggests that this will have an insignificant impact on Shortland Wetlands although it may impact slightly on the western edge of the site. Currently, the Hunter Catchment Management Trust is conducting a trial by opening the floodgates in a limited way in order to monitor change. There is potential for development of the landfill site adjacent to Shortland Wetlands that is owned by Newcastle City Council and has been closed since 1992. A proposed extension to the existing freeway to the east of the site could potentially impact on the wetland. There is, however, a buffer zone between the Ramsar site and the development proposal. Many exotic plant species occur at Shortland Wetlands (see Appendix 4). The spread of weeds may be enhanced by local residents who dump rubbish on the site, clear vegetation near their fences and plant exotic tree species. The most serious aquatic weed species include Alligator Weed (Alternanthera philoxeroides), Dock (Rumex spp.) and Pennywort (Hydrocotyle bonariensis).

Potential: Introduced animals that pose the most serious threat to native fauna at the site include the Black Rat (Rattus rattus), House Mouse (Mus musculus), Red Fox (Vulpes vulpes), domestic Cat (Felis catus), Common Myna (Acridotheres tristus), Common Starling (Sturnus vulgaris) and Mosquito Fish (Gambusia holbrooki). The Black Rat poses a threat to shore-breeding birds, shorebirds, and the Long-necked Tortoise by predating eggs and nestlings. Red Foxes have been recorded preying on juveniles of Egrets and pose a threat to other species such as ground nesting and ground feeding birds. Rabbits may enhance the effects of soil erosion and Brown Hares pose a threat to the regeneration of vegetation. Predation by Mosquito Fish is listed as a key threatening process under the NSW TSC Act 1995. It is considered a threat to the Green and Golden Bell Frog (Morgan and Butterner in NPWS 2002b) as well as macro-invertebrate communities. Some of the remnant natural wetlands on the site have exhibited signs of eutrophication, such as emission of odorous gases (e.g. Hydrogen sulphide), algal blooms and dominance by eutrophytes (e.g. Triglochin procera, Spirodela pusilla, Azolla spp.). Eutrophication may occur as a result of a concentration of nutrients, changes in water quality parameters such as pH, urban run-off and a buildup of bird faeces. The substrate of the artificial ponds may also increase eutrophication as it contains high nutrient material which was previously dumped on the site as fill.

25. Conservation measures taken:

Kooragang Nature Reserve: Since the gazettal of Kooragang Nature Reserve in 1983, 720ha have been added to the Reserve which currently totals 2,926ha. The Plan of Management (NPWS 1998) which aims to preserve and enhance the area for nature conservation has been implemented and includes: water quality and catchment management; management of native and introduced flora and fauna; wetland rehabilitation; cultural heritage; fire management; and use and promotion of the Nature Reserve. Specific conservation measures currently being undertaken, or undertaken recently, include: rehabilitation of Sandy Island for migratory shorebird roosting; mangrove removal and ongoing management of the Stockton Sandspit for shorebird roosting; artificial roost construction in Fullerton Cove; monthly shorebird monitoring; Pampas grass control is anticipated in early 2003; and a management strategy for the control of Alligator weed. Shortland Wetlands: The site was established as a conservation reserve in 1985. The site restoration has included the creation of two new ponds, development of tracks, building of structures and interpretation to support education uses. Management plans using a catchment management approach were developed and implemented to guide restoration work, on-going management and public access. A long-term revegetation plan has been implemented to improve degraded habitat and introduce new habitat types. Management is under the direction of a volunteer site committee which meets quarterly and includes staff, volunteers and technical advisors. Monitoring of a broad range of ecosystem functions and values has been intermittent. Monitoring of bird species, egret breeding and ibis roosting and recording of plant species have been maintained. The Wetlands Centre is one of four centres hosting a Freckled Duck captive-breeding program. The program began with 17 ducks and since 1993, 52 ducklings have hatched and 36 have survived. Fifteen of these have been given to Tidbinbilla Nature Reserve as part of their captive-breeding program. The restoration of the site has been used to promote broad conservation of all local wetlands. The involvement of the local community has played a major role in the restoration project, site management, project development, plantings, programs and administration. Some areas of Shortland Wetlands and Kooragang Nature Reserve (see Map 2) are covered by State Environmental Planning Policy 14, Coastal Wetlands (SEPP 14), which aims to ensure coastal wetlands are preserved and protected.

26. Conservation measures proposed:	Kooragang Nature Reserve: Rehabilitation of wetland areas within and adjacent to the Reserve have been undertaken under the auspice of the Kooragang Wetland Rehabilitation Project. The Project aims to restore and/or enhance the habitat for migratory birds and waterfowl and has proposed that: lands within the Reserve previously reclaimed for agriculture and flood mitigation are to be rehabilitated to wetland; the hydrology created by artificial regulation devices on parts of Kooragang Island are to be modified; and degraded vegetation communities in the Reserve are to be rehabilitated. Tidal regimes will be introduced into the Tomago buffer lands to increase the wetland habitat in the Nature Reserve. Shortland Wetlands: A Management Plan to guide the on-going management and wise use of Shortland Wetlands is currently being prepared. The Plan builds on and aims to enhance the management practices that have been in place since the start of the restoration project in 1984-85. The Plan is designed to accommodate the on-going involvement of local communities. The Wetlands Centre's focus on communication, education and public awareness has influenced the objectives and actions in the Plan. A key aim will be the development and implementation of a Monitoring Plan to identify changes in key factors relevant to the ecological character of the site.
27. Current scientific research and facilities:	Kooragang Nature Reserve: The only research facility in the Nature Reserve is a small bird hide at Stockton Sandspit. Kooragang Island has been the subject of a number of ecological studies undertaken by various parties including the University of Newcastle, Hunter Bird Observers Club, Shortland Wetlands Centre, Hunter Catchment Management Trust, Ironbark Creek Catchment Management Committee, Kooragang Wetland Rehabilitation Project, Hunter Water Corporation and various environmental consultancy companies. Currently research is being undertaken in the following areas: Banding and plumage studies of wading birds, water bird counts, the success of waterbird breeding and changes in migration patterns; Geomorphological changes to the Hunter River Estuary; Water quality monitoring; and Alligator weed. Shortland Wetlands: There are no active research facilities currently operating on the site. However, there is a significant body of work about the site, its development and Centre activities that has been produced by students and by technical staff employed as consultants in past years. The Wetlands Centre has produced 37 scientific publications, 4 reports, poster papers at international conferences and contributed to three books. An extensive bibliographical list of publications relating to The Wetlands Centre (Burgess 2002) is held in the Wetlands Centre Library. Research related to the site forms part of the Wetlands Centre Library collection. The library is extensive and unique. It has grown over the past 17 years to form a detailed collection of resources which describe local wetlands

	and environmental issues. The library is available to the public and is staffed by volunteers who respond to community needs. There is good potential for the on-going involvement of research students from nearby Newcastle University in projects relevant to the management of the site.
28. Current conservation education:	Kooragang Nature Reserve: Kooragang Nature Reserve offers significant opportunity for environmental education since it is readily accessible to a large number of people from Newcastle and the lower Hunter Valley. Shortland Wetlands Centre provides interpretation of the area. It also organises regular visits to the Nature Reserve for researchers and students of wetland conservation. The Kooragang Wetland Rehabilitation Project also has interpretation facilities and a model environmentally sustainable farm adjacent to the Nature Reserve. The erection of education facilities in the bird hide at the Stockton Sandspit are also proposed. Signs that outline the principles of the Ramsar Convention and the conservation values of the Ramsar Site have been erected at the site. Shortland Wetlands: The Wetlands Centre uses communication and education as key processes to promote wetland values, conservation and wise use management. Development on the site to support education includes the Visitors Centre, an extensive system of tracks, viewing platforms, decks, boardwalks and interpretation signs. An elevated birdhide provides access to nesting and roosting birds. Canoe facilities allow access to tidal creeks adjacent to the site. The Visitors Centre is a large building containing an interpretation display with live and static displays, free-standing binoculars, information booklets and brochures, a souvenir shop, cafe, facilities and offices. Disabled access is available in the Centre and on some of the walks. A Sensory Trail provides access to the wetlands for visitors with sensory impairment. The Wetlands Centre's school education program is underpinned by a valuable partnership with NSW Department of Education and Training (DET). The Wetlands Environmental Education Centre, a DET facility, manages the programs for approximately 8000 school visitors annually. Students from kindergarten to year 12 enjoy programs relevant to the NSW curriculum and their stage of schooling. The Wetlands Centre programs and achievements have resulted in a greater understanding of wetlands in the Hunter region, increasing community support for other major wetland rehabilitation projects. This provides an excellent demonstration of the role education can play to build understanding of wetland values and functions.
29. Current recreation and tourism:	Kooragang Nature Reserve: Kooragang Nature Reserve is not promoted as a tourist destination. Some limited, low impact recreational uses are permitted within the Nature Reserve and include fishing, boating and bird watching. The Nature Reserve has approximately 5000 visitors per year. Shortland Wetlands: Shortland Wetlands offer a range of outdoor recreation facilities with very easy access to high-conservation-value wetlands for visitors. Facilities include bush-walking trails, boardwalks, observation decks, elevated bird hide and canoes. As an ecotourism facility, The Wetlands Centre complements other attractions in Newcastle and provides environment-focused tourism supported by environmental education.
30. Jurisdiction & 31. Management authority:	Jurisdiction: Territorial: Government of New South Wales. Functional: NSW National Parks and Wildlife Service; Newcastle City Council. Management authority: Shortland Wetlands Centre Ltd is responsible for management of

Shortland Wetlands: The Wetlands Centre Ltd, PO Box 292, Wallsend NSW 2287, Phone: 02 4951 6466. NSW National Parks and Wildlife Service is responsible for management of Kooragang Nature Reserve: Manager, Hunter Coast Area, Locked Bag 99, Nelson Bay Delivery Centre NSW 2315, Phone: 02 4984 8200.

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Appendix D: The Ramsar classification of wetland types

The 42 categories of wetland types contained in the Ramsar classification are listed below. The categories in the classification are intended to provide only a very broad framework to aid rapid identification of the main wetland habitats represented at each site.

Marine/Coastal Wetlands

- Permanent shallow marine waters in most cases less than six metres deep at low tide; includes sea bays and straits.
- Marine subtidal aquatic beds; includes kelp beds, sea-grass beds, tropical marine meadows.
- Coral reefs.
- Rocky marine shores; includes rocky offshore islands, sea cliffs.
- Sand, shingle or pebble shores; includes sand bars, spits and sandy islets; includes dune systems and humid dune slacks.
- Estuarine waters; permanent water of estuaries and estuarine systems of deltas.
- Intertidal mud, sand or salt flats.
- Intertidal marshes; includes salt marshes, salt meadows, saltings, raised salt marshes; includes tidal brackish and freshwater marshes.
- Intertidal forested wetlands; includes mangrove swamps, nipah swamps and tidal freshwater swamp forests.
- Coastal brackish/saline lagoons; brackish to saline lagoons with at least one relatively narrow connection to the sea.
- Coastal freshwater lagoons; includes freshwater delta lagoons.
- Karst and other subterranean hydrological systems, marine/coastal
- Inland Wetlands
- Permanent inland deltas.
- Permanent rivers/streams/creeks; includes waterfalls.
- Seasonal/intermittent/irregular rivers/streams/creeks.

- Permanent freshwater lakes (over 8 ha); includes large oxbow lakes.
- Seasonal/intermittent freshwater lakes (over 8 ha); includes floodplain lakes.
- Permanent saline/brackish/alkaline lakes.
- Seasonal/intermittent saline/brackish/alkaline lakes and flats.
- Permanent saline/brackish/alkaline marshes/pools.
- Seasonal/intermittent saline/brackish/alkaline marshes/pools.
- Permanent freshwater marshes/pools; ponds (below 8 ha), marshes and swamps on inorganic soils; with emergent vegetation water-logged for at least most of the growing season.
- Seasonal/intermittent freshwater marshes/pools on inorganic soils; includes sloughs, potholes, seasonally flooded meadows, sedge marshes.
- Non-forested peatlands; includes shrub or open bogs, swamps, fens.
- Alpine wetlands; includes alpine meadows, temporary waters from snowmelt.
- Tundra wetlands; includes tundra pools, temporary waters from snowmelt.
- Shrub-dominated wetlands; shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils.
- Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils.
- Forested peatlands; peatswamp forests.
- Freshwater springs; oases.
- Geothermal wetlands
- Karst and other subterranean hydrological systems, inland
- Human-made wetlands
- Aquaculture (e.g., fish/shrimp) ponds
- Ponds; includes farm ponds, stock ponds, small tanks; (generally below 8 ha).
- Irrigated land; includes irrigation channels and rice fields.
- Seasonally flooded agricultural land (including intensively managed or grazed wet meadow or pasture).
- Salt exploitation sites; salt pans, salines, etc.
- Water storage areas; reservoirs/barrages/dams/impoundments (generally over 8 ha).
- Excavations; gravel/brick/clay pits; borrow pits, mining pools.

- Wastewater treatment areas; sewage farms, settling ponds, oxidation basins, etc.
- Canals and drainage channels, ditches.
- Karst and other subterranean hydrological systems, human.

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