2.2.7 Sewerage Management

The reticulated sewerage system of Wyong Shire is generally confined to the urban areas, with septic systems being used in the rural areas. The reticulated system has built-in failure points where sewage can overflow in case of pump failure, or similar problems. Generally, the overflow points will be adjacent to stormwater systems or a waterway. Given that sewage is high in nutrients and turbid, it can have a significant impact on downstream environments. Septic systems, if well contained and frequently serviced, do not necessarily increase sediment and nutrient loads. However, poorly maintained systems can overflow or fracture, leaching nutrients and sediment into surface and groundwater flows.

The reticulated system overflows relatively infrequently. However, it should be remembered that the reticulated system is composed of both a domestic sewerage line and trade waste line. Both lines have an overflow capacity, which allows discharge into the stormwater system. A significant overflow to Tumbi Creek occurred in May 2003, which saw 72,000L of effluent discharged following a combined pump/power failure at a pumping station (WSC, 2003a). Although unintentional and quickly rectified, this kind of discharge can have significant nutrient impacts on downstream environments. Four non-significant sewage overflows occurred in the Wyong system during 2001/02. Two were due to blockages of mains and two due to power failure at pump stations (WSC, 2002). The overflow points are sometimes located adjacent to sensitive environmental areas. For example, the overflow at Fishburn Drain can discharge sewage and trade waste to the Porters Creek wetland.

There have been a number of positive steps taken to limit the contribution of sewage to sediment and nutrient loads to the estuary, wetlands and rivers. The Charmhaven Sewerage Treatment Plant is no longer discharging secondary treated wastewater to Wallarah Creek (it is discharged off Norah Head). Septic systems that were common in urban areas fringing the estuary have been replaced with the reticulated system. The water and sewerage network of Wyong Shire has an extensive telemetry system that alerts base monitoring stations in the event of a pump failure or large change in flow conditions. As part of Y2K planning, many major pump stations were fitted with backup generators. Although not the design intention, the generators assist in minimising overflows that occur during power outages. Council also has an active maintenance programme to minimise the occurrence of network failures and subsequent sewer overflows.

2.2.8 Hydrodynamics

The hydrodynamics (circulation, mixing and flushing) of an estuary are a function of its geomorphological characteristics such as shape, width, depth, and tidal regimes. The Tuggerah Lakes system is comprised of three coastal lagoons, which are open to the sea at the tidal delta at the entrance (Fig. 17). The estuary process study (Roberts, 2001) examined the hydrodynamics of the estuary and generally found that tidal flushing contributed very little to its circulation and mixing patterns. The shape and bathymetry of an estuary are important in modifying the circulation patterns. Human activities that may affect circulation patterns include dredging, channel diversion, breakwaters and regulation of the rivers and creeks entering the estuary. The three main driving forces for water circulation in an estuary are caused by density differences between fresh and salt water, tides and wind. In the Tuggerah Lakes estuary, oceanic water level changes over long periods may also form an important contribution to exchange with the ocean.

The process of mixing in an estuary occurs when neighbouring water masses join and dilute each other. In the Tuggerah estuary, moderate to strong winds are more important in this mixing process than are tidal flows. The surface area of the estuary is large and its depth is relatively shallow, which can at times result in waves and turbulence. Mixing within the open water is primarily driven by wind action, however the amount of mixing that occurs between the shallow seagrass habitats and the deeper open waters of the estuary should be assessed (see Issue KG3 and Option KG3a in Section 9).

The flushing of an estuary is determined by its circulation and mixing characteristics. Flushing of the entire volume of the Tuggerah estuary by exchange between the lakes and the ocean is dominated by the combined effects of river inputs and the subsequent flows following large floods, tidal motions and longer period oceanic oscillations. The combined effects give a flushing time of between 60 and 100 days. Flushing between the open waters of the three main lakes is predominantly wind driven with an average flushing time of about 12 days. Flushing times for the shallow fringing areas were estimated to be around 5 to 10 days although this was based on the assumption that there was limited mixing between shallow and open waters (van Senden, 1997).

Figure 17. The entrance to Tuggerah Lakes.

2.2.8.1 Entrance Management

There are many intermittently closed/open lakes and lagoons (ICOL'S) along the New South Wales coastline. The entrances of many of the larger coastal lagoons and barrier estuaries have been modified by seawalls and break walls and are kept open through maintenance dredging programmes. The entrance to Tuggerah Lake has been kept open by Wyong Shire Council since 1993 using a cutter suction dredge (Fig. 18). The dredge generally works on an as-needs-basis, but maintenance dredging generally starts around September of each year in the lead up to Christmas and costs around $250K annually. This strategy is aimed at minimising the possibility of the mouth to the estuary closing over from sand deposition. This can reduce the potential for flooding of low-lying areas around the lakes and increase the "flushing" of the estuary. The fact that "clean" marine water enters the estuary during the flood tides certainly assists in making this part of the lakes more attractive and therefore enhances tourism at The Entrance. The amount of flushing that is delivered from keeping the entrance open is questionable and modelling has shown that it is only the immediate area around the entrance that benefits (van Senden, 1997). Large floods from the catchment generally have a greater effect on "flushing" the estuary, whether the entrance is open or not.

There is now serious concern amongst managers of estuarine systems about the current practice of entrance management along the NSW coastline (HRC, 2002). The effects of interfering with natural entrance behaviour may cause unwanted changes to the ecology of an estuary. The salinity of an estuary is a major determinant of what types of animals and plants can live in it. The small invertebrates that live on and in the sediments of an estuary are very important in contributing to the nutrient cycling processes of estuarine systems. Significant changes to their diversity or abundance can alter natural ecological processes. Therefore entrance management has the potential to alter the ecology of an estuary. Recent research has revealed that patterns in the structure of benthic assemblages among a number of NSW coastal lagoons were largely unrelated to sediment characteristics but were linked to their open or closed status (Dye, 2004; Dye and Barros, 2005). The role of meiobenthos and their potential to be used as indicators of environmental conditions for Tuggerah Lakes was investigated (Dye, 2004). These assemblages were found to be typical of an isolated lake system with little tidal exchange, however their relatively low abundances may indicate that the estuary is under some stress (Dye, 2004). Allowing the entrance to close at this point may place further stress on nutrient cycling within the estuary, however this needs further assessment.

It has been estimated that if the current maintenance dredging programme at the entrance was to cease, the pattern of opening and closing would change. Prior to dredging, the entrance was closed to the sea approximately 13 times over the last 100 years. Any potential changes to current entrance management needs to be assessed on the basis of possible changes in circulation, mixing and flushing characteristics of the lakes as well as its ecology.

Wyong Shire Council currently maintains an open entrance channel to the sea to alleviate the effects of severe flooding in low-lying areas around the estuary and to improve the amenity at the entrance. The entrance channel is kept open by Council's dredge and the resultant spoil from the dredging is relocated to the beach immediately north of the entrance. Hydrodynamic and water quality monitoring suggest that the benefits of dredging to the flushing of the estuary are minimal and the effects on estuarine ecology are not known. Twin breakwalls at the entrance and opening a second entrance in the north-east section of Budgewoi Lake (Budgewoi Sandmass) have been suggested as a way to increase tidal exchange and flushing (Roberts, 2001).

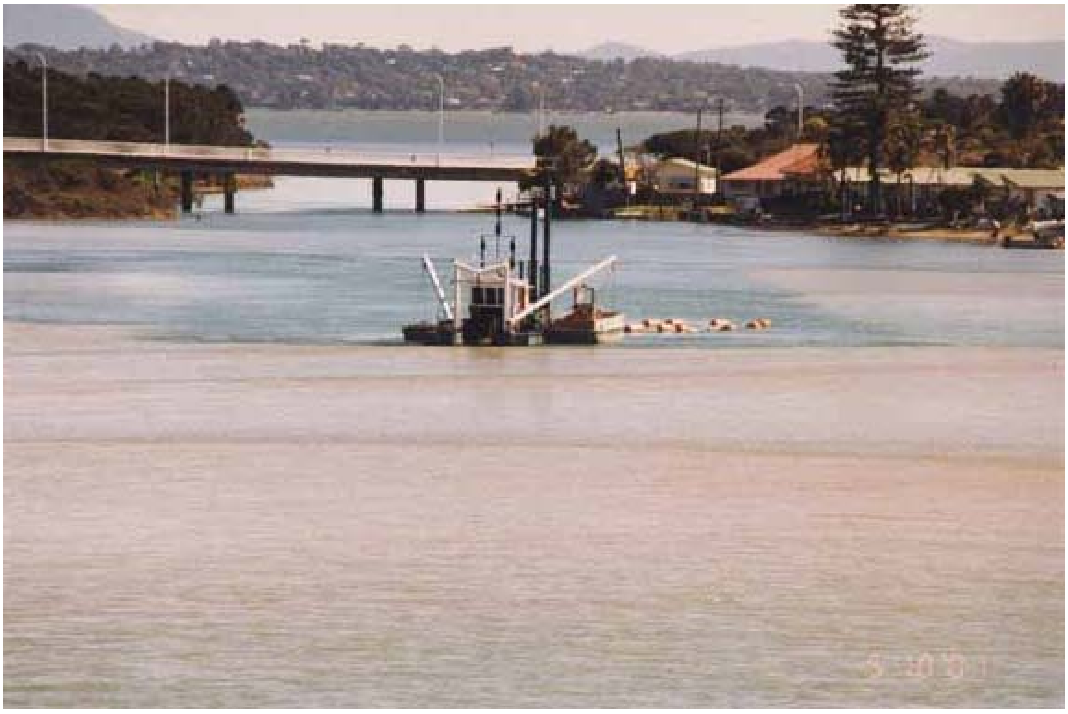


Figure 18. Maintenance dredging at the entrance.

2.2.8.2 Permanent Entrance

The community has often considered twin break-walls or a large permanent entrance as a solution to perceived problems of water quality and flushing within the estuary. Tuggerah Lakes is a wave dominated estuary and as such has a naturally high sediment trapping efficiency (Roy et al., 2001). The narrow entrance restricts marine flushing as only a small proportion of the estuarine water volume is exchanged on each tidal cycle (OzEstuaries website). The sediments that make their way into the estuary, either from the entrance or rivers, tend to stay within the estuary, unless there is some sort of intervention. Perceived benefits relating to training of the entrance to Tuggerah Lakes through the construction of breakwalls would probably not be realised or would be short lived. The marine sediments entering the entrance channel through this wave dominated deposition regime are presently managed by Wyong Shire Council through its dredging programme. After finding some sort of equilibrium post construction, it is highly likely that further maintenance dredging would be required to maintain the channel, as is the case with other trained entrances for the length of the NSW coast (Kelleher, 2004). Increased flushing potential for the Tuggerah Lakes estuary would also be very limited and does not take into account the potentially catastrophic effect that twin training walls could have on the properties adjacent to the channel (Kelleher, 2004). The construction of training walls would potentially attract liability to both Council and the Crown. The “owner” of any breakwalls would have to accept the liability associated with their construction, operation and any flow-on effects that could be attributed to their construction (Kelleher, 2004).

A study by Patterson Britton (1994) and investigations by Wallace (1999), examined the feasibility of such a permanent entrance. In general they concluded that a large permanent entrance would lead to greater tidal ranges (approximately three fold) with increased lake-flushing and recruitment of fish and prawns, however, it would be difficult to predict the entire range of ecological changes. The cost associated with building a permanent entrance was estimated at $13-20 million in 1994, and would now be in the vicinity of around $40 million. This is based on an average cost of $8,000 per lineal metre to construct approximately 2000m of wall and associated dredging and other engineering works. Maintenance costs associated with a permanent entrance have been estimated at around $100K annually. Due to the dynamic and aggressive nature of the coastal environment, it would be reasonable to assume that the breakwalls would have a finite lifespan and would require periodic major maintenance. Experience gained from managing breakwaters up and down the NSW coast would suggest that a figure of between 2% and 3% would not be unreasonable as an estimate for average annual maintenance.

The effect of entrance-intervention on the ecology of Tuggerah Lakes should be investigated. This research will enable logical decisions to be made about this important question of entrance management. What we do know is that a larger tidal prism associated with a greater tidal range would increase the amount of intertidal mud flats within the estuary. Whilst this may expand the habitat for wading and foraging birds, we may see a further decrease or change to existing seagrass meadows. There is also the potential for increased colonisation of mangroves, however the effect on existing saltmarsh meadows within the lakes is not predictable. The noxious aquatic algae *Caulerpa taxifolia* would also have more chance of entering the lakes system under these conditions. Greater tidal range associated with a “more efficient” entrance could lead to the exposure of hitherto unexposed foreshore areas. This may in turn lead to increased acidic runoff as Potential Acid Sulphate Soils are oxidised.

If it was proposed that the entrance would be navigable for coastal voyages the implications may be:

- Greater potential for spreading *Caulerpa taxifolia* and other potentially noxious pest species with increased boat traffic.

- Need to establish and staff a coastal surveillance/rescue facility on what may be a potentially dangerous “bar”.
- Increase the call for dredging to establish and maintain navigable channels and leads.
- Increasing the risk of vessels coming to grief on Tuggerah Reef.
- Loss of safety in shallow wading areas.

Physical and ecological changes would most probably be limited to Tuggerah Lake and the effects would be modest for Budgewoi Lake and Lake Munmorah. Increased tidal flows through the entrance could also lead to greater erosion and wave attack of existing foreshores and rock walls; however appropriate engineering may overcome these physical effects but at considerable costs. Effects on coastal processes would also occur with littoral drift causing a build up of sand against the training walls and erosion of the shoreline of North Entrance beach. Interactions of sand movement and increased currents may also affect the ecology of near-shore reefs close to the entrance (Owen, 2003). Interruption of littoral drift patterns and bar formation processes for surrounding beaches will significantly alter the position of the zone of stable foundation for the coastal embayments on either side of breakwaters, potentially placing millions of dollars of existing assets at risk and adversely affecting the recreational amenity of those beaches. It may also significantly interrupt littoral drift processes, leading to sand deficit on beaches to the north, which may in turn lead to increased erosion and long-term recession for these areas. The wide reaching implications are not fully known.

2.2.8.3 Second Entrance

A second entrance to the lakes has been touted as a solution to the problems of eutrophication and flushing in the Tuggerah Lakes estuary. The concept is based on the Dawesville channel, which was constructed on the Peel-Harvey estuary in Western Australia. The Dawesville channel was a major coastal engineering project, including significant excavation, construction of breakwaters, training walls, a bridge and installation of a sand bypassing system, and was completed in 1994. During the 1980’s there was increased political and environmental pressure to do something about excess nutrients from agricultural activities in the catchment of the Peel-Harvey estuary. The eutrophic conditions had led to blooms of the blue green alga *Nodularia*. A significant component of the managerial strategy was the construction of a second channel connecting the inlet to the ocean to increase tidal flushing and enhance the marine character of the estuary and thereby inhibit the growth of the algae.

Modelling (Walkerden and Gilmour, 1996) has clearly demonstrated that a second entrance situated in Budgewoi Lake would not result in any major benefits to its water quality and, in fact, there could be major ecological impacts with issues similar to those already highlighted and discussed in Section 2.2.8.2. Furthermore, it is conceivable that a second entrance would need to be built in conjunction with the construction of twin breakwalls at the entrance to Tuggerah Lake. The construction of a second entrance to the lakes would only have a limited (near-field) effect with regard to improving water quality. There would not be a circulation current established as has been popularly touted in the past. The driving mechanism for water to move in and out of any NSW river or coastal lake entrance is dependent on the 1.8 metre tidal range. As the oceanic water level at any given time at the entrances will be the same, there will be no gradient to drive a circulating current between them.

The area that has been nominated for a second entrance is the relic tidal delta, known as the Budgewoi Sandmass. This tidal delta has not been active for at least 1000 years (Roberts, 2001). A new entrance would need to pass through sand dunes of the Wyrrabalong National Park and also through significant areas of saltmarsh and wetlands. This entire area is considered an important habitat for migratory birds, fish and invertebrates (Roberts, 2001). The environmental implications of opening a second entrance have not been examined and a full evaluation of the ecological implications would be required and is beyond the scope of this study. Given that the modelling showed that a second entrance would not result in “flushing the lakes”, it is considered that this option should be given a low priority.

2.2.8.4 Dredging

The build up of sediments around creeks and inlets is a natural process of erosion and deposition, which occurs in all estuarine environments. Increased sedimentation associated with human disturbance in catchments has increased the rate of deposition in many estuaries. Dredging has been extensively used to alleviate the deposition of sediments from both natural and human sources. Dredging has occurred in the Tuggerah Lakes since the early 1900’s for a variety of reasons. Dredging was a common practice in the past to make more water-space available for human use, such as opening the mouths of creeks for navigation or deepening waterfronts so that larger vessels could enter or gain access to the lake through seagrass beds. Dredging is another human disturbance that places pressure on the marine and estuarine environment. This is especially so since much of our critical estuarine habitats have been either destroyed or badly disturbed (e.g. the destruction of seagrass and saltmarsh habitat). Tuggerah lakes has had an extensive history of dredging activities which included the Tuggerah Lakes Restoration Project, increasing the flow from Budgewoi Lake to Lake Munmorah via a canal, and the extensive dredging around the entrance and many of the creeks.

Dredging within estuaries is a regulated activity and as such requires extensive legislation and approvals. Generally, the bed of an estuary is unzoned Crown land that is not in the care and control of a Council and as such a licence from the crown is required to use or occupy this land. Prior to the lodgement of a Development Application the consent of the owner of the land (in this case the crown) is required. Under the provisions of State Environmental

Planning Policy 35 (SEPP35), Maintenance Dredging of Tidal Waterways, a “Public Authority” is able to undertake dredging to restore the functioning of an estuary without the initial requirement of the lodgement of an Environmental Impact Statement (EIS) (Kelleher, 2003).

The potential environmental problems associated with dredging are many, however the primary issues or concerns revolve around the:

- Destruction of marine invertebrates, fishes, seagrasses
- Mobilisation of nutrients causing eutrophication
- Mobilisation of pollutants such as heavy metals and pesticides with the potential for bioaccumulation
- Generation of acid from disturbance of Acid Sulphate Soils
- Methods to dispose of the spoil.

Historically, spoil from dredging was disposed of into the lake and resulted in many small islands at the entrance and off Ourimbah Creek (e.g. Pelican Island). When the practice of disposing of dredge-spoil back into waterways was ceased due to new environmental regulations, the solution was to take the spoil away. Generally, this is very expensive because the spoil needs to be treated for acid sulphate on site. This usually involves the construction of large settlement ponds on the shoreline where treatment takes place on-site or the material is trucked away and treated at a landfill site. It has been argued that the most economic and efficient solution is to place the spoil in the place to which it was heading before settling at the mouths of tributary creeks, i.e. out into the lake. However, the environmental impact associated with disposing of the dredge-spoil in this manner and specifically within the Tuggerah Lakes has never really been quantified.

The entrances to Tumbi Creek, Wyong River, Ourimbah Creek and Wallarah Creek require some form of maintenance dredging every five to ten years. This is primarily done for navigation purposes and to alleviate the potential for flooding (Roberts, 2001). Dredging of these entrances by WSC is now only done on an-as-needs basis.

2.2.8.5 Tumbi Creek (Case Study)

The entrance to Tumbi Creek became blocked with sediment in 2001, which caused restricted navigation to the point where NSW Waterways (now the NSW Maritime Authority) removed the navigation markers to the channel and closed it for boating access (Figs. 18-21). At the same time, WSC closed the existing boat ramp in Tumbi Creek with plans to upgrade another boat ramp facility in Saltwater Creek. The community were not happy with this decision and requested that Council dredge the mouth of the creek. Further investigation revealed that there were other issues to consider besides boat access. These included a reduction in the quality of the water behind the silt barrier in the creek and the potential for increased flooding of local residents living at the edge of the creek.

An examination of the Tumbi Creek catchment for possible sources of sediment was done and it was found that the principal sediment source appeared to be from the creek itself, with the worst areas being upstream from Wyong Road. The level of development in the catchment had increased both the volume and velocity of stormwater flows in the creek, leading to erosion and instability of sections of the creek banks and bed.

Council investigated the creek bank erosion sites and prepared design plans for remedial works. Many of the erosion sites were located at the tail-outs from stormwater drains serving developed areas. Where these drains empty into Tumbi Creek, turbulence appears to have eroded back along the drainage lines and undercut the drains and the creek banks.

Council examined a number of options to resolve the issue and a review of environmental effects was submitted to the State Agencies for approval to dredge and dispose of approximately 30,000 cu metres of spoil under the provisions of State Environmental Planning Policy No. 35: Maintenance Dredging of Tidal Waterways.

On closer investigation of the problem, it was found that the natural channel flowing from Tumbi Creek to the lake was not dredged back in the 1980’s but a new channel was cut which was perpendicular to the shore and was essentially the shortest route to the lake. Historical aerial photographs suggested that the channel leading from Tumbi Creek into Tuggerah Lake actually migrated across a range of alignments. This migration may be attributable to the discharge from the creek finding the most hydraulically efficient path into the lake. It may also explain the “patchiness” of the seagrass beds in the vicinity of the creek mouth. There was some discussion at this point about the logic of dredging this artificial channel when the water flowing from Tumbi wanted to run along the natural watercourse. It was therefore decided that it would be both economically and ecologically responsible to dredge the original natural channel. This was considered to be closer to the position of the original creek and should assist in maintaining the channel in an operational condition. The new channel would also have a larger volume, which was expected to provide a longer operational life. The proposal therefore was to cut a new navigation channel between the lake and the mouth of Tumbi Creek using a 10/8-cutter suction dredge, with discharge of the spoil under controlled conditions across part of the bed of Tuggerah Lake.

The very early dredging campaigns at the mouth of Tumbi Creek generally disposed of dredge spoil by depositing it on the adjacent lake foreshore, particularly on the eastern side of the creek mouth. As the surrounding residential areas have developed this practice has become less acceptable due to issues of noise, traffic movements and potential odours and other disposal options are now required. The dredging campaign in 1995 utilised a very small holding pond constructed at the northern end of the Adelaide Street Oval to provide a temporary storage site. This pond was located approximately 500 metres upstream of the creek mouth, and was constructed on the only available open space of any size in reasonable proximity to the work site. It was found in practice that this operation was extremely difficult and expensive due to the relatively small area of the pond and the difficulties experienced in excavating and removing the spoil. Furthermore, the spoil had a very long settling and drying time as well. In 1995, the cost of the work was in excess of $250,000 and involved removal of approximately 4,000 cu. Metres of material. This site is no longer considered to be suitable as a disposal or holding area due to its small size and disruption to the use of the adjoining Council sportsground.

Of all the alternatives considered for re-dredging the channel, cutting a slightly re-aligned new channel was considered to be the most appropriate and cost efficient. It required the discharge of the dredge spoil evenly across the bed of Tuggerah Lake where it would become incorporated into the existing bottom mud. It was estimated that there was approximately 10 years of sediment in the bed load of the creek that had been eroded from the catchment. It must be kept in mind that the bottom of the lake was the original destination for the eroded silt and sediments prior to them blocking the mouth of the creek. These sediments potentially would have been mobilised into the lake in a decent flood event.

It was originally calculated that approximately 30,000 cubic metres of material would need to be dredged for the new channel, however this was reduced to 15,000 cubic metres on further discussion with the consent authorities. The channel was to be approximately 50 m wide, 1.5 to 2 m deep and 460 m long. It was proposed to relocate the dredged material to an offshore discharge site that will spread the spoil across the adjacent bed of the lake in an area of approximately 300,000 square metres. This would have resulted in an initial increase in bed height of approximately 100 mm (on average) at the disposal site. The average water depths in the proposed disposal area when the lake was at an average height of 0.1 m AHD were approximately 1.5 to 2.0 m.

The material to be dredged was predominantly clay, with an overlying substratum of fine mud and organic matter. Clay will generally discharge in small spheroids, and these were expected to slowly settle into the deeper substratum of organic mud overlying the bottom of the lake.

The impacts on the ecology of the estuarine section of Tumbi Creek behind the sediment barrier were quite severe. Measurements of water quality variables immediately upstream of the sediment barrier indicated conditions that were deleterious for invertebrates and fish that live within the creek. Prior to the sediment plugging the creek mouth, water quality variables (eg. Dissolved oxygen (DO), salinity, turbidity and total nitrogen) within the estuarine section of Tumbi Creek were similar to those measured in other creeks entering the Tuggerah Lakes. When the mouth of the creek "silted up" there was a decline in the quality of water within the creek. As an example, the concentration of DO within the water immediately upstream of the sediment barrier was measured at 2.2 $\pm$ 0.4 mg/L and 2.6 $\pm$ 0.4 mg/L. At these concentrations fish kills were inevitable and assemblages of macroinvertebrates were probably also significantly altered. DO concentrations at similar sites within Wyong River and Ourimbah Creek measured at the same time ranged between 5.7-7.4 mg/L.

The habitat offshore of the mouth of Tumbi Creek is dominated by shallow-water and beds of seagrass (eelgrass *Zostera capricorni* and paddle weed *Halophila ovalis*). At the mouth of the creek, the seagrass beds are patchily distributed and generally in very poor condition. Healthy beds of *Zostera* occur away from the creek running parallel to the shoreline out to a depth of approximately 1.5 m. There were no significant seagrass beds within the proposed excavation channel or at the proposed disposal area as the water depth was too great.

Benthic assemblages within the shallow seagrass areas adjacent to the proposed channel were comprised of a range of macrobenthic organisms. The most abundant macroinvertebrate taxa found in the shallow seagrass sediments around Chittaway Bay were polychaete worms, molluscs and amphipods. In the deep-water sediments (at the location of the proposed disposal of spoil), the dominant macroinvertebrate taxa were polychaete worms. In general the number of species and the abundance of macrobenthic fauna were significantly smaller in the open-water habitats compared with the seagrass habitats (Roberts, 2001).

The sediment barrier at the mouth of Tumbi Creek had also impeded the passage of fish and crustaceans into and out of the creek, especially when the lake was at lower levels. A study was initiated by DPI (Fisheries) to assess the impact of the dredging on fish and other nektonic assemblages.

Saltmarshes are listed as threatened ecological communities in NSW, and within Tuggerah Lakes approximately 85% of these habitats have been lost or severely degraded. The foreshore in this area has been elevated through dredging during the Lakes Restoration programme. The edge of the lake has a rich assemblage of salt tolerant plants with very few weeds. The saltmarsh along these foreshores was considered healthy with up to 24 species identified (Sainty, 2002). An elevated zone, landward of the saltmarsh, was poorly vegetated, however behind this zone there was swamp forest dominated by *Casuarina glauca*. This small forest provided habitat for animals and despite the presence of many weeds warrants conservation and should not be destroyed. If large amounts of sediments or settlement ponds were to be built there, then much of this fringing saltmarsh and wetland vegetation would be disturbed or destroyed.

The impacts of cutting a new channel with the dredge on the water quality of Tumbi Creek and Tuggerah Lake was predicted to be short-term and would have been contained by the use of floating silt curtains. The nature and size of the dredging activities were not expected to cause any long-term erosion or sediment control problems to adjacent creek banks or the lake foreshore.

Samples taken from the area to be dredged showed that the material was likely to be acid sulphate or potential acid sulphate in nature. However, the material to be relocated was to remain in or under water at all times and therefore would not be given the opportunity to cause acidity-related problems. This assumption was questioned and further work was done to ascertain the risk associated with acid sulphate generation from the spoil.

Heavy metals and organochlorine pesticides can accumulate within sediments and have the potential to cycle through the food chain. Trace metals and pesticides within the sediments were examined in both the shallow seagrass and deeper open water habitats of Chittaway Bay (Roberts, 2001). These compounds can be toxic to aquatic organisms and have the potential to bioaccumulate in fish, shellfish and humans. The concentration of pesticides within the sediments in both seagrass habitats and deeper sediments were below detection limits. The sediments within the deeper open water had greater concentrations of trace metals compared with the shallow sediments. The concentration of trace metals in the sediments were below levels that can cause adverse environmental effects (Roberts, 2001).

The proposal to dredge accumulated sediments at the mouth of Tumbi Creek and discharge them across the bed of Tuggerah Lake was assessed for both positive and negative impacts. There would be some short-term, negative impacts during the removal of accumulated sediment in the Tumbi Creek channel from the boat ramp to Tuggerah Lake. These impacts were to be controlled so that any effects were Iocalised, of short duration and would cause minimal inconvenience to nearby residents.

In Councils submission, they concluded that the removal of sediment from the channel would have positive benefits by reducing the impacts of additional depths of floodwaters from large flood events on nearby residential properties. A new channel would allow boat users to travel safely between Tuggerah Lake and Tumbi Creek. In addition, the free passage of marine life would be possible, as well as improved water quality. Appropriate monitoring programmes were put in place to ensure that the works did not create further problems in terms of the local environment and flora and fauna.

A review on the effects of dredging and disposal of spoil made the following generalisations (1) increased turbidity and nutrients from dredging and disposal did not influence estuarine phytoplankton production; (2) estuarine nematodes could survive burial by 10 cm of dumped dredged sediment, provided that its physical characteristics were similar to those of the original sediment; (3) sessile benthic organisms such as mussels and oysters can cope with sediment deposition of only 1 – 2 cm; (4) macrobenthos can survive sediment deposition of 20 – 30 cm; (5) recovery of benthic assemblages at a dump site will occur if the interval between successive dumping is sufficiently long (WSC, 2003b).

The dredging and disposal of the spoil was not approved by Council, although all the consent authorities had given their permission. A ground-swell of opposition from the community to the disposal method forced Council to reconsider its position and seek further funding for alternative disposal options. The federal government offered further funding to the project and a new REF (WSC, 2004) was developed with a preferred option for on-shore disposal. At this time, the NSW State Government had still not given approval to dredge the mouth of Tumbi Creek.

Figure 19. The entrance to Tumbi Creek and the existing dredged channel.

Figure 20. The plug of sediment at the mouth of Tumbi Creek.

Figure 21. Backhoe sampling sediment at the mouth of Tumbi Creek.

2.2.9 Foreshore Management

Residents and holiday-makers from the 1930's through to the 1960's have memories of "clean sandy beaches" around the eastern shores of Tuggerah, Budgewoi and Lake Munmorah (Scott, 2002). These shallow sandy shoals have experienced siltation as a result of increased runoff and sedimentation from their catchment. The foreshores around the estuary have been modified significantly through urbanisation (see Figs. 22 – 25). Foreshore improvement and beach renourishment programmes have targeted places such as Canton Beach, Elizabeth Bay, Long Jetty etc. to improve the aesthetic appeal to recreational users. Such programmes are unlikely to provide sustainable solutions unless the disturbances that cause siltation are addressed.

The estuarine and riverine foreshores are some of the more popular recreational areas in Wyong Shire. Council has constructed a number of popular recreational areas along these foreshores. A bike path approximately 10 km long extends from The Entrance to Chittaway Point and is very popular for both walkers and bike riders. There are approximately 70 km of foreshores around the estuary. These areas support a number of different recreational activities including:

- Provision of access to the estuary (boat ramps, swimming beaches, jetties etc).
- Cycling.
- Walking.

- Aesthetic enjoyment.
- Picnics & BBQ's.
- Pet exercising.

Wyong Shire Council manages approximately 52 km of public foreshore (Table 5). It is zoned as Open Space and Recreation and is maintained according to Council's Open Space and Recreational foreshore policy and on an-as-needs basis (WSC, 1998a).

Table 5. Foreshore development around the Tuggerah Lakes estuary

Lake	Total length of foreshore (km)	Undeveloped foreshore (km)	Developed foreshore (km)	Loss of fringing vegetation since 1961 (ha)
Munmorah	11.4	4.2	7.2	22.0
Budgewoi	19.2	0.7	18.5	53.0
Tuggerah	39.35	13	26.35	42.4
Total	**69.95**	**17.9**	**52.05**	**117.4**

Of the 52 km of developed foreshore, approximately 20% is in private ownership. Some residents have at times requested that Council assist in managing parts of their foreshore property for aesthetic amenity. This usually relates to the removal of seagrass wrack on the foreshore and in the lake. Council has historically taken the view that this is private property and that they should only be managing public foreshores.

In New South Wales, many areas of saltmarsh have been cleared and the re-establishment or restoration of these habitats can be problematic (Chapman and Underwood, 1997). There are also remnant patches of saltmarshes around the estuary, some of which appear to be quite healthy (Sainty, 1998). There are also very large patches of disturbed foreshore, which once contained saltmarsh (Sainty and Duchatel, 2000). Seagrass wrack washed onto beaches may assist the establishment and/or growth and survival of saltmarsh plants (Roberts and Chapman, 2003; Chapman and Roberts, 2004). This may be because they provide a structure, which helps to reduce erosion and desiccation of the soil and may provide nutrients to what are essentially nutrient-poor sediments.

Figure 22. Unmodified foreshore with saltmarsh and fringing wetland.

Figure 23. Saltmarsh with fringing wetland replaced by houses.

Figure 24. Modified foreshore with saltmarsh and fringing wetland replaced by houses and exotic lawns.

Figure 25. Highly modified foreshore with saltmarsh and fringing wetland replaced by houses, exotic lawns and seawalls.

2.2.9.1 Floating Wrack Management

The harvesting of seagrass and macroalgal wrack from within the waters of the Tuggerah Lakes has been an ongoing activity for many years. In the past, Council used beach cleaners and swamp dozers to remove very large deposits of stranded wrack (often principally algal blooms) banked up from the shoreline out into the estuary however this method is no longer practiced due to the damage caused to the bed of the lake and the reduced extent of algal blooms. As previously discussed, the need for wrack removal was primarily aimed at aesthetic values. Some community groups and local residents also remove seagrass wrack from the waters of the estuary to enable unhindered access to boating and to improve the aesthetic quality of their foreshores. In the past, council has provided some small grants to residents and groups wishing to trial measures of removing wrack. A study was done which specifically examined the effects of raking seagrass meadows of wrack within shallow water areas of Chittaway Bay (Daley, 1997). This study found that whilst live seagrasses were not affected, the richness and abundance of macrobenthic organisms was significantly reduced.

As part of the Lakes Restoration Project, a mechanical aquatic weed harvester was purchased to remove floating seagrass and macroalgal wrack from high priority shallow areas around the estuary (Fig. 26). The intention of the harvester was minimise the amount of wrack that reaches shore by harvesting in the shallow areas. The priority for harvesting, as in the case of beach cleaning, was determined on an-as-needs basis and in specifically targeted areas where public amenity could be reduced due to large accumulations of wrack. Generally this included popular recreational areas. Wrack is only collected from and in front of public land. Presently, the harvester is completely funded by Council and approximately $150,000 is spent annually as part of its operations.

As part of DPI (Fisheries) approvals for the harvester, an experimental permit was issued on the basis that environmental monitoring was done. Research by the University of Newcastle was done into the potential effects of the harvester on seagrass meadows, macrobenthic organisms and fish assemblages (Casey, 2001). The monitoring programme required regular sampling at different spatial and temporal scales, as well as manipulative field based experiments. Whilst the study showed that there were no direct effects of the harvester on seagrass, benthos and fish at the measured sites, the results indicated that live seagrass was collected and examination of discarded piles of wrack have been found to contain by-catch including live seagrass, prawns, molluscs and fishes. Many of the local commercial fishers also complain about the potential effects of the harvester and specifically the by-catch. Initial indications from DPI (Fisheries) were that the harvester may need to be modified so that it did not pick up bottom dwelling organisms such as molluscs. Recent investigations and research into the impacts of the wrack harvesting on Syngnathid populations in the estuary have led to recommended modifications to the harvester to reduce by-catch (Roberts and Murray, 2005a; Roberts and Murray, 2005b).

Figure 26. The weed harvester used to collect floating algal and seagrass wrack from shallow water around the estuary.

2.2.9.2 Beach Cleaning

Council regularly removes rubbish, seagrass and macroalgal wrack that has been blown or washed onto selected beaches around the foreshores of the estuary. The reasons stated for this are to improve the visual appearance and appeal of the beaches, especially in high profile tourist areas such as Canton Beach. Dangerous objects such as broken glass and syringes are also removed in the process. The removal of wrack from the beaches reduces problems associated with its slow breakdown into organic matter, which can lead to odours. The regular removal of wrack and rubbish means that this material does not bank up along the shoreline. Council spends approximately $300,000 per year on beach cleaning.

The beach cleaning equipment includes a 4WD tractor and trailer with a conveyor belt of woven wire, which picks up the wrack and drops it into a hopper (Fig. 27). Sometimes a rake is used to move the wrack along the water's edge into piles, which are later picked up by the beach cleaner. Council also has used a contract machine, which is a 6WD ex-logging machine fitted with a tip tray and extendable arm and rake. This process of collecting wrack can cause significant damage to the beach front and associated saltmarsh and seagrass, as well as remove quantities of sand that then have to be replenished (Fig. 28). Council has experimented with numerous methods to make the process more environmentally friendly which has included the use of long reach excavators with a rake. All these techniques have been examined with the aim of reducing damage to the beaches, lake-bed and disturbance to seagrass meadows. DPI (Fisheries) require a permit to remove seagrass wrack and algae under their Fisheries Management Act, and Councils permit is reviewed annually.

The frequency and priority for cleaning beaches is done on an-as-needs basis, with places like Canton Beach and Long Jetty receiving the greatest attention due to their high profile and greater public use. In general, beach cleaning is required from spring, through summer and into autumn. Council has been collecting seagrass wrack from public foreshores for many years, however the potential environmental impacts associated with these operations had not been quantified. Potential effects include the physical disturbance to the structure of the beach and the fauna and flora that live there. Council funded a study through the University of Newcastle, which examined the effects of beach cleaning on macroinvertebrates and birds (Adams, 2000). The study found that continual cleaning of beaches can reduce the populations of invertebrate fauna by 50%, however their subsequent colonisation back to the beach was relatively fast. There were no differences in bird populations between cleaned and uncleaned beaches. Council is currently assessing its beach cleaning operations with respect to the potential impacts on saltmarsh.

Figure 27. Removing stranded wrack from the shallows using the beach cleaner.

Figure 28. The damage done to the foreshore as a result of beach cleaning.

2.2.9.3 Mowing

Wyong Shire Council recognises the need to manage reserves and sporting and recreational facilities for both residents and visitors. Council has developed policies and guidelines for mowing public reserves to control vegetation within designated limits along roads and reserves for public safety, public amenity and preservation of public assets. Mowing of reserves and privately owned land along the foreshores of the estuary commonly occurs all year round (Fig. 29). Council has a mowing and weeding schedule with the major mowing period starting around October and ending around March of each year. Within the guidelines it is emphasised that no mowing should be done within three metres of the edge of the water on waterfront reserves, except where there are adjoining houses. In the past, an established practice was to mow the entire reserve, however Council recognised that leaving a section unmown will act as a vegetation filter for the lake or watercourse. The problem with mowing foreshores is that saltmarsh should be in these areas and not exotic lawns. Approximately 85% of the saltmarsh habitat around the estuary has been lost through disturbance. Balancing public amenity with ecological function in this case is quite difficult. How do we manage activities that affect the estuary for its ecology, whilst providing public access and amenity around the foreshores?

In almost all cases where residences have been developed and there is reserve, mowing (by Council and residents) extends to the shoreline wherever there is vegetation. Some saltmarsh species persist under the mowing regime, particularly the saltmarsh grasses and *Cotula coronopifolia*, but are stunted in growth and do not provide habitat or other ecological functions.

In instances where mowing has not occurred, often only over a short period of time, saltmarsh species and the reed *Phragmites australis* rapidly grow amongst the overgrown lawns to distances of up to 45 metres from the edge of the lake. During flood events in 1998, many grassed areas died and were being re-colonised by saltmarsh species. In some areas, saltmarsh vegetation is persisting in narrow bands along the shoreline where they are either not mown or mown infrequently. Where residences are separated from the foreshore reserve by roadways, these saltmarsh zones appear to be more abundant.

The practice of dumping lawn clippings in saltmarsh zones is common. In areas where the land is elevated and steeply sloping towards the lake, it is also common practice for lawn clippings and other gardening debris to be dumped over the edge.

A number of residents in Chittaway Bay are raising the elevation from their property boundary onto the foreshore by collecting wrack and using it as fill, which is then planted with grass (mostly Buffalo grass). In Budgewoi Lake, Buffalo grass has been introduced into areas of saltmarsh on Council land. Council is currently reviewing the impacts of mowing on saltmarsh habitats around the estuary.

Figure 29. Example of mowing of saltmarsh.

2.2.9.4 Seawalls, Jetties and Hard Structures

Jetties and seawalls in the tributary creeks and in the estuary have significant effects on the ecology of riparian and aquatic habitats. Within the Tuggerah Lakes there are numerous privately owned and some public jetties, wharfs and boat ramps. These structures are important for users of the estuary to be able to access the deeper waters of the lake. Recent research has shown that jetties and similar structures can alter patterns of seagrass growth adjacent to foreshores (Owen and Gladstone, 2003). Wyong Shire Council does not have a DCP for new or altered jetties within Tuggerah Lakes although several DCP'S have regard for seagrasses. Any new applications for structures, which are to be built on the foreshore, are also passed onto the appropriate state agencies for their approval. In terms of aquatic ecological impacts, approval from DPI (Fisheries) is required for new or modifications to jetties or other structures where there is a potential to impact on seagrasses. No structures can be built over the seagrass *Posidonia australis* (does not occur in Tuggerah Lakes), and new jetty constructions over the seagrass *Zostera capricorni* need to have mesh decking that allows light through. A review of the impacts of jetties on seagrass habitats has been done with only a small number of published studies into their effects worldwide (Owen and Gladstone, 2003). Light reduction and damage to seagrasses by boats, propellers and anchors were the primary impacts. No work has been done on the effects of jetties or other structures on foreshore habitats.

Seawalls and shoreline modifications have the potential to alter ecological processes at the shore/water interface. Within tributary creeks seawalls can directly impact on foreshore vegetation and indirectly cause changes to flow patterns, which can result in significant streambank erosion on either side of the structure. This usually leads to the establishment of more structures to counter the effects of the original structure. Whilst there are few seawalls within the estuary there are many within the tributary creeks entering the Tuggerah Lakes.

Whilst there are not many seawalls within the estuary there may be a need in the future with the potential for sea level rise associated with global warming processes. When seawalls are constructed along the foreshores of estuaries the first casualty is the saltmarsh meadows fringing the shoreline. What is not directly destroyed will eventually die because the seawall prevents tidal inundation, which is essential for a healthy saltmarsh. Also, when a hard structure is placed against a foreshore where there is potential for wave action or strong currents, erosion is generally exacerbated adjacent to the structure. The seawall also acts as a barrier to natural wrack movement up the shore and therefore floating wrack can build up and form floating mats in front of the seawall (wrack accumulation zone). Under these conditions, the underlying seagrass generally dies whilst sediments become anoxic releasing nutrients and the benthic fauna are also killed (Cummins et al., 2004b). A recent small-scale study of benthic assemblages associated with seawalls in Lake Macquarie found that species richness and abundance were significantly reduced in sediments in front of seawalls compared to naturally sloping saltmarsh vegetated foreshores (Chapman, 2004). This process is similar to that which occurs when algal blooms cover the water surface of shallow-water seagrass habitats, and on large-scales can alter nutrient cycling processes within the estuary.

A survey of boat ramps was done and it was concluded that there was a general paucity of appropriate boat ramps within the estuary that provided facilities for the launching of larger vessels or deeper water access to the lakes. Whilst there are not that many boat ramps within the Tuggerah Lakes estuary, their construction and associated use has the potential to impact on seagrass and foreshore habitats. Propeller wash from boats can cause severe scouring of bottom sediments close to boat ramps. If council were to construct more boat ramps then both saltmarsh and seagrass habitat would need to be assessed as part of any development process. Areas of foreshore where there are viable healthy saltmarshes or where potential rehabilitation could take place should be avoided.

Another potential structure that has become popular in recent years is the construction of cycle-ways around the foreshores of estuaries. These cycle-ways provide significant recreational amenity and access to the estuary. They are generally made of concrete and built at a slightly higher level to the natural height of the foreshore. These structures have the potential to act as barriers to saltmarsh colonisation landward. In recent times, Council has adopted a policy of using the cycle-ways as an indicator “line-in-the-sand” in terms of associating maintenance activities between residents and council. This managerial practice is now being assessed in light of the declaration of saltmarsh as an endangered ecological community.

2.2.10 Conservation and Fisheries

Estuarine ecosystems within NSW coastal regions have been placed under increasing pressure due to a range of human disturbances. These disturbances tend to impact on estuarine habitats, which can result in loss of biodiversity within the estuary. Estuaries are popular places for people to live because they are productive in terms of fisheries as well as agricultural activities associated with the nutrient-rich floodplains found in their catchments. They also provide a range of recreational activities such as boating, swimming and fishing. Many of the developed estuaries have experienced symptoms of human pressure in the form of eutrophication (nutrient enrichment), sedimentation and pollution by contaminants such as heavy metals and pesticides. Key estuarine habitats have also been degraded through urbanisation, reclamation and dredging. These habitats include seagrass meadows, saltmarsh and mangrove forests, and intertidal mud and sand flats. The list of potential impacts to estuarine habitats and biodiversity is large, however some of the more important ones include eutrophication, stormwater, sedimentation, dredging and reclamation, beach cleaning and weed harvesting, boating and the construction of sea walls, jetties and other structures.

There are many potentially threatening processes that can impact on conservation and many are interactive. The major issues for conservation identified in the Tuggerah Lakes Estuary Process Study included:

- Habitat Protection.
- Fisheries Resources.
- Threatened Species and Ecological Communities.

Within these broad headings, a number of sub-issues were also identified which included seagrasses, saltmarshes and impacts associated with invasive algae.

There are a number of critical habitats within the Tuggerah Lakes that may require some form of conservation. Seagrass meadows and saltmarshes are the primary structural aquatic vegetation habitats within the estuary. These habitats are important in terms of stabilising sediments, nutrient cycling processes, as nursery grounds for fish and other commercially important species as well as habitat for birds. Specific areas within the estuary that were also highlighted as being ecologically important or sensitive included the Budgewoi Sandmass and Tuggerah Bay.

2.2.10.1 Seagrass Meadows

Seagrasses are aquatic angiosperms (flowering plants) that are important biological components of coastal estuaries (Fig. 30). They provide nursery grounds and food for commercially important prawns, fish and wading birds and generally act as a structural habitat for a variety of estuarine animals and plants. Seagrasses provide a role in stabilising bottoms and shorelines and act as a natural water filter for suspended solids. In biodiversity role, seagrass beds are considered as one of the most ecologically diverse communities, alongside rainforests. Unfortunately many of the organisms are small or cryptic and not seen by casual observers. Large-scale declines (up to 85%) in seagrass meadows have been recorded within NSW estuaries. Increased turbidity, siltation, nutrients and epiphytic and benthic algae have the potential to cause a reduction in the distribution and abundance of seagrasses. In extreme cases, large ‘blooms’ of macroalgae can reduce the light available for seagrasses and cause a reduction in their diversity and abundance. The combined effects of respiration and subsequent processes of decomposition can create anoxic conditions at the sediment-water interface, resulting in significant increases in nutrients being recycled back into the water column. Severe anoxia and the production of toxic sulphide can also cause massive migration or mortality of the benthic fauna which further impact on the system.

In the 1960’s, it was estimated that there were over 40 km^2 of seagrass meadows within the Tuggerah estuary and by 1996 this had declined by approximately 50% (Roberts, 2001). It was estimated that at this time the seagrass meadows within the lakes probably represented between 15-20% of the entire lakes area. Such declines have been documented in estuaries worldwide, and the mechanisms that have caused this include dredging, reclamation and eutrophication. As a general rule, in healthy lakes and estuaries, macrophytes will occupy approximately 20% of the aquatic plant biomass. Under eutrophic conditions, this ratio can fall below 20% and other primary producers (eg. Macroalgae and phytoplankton) can dominate. In aquatic systems where phytoplankton populations dominate as the primary producer, toxic algal blooms can cause major problems and become difficult to manage (eg. Peel-Harvey Estuary and Chesapeake Bay). The Tuggerah estuary and its seagrass meadows experienced the effects of large-scale macroalgal blooms during the 1980's as a result of eutrophication (Collet et al., 1981; Roberts, 2001).

The seagrasses of Tuggerah Lakes are situated within the shallow margins of the estuary and some of the largest meadows can be found in Tuggerah Bay, the south-eastern section of Budgewoi Lake, and along the eastern shoreline of Eel Haul Bay (Roberts, 2001). Whilst seagrass extent may have declined in Tuggerah, recent studies have found that the length of seagrass leaves within the lakes is significantly longer than in other local estuaries, such as Brisbane Waters and Lake Macquarie (McCarthy, 2003). One model used to explain this pattern is that the turbidity within the Tuggerah Lakes estuary is greater than the other two estuaries and therefore seagrasses must grow longer to be able to access the light required for photosynthesis. It has been hypothesised that this process may account for the increased wrack production observed within the Tuggerah Lakes estuary.

Management of seagrasses currently falls under the jurisdiction of DPI (Fisheries) (Fisheries Management Act 1994). Management issues and actions are contained within their policy and guidelines for aquatic habitat management and fish conservation (Smith and Pollard, 1998). This policy also includes the protection of other estuarine habitats such as un-vegetated shallow mud and sand flats as well as deeper soft sediment habitats.

The objectives of the Fisheries Management Act 1994 are to conserve fish stocks and protect key fish habitats, promote viable commercial fishing and aquaculture, promote quality recreational fishing opportunities and to share fisheries and promote ecologically sustainable development. Habitat Protection Plans have been produced as a strategy to help conserve biodiversity in estuarine areas which includes seagrass habitats (Fish Habitat Protection Plan No 2: Seagrasses).

Urban development and activities by the community and other stakeholders continue to place pressure on seagrass habitats within the Tuggerah estuary. Indirect impacts include stormwater runoff, sedimentation and increased turbidity, whilst small-scale blooms of macroalgae occur probably as a result of eutrophication. Direct impacts to seagrasses include dredging, weed harvesting, hauling and some aspects of boating, e.g. propellers and anchors.

As previously discussed, there have been large-scale declines of seagrass meadows within NSW estuaries due to human disturbance. The proliferation of macroalgae associated with eutrophication also has the potential to reduce the distribution and abundance of seagrass meadows. The introduction of the exotic algae *Caulerpa taxifolia* to a number of estuaries in recent times has added new problems for managers of these estuaries. The genus Caulerpa is highly invasive and direct disturbance associated with dredging or fishing has the potential to exacerbate its spread. *Caulerpa taxifolia* can now be found in some places within Lake Macquarie, and DPI (Fisheries) require that prior to any disturbance (e.g. dredging) an assessment of the presence or absence of this noxious marine alga be determined. Caulerpa can take over seagrass beds, which results in a loss of biodiversity and potentially impacts on fisheries. Research is currently being done to assess ways of controlling this noxious seaweed, although experience in Europe indicates that once it is established it is almost impossible to eradicate.

Caulerpa taxifolia has not been found within the Tuggerah estuary, however there is no reason that it would not survive in certain areas if it were introduced to the lakes. The spread of *Caulerpa* into Tuggerah Lakes would cause major changes to the way the lakes are currently managed. For example, the weed harvester and entrance dredging may not be possible due to the fact that the weed can be spread by physical disturbance. Appropriate monitoring for this invasive weed must therefore be given a high priority and if found, DPI (Fisheries) must be notified of its presence immediately.

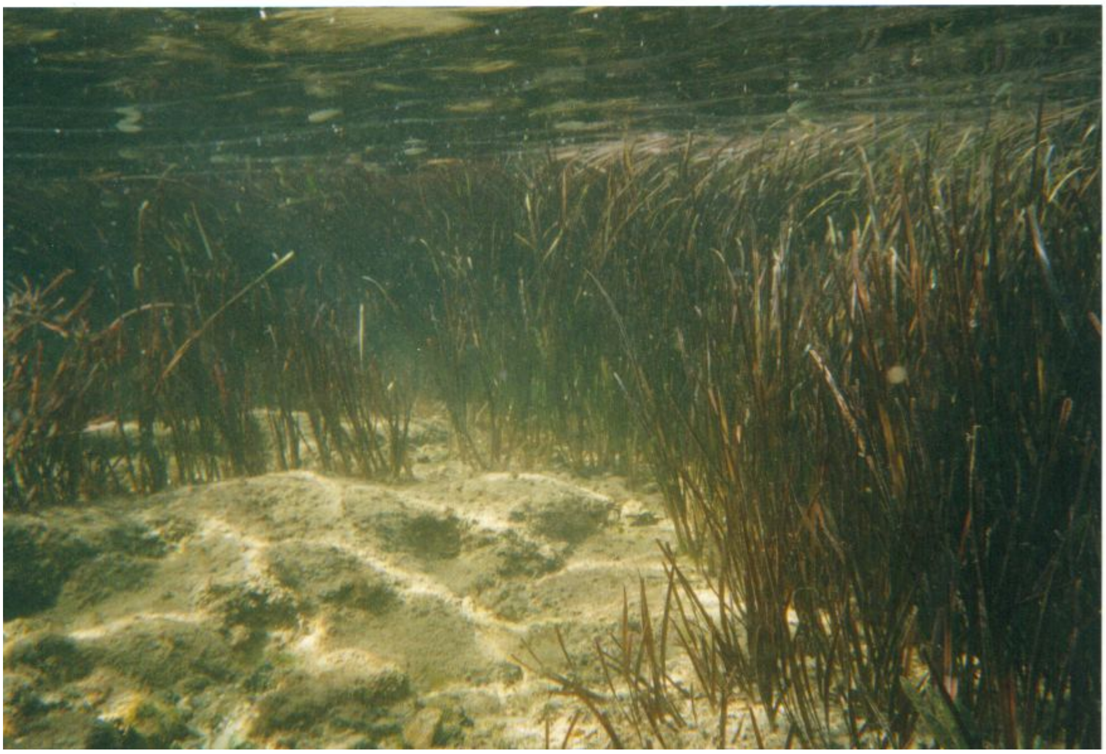


Figure 30. The seagrass *Zostera capricorni*.

2.2.10.2 Saltmarshes

Saltmarshes are salt-tolerant species of plants that are important in the nutrient cycling process in estuaries and as feeding and nursery habitats for many birds, fish and invertebrates (Fig. 31). The importance of fringing wetland vegetation such as saltmarsh to ecological processes and the health of an estuary has been well established (Minello et al., 2003). The plants living in these low-nutrient, stressful habitats can cycle nutrients very efficiently. They tend to have particular characteristics in common – i.e. they grow slowly, have long-living foliage, photosynthesise slowly and are very efficient in the uptake of nutrients (Chapman and Roberts, 2004). Wrack (detached leaves of seagrass and floating macroalgae) stranded in saltmarshes has been shown to enhance diversity of saltmarsh vegetation, as it may provide a structure, which helps to reduce erosion and desiccation of the soil, reducing physical stress, or may directly provide nutrients to what are essentially nutrient-poor sediments. Conversely, saltmarsh may provide an important mechanism to help break down wrack within estuaries. These processes are currently being investigated in the Tuggerah Lakes estuary (Roberts and Chapman, 2003).

Around fifty percent of the saltmarsh habitats have been destroyed in NSW through the direct results of development and the indirect effects of human disturbance (Saintilan and Williams, 2000). These habitats are generally high up on the shore of estuarine intertidal mudflats and are usually located behind mangrove forests. Saltmarshes are frequently inundated by seawater through tidal action, however in the Tuggerah estuary, daily tidal effects are negligible and inundation only occurs with flooding or long-term changes to mean lake level. Although there has been considerable urban development around the Tuggerah Lakes estuary, fringing viable saltmarsh and wetland communities still exist in undeveloped areas. Saltmarshes are threatened in many parts of the world because they are considered wastelands rather than valued wetlands. This is particularly true in urbanised parts of Australia. As much as 85% of saltmarsh has been lost or severely damaged in the Tuggerah Lakes due to human disturbance. With this habitat loss, it is conceivable that 85% of the organisms that rely on this habitat have also disappeared. Activities by the community and other stakeholders continue to place pressure on what little remains. These disturbances include; clearing, mowing, beach cleaning, reclamation, seawalls, weed invasions, vehicles and horses (Roberts, 2001).

The largest and most viable saltmarsh meadows remaining can be found adjacent to the Budgewoi Sandmass and within Tuggerah Bay. These saltmarshes probably account for at least 10% of what is left around the lakes. Many of the disturbed shores surrounding the estuary still contain remnant and fragmented patches of saltmarsh, which account for the remaining 5%. Whether these remnant patches can be rehabilitated is the focus of ongoing research within the estuary.

Figure 31. The saltmarsh *Sarcocornia quinqueflora.*

2.2.10.3 Tuggerah Bay

Tuggerah Bay was identified as an important ecologically sensitive habitat within the Tuggerah Lakes estuary (Fig. 32) and is one area within the lakes system that has not been heavily impacted by urban development, primarily because of its significant flood prone nature. There has been some urban development along the thin strips of land on the deltas of Wyong River and Ourimbah Creek, however much of the fringing wetlands are still relatively undisturbed. Physical disturbance to saltmarsh habitat does occur through horse riding, four-wheel driving and motorcycling activities. Wyong Shire Council has attempted to “seal off” these areas so that disturbance to the saltmarsh and fringing wetlands is minimised (Roberts, 2001).

Tuggerah Bay has one of the largest and most diverse seagrass beds within the Tuggerah Lakes estuary (accounts for approximately 15% of seagrass in the estuary) and all three species of seagrass occur within it, i.e. *Halophila*, *Zostera* and *Ruppia*. The seagrass meadows within Tuggerah Bay are rich and support prolific birdlife, invertebrates and fish assemblages. A large erect species of sponge (Suberites) is also found within Tuggerah Bay but not within areas where haul nets are used. Sponges were probably very common within the Tuggerah estuary prior to European development. Sponges are generally sensitive to heavy siltation and sedimentation and preliminary studies on this particular species have shown it to be sensitive to siltation. This species of sponge is also found in the north-western seagrass beds in Lake Munmorah and in some places in Lake Budgewoi (Barnes, 2004). Records of sponges from Lake Illawarra in the 1800’s described 25 species of sponge, however recent studies have found none within the estuary. It is conceivable and highly likely that Tuggerah also once contained a diverse sponge assemblage given its similarity to Lake Illawarra.

The proximity of Tuggerah Bay to the entrance of the estuary ensures that it receives good flushing and recruitment of marine spat. It also is unique because the habitats within the bay follow a classical zonation pattern of fringing terrestrial and wetland flora, saltmarshes and mud flats leading into seagrass meadows. This natural zonation no longer occurs anywhere else in the estuary because of urban development. One of the largest freshwater wetlands in the shire is also situated behind Tuggerah Bay and its connectivity with the estuary is considered to be very important. There are records of threatened and endangered species within the area such as squirrel gliders and green and golden bell frogs. Many migratory birds also utilise the bay and black swans can be observed in large numbers feeding on the seagrass meadows. The bay also supports significantly greater numbers of species of fish than other areas within the estuary and there are probably many interactions that occur between the tributaries of Wyong River and Ourimbah Creek and the open waters of Tuggerah Bay. The concentrations of heavy metals and nutrients within the sediments of Tuggerah Bay are also much lower than other places within the estuary.

Commercial hauling occurs within Tuggerah Bay, however it is not clear what impacts these activities may have on its ecology. Future activities which include the potential for coal mining and subsidence may also be detrimental to the seagrass meadows within Tuggerah Bay. Subsidence could lead to loss of seagrass because seagrasses are light limited and depth would increase leaving less area for seagrass colonisation.

2.2.10.4 Budgewoi Sandmass

The Budgewoi Sandmass is a relic tidal delta that was open to the sea approximately 1000 years ago and formed as a result of marine sands being deposited into the estuary through tidal exchange and storm events. The sandmass is a valuable and unique ecological area within the estuary because it provides a range of relatively pristine habitats, which includes large open sand-flat, non-tidal areas for feeding and roosting for many migratory and local waterbirds, extensive wetlands, saltmarshes and seagrass meadows (Fig. 33). The only comparable area within the Tuggerah Lakes estuary is the active tidal delta at The Entrance, however this delta has been highly modified and fragmented from dredging and experiences human disturbance and use. The Budgewoi Sandmass therefore represents unique habitat for invertebrates and fish within the estuary and the saltmarsh, wetlands and trees adjacent to the sandmass provide key roosting sites for many migratory and wading birds. Its close proximity to the ocean and relative inaccessibility also makes it an important site for seabirds that frequent the area. The saltmarshes adjacent to the sandmass account for approximately 5% of the viable and healthy saltmarsh within the entire estuary. The second largest seagrass meadow within the lakes can also be found along the south-east edge of the sandmass. There have been proposals to mine the sandmass in the past and a number of Environmental Impact Studies have been prepared. To date, Wyong Shire Council and other determining authorities have not supported the mining of sand from this area due to uncertainties about the ecological consequences of such actions. These uncertainties included loss of fish and bird habitat and small-scale changes to hydrodynamics within Budgewoi Lake.

Figure 32. Seagrass meadows, mud flat and saltmarsh in Tuggerah Bay.

Figure 33. The relic tidal delta or Budgewoi Sandmass.

2.2.10.5 Threatened Species and Ecological Communities

Conservation of biodiversity is seen as critical to the principals of ecologically sustainable development. Wyong Shire Council has introduced wetland protection under the 7G zoning and whilst this protects wetlands within the coastal plains, those to the west of the freeway are not protected.

A search of the EPBC database listed 40 threatened and 29 migratory species that had the potential to occur within the Tuggerah Lakes system. Of the 40 threatened species, most were either vulnerable or endangered species of birds, frogs, mammals, reptiles and plants. The migratory species were primarily birds with migratory wetland species those most likely to occur around the lakes. There were also 43 listed marine species that had the potential to live within the lakes system. A number of fish were listed, primarily comprised of pipefish and seahorses. Saltmarshes and freshwater wetlands have recently been listed as threatened ecological communities within NSW under the *Threatened Species Act*.

DPI (Fisheries) is currently assisting in reviewing the NSW Biodiversity Strategy, to include the consideration of issues relating to aquatic biodiversity. The NSW Biodiversity Strategy aims to coordinate work by the Government and the community to address the causes of the loss of biodiversity across all terrestrial, freshwater and marine ecosystems. DPI (Fisheries) is also involved in a range of other programmes to help conserve the aquatic biodiversity of NSW. These include protected and threatened species conservation, fish habitat, managing pests, marine protected areas, ecological research, and environmental assessments of fisheries.

In NSW, the responsibility for threatened aquatic species is divided between DPI (Fisheries) and the DEC (Parks & Wildlife). DPI (Fisheries) looks after threatened freshwater and saltwater fish and invertebrates, and marine vegetation. Other types of animals, including whales, dolphins, seals and waterbirds, and plants, including freshwater plants, are the responsibility of DEC (Parks & Wildlife). DPI (Fisheries) is responsible for all species of fish, including sharks and rays, aquatic invertebrates, such as worms, snails, mussels, corals, sponges, sea urchins, barnacles, crabs, crayfish, aquatic insects and prawns, and all seagrasses and attached macroalgae.

DPI (Fisheries) legislation has been strengthened with the inclusion of threatened species conservation provisions to declare and list threatened species of fish, marine vegetation, endangered populations and ecological communities and key threatening processes. Threatened species are one category of protected fish however there are also a number of other rare fish that are protected from fishing or collecting. Although populations of these species are not currently declining, they must be protected so that they do not become threatened with extinction at some time in the future. Species such as mangroves, seagrasses and seaweeds are important fish habitat and must be protected to maintain the health of aquatic communities and the productivity of fisheries. There are seven marine and estuarine fish listed as protected in NSW, none of which occur in the Tuggerah Lakes. All seagrass, seaweed and mangrove species are protected.

Syngnathids are a unique family of fish, which includes seahorses, pipefish, pipehorses and seadragons. They are highly vulnerable to human impacts due to their low reproductive and dispersal rates and their sedentary nature. There are approximately 31 species of Syngnathids found in NSW. While most Syngnathids in NSW are not currently threatened, increased fishing and their high vulnerability to human impact could mean a decline in local populations. The NSW Government has recently listed all seahorses, pipefish, pipehorses and sea dragons as protected under the NSW Fisheries Management Act. With this listing, anyone unlawfully taking seahorses, seadragons and other Syngnathids from NSW waters could face heavy penalties. There are at least five species of Syngnathids that can be found within the seagrass beds of Tuggerah Lakes (Roberts and Murray, 2005a). This listing forced Wyong Shire Council to examine the impact of the harvester on Syngnathid populations within the estuary. Modifications to the harvester were recommended and DPI (Fisheries) issued an experimental permit to continue harvesting macroalgae and seagrass wrack within the Tuggerah Lakes estuary (Roberts and Murray, 2005b).

A sponge species from the family Suberites has also been found in seagrass meadows in Tuggerah Bay, north Budgewoi Lake and in the north west of Lake Munmorah (Roberts, 2001). Whilst this species has been found in some other estuaries, it may need protection from dredging, harvesting and fishing. Threatening processes that could also impact on this species include siltation and increased turbidity as well as haul nets and the weed harvester (Fig. 34).

Figure 34. The sponge Suberites may be threatened within the Tuggerah Lakes.

2.2.10.6 Commercial and Recreational Fisheries

Commercial fishing is managed by DPI (Fisheries) and has been valued at more than $90 million per year in NSW. The conservation of biological diversity of fish and marine vegetation and the protection of threatened species, populations and ecological communities and key fish habitat are primary objectives under the Fisheries Management Act.

To ensure that commercial fisheries are managed in a sustainable way, environmental impact statements and fishery management strategies are being prepared for each of the major commercial fisheries in NSW. The assessments examine the environmental impacts of fishing activities for each strategy and include biological, economic and social aspects. The environmental impact statements are aimed at predicting the impacts of fishing on target species, by-catch species, and important fish habitat as well as economic and social issues. Fishery management strategies are valuable because they provide a long term vision for management of a fishery, outline the strategies that are in place to achieve that vision, provide stakeholders with greater certainty by knowing the management programmes that apply in the fishery, and provide useful background information. The strategies will allow the community to scrutinise the management arrangements for each fishery and will ensure that the management arrangements in place provide sustainable fisheries into the future (DPI Fisheries, 2004).

The Estuary General Fishery is the most diverse commercial fishery in NSW, with approximately 700 fishers operating in 102 estuaries along the NSW coast and employing more than 17 types of fishing gear. The fishery includes all forms of estuarine fishing except for prawn trawling. The most common fishing methods are meshing and hauling nets. The main species harvested are sea mullet, bream, flathead, luderick and school prawns.

The Estuary General Fishery is managed predominantly by limiting the amount of effort commercial fishers put into their fishing activities. These controls include restrictions on the numbers of fishers endorsed to operate in the fishery, restricting the operation of fishers to one region, a range of seasonal, weekend and area fishing closures, and a range of restrictions on the size and dimensions of the fishing gear used. Size limits also apply to some species, while others are totally protected. Changes introduced on September 16, 2002, as a result of the strategy, include: minimising the environmental impact of estuarine hauling nets by reducing their length and increasing their mesh size in set nets to avoid catching undersized fish; banning fish spikes, clubs or other implements which could harm species which need to be released; banning all forms of hauling over seagrass beds to better protect aquatic habitats.

An information base to support the management of commercial and recreational fishing and protect aquatic resources is available for the commercial sector where mandatory reporting programmes have been in place for decades. Within NSW there are a significant number of recreational fishers, however there were no arrangements to collect fishery statistics on the catches or effort involved. The significant number of people involved in recreational fishing has the potential to impact fishery resources. The quantification of the commercial and recreational harvest by species and region is fundamental to the determination of appropriate fishing regulations, sustainable harvesting and good management. Recreational fishing surveys have now been done, and estuaries were the major area where effort was placed. The catch of individual fishers was not large (about 2 fish per event), however the recreational sector as a whole has the potential to impact aquatic resources. The recreational catch of several common estuarine species is larger than the commercial catch. For most species, the commercial catch is substantially greater than the recreational catch. Recreational fishers spend substantial sums of money in pursuit of their sport and this expenditure is likely to be important to regional economies.

Tuggerah Lakes is the 5th largest commercial fishery in NSW and the 9th largest recreational fishery (Fig. 35). The Estuary Process Study (Roberts, 2001) identified potential conflicts between commercial and recreational interests that would need to be explored through community consultation. The question of whether commercial fishing should be banned or restricted in Tuggerah Lakes has been raised. Both Lake Macquarie and Brisbane Waters are closed to commercial fishing however there are no data to support whether fish stocks or habitats are any better off in these estuaries compared with Tuggerah Lakes or other estuaries. Although conflict between commercial and recreational anglers is minimal, there have been numerous calls by the community to ban commercial fishing in the Tuggerah Lakes. The only data available to assess the long-term fish stocks within the Tuggerah Lakes are commercial fish-catch records and anecdotal evidence. Both these data sources are questionable in terms of being able to make definitive claims about the status of fish stocks within the Tuggerah Lakes. Whilst it can be argued that the precautionary principle should be applied and that commercial fishing be banned, this action would have impacts on professional fisher families that have been operating in the estuary for many years. The decision to ban fishing in Lake Macquarie was effectively a political decision based on community opposition to commercial fishing. Unfortunately, no studies were instigated to examine the effects of banning commercial fishing in Lake Macquarie, so it is not possible to ascertain the success of this particular management strategy.

In 2001, the Recreational Fishing Trusts invited the community to nominate locations that they would like to see considered as potential recreational fishing areas. A summary issues paper of the results of the nominations, which includes the Tuggerah Lakes, can be found on the DPI Fisheries web site. Options for the creation of recreational fishing areas were put forward as a means of resolving conflict between commercial and recreational fishers, and removing impacts of commercial fishing on fisheries resources and the physical environment. Fair compensation was to be offered for any fishing business acquired as part of the creation of recreational fishing areas. Commercial fishing licence entitlements will be bought out using funds from the Recreational Fishing Saltwater Trust, which is funded by the recreational fishing fee. One option being considered is the closure of Tuggerah Lakes to commercial hauling to improve the quality of recreational fishing. This involves the complete buy-out of commercial fishing licence entitlements. Under this option, approximately one to two commercial fishing licences would be acquired at an estimated cost of up to $195,000. At this stage the Tuggerah Lakes estuary has not been nominated for closure to commercial fishing.

Figure 35. Fishing within the estuary.

2.2.10.7 Birds

The Tuggerah Lakes estuary has many important bird habitats, which include the proposed Tuggerah Nature Reserve, Tuggerah Lakes, Tuggerah Reserve (Pioneer Dairy), Wyrrabalong National Park, Munmorah State Conservation Area, Colongra Nature Reserve and Wyong Council bushland reserves (Morris, 2005). The Black Bittern, a vulnerable species, is known to nest within the fringing vegetation of the lower reaches of Wyong and Ourimbah Creek and has been recorded along the lower end of Mardi Creek, Porters Creek and at Berkley Vale. This bird could be expected to occur along all the inflowing creeks into the lakes, especially following re-vegetation activities to some of the streambanks of many of the local creeks (Morris, 2005). The nationally threatened Australasian Bittern has also been reported for Tuggerah Lakes. Single birds have been reported from the foreshore at Berkley Vale, Berkley Vale industrial estate and in the Porters Creek Wetland (Morris, 2005).

The nationally threatened Swift Parrot has been observed in the flowering Swamp Mahogany and Forest Red Gum groves around the foreshore of the estuary. In 2002, over 620 Swift Parrots, 35% of the total Australian population were found feeding in suburban trees and public reserves in the northern areas of the lakes (Morris, 2005). The stands of Swamp Mahogany and Forest Red Gums are very important as a source of nectar in winter for Swift Parrots. The protection of these trees and the rehabilitation of council reserves is considered very important for this species (Morris, 2005).

The nationally threatened Regent Honeyeater has been reported in significant numbers (up to 72 birds) in three different years in the flowering Swamp Mahogany forests in the Tuggerah estuary close to Tuggerah Bay and Wyong River. Smaller numbers have been reported from around the Tuggerah sewage treatment works near Ourimbah Creek. Replanting and re-vegetation of Swamp Mahogany and Forest Red Gum will contribute to improving habitat for this species (Morris, 2005).

The estuary, particularly Picnic Point, entrance channel area, Chittaway Bay, Tuggerah Bay and the Budgewoi sand mass, provides important feeding habitat for up to 22 species of migratory shorebirds that visit Australia each summer from the northern hemisphere. These species are listed in the schedules of the Japan-Australia and China-Australia Migratory Bird Treaties (Morris, 2005). The most common of these species includes the Bar-tailed Godwit, Sharp-tailed Sandpiper, Red-necked Stint and Curlew Sandpiper. Birdlife International estimated that 1% of the total population of these birds in the bio-regional population of Australia was 1500, 1600, 3200 and 1800 birds respectively. Since 1988, regular monthly counts of waterbirds have been carried out by members of Birding NSW. Peak counts for these species on Tuggerah Lakes has been 505 Godwits (September 1991), 2859 Sharp-tailed Sandpipers (November 2002), 998 Red-necked Stints (November 2002) and 1723 Curlew Sandpipers (December 1991). Sharp-tailed Sandpipers were recorded in October 1991 (2859) and January 2003 (1682) (Morris, 2005). The Tuggerah Lakes estuary has proved to be one of Australia's most significant regions for both Sharp-tailed Sandpipers and Curlew Sandpipers (Morris, 2005).

The estuary also provides habitat for 12 species of migratory terns, most of which are also covered by migratory bird treaties (Morris, 2005). Birdlife International has set the population of Caspian Terns at 1% of the Bioregional population however the population of Caspian Terns around the estuary often exceeds this number (Morris, 2005). The Little Tern, a vulnerable species, nests on the Karagi Point sand spit at The Entrance. For the past five years approximately 25 pairs have nested on the spit raising 20 – 50 young per year. Unfortunately, foxes wiped out the colony last summer just as hatching had started (Morris, 2005).

The estuary is particularly important for Black Swans that graze on the seagrass beds. The numbers of swans are greatest in summer and smallest in autumn/winter when part of the population departs to breed inland or on other local coastal lagoons (Morris, 2005). Birdlife International has set 1000 birds as being 1% of the Bio-regional population. Tuggerah Lakes often has over 3000 birds each summer and reached a maximum of 3515 in February 2003 (Morris, 2005).

The estuary is also important for species of ducks. Their numbers are generally greatest in dry years when many ducks from inland wetlands migrate to the coast. Species include the Grey Teal, Chestnut Teal and Australian Shoveler. Birdlife International have set the 1% of the Bioregional Population for Chestnut Teal and Shoveler at 700 and 200 respectively, so that in the early 1990s, the numbers of these ducks present on the estuary was quite significant (Morris, 2005). The nationally threatened Freckled Duck is found at the Pioneer Dairy Swamp and in Tuggerah Lagoon (Morris, 2005).

Two vulnerable species, the Black-necked Stork and the Pied Oystercatcher, occur around the estuary. A pair of Black-necked Storks has been a regular visitor to the Pioneer Dairy Swamp, Tuggerah Reserve, Yarramalong and Dooralong Valley wetlands and Chittaway and Berkley Vale during the 1990s and in various ephemeral wetlands over the years. Two pairs of Pied Oystercatcher are also resident in the estuary, one pair concentrating around The Entrance/Chittaway Point, the other pair on Budgewoi Lake and Birdie Beach from Soldiers Point to Red Ochre Beach (Morris, 2005).

The forested reserves around the lakes are important as nesting habitat for the White-bellied Sea-Eagle. A minimum of five pairs have territories based around forested sites around the estuary and it is important that disturbance is kept at a minimum at the nest sites (Morris, 2005).

The White-fronted Chat is one bird species that has disappeared completely form the coast in recent years. This bird was previously common in saltmarshes and estuarine areas at The Entrance and in the Tuggerah Bay area. It disappeared from The Entrance in the 1970's and from the Tuggerah Bay area in the late 1980's due to degradation of the saltmarsh. Rehabilitation of the Tuggerah Bay saltmarsh could see the return of these birds (Morris, 2005).

The Central Coast Group of Birding NSW supports the rehabilitation and protection of bird habitats around the estuary (Morris, 2005). The protection and rehabilitation of saltmarshes and revegetation of council foreshore reserves is seen as critical and a major priority. Examples include better protection of the Karagi Point Little Tern colony, rehabilitation of the saltmarsh in Tuggerah Bay and the revegetation of Swamp Mahoganies and Forest Red Gums in council reserves (Morris, 2005). The protection and rehabilitation of bird habitats will be an important component of the Estuary Management Plan.

The Central Coast Group of Birding NSW recommend that the supplementary feeding of Pelicans at boat-ramps as a tourist activity should be stopped. The group believes the Pelican population is being maintained at an artificially high level within the estuary by this practice

(Morris, 2005). An artificially high pelican population is undesirable as it can have impacts on other species. For example, Pelicans are known to trample the nests of Little Terns and also eat their young. Similarly, the extra feeding of Silver Gulls and Rainbow Lorikeets is known to affect other species such as Little Terns and Crested Terns (with Silver Gulls) and Scaly-breasted Lorikeets (with Rainbow Lorikeets).

2.2.11 Tourism and Recreation

A number of organisations were approached to obtain statistics on tourism in the Tuggerah Lakes catchment. Wyong Shire Council, Central Coast Tourism (Terrigal and The Entrance Branches) and The Entrance Town Centre Management were all contacted, and none were able to provide statistics on tourist activity with respect to the estuary.

While figures were not made available, The Entrance branch of Central Coast Tourism was able to provide some information regarding tourist activity in the area. They included:

- Tourists are attracted to the area more because of the natural features than attractions or services.
- While it cannot be said that tourists come to the area for any one of the following, the main activities of tourists during their stay are fishing, boating and beach/coast activity (swimming, snorkelling, walking).
- More than 60% of tourists who contact the CC Tourism (The Entrance) enquire about the National Parks in the area including Wyrrabalong National Park and Munmorah State Recreation Area.
- Accommodation closest to the beaches is most expensive and also most heavily booked.
- Some of the concerns of tourists who contact CC Tourism (The Entrance) about using the estuary include the prevalence of “Pelican Itch”, safety of swimming in The Entrance channels and the hazards of boating near The Entrance channel.

Further investigation of tourist activity and the importance of the estuary, would be a valuable tool in reaching a co-operative solution to sustainable management of the estuary.

2.2.11.1 Boating

Boating is one of the most popular recreational activities on the estuary. There are approximately 150 private and commercial mooring licenses on Tuggerah Lakes, limited mainly to Wyong and Ourimbah Creeks. Commercial mooring licenses include Licensed Fishing Boats (LFBs) and Wyong Council’s floating plant (wrack harvester and dredge).

Due to the shallow nature of Tuggerah Lakes and the fact that vessels cannot navigate the bar at The Entrance, the estuary tends to be predominantly used by trailer and hire boats.

Private mooring licenses are concentrated in the densely populated foreshore areas of Wyong and Ourimbah Creek. These areas offer protection from the elements and are popular both from a social perspective and as added value to property prices. Tuggerah Lakes tends to be more popular with sailing craft than power boating (Fig. 36). Budgewoi is used for both sailing and power boating (presumably due to its more protected waters), while Munmorah tends to be used mainly for power boating.

There are approximately 30 boat ramps around Tuggerah Lakes, most of which are owned and maintained by Wyong Shire Council. Council spends approximately $11,000 annually on their maintenance. Due to the shallow nature of the foreshore around Tuggerah Lakes many boat ramps are only suitable for small vessels. The main boat ramps are at:

- Picnic Point Boat Ramp – The Entrance. Offers deep-water access. Most used boat ramp on Tuggerah Lakes and suffers overcrowding on weekends, public holidays and peak periods. Facilities include fish cleaning, public toilets, picnic tables, picnic area, and skateboarding facility. Current facilities are inadequate with insufficient car trailer parking, boat ramp in need of widening and upgrading, and the seawall requiring upgrading. There is a requirement for a pontoon/wharf for vessels waiting to use the ramp.
- Long Jetty Boat Ramp – Long Jetty. The boat ramp offers deep-water access. Although not immediately adjacent to the ramp, the general area has picnic facilities car-parking facilities and public toilets. However the facilities themselves are rarely used as the ramp is in poor condition, and the foreshore is not conducive to other forms of recreation. The location offers some of the best water skiing areas on Tuggerah Lakes and is also popular for jet skis. These social recreational boating activities require foreshore picnic areas from which to operate. This area offers unlimited possibilities for recreational boating development and infrastructure.
- Wyong River Boat Ramp. Offers deep-water access. Current facilities – foreshore river front reserve with very limited parking – no public toilets – no fish cleaning facilities – no BBQ facilities. This boat ramp is the main access point to Tuggerah Lake from the western side of the Lake. The ramp is heavily utilised over summer. The boat ramp was recently repaired however there are no facilities for users.
- The Entrance North Boat Ramp. Secondary to Picnic Point Boat ramp. Fairly good access but poor boat ramp limits many types of vessels. There is foreshore reserve however there is limited toilet and picnic facilities. Very popular boat ramp during summer to access the North Channel and Tuggerah Lakes generally from the eastern shore.
- Gorokan Boat Ramp Budgewoi Lake. This is located near the Fish Co-op and has sufficient parking area, public toilet and picnic area. However, due to the shallow nature

of the foreshore in this location the boat ramp is restricted in the types of vessels that are able to use the ramp. The jetty is in poor condition.

- Coast Guard Boat Ramp – Toukley. This is a large ramp and it does not have deep water access, however most trailer boats are able to use it. It is under lease to the Coast Guard who allow general public access, except when aquatic race events are underway. This is a popular boat ramp for water skiers and jet skiers. There is suitable foreshore reserve land immediately adjacent to the boat ramp that allows family picnicking and boating. Facilities could be provided in the form of picnic tables, shelter, BBQ facilities and public toilets.
- Budgewoi Channel Boat Ramp (East) – Boat ramp very popular during summer and offers good launching access for most trailer boats. This boat ramp is popular for ski boats accessing Elizabeth Bay and Budgewoi Channel (both have picnic areas for boating activities). There is potential for improved access to the foreshore from the water.
- Budgewoi Channel Boat Ramp (West) – Ramp access is not as good as the east ramp. No facilities except car parking. Boat ramp does have a good wharf which is extremely popular for fishing especially for children. Wharf condition is deteriorating.
- Elizabeth Bay Boat Ramp – Ramp access is not good due to shallow nature of the area. However as this area offers excellent conditions for water skiing and foreshore picnics many operators manage to get their boats in the water somehow or access the area from Budgewoi Channel boat ramp. This particular area is very popular for recreational water skiing, jet skiing etc. The area has a sandy foreshore and is a popular swimming area for children. The boat ramp area is adjacent to the National Park and provides excellent conditions for water skiing. There are however limited facilities and as the area is growing in population, it could be expected that demand will increase.

The estuary is also popular for boating events with a number being held throughout the year under licence from the Maritime Authority. Such events include the annual barefoot ski races on Wyong River and Formula 1 racing in Lake Budgewoi. In addition, a number of sailing and aquatic clubs have licences to conduct events on the estuary.

Figure 36. Sailing is a popular activity on Tuggerah Lakes.

2.2.11.2 Swimming

Canton Beach is the most popular lakes beach and is used for swimming, sailing, paddle boating, parasailing and prawning. Generally, swimming is not a popular recreational activity in the estuary when compared to boating or fishing. This may be the result of a number of factors including:

- Turbidity – the high turbidity in the estuary is less likely to appeal to swimmers as the clear water of nearby ocean beaches.
- Shallow water – in many parts of the estuary, swimmers would have to walk out 50-150 metres to reach deep water.
- Aquatic vegetation – generally, swimming locations with vegetation underfoot are less popular than those with rocky or sandy floors.
- Poor recreational water quality – a number of locations have high faecal coliform counts, occasionally registering results incompatible with primary human contact.
- Odour – some shallow parts of the estuary have black odorous sediments. While not generally prevalent in swimming locations the perception may exist in the community that all foreshores suffer from this problem.

There are no statistics available on the usage of lake beaches over time, however anecdotal evidence suggests that there was increased use in some locations (Long Jetty and Canton Beach) after the completion of the Restoration Project. Council conducts water quality monitoring for faecal coliforms at a number of recreational sites. These are listed below (Table 6) from the 2001 State of the Environment Report (WSC, 2001), along with the percentage of failures to comply with ANZECC guidelines.

Table 6. Percentages of failure to comply with water quality guidelines for faecal coliforms for primary contact recreation at lake beaches (as a % of sampling times).

Location	1996/97	1997/98	1998/99	1999/00	2000/01	*% failures*
Canton Beach	79	87	72	71	71	76
Tumbi Creek	63	33	74	100	100	74
Ourimbah Creek	50	50	71	86	71	66
San Remo	32	0	29	43	29	27
Toukley Aquatic Club	18	17	17	0	0	10
Long Jetty	3	0	12	0	0	3
% failures	35	23	40	38	36	

It is evident that faecal coliforms are an issue for recreational water quality at most lakes beaches. A study was commissioned into the use of faecal sterols to discriminate between the sources of faecal pollution within the Tuggerah estuary. The results indicated that human faecal matter is only a minor component of the total faecal pollution within the receiving waters during rain events. Faecal pollution at all sites is significant, but it appears to be derived principally from native birds and to a lesser extent, domestic pets (Roberts, 2001). Further examination of the faecal sources should be undertaken in order to address this issue.

2.2.12 Monitoring

Wyong Shire Council undertakes monitoring programmes in the estuary and its tributaries. Council plans to monitor the response of the estuary over time and record changes in environmental conditions, as well as responses to managerial practices.

Currently Council measures the following water quality and biological variables:

- Total Nitrogen (TN)
- Nitrate and Nitrite (NOx)
- Ammonium (NH3)
- Total Phosphorus (TP)
- Orthophosphate (OP)
- Dissolved Oxygen (DO)

- Temperature
- Conductivity
- Salinity
- pH
- Phytoplankton
- Faecal coliform and enterococci presumptive colonies

Approximately $60,000 is spent annually on the monitoring of water quality variables, while $14,400 is spent on phytoplankton. Faecal coliform (FC) and enterococci (EC) sampling is budgeted at approximately $25,000/yr.

The “health” monitoring (FC and EC) will continue indefinitely to ensure the health and safety of swimmers using lakes beaches especially following rainfall events. The water quality and phytoplankton monitoring has recently been evaluated (Roberts and Barnes, 2004). A decision on future monitoring programmes will be evaluated as part of the peer review process and incorporated into the Tuggerah Lakes Estuary Management Plan.

2.3 EXISTING MANAGEMENT STRATEGIES

2.3.1 Tuggerah Lakes Adaptive Management Strategy

2.3.1.1 Overview

The Tuggerah Lakes Adaptive Management Strategy (TLAMS) (WSC, 2001) was developed to provide an adaptive management framework to catchment and estuarine management for the lakes. The strategy (Fig. 37) forms the basis for the managerial approaches taken by Council in trying to minimise the effects of a rapidly developing catchment, on the downstream estuary.

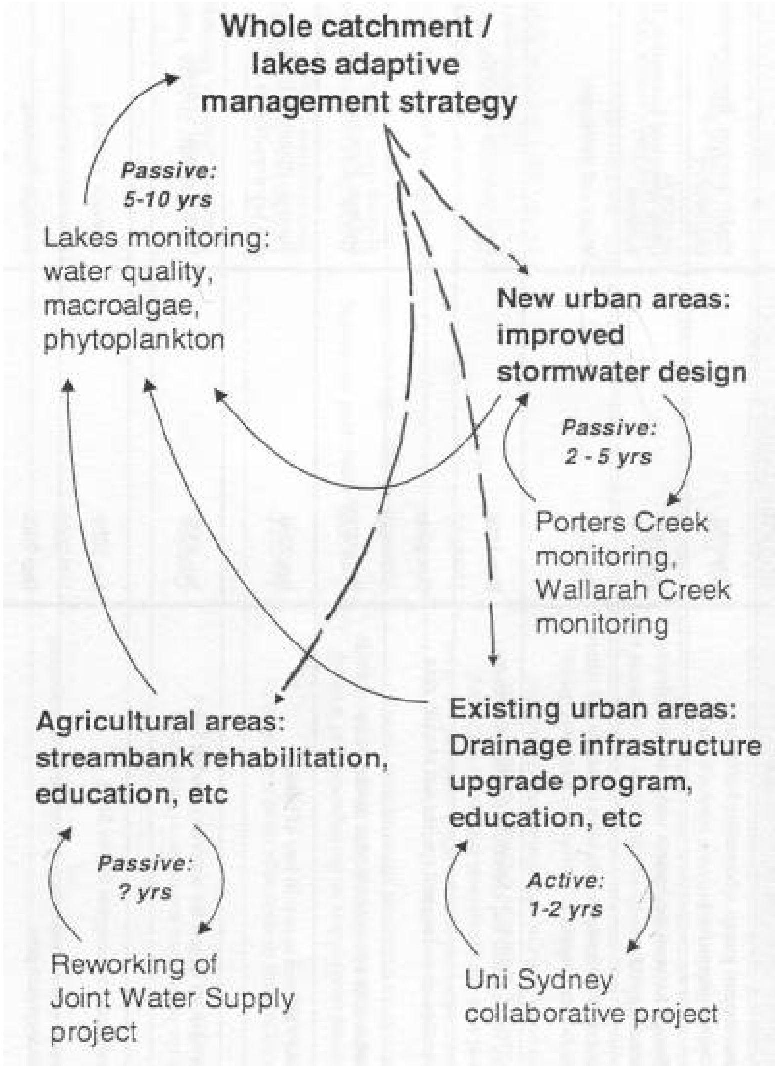


Figure 37. Tuggerah Lakes Adaptive Management Strategy (WSC, 2001).

There are three main activity areas within the TLAMS. Recognising the importance of catchment inputs to estuarine health, these areas correspond to the three largest landuse types that are within Wyong Council's administrative responsibilities; existing urbanised areas, new urban areas and agricultural areas.

Each activity area has at least one monitoring/research programme underway that feeds back into the current approach, i.e. a "review" loop that allows management to adapt its thinking on the basis of new information from these monitoring/research programmes. As part of the adaptive management process, it is important to review current management strategies to determine if the arguments for intervention and monitoring are still valid.

2.3.1.2 Documentation

The TLAMS is presented in a number of Council documents however it is not provided as a standalone policy document. Such a document is required so that aims, objectives, benchmarks, review processes and key assumptions are clearly articulated. In this way, Council's guiding strategy for managing the catchment and estuary is contained in one location and can be referenced by other important operational documents.

Documenting the assumptions behind the strategy would provide a higher level of transparency. It would also provide reasoned argument that could be drawn on, when stakeholders seek to change management approaches without having an appreciation for the complexities of estuarine and catchment processes. Difficulties can also arise when assumptions are not published and are therefore unable to be peer reviewed or assessed against new information that may have been revealed since the strategy was developed, making adaptation difficult.

2.3.2 Environment Business Plan

Wyong Shire's Environment Business Plan is the principal document for describing the functions of the environment section on an annual basis. The plan is in keeping with those produced by other major departments within Council as part of the annual Management Plan process.

The reporting is based around the elements reported as part of the State of the Environment report (SOE), namely land, water, biodiversity, air, heritage and noise. Each element is discussed in detail and includes:

- Goals
- Activities
- Outcomes
- Programmes and Targets
- Improvements

As this is the primary document used to drive the Environmental Systems unit of Wyong Shire Council, it is important to discuss its merits and identify potential improvements, before making recommendations about how it should be linked with the estuarine management planning process.

The plan contains a number of analyses, which are excellent for assessing whether Council's activities are the right mix for the issue. One of particular value to the estuary would be the analyses of spending. This technique separates the various management activities and determines which of them are treating "causes" of problems/issues and which are treating "symptoms". Often in environmental management, it is difficult to maintain focus on treating the causes, as the symptoms tend to be what the community and stakeholders react to. The plan also provides a SWOT analysis of the existing programmes and readily identifies deficiencies in approach.

There are some difficulties in working with the document. It is hard to extract clear indications of funding of various works throughout the estuary and the catchment. Programmes of works that are undertaken by other departments but have/or contribute an environmental benefit, tend to be counted in the environmental expenditure in a given year. The difficulty with this approach is that, while the undertaking of environmental programmes is a positive move, some programmes may be undertaken as incidental works, rather than specific environmental projects with clear measurable outcomes. In addition, there is a risk that by overestimating "core" environmental programmes, there is an appearance that the programme is well funded which may reduce political leverage in obtaining additional funding.

Another difficulty is that programmes which cross a number of the ecosystem elements (Air, Water, Biodiversity) tend to be counted twice in the accounting. For example, monitoring for Porters Creek wetland is counted as say $20,000 towards the biodiversity expenditure and also $20,000 towards meeting the water objective (despite the total programme being worth $20,000). This kind of accounting makes it difficult to assess the expenditure throughout the various elements. The other difficulty with the document is that key assumptions behind management decisions do not appear explicitly (as with the TLAMS). It is a necessary part of the science-management interface that assumptions are made clear so that they can be challenged where appropriate.

The Tuggerah Lakes Adaptive Management Strategy and the Tuggerah Lakes estuarine management planning process are inherently linked (most of the objectives implicit within the strategy are to manage activities that lead to symptoms by tackling the cause). These links could be strengthened, if the Business Plan was made the central document for managing the catchment and estuary, complete with clear spending allocations, analyses of the spending, and a transparent presentation of the assumptions that drive the current management regimes.

2.3.3 Regional Environmental Management Strategy

The Hunter & Central Coast Regional Environment Management Strategy (HCCREMS) is an innovative and highly successful regional initiative currently being implemented by the seven Councils that comprise the Hunter and Central Coast Region (Gosford, Wyong, Lake Macquarie, Newcastle, Port Stephens, Cessnock and Maitland). HCCREMS was developed to assist, support and resource local government to more efficiently develop and implement environmental management programmes. It seeks to facilitate a regional approach to improved environmental management throughout the Hunter and Central Coast by actively encouraging greater co-operation between member Councils, other authorities, industry and community groups (HCCREMS, 2005).

The position of HCCREMS is unique in terms of its ability to garner regional approaches to environmental management for the local area. It would be expected that any management plan for Tuggerah Lakes be consistent with regional objectives and plans (such as those for Brisbane Water and Lake Macquarie), and wherever possible, management actions should be collaborative and/or complimentary. Such an approach minimises the likelihood that individual Councils will be impacted by the environmental management decisions (or lack thereof) of neighbouring Councils.

2.3.4 Water Sharing Agreements

The water reform package discussed in Section 1.5.6 precipitated the development of water sharing agreements as a method for managing the State's water resources. Under the Water Management Act 2000, Water Sharing Plans are being put in place to define the water sharing arrangements between the environment and water users, and between different categories of water users. The plans are designed to provide for healthier rivers, aquifers and dependent ecosystems and provide water users with clarity and certainty about their water access rights (DIPNR, 2003).

For the Tuggerah Lakes catchment, these plans are important. There are strong ecological links between the freshwater inflows of the catchment and the overall health of the estuary. Gosford and Wyong Shire Councils are facing a long-term water shortage as the population of the area increases. This shortage places increasing pressure on the river systems generally expected to provide the water supply. The plans have the ability to provide set volumes for environmental flows.

There are two intertwined shortcomings in the current water sharing plans in the Tuggerah Lakes catchment. Firstly, the environmental requirement is established by taking the daily flow and subtracting the basic landholder requirements, not based on what is appropriate for the environment. Secondly, the plans do not address the current lack of understanding in terms of flow requirements for the ecological health of downstream environments. While the plans have the ability to set appropriate targets, they are limited by available knowledge. The plans do however represent a likely increase in total flows being provided for environmental water which is important given that the water supply shortage is becoming an increasing political and community concern.

So far, plans have been prepared for Jilliby Jilliby Creek (a tributary of Wyong River), Ourimbah Creek and the Kulnura-Mangrove Mountain Aquifer. It is unlikely that further plans will be developed in the same manner as these three, due to time and resource constraints. The new CMA will most likely drive any additions to these plans (say for Wyong River & Wallarah/Spring Creek). Table 7a defines the various flow conditions used in the plans while Table 7b indicates the environmental water and landholder allocations (DIPNR, 2003a).

Table 7a. Flow classes for creeks with Water Sharing Plans

Flow Class	Jilliby Jilliby Creek	Ourimbah Creek
Very low flow	0.5 ML/day for Year 1 0.75 ML/day for Year 2 1ML/day for Year 3	< 4 ML/day on falling river < 6 ML/day on rising river
A class	None	– 7 ML/day on falling river 6 – 7 ML/day on rising river
B class	0.5 – 3.3 ML/day for Year 1 0.75 – 3.3 ML/day for Year 2 1.0 – 3.3 ML/day for Year 3	7 – 25 ML/day
C class	3.3 – 8 ML/day	25 – 60 ML/day
D class	> 8 ML/day	60 – 160 ML/day
E class	None	> 160ML/day

Table 7b. Environmental water provisions for plans

Flow Class	Environmental Water	
	Jilliby Jilliby Creek	**Ourimbah Creek**
Very low flow	Flow – 0.51 ML/day	Flow – 1.37 ML/day
A class	None	Flow – 3.37 ML/day
B class	Flow – 1.51 ML/day	Flow – 13.87 ML/day
C class	Flow – 2.51 ML/day	Flow – 28.37 ML/day
D class	Flow – 3.51 ML/day	Flow – 47.37 ML/day
E class	None	Flow – 47.37 ML/day

The Joint Water Supply Expert Panel has made a number of recommendations to address the knowledge gaps surrounding the ecological requirements of downstream environments in the water supply catchment area (Muston, 2001). It is important for revisions of the Water Sharing Plans to include any new information that refines our understanding of the above environmental flow requirements.

2.4 ONGOING RESEARCH

2.4.1 Bio-indicators

The use of organisms as “indicator species” has been attempted in a wide variety of applications, ranging from the microbial level to the ecosystem. Biological indicators are organisms that, by their habit and interactions with the environment, provide an easily measurable, easily interpreted indicator for assessing the state of an ecosystem’s health. An indicator for “ecosystem health” assumes that this is a defined, operational concept. Unfortunately, no such definition has yet been developed. The other problem with a broad definition of indicators is that generally they are only measuring something we need to know about, and not actually indicating anything. As an example, the measurement of algal growth can only be considered an indicator if there is something tangible that they would be indicating, eg. Nutrient status. A wish list of things that need to be monitored is not a useful way forward in terms of trying to determine the "health" of an estuarine system. DIPNR with NHT funding have recently formed an expert panel to examine the potential range of bio-indicators that may be used to assess estuarine health. To be useful, biological indicators must be tightly correlated with the variables that we are trying to indicate. They must also show related and predicable changes when disturbances alter them. Indicators must be cheaper, quicker and simpler to measure than the thing they are trying to indicate. They must also have smaller precision when estimated. Unfortunately, many so-called biological indicators do not display these properties (Underwood, 2005).

Some potential bio-indicators were assessed as part of the Estuary Process Study and included the use of epiphytes, macroalgae and phytoplankton to predict the nutrient status of the water (Roberts, 2001). Assemblages of drift macroalgae were examined (Cummins et al., 2000), however they were deemed unsuitable as a potential bio-indicator of nutrient status because of the problems in quantifying their biomass and the extensive resources required to collect and sort samples.

Assemblages of phytoplankton were also extensively sampled within the estuary (Roberts, 2001; Cummins et al., 2004a). Areas with seagrass often supported a significantly different assemblage of phytoplankton from those in open water habitats, however the differences were not consistent across habitats or from one time of sampling to the next. In each habitat, most variation in abundances of taxa was at the smallest spatial scale, i.e. among replicate samples (< 10 m apart). These findings emphasise the need to incorporate different habitats and hierarchies of scales in programmes designed to understand and predict under what circumstances blooms of phytoplankton occur (Cummins et al., 2004a). Their use as a biological indicator of estuarine health is debatable however the programme is useful as an indicator of potentially toxic species which may be harmful to human health (Roberts and Barnes, 2004).

Macrobenthic invertebrates are animals that live on or in the muddy and sandy sediments of an estuary and are considered to be those animals that are retained on a 0.5 mm sieve (Poore, 1992). Macrobenthic organisms in estuarine waters are generally diverse and most species are relatively non-mobile (Day et al., 1987). They are represented by different feeding groups such as suspension and deposit feeders, grazers, predators and scavengers (Day et al., 1987). They play a major role in nutrient cycling processes, and are an important source of food for a variety of organisms (Coull, 1999). Macrobenthic organisms are also sensitive to human disturbance, which can make them an ideal bio-indicator of potential environmental impact (Underwood et al., 2003).

The meiobenthos are those invertebrates ranging in size fro 0.045 to 0.5 mm and are the most abundant and diverse animals inhabiting marine and estuarine sediments. They are recognised as being very important in processes such as nutrient re-mineralisation of organic material and enhancing bacterial activity (Dye, 2004). They are also important food for higher trophic levels (Dye, 2004). Meiobenthos are sensitive to human disturbance and pollution (Warwick, 1993) and their potential as indicators of environmental condition is widely recognised (Schratzberger and Warwick, 1998). Meiobenthos in estuaries and lagoons are exclusively of marine origin (Warwick, 1971) and their abundance and taxonomic diversity tend to decrease under conditions of great physical and chemical variability (Coull, 1999).

Studies of meiobenthos have been done in ICOLs (Intermittently Closed and Open Lagoons) in NSW (Dye, 2004, Dye and Barros, 2004). A recent survey of meiobenthos within the Tuggerah Lakes found that they were typical of isolated systems that experience little tidal exchange, and that their diversity and abundance was relatively smaller than what is found in similar estuaries (Dye, 2004). Further work is being done on meiobenthos in Tuggerah Lakes as they may be a suitable indicator of estuarine health.

At least three species of sponge occur in the Tuggerah Lakes (Barnes, 2004). Of these, the most conspicuous and abundant is a species in the genus Suberites. The sponge fauna of NSW lakes is poorly described and it is likely that this Suberites may be a species new to science. It is not restricted to the Tuggerah Lakes and has also been found in Wallis Lake, Smiths Lake and Lake Macquarie. A similar, but possibly different species of Suberites has also been found on the NSW south coast in Lakes Conjola and Burrill. Suberites is usually found in the shallower habitats (less than 1.5m) on soft sediments among patchy beds of seagrass and/or macroalgae or on bare sediment. In Smiths Lake, it is also found in deeper water to 4 metres. Suberites may live attached to the substratum or unattached. Individuals may become unattached, move metres per day during periods of storms or strong winds and then reattach to the substratum or each other. It is a species tolerant to freshwater, able to survive for at least 2 weeks at salinities of 13 parts per thousand. Recent results, suggest distributions within lakes may be, at least in part, restricted by predation by fish (probably leatherjackets).

Historical patterns of distribution of Suberites were compiled after discussion with local commercial fishers (Byles, pers altm., 2004), observations and as part of a quantitative survey of Tuggerah Lakes (Barnes, 2004). Two populations were known to occur in Lake Munmorah. In 2002, numerous large sponges were observed in the north-western corner of Lake Munmorah amongst patchy Zostera and Ruppia in less than 1 metre of water. A few relatively smaller individuals were observed close to the western shore, south of Yellow Rock Point. In Lake Budgewoi, Suberites were observed near to the outlet of Munmorah Power Station in 2001. In addition, local fishermen reported Suberites to be common along the western shore of Lake Budgewoi from the Toukley Bridge to the north of the lake before Munmorah Power Station was commissioned. Suberites has been observed in at least five locations in Tuggerah Lake. Roberts (2001) reported a population north of Tuggerah Wharf in Tuggerah Bay, however a recent survey of the Lakes in November 2003, failed to find the sponge at most known locations. Similar lake-wide declines were not observed over the same period of time in Wallis nor Smiths Lakes. This species is now being investigated as a potential bio-indicator of estuarine health (Barnes, 2004).

2.4.2 Mixing and Algal Growth

The AEAM model that was developed for the Tuggerah Lakes used a nine-box model which separated the shallow seagrass habitats from the deeper open waters of the estuary and assumed there was limited or no mixing between these zones (Walkerden and Gilmour, 1996). The data that were used to establish the model was based on previous assumptions about mixing in the lakes as well as data collected at one transect at Long Jetty over a 12-18 month period. Some further mixing experiments were done at three other places over a full day and these data indicated that mixing between these zones was variable, i.e. it depended on which place in the estuary was sampled.

Increased biomass of macroalgae was reported adjacent to developed shorelines in the Tuggerah Lakes compared with undeveloped shorelines (Cummins et al., 2000), however this reported pattern may be an artefact of the sampling strategy used in the design of the monitoring programme. Increased growth of macroalgae close to stormwater outfalls and along developed shorelines was thought to be caused by runoff from localised sub-catchments. Studies of mixing of water and nutrients between open water and shallow seagrass habitats have not provided clear evidence that there is a distinct separation between the shallow edges and the deeper waters of the estuary. If blooms of macroalgae in the estuary occur at the scale of sub-catchments, then the construction of wetlands and other stormwater controls would be best placed within these sub-catchments rather than the wider catchment. If on the other hand, nutrients can enter these shallow zones from the open water habitats of the estuary through mixing processes, then placing resources into managing sub-catchments may not be the best “bang for the buck”.

The growth of algae at a number of locations was investigated in developed and undeveloped regions of Tuggerah Lake, Budgewoi Lake and Lake Munmorah (Chapman and Underwood, 2003). The ephemeral alga, *Chaetomorpha linum*, which is a major contributor to algal blooms in the lakes, was experimentally grown in cages. Growth was extremely variable among locations within each of the regions, particularly in Tuggerah and Budgewoi Lakes and there were no general patterns between developed and undeveloped regions. Nevertheless, growth was significantly greater in some locations than others, indicating large differences in patterns of growth among places only 100 m apart. This suggested that factors influencing algal growth operate at these relatively small spatial scales. Further experiments on algal growth were done to evaluate the model that variation in growth of algae is generally variable at relatively small spatial scales. Algal growth was again compared among locations in developed and undeveloped regions in Budgewoi Lake. This was to be repeated in the same locations on two occasions to test the alternative models that: (a) algae consistently grow better in some places than others, or (b) spatial patterns of algal growth vary from time to time. This would allow focus on more realistic processes that cause algae to increase growth in some places and/or at some times. Algal growth was also compared in locations where there was a bloom and locations where there were no blooms to evaluate the model that growth is faster in areas with blooms (hence, the bloom is the result of ongoing, rapid algal growth). This may occur because local environmental conditions favour algal growth, or because nutrients are increased in such areas due to algal decomposition, which, in turn, enhances algal growth. An experiment examining rates of algal growth outside constructed wetlands was also done however large floods occurred during the study, which confounded the experiment. Research on mixing and associated algal growth is an ongoing collaboration between WSC and the EICC.

2.4.3 Saltmarsh Rehabilitation and Wrack Management

Estuarine foreshores around the Tuggerah Lakes are severely degraded due to human disturbance with approximately eighty five percent of saltmarsh lost (Roberts and Chapman, 2003). Activities by the community and other stakeholders continue to place pressure on what little remains. The importance of fringing wetland vegetation to the health of an estuary, in terms of ecological processes, has received considerable attention in recent years. The need to rehabilitate wetland/saltmarsh habitat within the Tuggerah Lakes estuary was highlighted in the process study as an important and high priority management issue (Roberts, 2001). Current research indicates that the importance of these habitats to both nutrient and seagrass wrack recycling is very high. Preliminary investigations have shown that where seagrass wrack is deposited on saltmarsh, the wrack breaks down faster than on disturbed land, exotic lawns and un-vegetated surfaces (Figs. 38-40). The process of faster wrack breakdown within saltmarsh may be explained by increased aeration of the wrack (i.e. the wrack is kept elevated by the structure of the plants allowing it to dry out quicker) and greater biological and chemical activity (Roberts and Chapman, 2003). These mechanisms are still being investigated, however the importance of saltmarsh in recycling seagrass wrack within the estuary is clear.

Wyong Shire Council was successful in obtaining Coast and Clean Seas (NHT) funding to establish the role of saltmarshes in nutrient and wrack recycling within Tuggerah Lakes. This grant involved collaboration with the EICC and a number of community groups. The aim of the project was to identify the role of saltmarsh in recycling processes as well as establish techniques to passively and actively rehabilitate these habitats. Areas for potential rehabilitation were identified and ranked around the estuary. Long Jetty was identified as an area where council could trial rehabilitation of saltmarsh on foreshore reserves. Furthermore, it was envisaged that with some minor engineering works, the large saltpan in Tuggerah Bay could be passively rehabilitated creating a significant and viable saltmarsh community.

Saltmarshes are threatened in many parts of the world because they are considered wastelands rather than valued wetlands. This is particularly true in urbanised parts of Australia (Stricker, 1995). As much as 85% of saltmarsh has been lost or severely damaged in the Tuggerah Lakes. Seagrass wrack has been shown to promote the diversity of saltmarshes, by shading the soil and reducing physical stress and/or by directly providing nutrients to nutrient-poor soil. In many parts of the world, wrack comes from the saltmarsh plants themselves. In the Tuggerah Lakes, there are large amounts of seagrass wrack, which are stranded along the shoreline and in the remaining saltmarshes. It is very expensive to clean up this wrack, which WSC are under constant pressure to do because the wrack is perceived to have no ecological value and to be a nuisance. Council in conjunction with EICC examined the value of wrack in promoting cover and diversity of saltmarsh and in adding organic matter and benthos to the sediment (Roberts and Chapman, 2003). There was a rapid increase in biomass of the dominant plant, *Sarcocornia quinqueflora*, but no change in diversity over the experimental period. There was also no evidence of changes to benthos or nutrients in the sediment in the wracked compared to un-wracked treatments. Nevertheless, increased biomass in dominant species has been shown to reduce physical stress for other smaller saltmarsh plants.

The next phase of this study examined the potential for both passive and active rehabilitation of larger areas of denuded saltmarsh habitat (Roberts and Chapman, 2003). It was apparent that similar results would be obtained to those found in the small-scale experimental studies. These experiments were done in Tuggerah Bay and preliminary results indicated that they will provide a basis for rehabilitation at much larger scales. Large-scale rehabilitation of saltmarsh would be an important step in restoring some of the lost ecological function of the estuary.

The role of saltmarsh in aiding the breakdown of wrack was also examined using field-based manipulative experiments. An experiment was designed to measure the breakdown of wrack on saltmarsh and bare areas. Measuring break-down of leaf litter or equivalent degraded plant matter is not very easy. Traditionally, litter bags are used, but they have many inherent problems because they provide such an artificial set of conditions. In addition, litter bags are traditionally small, containing relatively little litter, whereas the deposition of seagrass wrack on the shores of Tuggerah Lake is patchy and often very thick. In addition, litter bags are usually buried or deposited among leaf litter on the ground, whereas here the investigations are about wrack deposited on the saltmarsh plants themselves. A number of preliminary experiments were done, in which litter bags of different sizes were investigated and these were deployed either on or under natural saltmarsh. These experiments indicated that litter bags were not appropriate because the confined wrack could not easily break down and fall amongst the salt marsh plants as happened naturally. It was therefore decided that the wrack should be placed in cages with large mesh in areas with or without saltmarsh plants. These cages were designed to exclude new wrack arriving in the plots, or existing wrack being washed away, while allowing added wrack to break down in a natural manner. Seagrass wrack was weighed and applied to the experimental plots of saltmarsh and bare ground. A cage was placed over the plot to stop the wrack being washed or blown away. Unfortunately these experiments were destroyed by vandals before any quantitative data could be collected (Roberts and Chapman, 2003). Observations on these plots through time indicated that wrack was diminishing in plots with saltmarsh compared to bare areas. The overall aim of this work was to quantify the ecological value of saltmarsh to estuaries in terms of their recycling ability and put in place sustainable management practices, which protect the function of the saltmarsh under the pressures of a much larger human population. The current management of seagrass wrack is considered a liability with a significant economic burden on the community. The results of this project indicated that we may be able to turn this abundant resource into an ecological asset. There has been significant interest in the outcomes of this project from managers of other estuaries in NSW. In some of these estuaries, seagrass wrack is not abundant and Tuggerah may be a potential source for other saltmarsh rehabilitation projects.

Figure 38. The growth of saltmarsh in a wracked plot after 6 months.

Figure 39. Wracked plots at the same site at the end of the study in December 2002 (note un-wracked plot in foreground marked by a stake).

Figure 40. Application of seagrass wrack over large bare areas.

3 Developing a Strategy for the Future

3.1 IMPORTANT CONSIDERATIONS

3.1.1 Importance of Catchment Management

Many coastal estuaries in Australia are dominated by high recreational and commercial use. This places a necessary emphasis on managing these activities. Tuggerah Lakes is not used as highly for recreation compared with surrounding estuaries like Lake Macquarie, Brisbane Waters or the Hawkesbury-Nepean Rivers. Limited recreation tends to concentrate on some areas of the foreshore and around the entrance channel. There is a commercial fishery operating in the estuary, however little is known about its state or pressures (Sections 2.2.10 and 6.5 cover this in more detail). Water quality and flow patterns in the estuary are not widely affected by the ocean entrance and are more likely to be affected by catchment runoff. The rapid development of the catchment and associated changes in runoff quality and quantity is likely to continue to place pressure on the estuary, making a focus on catchment management a central part of trying to manage the activities that affect the estuary in a sustainable way.

The State government recently formed the Hunter Central Rivers Catchment Management Authority (see section 1.2.3), which will be responsible for implementing the recommendations from the Catchment Blueprint (and subsequent Catchment Action Plan which is under development). Given the importance of the catchment to the health of the estuary, it is important that the Blueprint link with the Estuary Management Study. This was achieved in this report by adopting the primary objectives from the Blueprint and assigning them as principles by which to manage the estuary and the catchment. From these principles, component objectives can better target important estuarine management issues.

3.1.2 Organisational Considerations

In preparing a document for Wyong Shire Council, a number of important organisational characteristics needed to be taken into account in order to prepare a study and plan that would assist in managing activities that affect the estuary and catchment.

Existing management approaches are not well documented or “public facing” and don’t adequately link the breadth of catchment activities (such as tourism) with estuarine management. This issue was addressed by matching the over-arching principles of the study with the first order objectives of the Blueprint (the regional plan for catchment management actions). The Blueprint principles/objectives provide focus to most catchment activities and have the advantage of having already been signed off by catchment managers and the community, as well as forming the basis for the Blueprint. Blueprint actions are currently being integrated into the Hunter Central Rivers Catchment Action Plan.

There was also a need for a detailed suite of objectives aimed at managing the local activities (in the catchment and estuary) that affect the estuary. This was resolved by developing objectives that comply with the Blueprint principles but are also specifically relevant for the Tuggerah Lakes and catchment.

Councils existing management plans do not allow for a range of interests (environmental, recreational, ecological, economic and community education needs) to be incorporated into catchment and estuarine management planning. To address this, objectives representing these various interests were also worked into the document to provide for input from representative groups.

Historically, public comment on management of the estuary does not adequately recognise the range and complexity of interests involved in managing the estuary and catchment. In response, the 6 core principles have been placed in separate chapters to ensure that each principle remains on the agenda. This should also encourage the community and managers to think of catchment and estuarine management not in terms of a problem requiring a solution, but as a number of core elements requiring balanced management. The separation of these elements also has the advantage of encouraging managers on a tight budget to trade-off actions from within a core area (e.g. one water initiative for another water initiative) - rather than trading off between say a water initiative and a vegetation initiative which can happen in larger plans where all options are addressed together.

Currently there is no formal recognition of the need to continue research on the estuary and distribute this knowledge to the community. This has been addressed by developing a new principle and objectives that should improve this situation. It is hoped that by addressing social and economic issues (e.g. improvements in amenities, foreshore areas and beaches) and keeping the community informed there will be more positive discussions about the estuary.

The study lists options and programmes that require attention, however they are not costed or detailed. This is deliberate and has a number of advantages: 1) It is scalable - managers can do as little or as much as they can afford, and 2) the cross-Council teams can use their own experience and knowledge to extract funding, possibly even by lobbying within their departments for funding. The options were developed based on consultation with the Tuggerah Lakes Estuary and Coastal Management Committee, special working groups (comprising technical, community and business groups), community meetings, relevant Council reports.

There is a large amount of detail in each of the principle areas. A comprehensive range of issues and options were developed, with recommended programmes only coming in response to high priority issues. It was felt that the list should be comprehensive so that the document could be referenced during annual reviews of the management plan. Once a particular issue was resolved, others could be selected without having to conduct a review of the entire document. Many estuarine management studies and plans do not have longevity as only priority issues are handled. Once the issues are resolved, the document loses its importance. It is hoped that the approach described will ensure this study has a longer lifespan than others.

3.2 KEY STEPS COMPLETED

3.2.1 Initial Consultation

A consultation programme was undertaken as a precursor to the development of the study. Reference groups were formed comprising representatives from the community and local businesses. A technical reference group was also convened with members from key departments within Council and external government agencies providing advice and guidance. Participants were provided with briefing material that gave them a background on the issues facing estuarine managers and potential options to address them. The intention of the workshops was to provide a clear and prioritised list of issues and options that could be incorporated into the study and managed in detail in the upcoming Management Plan. The relevant issues and options from the final report (Duncan and Smith, 2004) were incorporated into Sections 4 - 9.

3.2.2 Consolidating Input and Strategy

Following the initial consultation it was necessary to build a strategic framework that articulated the future direction and aims for managing activities that affect the estuary. After reviewing a number of key reference documents, it was decided that linking the study to the Central Coast Catchment Blueprint would ensure that the same overarching principles governed both the estuary and the catchment. This was particularly important given the increasing role of the catchment management authorities in prioritising and funding catchment programmes.

As detailed in the Blueprint, the principles represent the six areas of ongoing concern for managing the Tuggerah Lakes estuary; water quality and quantity, vegetation, diversity and threatened species, land use and human settlement, social and economic needs, and improving knowledge. Under each principle a series of objectives were developed that specifically addressed areas of concern for estuarine management. In many cases the objectives relate to the catchment, recognising that estuarine health is strongly influenced by catchment activity.

3.2.3 Establishing a Framework with the Committee

The principles and objectives were developed in consultation with staff from Wyong Shire Council and DIPNR. Once this framework had been prepared, it was presented to the Tuggerah Lakes Estuary and Coastal Management Committee. The Committee had a number of suggestions for improving the wording and focus of catchment/estuarine objectives which were then incorporated. The final version of the principles and objectives were presented to the Committee and endorsed in March 2004.

3.2.4 Further Consultation

Draft versions of the Estuary Management Study were presented to the Committee and key Council and DIPNR staff in April, July and October 2004. The document was reviewed and a number of structural edits were requested in addition to minor content changes. These changes were incorporated and the revised document was then sent back to the Committee and out to the technical, community and business groups for their comment. Comments were incorporated before the document was sent out for Peer Review. Following the incorporation of comments from Peer Review, the document was put to Council for their approval and then placed on exhibition. During this exhibition period, three “town-hall” style community meetings were held to introduce the Study and encourage feedback. Following this consultation, final modifications were made to the document.

4 Water Quality and Quantity

4.1 INTRODUCTION

This section defines the overarching principle and sets future objectives for managing the quality and quantity of water for the estuary. In order to meet these objectives, it is necessary to a) define any issues that currently prevent the objectives from being met and b) implement options to address these problems.

Managing the quality and quantity of water both within the estuary and for flows entering the estuary is important for protecting long-term estuarine health. Increasing urbanisation has changed stormwater quality, which is thought to influence macroalgal blooms and increase sedimentation close to the shoreline. The extraction of water from rivers for community and commercial use has reduced the overall movement of freshwater into the estuary and may be impacting circulation patterns.

This section examines each objective in detail, focussing on the issues that prevent the objective from being met, and providing potential options to address such issues.

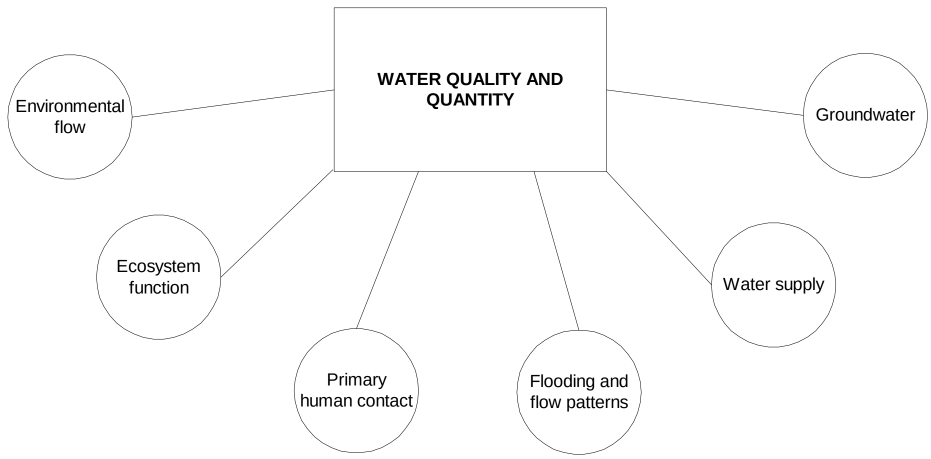
4.1.1 Principle

The Central Coast Catchment Blueprint identified a number of “first-order” objectives for ongoing catchment management. Water quality and quantity was one of the first order objectives and was expressed as:

Water quality and quantity meet community needs
and natural ecosystem requirements

This principle was developed for the catchment but is an important consideration when trying to sustainably manage activities that affect the estuary.

4.1.2 Elements



4.2 ENVIRONMENTAL FLOWS

Objective WF: Provide adequate environmental flow to sustain estuarine and riverine ecology

Environmental flows are the flows required to maintain natural stream conditions and these flows are thought to be essential for the “health” of instream biota. It is thought that the instream ecology of both Wyong River and Ourimbah Creek are under stress from reduced flow and/or increased inputs of nutrients (TEL, 1999), which has ecological implications for the receiving waters of the estuary.

Gosford and Wyong Councils Water Authority is currently evaluating options for management of environmental flows in the waterways within its sphere of operations (TEL, 1999). There is a strong focus on understanding the ecology of the streams before making environmental flow recommendations (Muston, 2001). This reflects the importance of managing environmental flows in a sustainable way for water supply and ecology.

Water Sharing Plans have been developed in response to the *Water Management Act 2000*. These plans are intended to balance the often competing needs of community, industry and the environment. Ourimbah Creek, Jilliby Jilliby Creek and the Mangrove-Kulnura aquifer have plans in place. The implemented plans have made specific provisions for environmental flow under a range of conditions, however the specified flows are not based on stream-specific ecological data. Water Sharing Plans only apply to GWCWA’s extractions when an application is made for an increase to existing licensed pump capacities (Wynn pers com., 2005).

It is important to note that baseflow from groundwater can be a significant component of environmental flows. This study deliberately makes a distinction between the two, to ensure that they both remain on the agenda (this is important considering the differences in the management approach between the two). Hydrologic models should ensure that both are taken into account, including assessments of altered hydrology in development areas.

4.2.1 Issues & Threats

WF1. Water supply and irrigation get priority over river flow for environmental needs

Traditionally, water flow has been allocated to primary industries such as agriculture and to community water supply, above the requirements of the environment. The environment has been affected in many ways by this change in flow allocation. Water Sharing Plans and the Water Authority’s Strategy for environmental flows aim to improve the allocation of water for ecology.

WF2. Sedimentation, weirs, drains and river crossings can create migration barriers and affect natural flows

Migrations and breeding cycles have been altered by barriers across rivers, and habitats have been altered, creating favourable conditions for pest species such as carp. There have also been local extinctions of fishes upstream of some barriers. Improved management by providing effective fish ways, appropriate flows and removing redundant structures will provide increased access for migratory fish and re-establish population distributions (Muston, 2000).

In the Tuggerah Lakes catchment, there are a number of weirs, two of which are used to pool water for water supply extraction. Wyong River has a weir approximately 6km from its discharge into the estuary. It is 1m in height and stores 300ML of water behind its sloping rock rubble and vertical concrete wall. This weir is a barrier to aquatic organisms and to the exchange of saline and freshwater. It is however, overtopped during high flows (TEL, 1999). Wyong weir has a rock ramp for fish passage, however Muston (2000) identified a risk of sub-optimal fish migration related to weir pool and fishway configuration.

There are two weirs on Ourimbah Creek; Ourimbah Creek Weir and Lower Ourimbah Creek Weir. The latter acts to prevent saltwater incursion upstream, while the former is used to pool water for transfer to Mardi Dam. The channel between the weirs is actively managed to prevent saltwater intrusion which can result from the pumping of water at the upper weir. The upper weir also has a fishway and outlet pipe, which remain open at all times and in all flow regimes. The upper weir fishway is considered ineffective in allowing fish passage (Muston, 2000). Lower Ourimbah Creek weir has a rock ramp fishway that is designed for low flow regimes (Muston, 2000).

The weirs are also a barrier to aquatic organisms that would ordinarily migrate/populate areas along the reaches of the system. For example, Towell (2000) found greater abundances of macroinvertebrates upstream of Upper Ourimbah weir, compared with below the weir.

There are other migratory barriers to biota in the aquatic habitats of the catchment. Changes to flow regimes from irrigation, bridges, culverts etc. can create ponding in some areas of the rivers, which then impedes movement. It is thought that the instream ecology of both Wyong River and Ourimbah Creek are under some stress from reduced flow and/or increased inputs of nutrients, which has ecological implications for the receiving waters of the estuary (Roberts, 2001).

The interaction between freshwater and saline inflows is a feature of the estuarine environment. The weirs and their associated pumps act as a barrier to this mixing that occurs at various distances from the estuary depending on the flow of freshwater.

WF3. Subsidence can drain river flow

Subsidence can damage a river bed to the extent where water is drained. It is often associated with mining, and in some cases, subsidence has completely stopped the flow in a river. Cracking of the stream bed has been noted in some catchments south of Sydney where streams were drained, causing a major problem to the aquatic ecology along the length of the stream. Increased mortality, decreased migration and breeding and the potential for invasive species recruitment are all possible effects of a subsidence event. With coal mining being considered in the Tuggerah Lakes catchment, the threats from subsidence should be clarified.

WF4. Current monitoring is inadequate for assessing environmental flow

One of the obstacles to monitoring the implementation of a realistic environmental flow regime is that the flow monitoring equipment can be sparsely distributed within a river system because of costs and they can also be inaccurate (up to 20%) (McLeod pers com., 2003). Any attempt to audit flow extraction figures against total and environmental flow would be problematic.

WF5. Inadequate understanding of riverine ecological processes and riverine water quality to allow for environmental flow management

There was no formal study of baseline flows and their relation to aquatic and riparian ecology prior to the alteration of flows in the tributaries of the estuary. An Environmental Impact Statement (EIS) was prepared for proposals for the construction of an upper weir on Wyong River and for the raising of the existing weir on the lower Wyong River. The EIS did not provide a quantitative baseline of information on the ecological condition of the systems before the approval (Muston, 2000).

Based on available information, it appears that Ourimbah Creek and Wyong River are under some stress, either from reduced flows or from inputs of nutrients (TEL, 1999). Towell (2000) noted the following:

- Macroinvertebrate assemblages in benthic habitats were similar between Wyong River and Ourimbah Creek.
- Wyong River and Ourimbah Creek ranked highly in terms of abundance and richness for benthic and edge habitats when compared with other streams entering the estuary.

- Little variation between Wyong River and Ourimbah Creek in terms of macroinvertebrates in edge habitat compared with the other streams.
- Total abundance of fish was highest in Ourimbah Creek while species richness was highest in Wyong River.

The recommended strategy for environmental flows in the catchment (Muston, 2000) included assessment of macroinvertebrate assemblages to assess stream health (see Roberts, 2004) and also a risk assessment of pests, pathogens and thermal pollution on instream ecology.

4.2.2 Options

Issue	Option	Outcomes		Cost	Ability to address Issue?	Responsibility
		Benefits	Difficulties			
WF1. Water supply and irrigation get priority over river flow for environmental needs	WF1a. Adopt Water Sharing Plans	• Responsibility of State Government not Wyong Shire Council • Criteria are prescriptive	• The targets are not based on local ecological data – perhaps not most appropriate for streams	Low-Med	High	DIPNR
	WF1b. Implement Joint Water Supply Recommendations	• Local targets based on coarse ecological assessment	• No numbers for design engineers to work with in lower streams	Low-Med	High	WSC, GWCWA, DIPNR
WF2. Sedimentation, weirs, drains and river crossings can create migration barriers and affect natural flows	WF2a. Remove existing barriers	• Restore ecological passage between the rivers and estuary • Allow for water quality changes through increased mixing	• Removing weirs creates threats to the water supply • Alteration to current flow patterns • Management of potential nutrient and sediment stores behind weirs	High	High	WSC, GWCWA, DIPNR, DPI (Fisheries)
	WF2b. Modify existing barriers to improve flow mixing and allow for migration of key species	• Retain Water Supply access for pumping • Allow for water quality changes through increased mixing • Some ecological migration	• Does not allow for full migration • Could have impact on effectiveness of pumping for water supply	Med-High	Medium	WSC, GWCWA, DIPNR, DPI (Fisheries)
	WF2c. Do nothing	• Maintain water supply access and efficiency	• Isolation of rivers and estuary in low flow continues • Does not support migration during water quality changes	Low	Low	WSC, GWCWA, DIPNR
WF3. Subsidence can drain river flow	WF3a. Ban mining under rivers	• River flow protected from draining • Protection of water quality and habitat	• Loss of potential employment in the shire • Loss of potential economic stimulus	Low-High	High	DIPNR

Issue	Option	Outcomes		Cost	Ability to address Issue?	Responsibility
		Benefits	Difficulties			
	WF3b. Do nothing	• Allows mining to proceed – likely to stimulate local economy and provide jobs	• Potential for damage to environmental flows and sensitive habitats	Low	Low	DIPNR
	WF3c. Manage damage if/when it occurs	• Permits the benefits of mining • Accepts the possibility of risk • Create management plans for high risk areas	• Unlikely to be able to correct damage once it occurs • Too late for treating • Intensive high tech remediation required to fix	High	Low	
WF4. Current monitoring is inadequate for assessing environmental flow	WF4a. Install more flow meters	• Increased data coverage of catchment streams • Improve ability to monitor water extractions under Water Sharing Plans	• Determining who would fund and undertake the increased monitoring	Low-Med	High	WSC, DIPNR
	WF4b. Increase accuracy and frequency of monitoring at existing gauges (currently ± 20%)	• Improved data and potentially increased frequency	• No new information for flow higher in the catchment	Low	Medium	WSC, DIPNR
	WF4c. Do nothing	• Continue to gather some data	• Insufficient data to gauge environmental flows and monitor the terms of the water sharing plans	Low	Low	WSC, DIPNR
WF5. Inadequate understanding of	WF5a. Do nothing	• Nil	• Difficult to determine if environmental flows are having an ecological effect	Low	Low	WSC, DIPNR

Issue	Option	Outcomes		Cost	Ability to address Issue?	Responsibility
		Benefits	Difficulties			
riverine ecological processes and riverine water quality to allow for environmental flow management	WF5b. Conduct extensive ecological survey & risk assessments	• Strong ability to measure ecological change over time (especially response to environmental flows and changes in water quality) • Potential to redefine environmental flow requirements based on local ecology (may require less environmental flow than advocated by Water Sharing Plan)	• Baseline conditions have long since passed – would be assessing current conditions and in doing do, the study would be limited by spatial and temporal variability	Med-High	High	WSC, DIPNR, GWCWA
	WF5c. Use indicators to assess ecological conditions	• Provide a cheaper method of measuring change in the system • May be able to indicate current ecological health	• Does not provide a full picture, rather indicates likely positions • Relatively new methodology – full capability may not be realised	Med	Medium – High	WSC, DIPNR, GWCWA
	WF5d. Undertake manipulative experiments on trial releases to assess ecological response	• Able to determine ecological response to certain flow regimes • Allows for an assessment to be made before making a decision on the appropriate long term flow scenarios	• May have to release precious supplies in periods of water shortage • The spatial and temporal scales of the experiment are unknown but could be prohibitive	Med	Medium	WSC, DIPNR, GWCWA