Managing Water Quality in the Richmond River Estuary, Australia

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Abstract

The Richmond River catchment has changed significantly since European settlement. The catchment surrounding the estuary has been modified from a (Pre-European) heavily timbered forest to a (current) mix of intensive agriculture, grazing and urban development. These changes have substantially increased the amount of pollutants discharged to the estuary. To assess the state of water quality within the estuary, relevant water quality data from over 100 locations within the estuary was collected and collated into a database, which consists of customised common desktop packages for database management, geographical interrogation and data analysis. The collated data showed that given target levels for a number of water quality indicators were not being achieved within the estuary. In particular, dissolved oxygen and pH levels are well below recommended limits for the protection of aquatic ecosystems and are the cause of several recorded fish kills within the estuary. Key factors degrading the water quality of the Richmond River estuary have been identified, and include acid sulfate soils and diffuse pollutant runoff (from agricultural and urban areas). A significant proportion of the 6,850km^2 catchment is susceptible to inundation. This highlights the importance of sound floodplain management in the ensuring the short and long-term health of the Richmond River estuary. A number of programs, projects and initiatives have been implemented to improve water quality within the estuary. These include mapping priority areas for acid sulphate soil management, floodgate management, drain bank management, in-filling of drains, wetland and creek rehabilitation/ restoration, land-holder/ community education/ interaction and research on salient issues within the estuary (eg. black ooze discharges from acid sulphate soil areas). This paper describes the state of the water quality within the estuary, key pressures affecting water quality and actions being undertaken or proposed to improve water quality within the estuary.

Introduction

The Richmond River is located in the far north of New South Wales, Australia. The Richmond River estuary extends from the ocean entrance at Ballina, to near Casino on the Richmond River and to Lismore on the Wilsons River. It has a catchment area of 6,850km^2 making it the sixth largest river catchment in all of NSW. The Richmond River floodplain is estimated to be in excess of 1000km^2. Figure 1 provides the extent of the Richmond River and its location within NSW.

WBM recently completed an Estuary Processes Study of the Richmond River estuary on behalf of the Richmond River County Council and the NSW Department of Natural Resources. The study area included all tidal waterways, foreshores and lands immediately adjacent to the estuary (and the wider Richmond River catchment where relevant). Since the Richmond River is tidal for over 100km from its entrance and the study area was required to extend to encompass all tidal regions. The resultant study area size was 1,600km^2 and it is shown in Figure 2.

Figure 1 – Richmond River Locality Plan

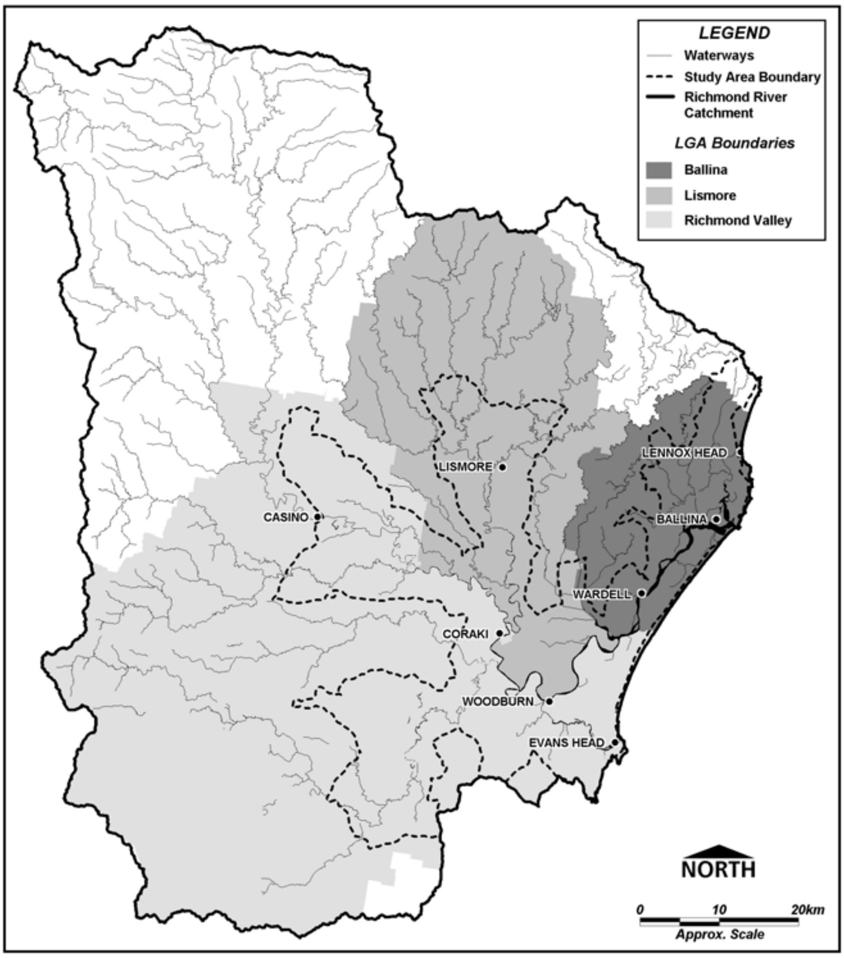

Figure 2 – Richmond River Catchment and Study Area Bounds

The focus of the Estuary Processes Study was to investigate the social, ecological and environmental processes that have shaped and are continuing to influence the estuarine portions of the Richmond River. This study was performed in accordance with the NSW State Government's Estuary Management Program.

One of the major study components was water quality. In the years immediately prior to the study there had been numerous issues associated with the effects of poor water quality, such as major fish kills and high oyster mortality. These issues are considered to be the result of a series of cumulative actions which have occurred within the study area (and potentially greater catchment) since the region was settled approximately 160 years ago.

Catchment and waterway changes since European settlement

Since European settlement there have been numerous changes to the catchments surrounding the Richmond River estuary and its waterways. A brief timeline of key events is provided below:

1828	Captain Henry Rous "discovered" the area on 26 April 1828, Ballina settled around 1840
1840's	Commencement of large scale clearing associated with cedar logging
1863	Commencement of sugar cane cultivation
1879	Settlement reaches the tidal limits of estuary (i.e. Lismore is settled)
1885	Practice of slashing and burning, followed by seeding of pasture/maize
1889	Ballina seawall construction commenced, finished in 1911
1892	Paspalum grass planted, beginning of major development of dairy pastures
1900's	Drainage unions commence flood mitigation works, including wetland draining
1900's	Tuckombil canal constructed to mitigate flooding, large areas of 'Big Scrub' cleared
1903	Casino rail station open and Casino and Lismore were then connected to Queensland
1912	Water hyacinth prevents navigation in Richmond & Wilson Rivers
1917	Large fish kill in mid Richmond estuary
1930's	Works completed on the North Coast Railway Line, which connected Sydney and Brisbane
1951	Massive fish kill in the mid Richmond
1955	Large scale flood mitigation works commence
1959	Formation of the Richmond River County Council
1960's	Tuckombil canal enlarged Expansion in area of sugar cane farms
1970's	Major decline in dairying, replaced by other agriculture
1971	Construction of Bagotville Barrage (Tuckean Swamp) completed
1974	End of use of the estuary for the transport of cane to mills
2001	Major fish kills in the river following flooding
2003	Floodgates constructed on Bagotville barrage to improve flushing of Tuckean Swamp
2005	Existing flood mitigation infrastructure includes 76 drainage canals with a total length of 140 km; 391 flood control structures; 33 levees with a total length of 75 km; Tuckombil Canal. 'Big scrub' remnants cover <400 ha (<1% of pre-European area).

In summary, since settlement, there have been a number of major man affected changes. Today less than 1% of the 'Big Scrub' exists. The Big Scrub was the largest area of lowland subtropical rainforest in Australia, extending from Lismore to Byron Bay. Many of the forested portions of the catchment and nearly all of the lowland portions of the catchment were cleared initially for timber production. Farmers then occupied these cleared lands and commenced using the land for agricultural purposes. Over the past one hundred and thirty years, the principal agricultural pursuits have been sugar cane (increasing in the present day), dairying (declining in the present day), broad acre agriculture and beef cattle grazing.

During the period since settlement there have been numerous flood events. Vast areas of the catchment form part of the floodplain (around 15% of the total catchment area). It is principally on these lands that agriculture started and continues today. As a result extensive flood mitigation works in the form of canals, levees and other structures have been built to alleviate and control the effects of flooding in the catchment. Associated with this was the draining and removal of numerous wetlands to provide additional agricultural land.

The waterway itself has also been subjected to significant change, including the training of its entrance and construction of several kilometres of training walls. These works were initially constructed to aid the thriving port industry of the early settlement and facilitate the shipping of timber, dairy and related supplies into and out of the catchment. These works are considered to have had some minor continuing impacts on hydrodynamics, tidal heights and tidal flushing. Limited recreational boating activity presently occurs through the entrance of the Richmond River.

Also, the population of the catchment has significantly increased. At 2001 it was estimated that the population of the entire Richmond River catchment was 138,885.

These 'key' events have all occurred within a relatively short period of time and had an individual cumulative impact on river hydrodynamics and water quality. The water quality situation has become very serious in the catchment with a very large fish kill occurring in 2001 after a flood event. While there is little historical evidence against which to quantify the extent of change, it is known that there have been extensive water quality changes and there is a need to improve practices throughout the catchment, which adversely impact on water quality.

Managing water quality data

There are many issues in the use of water quality indicators understand catchment health. Water quality data is transitory in nature, in that it can be affected by weather conditions at the time of sampling (wind, rain, cloud cover, temperature), tidal conditions (flood, ebb) as well as sampling and analytical procedures. As a result datasets of indicator values are typically required over a large number of years for later interrogation and interpretation. If such a system is not in place for the safe storage and easy use of data, it is unlikely that proper analysis of data could be undertaken.

In recognition of this fact, WBM as part of the Estuary Processes Study, developed a Water Quality Data Base (WQDB). The WQDB is a custom designed PC application that uses common desktop packages for database management, geographical interrogation and data analysis. As such, it functions as the tool via which incoming water quality data can be systematically stored. It also functions as the tool via which water quality data can be extracted. The WQDB has a Geographical Information System (GIS) interface that shows the user where water quality data has been collected within the system in question. The user can then select the locations of interest and search by indicator type and time, to output data to a data analysis package. The data analysis package can then graphically display the results of the search.

To initially populate the WQDB, WBM collected available sets of relevant water quality data measured in the Richmond River catchment from the Manly Hydraulics Laboratory, NSW Food Authority and the four local Councils within the estuary (Ballina Shire Council, Lismore City Council, Richmond Valley Council and the Richmond River County Council). In total, water quality data for over one hundred locations within the Richmond River catchment were collected and entered into the WQDB. This has provided over 11,000 monthly data sets, with some data sets containing up to 3000 individual water quality readings.

Status of water quality in the Richmond River

As part of the study, the WQDB was used to identify how the recorded water quality data within the estuary compared with the interim Water Quality Objectives (WQO) established by the NSW Department of Environment and Conservation for the Richmond River and ANZECC (2000) Water Quality Guidelines.

The analyses showed that the WQO for a number of indicators were not being achieved within the estuary. Regular exceedances of dissolved oxygen (DO), pH, turbidity, nutrients, chlorophyll-a and faecal coliforms were observed across almost all monitoring locations. In particular, DO and pH levels are well below recommended limits for the 'Protection of Aquatic Ecosystems' and have been the cause of numerous recorded fish kills within the estuary. An example output from the WQDB is provided in Figure 3. In this instance, the WQDB has provided a 15-month timeseries of recorded pH results at one monitoring location within the estuary.

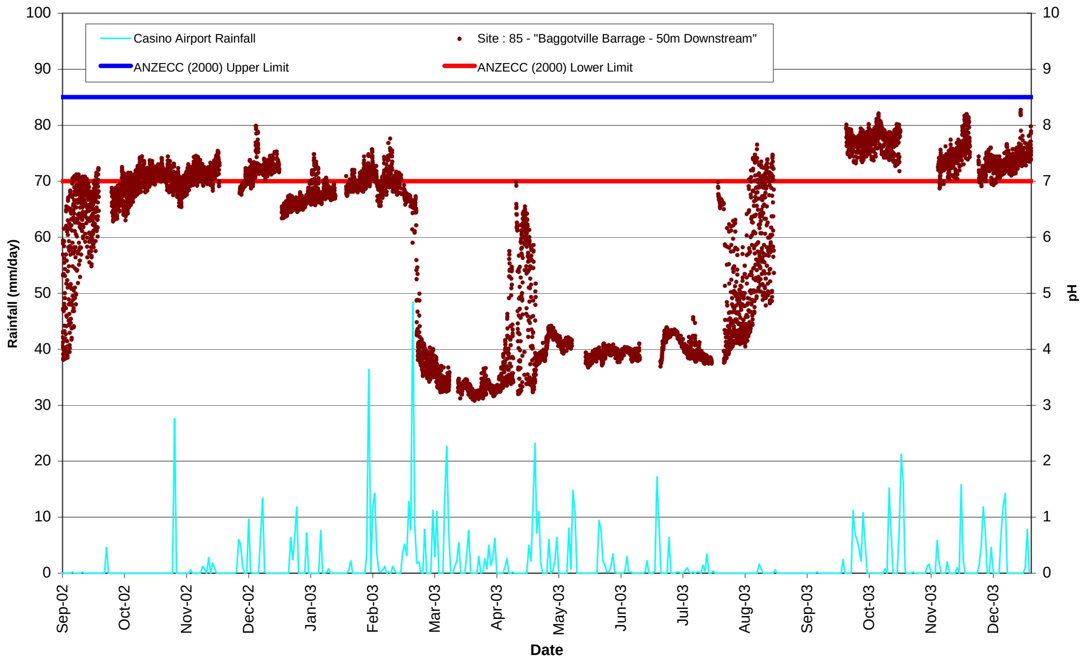

Figure 3 – Recorded pH levels and antecedent rainfall downstream of Bagotville Barrage

Overall, the study concluded that many of the desired environmental values of the Richmond River estuary were not being achieved, particularly the 'Protection of Aquatic Ecosystems' (DO, pH, turbidity, nutrients and chlorophyll-a criteria are typically not met), 'Primary Contact Recreation' (pH, turbidity and faecal coliforms criteria exceeded) and 'Consumption of Cooked Aquatic Foods' (faecal coliforms criterion exceeded).

Pressures on water quality

Key factors affecting the water quality of the Richmond River estuary were identified as part of the study and are considered to include acid sulfate soils (ASS), diffuse pollutant loadings (from agricultural and urban areas) and poor floodplain management.

Some 68,000 ha of Richmond River floodplain is classified as either high or low risk ASS. The disturbance of these areas by historical and ongoing agricultural practices (described previously) results in the transportation of large quantities of sulfuric acid into the estuary. Severe acidification of the estuary (evidenced by low recorded pH levels) has occurred from time to time around Tuckean Swamp, Sandy Creek, Bungawalbin Creek, Rocky Mouth Creek and upper North Creek.

Diffuse pollutant loads are mostly responsible for the high turbidity and nutrient levels experienced throughout the mid to upper estuarine reaches. These pollutants are principally derived from the surrounding catchments, but primarily from those catchments being used for agriculture. The diffuse loads are transferred to the estuary via stormwater runoff. The Wilson River and Upper Richmond River catchments are considered to contribute the highest sediment loads to the estuary. The pollutants are mostly delivered to the estuary during flood events, as a result of erosion within the catchment (eg sheet erosion, gully erosion etc). Large flood events convey most of the sediment out to the ocean (where it settles out on the continental shelf), whereas smaller flood events typically result in sediment deposition within the estuary and backswamp areas.

Nutrient loads to the estuary from rural areas are significant during runoff events, and are considerably greater than the combined loads from urban runoff and sewage treatment plants. Agricultural fertilisers are a major source of nutrients, with the Wilsons River catchment predicted to generate the highest phosphorus loads, and the coastal sub-catchments downstream of Coraki predicted to generate the highest nitrogen loading. Similarly as for nitrogen, large flood events convey most of the nutrient to the ocean, whereas, smaller floods and runoff quantities tend to remain within the estuary and influence estuarine water quality processes.

In certain locations, catchment runoff can also contain large amounts of organic matter. The organic matter, which as it biodegrades in the water column, consumes available oxygen (i.e. it exerts a Biological Oxygen Demand (BOD)). This can lead to the deoxygenation of waters and the suffocation of aquatic animals. This process is driven by bacteria and accelerated by hot weather conditions. Highly deoxygenated water can also be discharged to the estuary from surrounding floodplain drains, wherein previous organic decomposition has already consumed available oxygen. Many of the floodplain areas now contain vegetation that is intolerant of sustained waterlogging which increases organic decomposition rates during periods of inundation.

The disturbance of Monosulfidic Black Ooze (MBO) in drainage lines, backswamps and tributaries of the floodplain where ASS are present, can also lead to the deoxygenation of entrained waters. The disturbance of the sulfide rich sediments by floodwaters leads to the oxidation of the sulphidic material. These chemical reactions consume available DO from the water column (i.e. the reactions exert a Chemical Oxygen Demand (COD)) and can rapidly deplete oxygen levels in the drains.

The February 2001 flood event illustrates the major impact these floodplain processes can have on estuarine water quality. During the flood event, extensive areas of the catchment were inundated. During the subsequent draining of floodwaters from the floodplains and drainage systems, a substantial volume of deoxygenated waters was released into the estuary. This resulted in large stretches of the river containing highly deoxygenated waters for a significant period of time. This lead to a massive kill of aquatic organisms in the lower reaches of the Richmond River and the closure of the commercial and recreational fishing on the estuary for several months. A total estimate of fish, crustaceans and worms killed over the 20km stretch of river most affected was at least 2 million. The 2001 flood event was, however, worsened by the several factors including high ambient temperatures (35 C plus) and long residence time of floodwater on the floodplain. The 2001 flood event is considered to have been a worst-case scenario for the Richmond River estuary.

Actions to improve water quality

Management of water quality in the Richmond estuary poses a significant challenge to floodplain managers and agencies. The two critical parameters that are linked to fish kills are low pH and deoxygenated waters. To address the impacts of pH and deoxygenated water, the Richmond River County Council (RRCC) has implemented a variety of programs to improve the situation.

Tidal gate management

The RRCC has implemented a program of controlled tidal flushing using specially designed slide gates to improve the quality of drainage water from the extensive flood mitigation channels on the floodplain. This strategy is most effective in dry weather and can reduce problems such as chronic acidification of smaller water bodies.

Wetland restoration

Wetland restoration is another key area where floodplain health can be enhanced and wetland systems in the Bungawalbin catchment are currently being restored. These works provide short-term outcomes, but are all part of a much longer-term strategy to improve the interface between the estuary and the floodplain wetlands, which have now been mostly separated by control structures.

Flood management research

The episodic flood impacts are a focus of current research within the region. Summer floods in particular are capable of deoxygenating the Lower Richmond estuary and cause major fish kills (as evidenced in 2001 and again in 2006). Deoxygenated water either generated by the disturbance of MBO, or by the decomposition of floodplain vegetation (predominant mechanism) are considered the major management issues. Compounding the problem is the fact that estuary is in parts poorly flushed, and plugs of anoxic water can remain in the mid estuary for up to 160 days, although there are few management actions, which can be implemented to address tidal flushing.

The RRCC through its floodplain committee is developing a risk assessment and management process for the control of deoxygneated waters. A scientific panel has developed a risk assessment and management matrix that highlights threats by sub-catchment and management options. A sliding scale rating system of impacts has been used to highlight impacts from each known source of deoxygenated water. Natural occurring forms (i.e. decomposition of naturally occurring wetland species, etc) were not rated as they are considered to pose little threat to aquatic life and do not form large deoxygenating plumes that lead to fish kills.

Recent flood events on the Richmond River have been used to further the understanding of the processes that are leading to fish kills in the estuary. Two separate flood events occurred on the 10^{th} and 20^{th} January 2006. These floods resulted in a decline in water quality that resulted in a fish kill near Wardell (no. 300-3,000) and at other locations in the lower Richmond River estuary. Snapshot water quality monitoring was undertaken prior to the rainfall events and between the two events. This was supplemented by data from project-based data-loggers at Rocky Mouth Creek and Tuckean Swamp.

The data loggers showed that immediately after the initial rainfall event on the 10^{th} of January dissolved oxygen crashed and apart from a spike around the 18^{th} of January remained < 1 mg/L up to and following the 20^{th} January flood event. These tributaries remained depleted of oxygen until tidal flushing reintroduced oxygenated waters. Kerr *et al* (2005) identified that water moving across the floodplains of the Richmond River is rapidly depleted of oxygen due to either the BOD or COD reactions, and that BOD driven processes alone have the potential to deplete all floodwater on the floodplain within 2-3 days at 25 C. These processes were repeated in the January 2006 flood whereby, deoxygenated waters from the major floodplains (such as the Tuckean and Rocky Mouth) were discharged to the Richmond River. This lead to the depletion of DO within sections of the river and subsequent fish kills.

Key learning from this and other recent flood events have been that summer floods are more problematic than winter floods in terms of depleting available DO. High summer temperatures accelerate organic decomposition by 2 – 3 times for every 1 C rise in temperature, thereby removing DO at a faster rate. With cooler winter temperatures the rate of decomposition are much reduced. The 2001 fish kill occurred at a time when clear hot conditions were experienced (i.e. 35 C plus temperatures), whereas in contrast the winter floods of 2005 and 1987 did not have a significant impact. Temperate is considered a major influence in these results.

Future management directions

The management of backswamps has been identified as a critical area for future research and management to reduce their potential to deoxygenation water, along with surface acid deposits. This is a long-term program within a highly modified and diverse landuse floodplain.

The management of MBO is a major issue for the health of river's tributaries. Tidal flushing improves the quality of the water column but the iron, sulfate and organic material (aquatic weeds) feed the MBO cycle. Further research into MBO is needed to identify viable management options. The carbon source is a major issue and a staring point is addressing exotic weed infestations like the Cape Water Lily.

Conclusions

Catchment and waterway changes since European settlement, including conversion of a large percentage of the catchment from forests to agricultural lands, wetland draining and flood mitigation works are believed to have brought about a large change in the hydrodynamics and water quality processes of the Richmond River. Interpretation of recently collected water quality data from around the catchment has highlighted that water quality within the Richmond River is well below its set objectives and many of its desired environmental values are not being achieved. Flooding has also been identified as a major problem, whereby the combined effects of lowered pH and DO can have a significant impact on the in-fauna of the river, as evidenced in recent flooding.

The Richmond River County Council in conjunction with the community, is continuing to implement range of practices to bring about short and long-term improvements in river health, by managing known ASS areas, improving management of tidal gates, rehabilitating wetlands, improving agricultural practices on the floodplain, supporting research and developing risk assessment and management processes to deal with the future threats of flooding.

References

Kerr *et al* (2005) Deoxygenation potential of the lower Richmond River floodplain, Northern NSW, Australia. River, Research and Applications.