Environmental Impacts of Tidal Dredging on the Brisbane River, Queensland

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ABSTRACT: *Over 173.2 million m^3 of material has been dredged from the Brisbane River estuary since the 1860s for navigational purposes, construction materials and flood mitigation. The detrimental environmental impacts of such large scale dredging have included substantial increases in water depths throughout the estuary; loss of pool-riffle sequences; channel widening; bank erosion; increased turbidity; changed tidal hydraulics, particularly an increase in tidal range, peak tidal discharge and peak tidal velocity; and increased tidal salinities. These physical impacts have also produced a number of largely unquantified biological impacts. It is recommended that a range of best management practices need to be implemented to improve management of tidal dredging.*

1. INTRODUCTION

Large scale tidal dredging has been carried out in the Brisbane River estuary for the construction and maintenance of navigation channels and ship berths, for the supply of sand and gravel to the building industry and for flood mitigation purposes over the last 130 years. While dredging has generated much controversy (see chapters in Davie *et al.*, 1990), no major review of the environmental impacts of dredging activities has been completed to date (Erskine, 1990; O'Faircheallaigh, 1995). The purpose of this paper is to briefly outline the history of tidal dredging in the Brisbane River, to review the major environmental impacts of such activities and to propose additional best management practices for the reduction of the identified environmental impacts.

2. STUDY AREA

The Brisbane River is a large drainage basin (13560 km^2) in south east Queensland with a major sea port and state capital city located on its estuary. For the purpose of this paper, the tidal section of the Brisbane River will be taken as the 84 km length between Mt Crosby Weir and the mouth at Fisherman Island (Figure 1). The major tributaries of the Brisbane River estuary are the Bremer River (1866 km^2), Oxley Creek (260 km^2) and Bulimba Creek (110 km^2). Mean annual rainfall over the entire basin is about 942 mm, of which 11% is converted to runoff, allowing for the effects of water abstractions (Davie *et al.*, 1990). The Brisbane River is significantly regulated by a series of dams and weirs above the estuary.

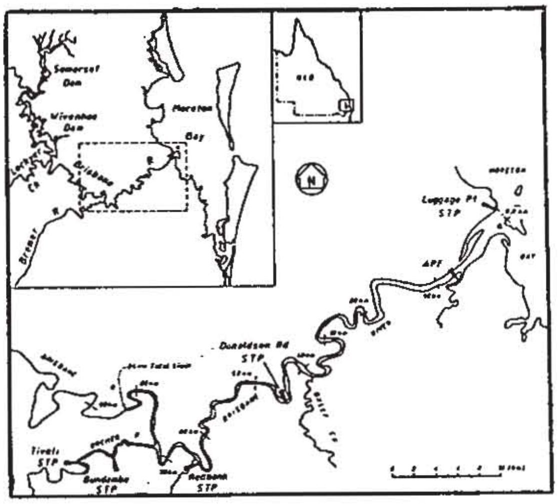

Figure 1 The Brisbane River estuary

3. TIDAL DREDGING

Dobson (in Davie *et al.*, 1990) reported that 140 million m^3 of material were dredged from the Brisbane River estuary over the last 130 years for navigation purposes alone. Furthermore, another 33.2 million m^3 were extracted between 1900 and 1990/91 for construction materials. No volumes are available for material dredged for flood migration purposes. Current dredging rates are about 1.2 million m^3/a for navigation purposes and 650,000 m ^{3}/a for construction materials (Davie *et al.*, 1990; O'Flynn, 1992). There are presently 9 dredging permits held by 5 companies for the removal of sand and gravel for construction materials from the estuary. Of the 9 permit holders, 8 are members of the Brisbane Sand and Gravel Producers' Association and two companies, Pioneer Concrete and Boral Resources, dominate production. Extraction is largely self-regulated by the Brisbane Sand and Gravel Producers' Association although the Department of Environment and Heritage has regulatory control. Extraction is restricted to the estuarine reach between Norris Point (New Farm) and Venus Pool (Karana Downs) and is controlled by permits which specify conditions, such as hours of operation, dredge areas, buffer zones, subaqueous batters, dredge depths, etc. The extraction reach is

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divided into 190 by 333 m long dredge zones which can only be worked for a maximum of 5 hours every two days (O'Faircheallaigh, 1995). Dredging is prohibited in some areas where previous bank failures have occurred or where there are important structures.

Dredging for navigation purposes has been concentrated in the reach downstream of the CBD although many navigation hazards have also been removed by dredging from the estuary upstream of the CBD (Davie *et al.*, 1990). The Port of Brisbane Corporation conducts navigation dredging within the port area to maintain channels and berthing areas. Suction dredgers and grab dredgers have been used and the material is usually pumped ashore for reclamation purposes although bottom dumping and side casting have occurred (Dobson, 1990; Connor and Copper, 1990). Measured sedimentation rates in selected berths are rapid at between 10 and 300 mm/month and are largely caused by nearby dredging activities (Connor and Cooper, 1990). Future navigation and berth dredging rates are likely to be approximately 1 million m^3/a (Connor and Cooper, 1990). Significant dredging of the Brisbane River estuary was also conducted for the reclamation of Brisbane airport (at a cost of $80.2 million according to Crabb, 1986).

While rates of construction material extraction have declined from their maximum values in the 1970s, all types of current dredging activities are producing environmental impacts which are still interacting with those of earlier dredging activities to have a significant effect on the estuary.

4. ENVIRONMENTAL IMPACTS OF TIDAL DREDGING

There has been little detailed scientific work conducted on the environmental impacts of tidal dredging on the Brisbane River (Erskine, 1990; Anon., 1991; O'Faircheallaigh, 1995). The purpose of this section is to identify the most significant detrimental environmental impacts from a detailed literature review. As all types of dredging activities have often occurred simultaneously but on different reaches of the estuary, their impacts are cumulative and interactive. No attempt has been made to partition either the cause or effect between the various types of dredging. The most significant detrimental impacts are briefly discussed in the following subsections.

4.1 Increased Water Depths

Wallace (1987) compared river bed levels for 1860 and 1974 surveys of the lower 25 km of the estuary and found that the average increase in depth below approximate low tide level was about 6m with a maximum of 15m. Dobson (in Davie *et al.*, 1990) documented the progressive increase in water depth at the river entrance by dredging from only 1.2 m at low water datum at the Outer Bar in 1860, to 3.1 m by 1867, to 4.5 m in 1886, to 6.0 m by 1900, to 7.1 m in 1912, to 11.6 m in 1965, to 13.0 in 1990. Furthermore, the navigation channel upstream of the entrance was progressively increased to a depth of 9.1 m. Oxley, the explorer, had to haul his whaleboat over rapids in the upper estuary where navigation occurs at all tidal stages today.

Increased water depths are produced by a combination of the passive removal of essentially immobile bed material and by extraction - induced degradation actively eroding and redistributing the bed material. Extraction-induced degradation is caused by the creation of 3 sediment transport discontinuities which result in bed erosion both upstream and downstream of the dredge hole as well as deposition within the dredge hole (Erskine, 1990). Degradation and increased water deposits in estuaries result from the extraction of bed material at rates in excess of the replenishment rate. (Erskine *et al.*, 1985). The gravel in the bed of the Brisbane River estuary is most likely a fossilised Pleistocene deposit which is not being replenished today. Sand replenishment, however, is also low because bedload transport is only active during large floods (such as 1974) (Sargent, 1978), post-flood modification of the resultant bedforms is by upstream-directed flood tides (Holmes, 1980), dredge holes remain unfilled voids (Holmes, 1980; Wallace, 1987) and Wivenhoe Dam and Mt Crosby Weir on the Brisbane River and Berrys Lagoon Weir on the Bremer River act as sediment traps, substantially reducing downstream bedload transport. Therefore, dredging is currently a non-sustainable industry on the Brisbane River estuary. If ecologically sustainable development is an aim of river and catchment management, then dredging for sand and gravel should be prohibited. Furthermore, gravel is needed to produce an armour layer or surface coat. Armouring is a natural self-sustaining process of rivers and estuaries (Lagasse *et al.*, 1980; Erskine *et al.*, 1985). Continued dredging destabilises the bed by removing the armour material. Therefore, either all gravel should be screened and returned to the bed (as is the present case for Monarch Sands) or armoured deposits should be identified and all extraction prohibited from these areas.

4.2 Loss of Pool-Riffle Sequence

The macro bedforms of the Brisbane River estuary consist of rhythmically-spaced, alternating pools and riffles. These are clearly shown on the 1974 bathymetric charts with relatively deep pools on bends, and much shallower sections at cross-overs between bends, which also display megaripples (Sargent, 1978). The height difference between a pool and a riffle is up to 6m. Bed sediments in the late 1970s fined downstream within each pool-riffle sequence (Holmes, 1980).

Dredge operators prefer to extract from the upstream coarser riffle sediments which causes the downstream lengthening of pools (Holmes, 1980). This results in the loss of habitat and substrate diversity as well as a general deepening of the estuary by the preferential loss of riffles. The photic zone does not extend to the bed because of bed deepening and high turbidity, and so bed-attached macrophytes and emergents do *not* grow throughout the estuary (Moss, 1987).

4.3 Channel Widening

Four points (Gardens, Kangaroo, Kinellan and Bulimba) plus parts of Parker Island have been extracted to improve boat manoeuvring around these very tight bends (Dobson in Davie *et al.*, 1990). These excavations were carried out between 1901 and 1920, except for Kinellan Point which was excavated in 1941. Some 22 ha of land and more than 4 million tonnes were extracted.

4.4 Bank Erosion

Bank erosion is a significant issue on the Brisbane River estuary with 46.9% of riverside residents experiencing moderate to severe erosion and 69% of the same residents using some form of erosion control (Davie *et al.*, 1990). Dredging and boat-generated waves were perceived as important causes of bank erosion (Davie *et al.*, 1990).

Coffey and Partners (1975) identified 6 types of slumps in the Brisbane River estuary following the 1974 flood. They carried out stability analysis using the modified Bishop method for large scale rotational failures (3 of the 6 types) identified for "idealised bank profiles" and "assumed soil strength parameters". Factors of safety were calculated for both normal flow conditions and for rapid drawdown following a flood for 3 types of bank sediments and for various bank heights. For rapid drawdown conditions following a flood, existing bank heights already exceed the initial bank height for stability. Dredging has been responsible for increasing the initial bank heights. However, other types of bank erosion such as the entrainment of bank material by tidal and flood flows, bank failure by topples, slides and flows, piping and erosion by boat-generated waves have not been investigated. As a result, the impact of dredging on these other erosional processes has not been determined.

While dredging was prohibited in 10 areas following the Coffey and Partners' (1975) report, all but one of these were subsequently reopened because Coffey and Partners (1982) found that the bank materials in the prohibited areas were more resistant than assumed in the 1975 report. To reduce bank erosion by dredging, excavated side batters are not supposed to exceed 1 vertical to 4 horizontal and dredging is not supposed to be conducted within 20 to 60 m of the bank (depending on bank materials).

Despite the importance of bank erosion to riverside residents and to the management of dredging, little meaningful work has been completed to date. Slip circle failure analyses suggest that dredging has predisposed river banks to slumping by excessively increasing bank heights. However, other slope stability models need to be applied and soil strength parameters must be measured. Furthermore, other forms of bank erosion are important and their role in determining long term bank stability needs urgent investigation. Boat-generated waves, in particular, are likely to be a significant cause of bank erosion.

4.5 Increased Turbidity

Moss (1987) used Secchi depth (strictly a measure of light penetration) as a surrogate for turbidity and found that the turbidity maximum in the estuary is usually located just upstream of the saltwater/freshwater interface (Figure 2). However, there is also an extensive (between 30 and 70 km upstream of the mouth), highly turbid mid-reach of the estuary with Secchi depths ≤ 0.2 m (Figure 2). Other data sources show identical trends (Davie *et al.*, 1990). Information collected by the Australian Littoral Society and summarised in Davie *et al.*, (1990) conclusively demonstrates that the estuary was often clear and did *not* exhibit a *permanent* highly turbid mid-estuary earlier this century.

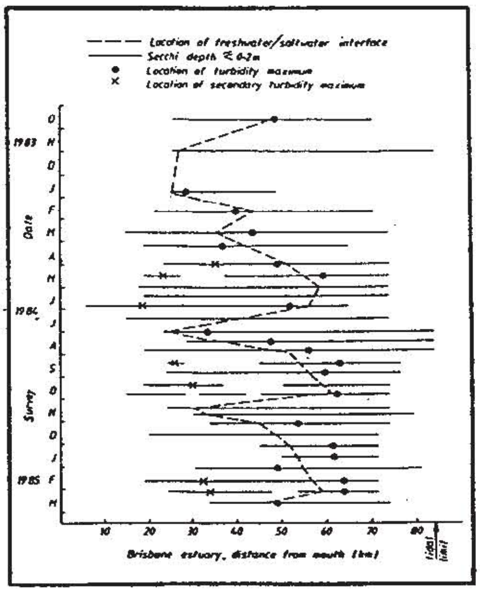

Figure 2. Temporal variations in turbidity of the Brisbane River estuary (After Moss, 1987).

Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.

Bristow (1986) found that clam dredges, by disturbing the bottom sediments, increased turbidity by at least 100% over that measured in immediately adjacent non-impacted sections of the Brisbane River estuary. The maximum turbidity of dredging-induced plumes can exceed background values by between 10 and 4,000% (Mayer, 1976; Erskine, 1990; Bell, 1991). However rapid settling of the coarser suspended sediment produces an exponential decline in suspended sediment concentration with increasing distance from the dredge (Erskine, 1990). Bell (1991) also found that peak tidal velocities in the lower Brisbane River estuary are sufficient to entrain bottom sediments and that harbour traffic has a significant effect on turbidity by also entraining these sediments. The discharge of bilge water and bin drainage water from dredging barges further increases turbidity (Bristow, 1986). Processing plants return minimally treated effluent directly to the estuary, further contributing to high turbidity. Extraction of sand and gravel bar and bed deposits and the flocculation of suspended clays has changed the bottom sediment composition of the Brisbane River estuary from relatively clean sand and gravel to much muddier sediments ((Davie *et al.*, 1990; O'Flynn, 1992). Flood flows are often capable of reworking these mud deposits.

The zone system of allocating dredge positions was implemented by the Brisbane Sand and Gravel Producers' Association to minimise complaints about extraction by maximising the length of estuary impacted. It maximises turbidity by permanently dispersing dredging over a greater length of estuary. Concentration of dredging activities would permit the use of silt screens and cutter suction dredges which would discharge the dredged slurry to a processing plant on the bank, thus enabling proper treatment of the effluent to accepted standards before being returned to the estuary.

4.6 Changed Tidal Hydraulics

Tidal hydraulics are important hydrodynamic processes in estuaries which control sediment transport, sediment deposition, nutrient mixing, plant and animal distributions, etc. Incomplete historical records show that by 1904, mean tidal range had increased by 0.25 m (Dobson, in Davie *et al.*, 1990). Mean high water readings did not change between 1860 and 1900 but mean low water dropped by 0.25m. This increased tidal range was caused by dredging of the navigation channel between the Bar Cutting and the Victoria Bridge to a rated depth of about 6 m. Increased tidal range would have also increased the tidal prism, peak tidal discharge and peak tidal velocity. Further changes may have also occurred but have not been recorded (Dobson, in Davie *et al.*, 1990).

The limit of tidal influence has also extended landwards. Navigation was relatively easy to Seventeen Mile Rocks in the early part of last century. Further upstream, various shoals and banks caused much difficulty for boats ((Davie *et al.*, 1990) and would have restricted tidal penetration. Today, the limit of tidal influence is located at Venus Pool (Karana Downs).

4.7 Changed Estuarine Salinity

Any changes in tidal hydraulics will also impact on salt intrusion. The Brisbane River is a salt-stratified estuary with a salt wedge at depth overlain by lower salinity water. At the time of European settlement, mangroves only extended upstream to Hamilton. Today, one species of mangrove, *Aegiceras corniculatum* has dispersed a further *48* km upstream (Davie *et al.*, 1990).

Acid sulphate soils contain pyritic sediments, the formation of which is a bacterial reduction process by which sulphate in seawater is reduced to pyrite (FeS_2). Pyrite is usually formed in vegetated tidal environments, such as mangrove flats. The recent colonisation of a large part of the Brisbane River estuary by mangroves may have resulted in the formation of sedimentary pyrite. Under reducing conditions, pyrite is stable but, once exposed to air, it oxidises, producing sulphuric acid. Stockpiling pyritic sands or muds will oxidise the pyrite as outlined by Lin *et al.* (1995) and Sammut *et al.* (1995). Dredge areas must not contain pyrite because the sulphuric acid produced can react further with other minerals to increase the soluble concentrations of pH-dependent elements to levels which are toxic to most biota. Aluminium, iron manganese and other trace elements increase with increasing acidity (Lin *et al.*,) 1995). When acid products are delivered to estuaries, pH can drop to 1.8 and fish kills and outbreaks of epizootic ulcerative syndrome frequently occur (Sammut *et al.*, 1995).

4.8 Biological Impacts

Erskine (1995) emphasised that dredging produces a multitude of physical impacts which, in turn, cause a range of indirect and direct biological/ecological impacts. In particular, increased water depths, increased turbidity and bank erosion cause loss of macrophytes and riparian vegetation, loss of aquatic habitat, reduced plant uptake of nutrients, water quality barriers to fish migration, reduced light penetration, reduced diversity of aquatic habitats and reduced productivity. While little information exists on these biological impacts for the Brisbane River, it is certain that they have occurred.

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5. RECOMMENDED BEST MANAGEMENT PRACTICES

To improve the management and to reduce the environmental impacts of tidal dredging in the Brisbane River estuary, a range of additional best management practices need to be implemented. In particular, state policies which establish major objectives and principles of management should be formulated for estuaries and sand and gravel extraction in Queensland to provide general guidance on the sustainable management of estuaries. To achieve sustainable management of estuaries, it is necessary to:

i) slow, halt or reverse the overall rate of degradation;
ii) ensure long-term sustainability of essential biophysical functions; and
iii) maintain beneficial uses of resources.

On an individual site or regional level, each dredging proposal should be carried out under an extraction plan, operation plan *and* a site rehabilitation plan which should specify the final productive use of the area. Tidal dredging has the potential for causing such large scale environmental impacts that *every* operation above an agreed threshold (say, of annual production rat or total area disturbed) should prepare an environmental impact assessment report. The threshold would need to be set in collaboration with the industry. Standards need to be set for environmental assessment reports to ensure that the predicted environmental impacts are accurate and that appropriate environmental management plans are framed.

On a day-to-day basis, changes to the present permit conditions are essential to reduce the current environmental impacts and to ensure that the activities conform to best management practices elsewhere. Lastly, further investigations are required to establish the environmental impacts of past tidal dredging activities so as to frame more appropriate permit conditions.

6. ACKNOWLEDGEMENTS

This work was funded by the Brisbane River Management Group and was completed with the full assistance of Gutteridge, Haskins and Davey and the Australian Littoral Society, particularly Dr W. Douglas.

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