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A Simple Technique for Estimating the Recovery Rate of a Subtropical Estuarine System After a Flood Event

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ABSTRACT

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The Fitzroy River is one of Australia's largest river systems, with an estuarine section extending 60 km from its mouth to a tidal limiting barrage. The Fitzroy River, whose catchment is 142450 km^2 experiences annual short-lived flooding as a result of intermittent heavy summer rainfall events. This study revealed that the Fitzroy River estuary behaves as an enclosed bay as it does not experience a freshwater inflow after the cessation of a flood event. There was a need to develop a predictive estuarine recovery graph as typical formulas, (such as the fraction of freshwater) did not apply. Implications of this simplistic (salinity recovery) graph will lead to a better understanding and knowledge base for both the independent and commercial fisheries. The reason for this being that a during a flood event, the majority of freshwater species (upstream of the barrage) and estuarine-dependant (downstream) species are washed into the adjacent Pacific Ocean. The re-migration of both the fresh and estuarine-dependant species after the flood event is closely related to the rate of salinity recovery.

ADITIONAL INDEX WORDS: *Flushing rate, flooding, salinity exponential decay, salinity distribution.*

INTRODUCTION

Australian estuaries exhibit highly variable flows and large peak and annual floods due to its lower than world-average annual precipitation, runoff rates and elevated evaporation rates (WARNER, 1986). As such, each system is vastly unique and requires its own hydrodynamic and transport analysis. However, depending on the severity and duration of a flood event, all estuarine hydrodynamic processes are bypassed with the advent of the increased floodwater. Often, pre-existing long-term monitoring schemes overlook these events because of their short-lived nature. This then becomes a problem as most nutrient and sediment transport occurs during a flood.

Typical estuarine systems comprise of a consistent freshwater input either from branching tributaries or anthropogenic inflows such as tertiary treated sewage. An increase in freshwater discharge (floodwater) gives rise to an increase in flow and circulation, thus resulting in a subsequent relocation of the salinity intrusion (not considering tidal influence). A series of adverse affects are followed by this setback of salinity. The most predominate being an increase in turbid suspended sediment/nutrient loading in the water column. This affects the light-dependent productivity and consequently trophic (food-web) structure, which directly influences the diversity of species in the river. Several surveys of the Fitzroy River catchment (both upstream and downstream of the barrage) have identified 97 species of fish (of which 26 are species of native freshwater fish (BURGHUIS and LONG, 1999), 12 species of prawns and three species of crab: mudcrabs, spanner crabs and sand crabs; the estuarine section of the Fitzroy River catchment is the focus of this study. The increased flow associated with a flood forces the non-tolerant freshwater species out of their estuarine habitat and into the ocean with the tolerant freshwater species (originating from upstream) closely following. After the flood, the freshwater species are then forced to migrate back upstream (over the fish-way (STUART and MALLEN-COOPER, 1999) at the barrage) before the saltwater reaches the barrage. Meanwhile, estuarine-dependant species migrate from the ocean to a region downstream of the barrage. The study of the saltwater penetration and estuarine recovery (*or flushing time)* after a flood indicates the diversity of species abundance at a time this has implications for commercial and recreational fisheries.

The flushing time is often a good indicator for the health of a system. A long flushing time can result in an increased chance of algal blooms as nutrients can build up in the system. The flushing time can be calculated using a variety of techniques, the most common and simplest method being the fraction of freshwater (RASMUSSEN and JOSEFSON, 2002; EYRE and TWIGG, 1997; ALBER and SHELDON, 1999). Other methods include the Water and Salt Budget Method, and one-dimensional analyses of the conservation of volume, momentum and mass (GILLIBRAND and BALLS, 1998). The only method that doesn't consider discharge is the Tidal Prism Method (the difference between the volumes of water at high and low tide). It has been stated that this method is limited as it yields flushing times of shorter durations than other calculations (KENNISH, 1986). Approximate calculations for the flushing time of the Fitzroy River generated values of an order of magnitude shorter than that observed. BOWDEN (1967) stated that the length of the flushing time depends on the river discharge. But what happens when there is no constant inflow and thus no river discharge (except for flooding events)? One must then assume that the estuary acts as an enclosed bay.

This paper presents a simplified method for obtaining the salinity-based recovery time of a bay like estuary after a flood event. For this study the site to be considered is the Fitzroy River estuary (Figure 1). The Fitzroy River is a unique estuary as it essentially behaves as an enclosed bay for 6075% of the year (during the dry season). A comparison is made with the salinity data observed over a three-year period (2000-2003). The motivation for this study was driven by the inherent lack of available community based data on the subject of flooding events and their recovery. Based on historical data, a graph predicting the salinity recovery in the Fitzroy River has been developed. The reason for this is that, because of the complicated morphology of the system more detailed calculations can only be obtained by means of a complete knowledge of the tidal current field and bathymetry, which we do not yet have.

DESCRIPTION OF STUDY AREA

The Fitzroy River, Australia is located in an agricultural sector of northeast Queensland and is one of the largest systems on the eastern cost of Australia. It has an estuarine section that extends

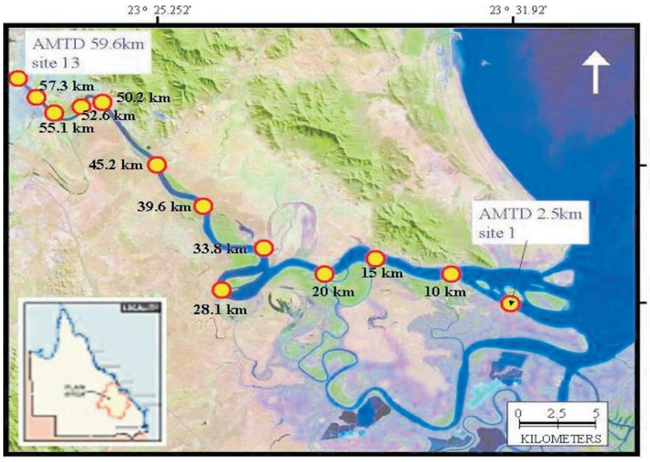

Figure 1. The Fitzroy River estuary Australia with thirteen EPA monitoring sites marked by a circle and distance (km) from mouth. Site 1 located at the mouth of the estuary (2.5 km AMTD) to site 13, located 59.6 km AMTD.

60 km from its mouth (which is typically defined as the cross-sectional transect between the last two points of land before widening into the ocean) to a barrage that marks the upper tidal limit. The catchment area of 142 450 km^2 comprises of almost 10% of Australia's productive agricultural land and as such, farms and local industries boarder the riverbanks. One of the main sources of nutrients (particularly phosphorous and pesticides) and sediment into the system are from the runoff of the surrounding agricultural areas. A large-scale rainfall event causes the system to flood at the barrage (site 13, Figure 1) thus allowing the sediment and nutrient laden floodwater to enter the lower Fitzroy River.

The semidiurnal tidal range at the barrage ranges from 1.7 m at neap tides up to 5.8 m at spring tides. The large tidal excursion results in high velocity tidal flows that dominate the mid-lower sections, closer towards the mouth (NOBLE, 2003). This leads to a constant increased level of turbidity and subsequent lower levels of algal growth.

METHODS

The Environmental Protection Agency (EPA) and Department of Natural Resources (DNR) Queensland, Australia, have implemented a consistent water sampling and monitoring regime on a monthly basis. Historical results can be found from 1978. However more reliant results with newer measuring techniques and instruments have only been available since 2000. There are currently thirteen (13) monitoring sites (Figure 1) located along the axis of the estuary from the mouth of the estuary to the barrage that these agencies use.

Water Quality Data

Each month, a survey of the river was conducted, taking six (6) hours (or a half tidal cycle) for the thirteen sites. At each site, the salinity was measured using a YSI Grant 3800 Water Quality Logger. This instrument is calibrated to EPA standards and is used for the majority of all EPA monitoring systems.

Decay Method

In situations where the decrease of a variable (salinity) in a fixed time interval (days) is proportional to the magnitude of the variable at the beginning of the time interval the exponential decay can be determined. In a bay the diffusion of a substance from a source can be considered to behave in an experimental manner of the form

$$D_t = D_o e^{-kt} \qquad (1)$$

can be used for the recovery of a freshwater inflow into a bay, where Dt is the Distance of the salinity intrusion (above 33 0/00) from the barrage at time t, D0 is the initial distance of the salinity intrusion, is the base of the natural log, k is the recovery

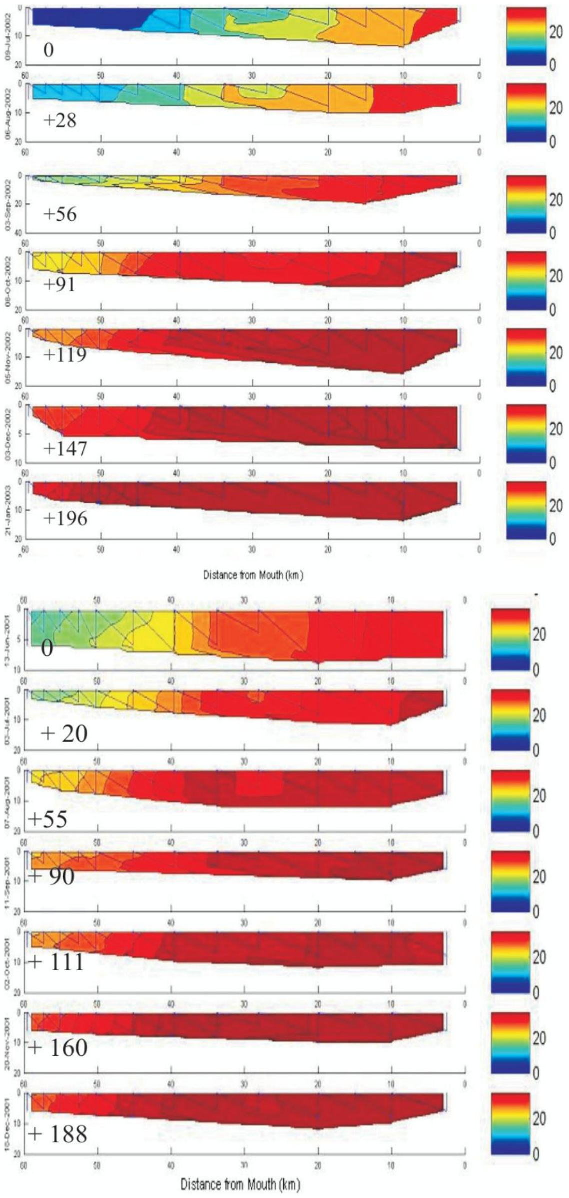

Figure 2. Vertical distribution of salinity (0/00) at the thirteen longitudinal sites from the mouth of the Fitzroy River at monthly intervals after a rainfall event. (a) 20 Feb 2001 18 Dec 2001, (b) 9 Jul 2002 21 Jan 2003. Numbers in bottom left corner denote number of days post-flood. Raw data set provided by EPA.

rate constant and t is the time interval. For the case of the Fitzroy River, the source is considered to be at the barrage. Values of k and t for the Fitzroy River are determined from the salinity time series data.

RESULTS AND DISCUSSION

At least once every year the Fitzroy River undergoes a flushing mechanism *or flooding*. The term flushing is adopted when the usual estuarine water has been replaced with that of fresh floodwater. Figure 2 demonstrates the salinity recovery at monthly intervals after a flood. Once the system has been fully flushed from a flood (with axial salinity distributions of ~ $0\ ^{0}/_{00}$) the recovery rate is independent of the magnitude of the rainfall event, because there is no further inflow. Figure 2 depicts the recovery of the Fitzroy estuary during periods of no inflows for the case of (A) 9 Jul 2002 21 Jan 2003, total of 196 days and, (B): 13 June 2001 18 Dec 2001, total of 188 days. For case (A), there was a minor flooding event on 10 June 2002 (15000ML/Day) and then there was no flooding of the barrage until after February 2003 (not included) where the flooding reached a peak flow of over 350000ML/Day. For case (B) there was a Peak flood (82500 ML/Day) on 10 Feb 2001, a minor flood recorded 5 March 2001 (20000ML/Day) and no flooding after 5 April 2001.

To determine the decay rate it is essential to determine a starting point. The time series commences at (Day 0) with a location rather than an ambiguous guess of time since flood. Day 0 is taken as time at which the saltwater penetration ($31^{0}/_{00}$) is in movement (upstream) and has reached the site AMDT 10 km (Figure 1). The reason for this location is that it is the first point at which the open mouth of the estuary converges to a uniform width.

Salinity Distribution

The salinity profiles during these two rainfall events (Figure 2) demonstrate a full spectrum of mixing regimes ranging from well mixed to highly-stratified. The most prominent feature of both Figure 2 (A) and (B) is that there is a distinct discontinuity of salinity that starts approximately AMTD 25 km and ends at AMTD 33 km. This is a direct result of the 'cut through'. Due to the shear force of the past floods, the morphology of the system has been altered and now the majority of all flow bypasses site AMTD 28.1 km (Figure 1) and travels via the 'cut-through'. This resulted in a salinity lag in the area. Even during periods of no rainfall, there is a receding spike of $5\ ^{0}/_{00}$ at this monitoring site. BALLS *et al.* (1997) suggested that a constant reduction in salinity at any given geographical location in an estuary corresponds with an increase in nutrient concentration at that site. This suggests that this area could result in algal blooms and should be monitored more rigorously (not in the scope of this paper)

Figure 2 (A) commences with a system that is fully flushed (not shown) and by Day 0, it can be seen that the $31\ ^{0}/_{00}$ vertical halocline is in motion as all overland flow from the flood has ceased and the salinity had reached AMDT 10 km. As the saltwater movement begins, there is evidence of salt wedge at a distance of AMDT 20 km (Day 0) at a depth of 7-9 m. After this stage, a partially mixed regime dominates and continues for the duration of the dry period (Day +196). It is at this stage all fresh floodwater has been dispersed, leaving saline-ocean water (>31 $^{0}/_{00}$) to reach the barrage.

Figure 2 (B) similarly starts just after the system has been flushed out (20000ML/Day on 5 March 2001) where salt wedge penetration has begun to make its way upstream (Day 0) on 13 June 2001. Once again, day zero was recorded as the point closest to AMDT 10 km, which was AMDT 20 km (or 40 km from the barrage). Further upstream, a more prominent halocline depicting that of a saltwedge can be distinguished from AMDT 40 50 km (or 10-20 km from barrage). At Day 20, the sharpness of the upstream haloclines had decreased and a partially mixed salinity regime dominated. The only mixing was induced by the tide and density differences as the flow had stopped since Day 0. The estuary progressed to return to a well-mixed state at Day +160 till the final Day +188 where the

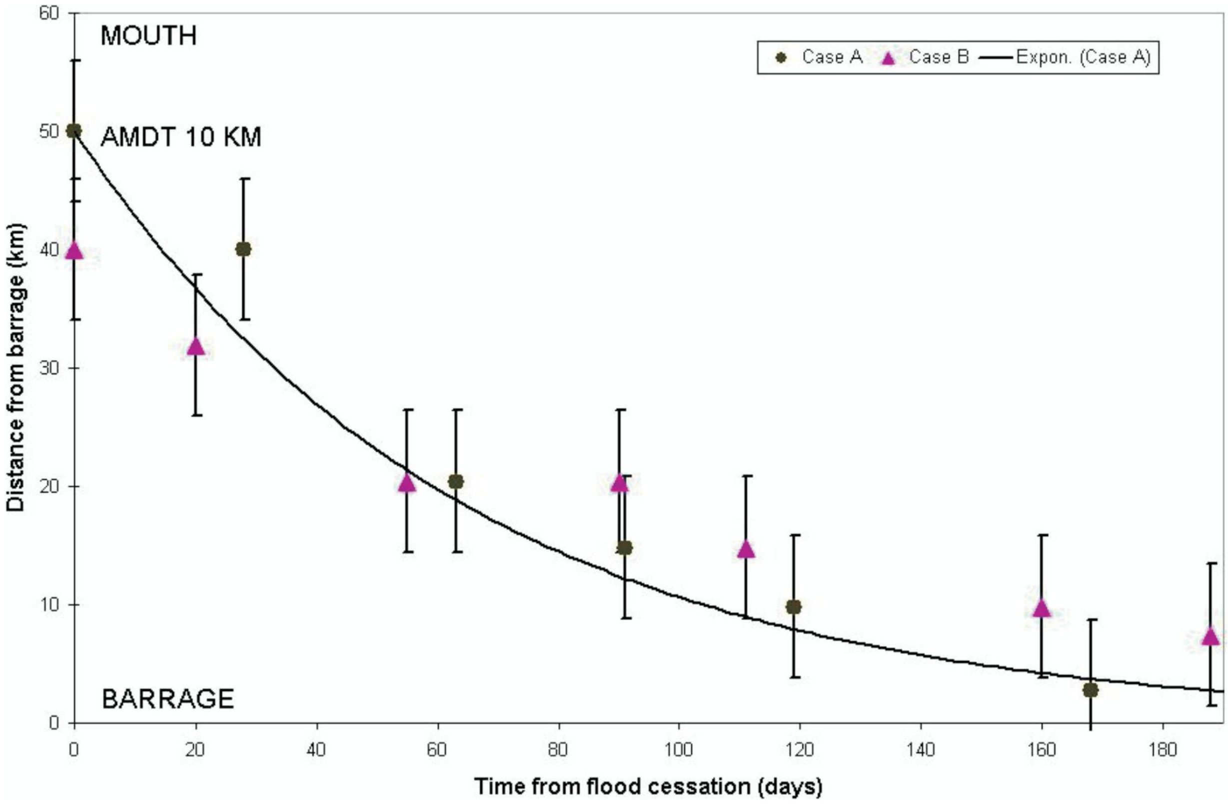

Figure 3. Salt water penetration (above 33 0/00) after a flood event. Vertical error bars denote an uncertainty of ± 6 km due to tidal excursion. Case A is fitted with an exponential decay function of D=50e-0.0155t (where D, is distance from barrage (km) and t is time since flood (days). Correlation coefficient is 0.9584.

salinity discontinuities evened out (at AMDT 30 km). It must be noted that the according to the hydrographs for the flow of the barrage, there was no recorded flow from 20 Feb 2001. However, due to excess overland runoff and groundwater flow from the flood, the salinity recession did not occur until 113

Saltwater Penetration After a Flood

The exponential decay equation has been used to define most dye-tracer experiments (Hales and Cahoon, 2003) and anaerobic sewage treatment for the determination of liquid retention time of the BOD_5 Biochemical oxygen demand after five days.

To asses the recovery time in days after a flood event, the saltwater penetration (for Case A) was monitored. This involved locating the first salinity reading above a nominal salinity level of $31\ {}^{0}/_{00}$ and plotting it as a function of distance form from the mouth (Figure 3). The inverse of the distance from the mouth (distance from barrage) was taken so that an exponential equation emerged (see equation 2).

Exponential decay function for Case A:

$$D = 50e^{-0.0155t} \qquad (2)$$

The limitation of this function, D_0 *= 50 km (from the barrage),* represents maximum (seaward) distance of fresh floodwater i. e. where the $31^{0}/_{00}$ isohaline starts. The other limitation of this function is the due to fact that it is an exponential decay function and as such the asymptote corresponds to the $31^{0}/_{00}$ saline water not ever reaching the barrage. Although not always the most precise measure of accuracy, the *rank correlation coefficient* yielded in an R^2 value of 0.9584. This value corresponds to the high strength of the exponential relationship between the two variables (distance and time). The decay constant for the relationship is 0.0155.

It can be observed that Case B, represented by the triangular plots in Figure 3, all fall within the error bars of Case A. For the purpose of this paper Case B was purely used for validation of the exponential decay function.

Influence of Tidal Excursion

As the monthly salinity profiles were taken at sporadic tidal times, it was important to factor in a degree of uncertainty. The tidal velocity and related hydrodynamics was intensely studied over a two-week period (01/06/03-14/06/03). This study (not included in this paper) involved conducting cross-sectional transects of a vessel-mounted RDI 1200 kHz ADCP fitted with pressure sensor and bottom tracking device at an average frequency of every ½ hour at various locations in the Fitzroy River. These results yielded in average tidal velocities ranging from 0 m/s (at both high and low tide) to 1 m/s (mid ebb tide). Taking a conservative average tidal velocity of 0.55 m/s results in an error of 6 km over a half tidal cycle (as observed by y-error bars in Figure 3).

Validity of Graph

The validity of the exponential function graph was tested with an extensive set of historical data, not included in this paper. This validity data was arbitrarily chosen from the EPA data set form 1980-present. Due to the conservative limits of the function, all data fell well within the bounds of the (Case A) exponential function and associated y-error bars.

SUMMARY

The study has provided an insight into the time-varying salinity distribution after a rainfall event that causes flooding at the barrage of the Fitzroy River. The distribution of salinity in the Fitzroy River is one that displays a plethora of scenarios depending on the freshwater inflow, evaporation, local rainfall, tidal response to mixing and the salinity of the adjacent Pacific Ocean.

Implications of this simplistic graph represent the migratory patterns of the species in the river. With the onset of the salinity intrusion after a flood one can expect an abundance of saline-tolerant fish species. Kimmer (2002) discovered that the abundance or survival of estuarine-dependant species increased with freshwater inflow, however the key mechanisms were difficult to quantify. There is therefore a need to further investigate the variations of flow patterns and salinity on a variety of species perhaps in a regulated laboratory environment. This study has provided an approximate salinity recovery graph for the Fitzroy River estuary after a flood event. It is encouraged that this graph be used as a basis for both commercial and independent fisheries for the associated recovery of saline-tolerate species with time after a flood event.

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LITERATURE CITED

Alber, M. and Sheldon, J.E., 1999. Use of a date-specific method to examine variability in the flushing times of Georgia Estuaries. *Estuarine, Coastal and Shelf Science,* 49, 469-482.

Balls, P.W.; MacDonald, A.; Pugh, K.B. and Edwards, A.C., 1997. Rainfall events and their influence on nutrient distributions in the Ythan Estuary (Scotland). *Estuarine, Coastal and Shelf Science (Supplement A),* 44, 73-81.

Berghuis, A.P. and Long, P.E., 1999. Freshwater fishes of the Fitzroy Catchment, Central Queensland. *Proc. R. Soc. Queensland.,* 108, 13-26.

Bowden, K.F., 1967. Circulation and Diffusion. *In:* LAUFF, G.H. (ed.), *Estuaries,* AAAS, Washington, pp. 15-36.

Dyer, K.R., 1997. *Estuaries: A Physical Introduction.* John Wiley and Sons, England, 192p.

Eyre, B. and Twigg, C., 1997. Nutrient behaviour during post-flood recovery of the Richmond River estuary Northern NSW, Australia. *Estuarine, Coastal Shelf Science,*44, 311-326.

Gillibrand, P.A. and Balls, P.W., 1998. Modelling salt intrusion and nitrate concentrations in the Ythan estuary. *Estuarine, Coastal and Shelf Science,* 47, 695-706.

Kennish, M.J., 1986. *Ecology of Estuaries: Volume 1, Physical and Chemical Aspects.* Franklin Book Company, USA, 245p.

Kimmerer, W.J. 2002. Physical, biological, and management responses to a variable freshwater flow into the San Francisco estuary. *Estuaries,* 25 (6B), 1275-1290.

Noble, B., 2002. Fitzroy Basin. [online] Available from: <http://www.coastal.crc.org.au/fitzroy/> (Accessed 28/04/2003).

Rasmussen, B. and Josefson, A.B., 2002. Consistent estimates for the residence time of micro-tidal estuaries. *Estuarine, Coastal and Shelf Science,* 54, 65-73.

Stuart, I.G. and Mallen-Cooper, M., 1999. An assessment of the effectiveness of a vertical-slot fishway for non-salmonid fish at a tidal barrier on a large tropical/subtropical river. *Regulated Rivers: Research and Management,* 15, 575-590.

Warner, R.F. (1986). Hydrology. *In*: JEAN, D.N., (ed.), *Australia A Geography Volume One: The Natural Environment,* Sydney University Press, Sydney, pp. 49-79.