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# Hydrodynamic, Water Quality and Ecological Study of Eprapah Creek Estuarine Zone: a Multi-Disciplinary, Cross-Institutional Approach

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**Abstract:** A series of detailed multi-disciplinary field studies was conducted in a small subtropical creek : i.e., Eprapah Creek, Victoria Point Queensland. Hydrodynamic and ecological measurements were conducted simultaneously in the river mouth to assess the complexity of the estuarine zone and the interactions between hydraulic engineering, environmental issues, biology and ecology. The results provide unique and original snapshots of a subtropical creek, and the methodology sets new standards for the comprehensive surveys of estuaries in the sub-tropical zone. A key feature of the field studies was the contrasted outcomes, and the results impact on the selection of "key indicators". Fauna observations showed strong bird and fish activities, but other results demonstrated on-going pollution.

**Keywords:** Field study, sub-tropical estuary, turbulence, water quality, ecology, key water quality indicator.

## 1. INTRODUCTION

Mixing and dispersion of matter in estuaries is of considerable importance. Applications include sediment transport and smothering of seagrass and coral, release of organic and nutrient-rich wastewater into the ecosystem (e.g. from treated sewage effluent), toxicant release and fate within the environment, and storm-water runoff during flood events. The monitoring of estuaries and marine environments is based upon key water quality parameters, including biological indicators (e.g. Ramsay et al. 2002). The effects of mixing are often ignored in assessing the overall ecosystem health of the waterways and how the water is impacted from activities such as wastewater treatment plant discharges. Although calibrated and validated water quality models are required to predict future changes in ecosystem health, their reliability depends on how well their structure and parameters best describe fundamental mechanisms such as mixing and dispersion.

In natural systems, mixing is driven by turbulence. Current knowledge is however limited since the vertical mixing coefficient is approximated by the momentum exchange coefficient, while transverse mixing and dispersion coefficients are often assumed constant. Both sets of assumptions are nearly always untrue. Predictions of contaminant dispersion in estuaries are almost always based upon empirical mixing coefficients. These coefficients are highly sensitive to the natural systems and flow conditions, and must be measured in-situ. Experimental findings are however accurate only "within a factor of 10" (at best!), and they can rarely be applied to another system (Ippen 1966, Fischer et al. 1979, Aoki 1999, Chanson 2004a). While there has been some research into pollutant dispersion in individual river catchments, very little research has been done on turbulent mixing and dispersion in complete estuarine systems, and in particular in subtropical zones. One reason for the minimal attention to this problem in the literature is the very complex behaviour of an estuary (Chanson 2004a).

In 2003, a series of detailed hydrodynamic, environmental and ecological field studies were conducted in the estuarine zone of Eprapah Creek (Victoria Point QLD). The purpose of field works was to assess the complexity of a small estuarine system, the interactions between hydraulic engineering, biology and ecology, and to gain a new understanding of basic mixing and dispersion processes in the estuarine system.

## 2. A CASE STUDY

Eprapah Creek is a small sub-tropical stream in Eastern Australia. Located in the Redlands shire, close to Brisbane QLD, the catchment is mostly urban in the lower reaches and semi rural/rural residential in the upper reaches (Fig. 1). The creek flows directly to the Moreton Bay at Victoria Point. It is basically 15 km long with about 3.8 km of estuarine zone. In the latter, the water depth is typically about 1 to 2 m in average in the middle of the channel, while the catchment includes several conservation areas hosting endangered species : e.g., koalas, swamp wallabies, sea eagles.

Water quality and ecology have been closely monitored at Eprapah Creek (Victoria Point QLD) for more than 30 years. The creek was heavily polluted in 1998 by illegal discharges of TBT and chemical residues leading to the first jail sentences as part of the 1994 Queensland Environmental Protection Act. Although the estuarine zone includes two environmental parks, there are some marinas and boat yards, and a sewage treatment plant impacting heavily on the natural system (Jones et al. 1999). The upstream catchment has been adversely affected by industrial poultry farms, land clearance and semi-urban development. Recent developments included the constructions of new shopping centres and residential lots.

In 2003, comprehensive hydrodynamic, environmental and ecological field studies were conducted (Table 1). The aim of investigations was to assess the complexity of the estuarine system, and to gain a new understanding of basic mixing processes in a system that was heavily impact about 4-5 years ago.

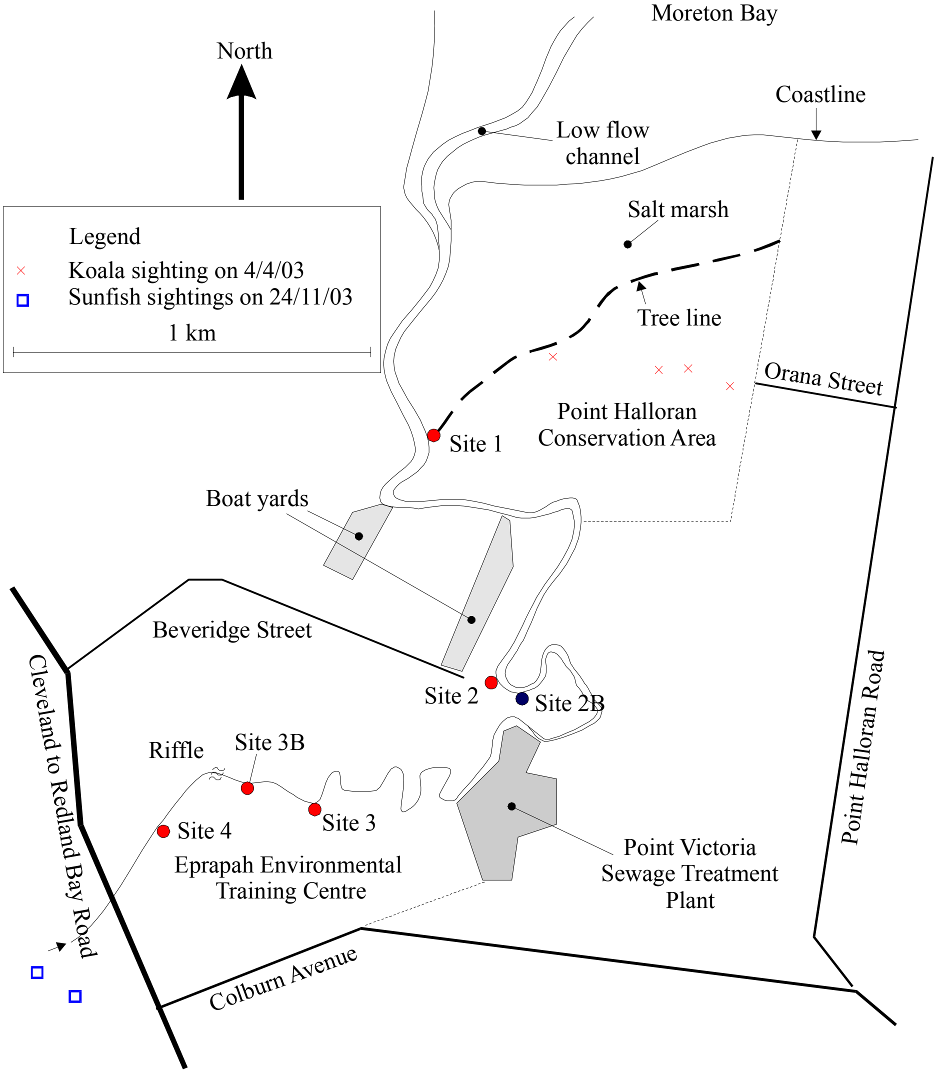



Fig. 1 - Estuary of Eprapah Creek, Redlands (Queensland)

## 3. EXPERIMENTAL PROCEDURES

Field works took place at several sites along the estuarine zone on three different days (Fig. 1, Table 1). They involved more than 80 people, including researchers, students, professionals and local community groups for a single-day each time (Fig. 2). Measurements were conducted for between 8 and 12 hours. The tidal and weather conditions are summarised in Table 2. On the night before the first field work, an intense but short rain storm took place around 6:00 pm, with possibly more showers overnight. The freshwater runoff was felt on 4 April 2003 and impacted on the results (e.g. salinity).

Table 1. Experimental measurements

| Field work (1) | Period (2) | Parameters (3) | Location (4) | Remarks (5) |
|---|---|---|---|---|
| 4 April 2003 | | | | Flood and ebb tides |
| Series 1 | 06:00-18:00 | Hydraulics, Water quality | Sites 1, 2, 3, 4 | Measurements from banks every 15 min.. |
| Series 2 | 08:00-14:00 | Water quality | Sites 1, 2, 3 | Measurements from boat (YSI 6920). |
| Series 3 | 10:10-14:05 | Turbulence, Water quality | Site 2B | ADV and YSI 6600 probes (25 & 0.2 Hz respectively) at 14.2 m from left bank. |
| Series 4 | 06:00-18:00 | Bird observations | Sites 1, 2, 3, 4 | Incl. wildlife observations. Continuous observations. |
| Series 5 | 06:00-18:00 | Fish sampling | Sites 1, 2, 3, 4 | Incl. crustaceans and invertebrates. One trap and net every 30 min. |
| 17 July 2003 | | | | Flood tide |
| Series 1 | 06:00-14:00 | Hydraulics, Water quality | Site 2 | Measurements from banks. Every 20 min. |
| Series 2 | 13:15 | Water quality | Site 2 | Measurements from boat (YSI 6920). |
| Series 3 | 06:10-14:05 | Turbulence, Water quality | Site 2 | ADV and YSI 6600 probes (25 & 0.2 Hz respectively) at 8.0 m from left bank. |
| Series 4 | 06:00-14:00 | Bird observations | Site 2 | Continuous observations. |
| Series 5 | 07:00-12:00 | Fish sampling | Site 2 and surroundings | Several traps each hour. |
| 24 Nov. 2003 | | | | Ebb tide. |
| Series 1 | 09:20-10:00 | Hydraulics, Water quality | Sites 3B, 4 | Measurements from banks. |
| Series 2 | 08:00-16:00 | Water quality | Sites 1, 2, 3, 3B | Measurements from boat (YSI 6920). |
| Series 3 | 09:18-15:55 | Turbulence, Water quality | Site 2B | ADV and YSI 6600 probes (25 & 0.5 Hz respectively) at 10.8 m from left bank. |
| Series 4 | 08:00-16:00 | Bird observations | Site 2 | Incl. wildlife observations. Continuous observations. |
| Series 5 | | Fish sampling | Site 3B, 4 and u/s of Site 4 | |
| Series 6 | 07:20-16:00 | Fish behaviour | Site 2 | Behaviour in recirculation zones next to outer bend |

On each day, several sites were simultaneously monitored (Table 1). Their location was AMTD 0.6, 2, 2.1, 3.1, 3.5 and 3.8 km for Sites 1, 2, 2B, 3, 3B and 4 respectively, where AMTD is the upstream distance from river mouth (Fig. 1). At each site, a series of hydraulic, water quality and ecological data were recorded from the bank: e.g., water elevations, surface velocity, air and water temperatures, conductivity, pH, dissolved oxygen, turbidity. Most readings were taken every 15 to 30 minutes while bird watching was continuous (Table 1). Vertical profiles of water quality parameters were conducted in the middle of the creek. These were performed at high tide and during ebb flow using a water quality probe YSI™6920 lowered from a boat drifting with the flow. Measurements of water temperature, conductivity pH, conductivity, dissolved oxygen content and turbidity were performed every 20 to 50 cm. In addition, a Sontek™ ADV velocitymeter and a water quality probe YSI™6600 were deployed and data-logged continuously at respectively 25 Hz and 0.2 Hz. The probes were located at Sites 2 and 2B (Fig. 1, Table 1). They were installed about the middle of the main channel in a moderate bend to the right when looking downstream. The two probes were positioned 300 mm apart and held by a metallic frame sliding on two poles (Fig. 2 Left). The measurement sensors were located 0.50 m beneath the free-surface and maintained at a constant depth below the free-surface for all studies. The probes were installed outside of the support system (i.e. outside of two poles) to limit the wake effects of the support.
For measurements from the bank, the data accuracy was about 1 cm for water level elevation, 0.2 to 0.5 ºC for water temperature, 1 to 2% for conductivity, 0.2 to 0.5 for pH measurement with pH paper, 5 cm on turbidity Secchi disk length, 10% on the surface velocity and 5 to 10% on the dissolved oxygen concentration. With the water quality probe YSI6920, the data accuracy was : ±2% of saturation concentration for D.O., ±0.5% for conductivity, ±0.15ºC for temperature, ±0.2 unit for pH, ±0.02 m for depth, ±1% of reading for salinity, and ± 5% for turbidity. With the water quality probe YSI6600, the accuracy of the data was : ±2% of saturation concentration for D.O., ±0.5% for conductivity, ±0.15ºC for temperature, ±0.2 unit for pH, ±0.02 m for depth, ± 1% of reading for salinity, and ±5% for turbidity. No information was available on the data accuracy on

chlorophyll levels. Further details are available in Chanson et al. (2003) and in the the website {http://www.uq.edu.au/~e2hchnas/eprapa.html}.

Fig. 2 - Photographs of field investigations
(Left) ADV and YSI6600 probes at Site 2B on 4 April 2003 in position, looking from the left bank
(Right) Interactions between students and professionals on 4 April 2003 at Site 2 (Courtesy of Student Group 2)

### 3.1 Discussion : practical issues

Some high level of noise was observed in the 3 velocity components recorded with the ADV velocitymeter. At rest, the measured ADV signal represents the Doppler noise itself. In the stream, the velocity fluctuations characterise the combined effects of the Doppler noise, velocity fluctuations and installation vibrations. It is acknowledged that the Doppler noise level increases with increasing velocity although it remains of the same order of magnitude as the Doppler noise at rest. Nikora and Goring (1998), Chanson et al. (2002) and more specifically Lemmin and Lhermitte (1999) discussed in details the inherent noise of an ADV system. In the present study, the ADV system was relatively old and some problems were experienced with the turbulent velocity fluctuation and vertical velocity component data. All suspicious data were discarded.
During the first two field studies, the YSI6600 water quality probe was set to record data every 5 seconds. But a few points were not recorded once every five minutes when the wiper cleaned the lens. The problem was not critical because the data acquisition timing was accurate within 1/100th of a second and it did not affect the data accuracy. The problem was resolved in the last field study when the data were recorded every 2 seconds.
The clocks of YSI6600 probe and of ADV data acquisition computers were synchronised within one second. For each study, it was expected that the cumulative errors on the time were less than 1 second for both YSI and ADV probes.

## 4. BASIC OBSERVATIONS

### 4.1 Hydraulic and water quality

Water level observations showed consistently maxima and minima slightly after the reference high and low tides (Brisbane bar). This is consistent with observed high tides at Victoria Point behind Brisbane bar records, and it is also typical of an estuarine system where the information on tide reversal must travel upstream. Surface velocity observations indicated that the flow reversal was clearly observed with greater delay than that observed with water depth data. This might be the result of possible recirculation zones next to the banks at high tide. For all 3 studies, the tidal influence was felt up to Site 3B but not at Site 4. The latter site was basically a freshwater system for each study. For the greatest tidal range (24 Nov. 2003), a very-shallow water zone was seen at low tide between Sites 2B and the sewage plant : i.e., depth less than 0.5 m. This "bar" reduced drastically mixing between the upper and lower estuarine zones at very low tides.
Water quality observations were conducted systematically from the bank (Table 1, Series 1), from a boat mid-stream (Table 1, Series 2) and with continuous recording 0.5 m beneath the free-surface at one site (Table 1, Series 3). Basic water quality results are summarised in Table 2, including the mean values, minima and

maxima. Water temperature data indicated an increase in water temperature near the middle of the day as the surface waters were heated by the sun. The flood tide also brought in some warm waters from the Moreton Bay.
Measurements indicated further that the dissolved oxygen (DO) contents were maximum around high tide. The downstream waters were more oxygenated than waters at upstream sites. Basically waters rich in oxygen were brought from the Moreton Bay by the flood tide. Turbidity data showed consistently a greater water clarity at high tide and at the beginning of ebb flow. Secchi disk and YSI probe turbidity data were about constant along the creek. Water conductivity data followed the tidal cycle with an influx of saltwater during the flood flow and a reflux during the ebb at Sites 1 to 3B. The data at Site 4 indicated a freshwater pool. Conductivity data suggested clearly a decrease in conductivity with increasing distance from the river mouth. Similarly, a decrease in pH with increasing distance from the river mouth was observed on all 3 studies. On 4 April 2003, pH data ranged from 6.4 to 7 which corresponded to slightly acidic waters, associated with a marked decrease in pH with increasing distance from the river mouth (Chanson et al. 2003). It is likely that the freshwater runoff contributed to the lower pH levels.
Vertical profiles of water quality parameters showed that the distributions of water temperature, dissolved oxygen content, turbidity and pH were reasonably uniform at high tide and in the early ebb flow for all studies. Conductivity data showed however a stratification of the flow with a fresh water lens above a saltwater wedge on all 3 days. The stratification was possibly the strongest on 4 April 2003 because of substantial freshwater runoff.

Table 2. Experimental flow conditions and basic observations

| Flow conditions (1) | 4 Apr. 2003 (2) | 17 July 2003 (3) | 24 Nov. 2003 (4) | Remarks (5) |
|---|---|---|---|---|
| Tides | 04:58 (0.53 m)<br>10:49 (2.02 m)<br>17:06 (0.43 m)<br>23:17 (2.20 m) | *23:42 (2:41 m)*]<br>06:30 (0.46 m)<br>12:01 (1.73 m)<br>17:47 (0.45 m) | 03:09 (0.09 m)<br>09:36 (2.52 m)<br>16:11 (0.34 m)<br>21:39 (1.91 m) | Brisbane bar. |
| Weather conditions | Sunny | Overcast | Overcast with few short showers | |
| Water temperature (Celsius) | 23.7<br>[20.4-28.4] | 16.7<br>[15.5-18.5] | 25.5 (*)<br>[22.7-28.0] | Sites 2 & 2B. |
| Air temperature (Celsius) | 22.2<br>[15.5-29] | 17.2<br>[10.5-21.5] | --<br>*[19-29]* | Site 2. |
| Conductivity (mS/cm) | 34.5<br>[23.9-48.3] | 37.2<br>[29.8-48.4] | 50.0 (*)<br>[42.7-55.1] | Sites 2 & 2B. |
| Dissolved Oxygen content (% Sat) | 0.85<br>[0.62-1.0] | 0.82 (*)<br>[0.66-1.06] | 0.81 (*)<br>[0.76-0.85] | Sites 2 & 2B. |
| pH | 6.8<br>[6.4-7] | 7.4<br>[6.6-7.8] | 7.8 (*)<br>[7.4-8.0] | Sites 2 & 2B. |
| Turbidity (m Secchi) | 0.68<br>[0.53-1.0] | 0.84<br>[0.5-1.2] | -- | Site 2. |
| Average turbidity (NTU) | 9.4 (*)<br>[5.8-13.9] | 11.0 (*)<br>[7.2-*24.6*] | 19.9 (*)<br>[7.1-43] | Sites 2 & 2B. |
| Others : | Storm event night before. Runoff felt on 4/4/03 | | | |

Notes : Mean [Min.-Max.] : average value and range; (*) : measurement 0.5 m below free-surface.

## 4.2 Short-term fluctuations of velocity and water quality

Turbulent velocity records, measured with the ADV, suggested distinct periods : i.e., a slack time around high and low tides, and some strong flushing during the flood tide (17 July) and ebb tides (4 April & 24 November). Around high tide, the velocity magnitude was small : i.e., typically less than 10 cm/s, and the velocity direction was highly fluctuating. The velocity magnitude increased with time after slack, and the strongest currents were observed during mid-ebb tides on 4 April and 24 November 2003 with instantaneous velocities of about 0.2 to 0.3 m/s. The detailed records showed consistently significant fluctuations with time of both velocity magnitude and direction, with fluctuations in instantaneous velocity directions of typically about 30º. During ebb tides, the velocity data showed significant flushing of the estuarine zone. The estimated discharge at mid-tide was important (up to 5 to 10 $m^3$/s) and such a mass flux would contribute to significant freshwater drainage out of the estuary associated with seawater renewal at the next tide. Instantaneous water quality data results showed relatively small fluctuations of water quality parameters with time. These fluctuations were at least one order of magnitude smaller than observed turbulent velocity fluctuations. Typical periods of fluctuations ranged from few minutes to 30 minutes. Such large periods would correspond to the effect of large vortical structures. Figure 3 presents a short series of instantaneous measurements of turbulent velocity and water quality parameters on 17 July 2003. Both graphs show results obtained around mid flood tide. The results emphasise the lesser fluctuations of water quality parameters compared to turbulent velocity fluctuations.

## 4.3 Fish sampling and bird observations

During each field investigation, more than 200 birds corresponding to more than 25 species were sighted at each site (Table 3, 1st and 2nd rows). Results must be considered with care since flocks of birds were seen and accounted for up to 1/3rd of the total number of sightings. Overall bird sightings showed a strong activity at all sites, particularly in the morning between 7:00 and 10:00. Yet, on 4 April 2003, there was always a minimum of five bird species seen every hour of day between 6:00 and 18:00 at each Site. This suggests a fair diversity of the bird population in the Eprapah Creek estuarine zone. Cooper (1978) indicated 120 bird species at Eprapah, while Melzer and Moriaty (1996) listed more than 70 bird species in Eprapah Creek between Cleveland-to-Redland Bay road and the river mouth. Present findings (Table 3) suggest that the bird population was diverse and active. However the surveys were limited and it is difficult to make any definite conclusion.

Fish sampling was possibly more intensive on 4 April 2003. Altogether more than 400 fish were caught corresponding to 21 species then. The largest numbers of fish were caught between 10:00 and 17:00. It is very likely that the combination of flood flow with higher dissolved oxygen contents and sun light induced significant fish activities during the period 10:00 to 16:00. At Site 4 (freshwater pool), 98.6% of the catches were Mosquito fish, an exotic species tolerant to environmental extremes. This might suggest that native species had difficulties in reduced dissolved oxygen conditions, although native fish activity were present. For example, Empire gudgeon, Firetail gudgeon and Flat headed gudgeon were caught on 4 April 2003 at Sites 3 and 4, while sun fish were observed in Eprapah Creek upstream of Site 4 on 24 November 2003.

A large amount of macro invertebrates and crustaceans were also observed during each investigation: i.e., shrimps, prawns, Fiddler crabs, mud crabs.

Table 3. Experimental observations (2) Fish and bird activities

| Observations<br>(1) | 4 Apr. 2003<br>(2) | 17 July 2003<br>(3) | 24 Nov. 2003<br>(4) | Remarks<br>(5) |
|---|---|---|---|---|
| Nb of bird sightings | 189<br>(496) | 200 to 300 | 293 | Site 2<br>(Sites 1, 2, 3 & 4) |
| Nb of bird specie sighting | 27<br>(72) | 28 | 38 | Site 2.<br>(Sites 1, 2, 3 & 4) |
| Nb of fish catch | 111<br>(437) | 185 | -- | Site 2.<br>(Sites 1, 2, 3 & 4) |
| Nb of fish specie catch | 8<br>(21) | 5 | -- | Site 2.<br>(Sites 1, 2, 3 & 4) |
| Nb of fish sighting in recirculation zones | -- | -- | > 500 | Site 2, outer bend. |
| Nb of fish specie sighting in recirculation zones | -- | > 2 | > 7 | Site 2, outer bend. |

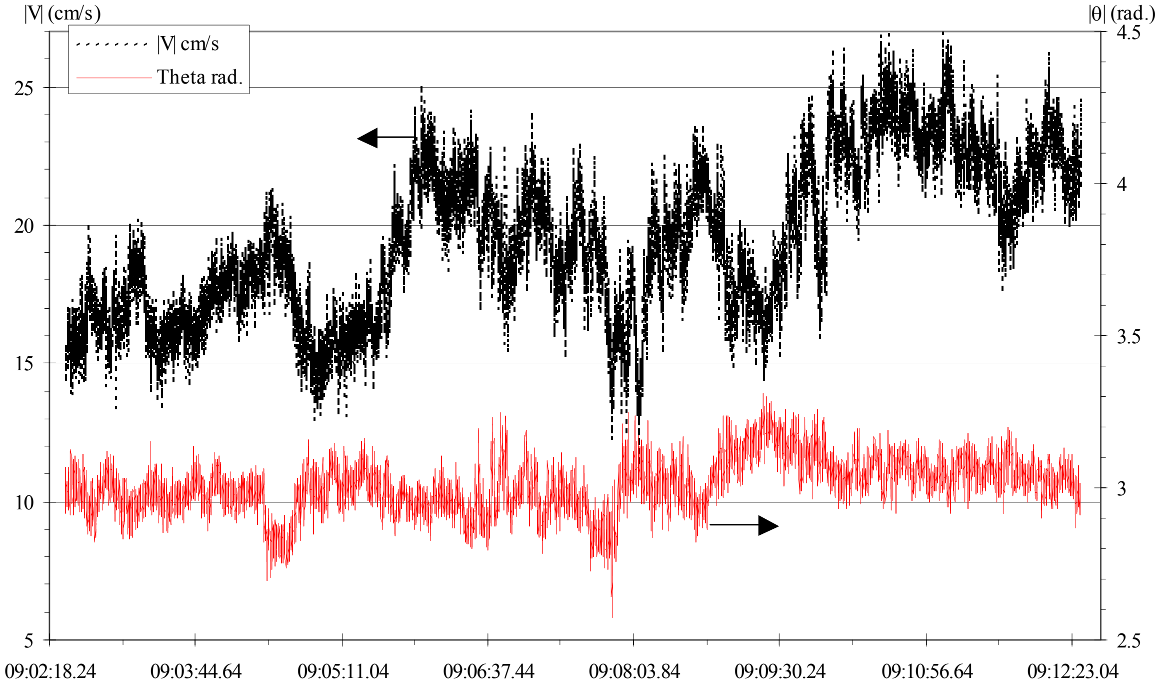
## 4.4 Discussion

Depth-averaged water quality parameters were calculated from vertical water quality profiles. Despite some salinity stratification, similar trends were observed between depth-averaged data and surface water data. These observations were valid on three specific days but should not be extrapolated without further comparative tests. Although such results confirm that surface water quality parameters were reasonable indicators of Eprapah Creek health, it is essential to understand that surface water sampling does not provide any information on the flow stratification nor on turbulence characteristics.

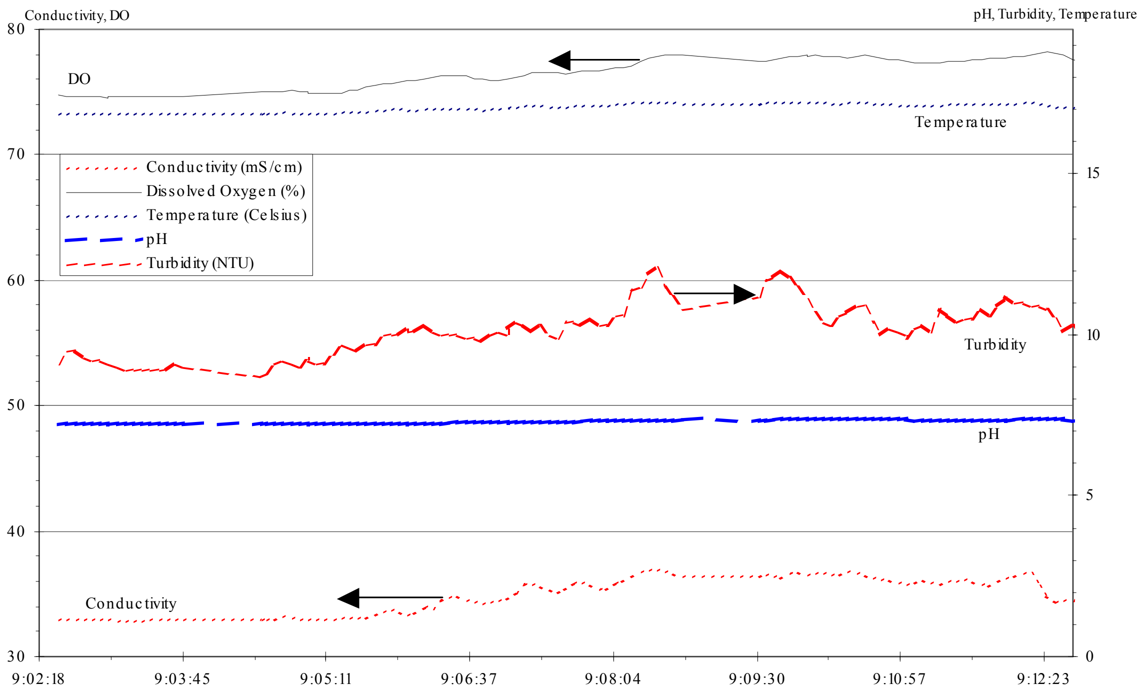
Along an estuarine zone, the depth-averaged density increases with increasing seaward distance. Basic momentum considerations show that a slope of the mean water surface must counterbalance the mean density gradient while the solution of the motion equation gives vertical residual velocity distributions (Chanson 2004a). The results yield residual surface velocities of up to 1 cm/s. The residual circulation is relatively significant, corresponding to a renewal of the estuarine waters in about one week.

During all 3 field works, recirculation zones were observed in the outer bend of the river (Site 2). On 17 July and 24 November 2003, some toad fish were seen utilising these recirculation regions for feeding, and detailed observations on 24 November 2003 are summarised in Table 3. The findings confirm the existence of an outer bank secondary current cell at Eprapah Creek (Site 2), discussed more broadly by Blanckaert and Graf (2001).

The observations showed that recirculation zones varied in space and in time with the tide, but they were always observed. The occurrence of recirculation regions is important since outer bend cells contribute to a reduction in bend scouring. They are "dead zones" which are thought to explain long tails of tracer observed in natural rivers. Their existence implies that the turbulence is not homogeneous across the river, and that the time taken for contaminant particles to penetrate the entire flow may be significantly enhanced (e.g. Valentine and Wood 1979a,b, Chanson 2004a).




(A) Instantaneous horizontal velocity magnitude |V| and velocity direction θ (ADV data)




(B) Instantaneous water quality parameters (YSI6600 data)

Fig. 3 - Short-term fluctuations of turbulent velocity and water quality on 17 July 2003 during mid flood tide

## 5. SUMMARY AND CONCLUSION

The results and outcomes of three field studies in a subtropical estuary are three-fold. First, these investigations provided unique snapshots of a small estuarine system. The single-day studies complemented long-term monitoring, and results should not be extrapolated without care and caution. The works provided a broad range of simultaneous data encompassing hydrodynamics, water quality and ecology, and they constitute the first comprehensive hydrodynamic survey of a subtropical system. It is the opinion of the writers that the methodology sets new standards for multidisciplinary, cross-institutional, comprehensive field studies.

Second, the measurements provided contrasted outcomes. Fish sampling and bird observations suggested a dynamic eco-system, while velocity measurements indicated high turbulence levels and a strong flushing process in the estuary. But other results highlighted poor water quality parameters in the upstream sections of the estuary. Serious concerns included low dissolved oxygen and pH levels (Sites 3 and 4), surface slicks (Sites 2 and 3), a large number of exotic fish (e.g. Site 4) competing with native fish species, and surface runoff (e.g. construction sites, shopping centres). All these demonstrated on-going pollution. Clearly a major issue is the definition of so-called "key indicators" which cannot describe the complexity and diversity of sub-tropical estuaries.

Third, the field works provided unique personal experiences to all parties involved. They fostered interactions between academics, professionals, and local community groups, while they contributed to the students' personal development. Field studies complement traditional lectures and laboratory work and anonymous student feedback demonstrated a strong student interest for the field works (Chanson 2004b). Group work contributes to new friendships and openings: e.g., between civil and environmental students, between Australian and international students, between students and professionals involved in the study. Such personal experiences are at least as important as the academic experience.

## 6. ACKNOWLEDGMENTS

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## 7. REFERENCES

Aoki, S. (1999). "New Coastal Engineering in Global Environment." *Fuji Technosystems*, T. Sawaragi Ed..

Blanckaert, K., and Graf, W.H. (2001b). "Mean flow and turbulence in open-channel bend." *Jl of Hyd. Engrg.*, ASCE, Vol. 127, No. 10, pp. 835-847.

Chanson, H. (2004a). "Environmental Hydraulics of Open Channel Flows." *Butterworth-Heinemann*, Oxford.

Chanson, H. (2004b). "Enhancing Students' Motivation in the Undergraduate Teaching of Hydraulic Engineering: the Role of Field Works" *Jl of Prof. Issues in Eng Educ. and Practice*, ASCE, Vol. 130, No. 2.

Chanson, H., Aoki, S., and Maruyama, M. (2002). "Unsteady Two-Dimensional Orifice Flow: a Large-Size Experimental Investigation." *Jl of Hyd. Res.*, IAHR, Vol. 40, No. 1, pp. 63-71

Chanson, H., Brown, R., Ferris, J., and Warburton, K. (2003). "A Hydraulic, Environmental and Ecological Assessment of a Sub-tropical Stream in Eastern Australia: Eprapah Creek, Victoria Point QLD on 4 April 2003." *Report No. CH52/03*, Dept. of Civil Engineering, University of Queensland, Brisbane, Australia, June.

Cooper, V. (1978). "Bird of Eprapah." *Scout Association of Australia*, Kelvin Grove Qld, Australia, 46 pages.

Fischer, H.B., List, E.J., Koh, R.C.Y., Imberger, J., and Brooks, N.H. (1979). "Mixing in Inland and Coastal Waters." *Academic Press*, New York, USA.

Ippen, A.T. (1966). "Estuary and Coastal Hydrodynamics." *McGraw-Hill*, New York, USA.

Jones, A.B., Prange, J., and Dennison, W.C. (1999). "An Assessment of the Ecological Health of Eprapah Creek." *Report*, Marine Botany, Univ. of Queensland, Brisbane, Australia, 23 pages.

Lemmin, U., and Lhermitte, R. (1999). "ADV Measurements of Turbulence: can we Improve their Interpretation ? Discussion" *Jl of Hyd. Engrg.*, ASCE, Vol. 125, No. 6, pp. 987-988.

Melzer, R., and Moriarty, C. (1996) "Flora and Fauna of Eprapah Creek" *Eprapah Creek Catchment Landare Association*, Victoria Point Qld, Australia, 56 pages.

Nikora, V.I., and Goring, D.G. (1998). "ADV Measurements of Turbulence: can we Improve their Interpretation ?" *Jl of Hyd. Engrg.*, ASCE, Vol. 124, No. 6, pp. 630-634.

Ramsay, I., Counihan, R, Webb, G. and Conrick, D. (2002) "Southern South-East Queensland Waterway Monitoring Technical Report 2000." *Queensland Environmental Protection Agency*, Brisbane.

Valentine, E.M., and Wood, I.R. (1979). "Experiments in Longitudinal Dispersion with Dead Zones." *Jl of Hyd. Div.*, ASCE, Vol. 105, No. HY9, pp. 999-1016.

Valentine, E.M., and Wood, I.R. (1979). "Dispersion in Rough Rectangular Channels." *Jl of Hyd. Div.*, ASCE, Vol. 105, No. HY12, pp. 1537-1553.