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MIXING AND DISPERSION IN SUB-TROPICAL ESTUARINE SYSTEM : FIELD WORKS AND EXPERIENCE AT EPRAPAH CREEK (AUSTRALIA)

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Abstract: In natural systems, mixing is driven by turbulence, but current knowledge is limited in estuarine zones, where predictions of contaminant dispersion are often accurate "within a factor of 10". A series of detailed multi-disciplinary field studies was conducted in a small subtropical creek in eastern Australia. Hydrodynamic, water quality and ecological measurements were conducted simultaneously to assess the complexity of the estuarine zone and the interactions between turbulence and environment. The results provide unique and original snapshots of subtropical creek to complement long-term monitoring. The methodology set new standards for comprehensive surveys of small estuaries in sub-tropical zone. A significant feature of the field studies was the contrasted outcomes, and the finding impacts on the selection of "key water quality indicators". Short-term fluctuations in water quality parameters were further observed to be at least one order or magnitude smaller than turbulent velocity fluctuations.

Keywords: Mixing, Estuary, Field experience, Turbulence, Water quality, Ecology, Sub-tropical stream

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 ecosystems including from treated sewage effluent, toxicant release and fate within the environment, and storm-water runoff during flood events. Current knowledge is limited : e.g., 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 very often untrue. Predictions of contaminant dispersion in estuaries are always based upon empirical mixing coefficients. These coefficients are highly sensitive to the natural system 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, CHANSON 2004a). Although mixing is driven by turbulence in natural systems, the interactions between hydrodynamics, water quality and ecology are rarely considered together. There has been some research into pollutant dispersion in individual river catchments, but very little research has been done on turbulent mixing and dispersion in complete estuarine systems, 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).

A series of multi-disciplinary field studies were conducted in the estuarine zone of Eprapah Creek (Australia) in 2003. The purpose of field works was to assess the complexity of a small estuarine system, and the interactions between hydraulic engineering, biology and ecology.

The results provide a new understanding of basic mixing process in sub-tropical estuaries, while the experience highlights important issues and practical considerations.

2 A CASE STUDY: EPRAPAH CREEK (LONG. 153.30º, LAT. -27.567º)

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

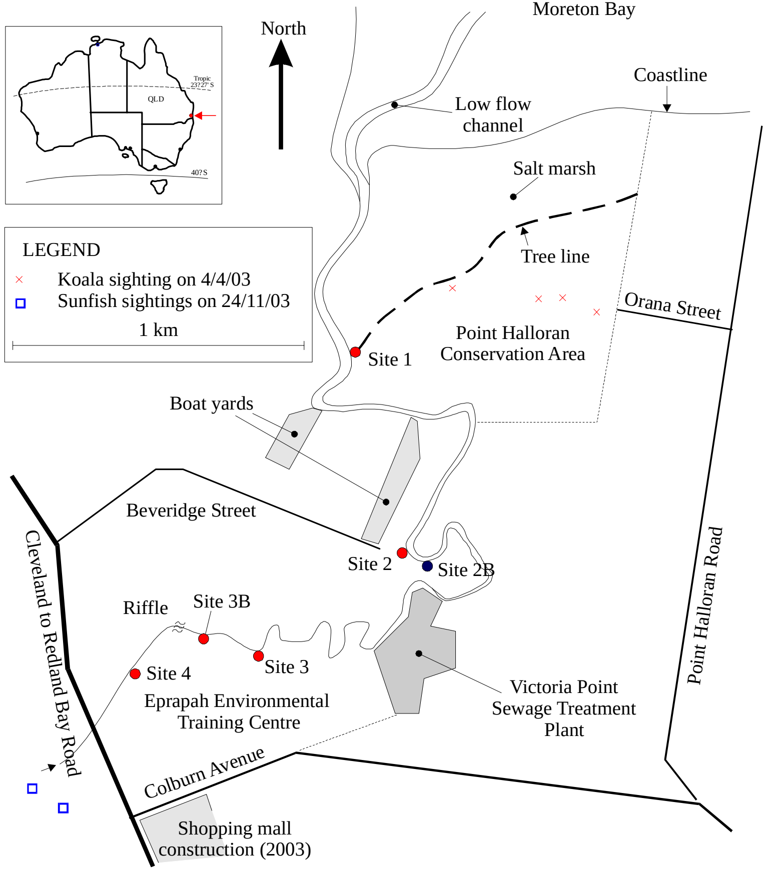

Fig. 1 Map of Eprapah Creek Estuarine Zone

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. Although the estuarine zone includes two environmental parks, there are some marinas and boat yards, and a sewage plant impacting heavily on the natural system (JONES *et al*., 1999) (Fig. 1). The upstream catchment has been adversely affected by industrial poultry farms, land clearance and semi-urban development. Recent works included the constructions of new shopping centres and residential lots. In 2003, comprehensive hydrodynamic, environmental and ecological field studies were conducted (Table 1, Fig. 2) and described herein.

Fig. 2 Photographs of Field Investigations in Eprapah Creek Estuary - From Top Left (clockwise), ADV and YSI6600 Probes at Site 2B on 24/11/03; Site 1 on 4/4/03; Site 3 on 4/4/03 at high tide; Site 2 on 17/7/03 after Boat Passage Next to ADV and YSI6600 Probes

3 FIELD OBSERVATIONS AT EPRAPAH CREEK. (1) EXPERIMENTAL METHODS

Field works took place on three different days at several sites simultaneoulsy (Table 1, Fig. 2). They involved more than 80 people, including researchers, students, professionals and local community groups for a single-day each time. Several sites were simultaneously monitored at locations AMTD 0.6 km, 2 km, 2.1 km, 3.1 km, 3.5 km 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, fish sampling. Most readings were taken every 15 min to 30 min while bird watching was continuous. The tidal and weather conditions are summarised in Table 2.

Vertical profiles of water quality parameters were conducted in the middle of the creek at several sites. They 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 cm to 50 cm.

Table 1 Experimental Measurements at Eprapah Creek

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
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
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
Series 4	06:00-14:00	Bird observations	Site 2	Continuous observations.
Series 5	07:00-12:00	Fish sampling	Site 2 and surrounding	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
Series 4	08:00-16:00	Bird observations	Site 2	Incl. wildlife observations. Continuous observations.
Series 5	07:00-16:00	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

At one site, 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 (or 0.5 Hz). The probes were located at Sites 2 and 2B. They were installed about the middle of the main channel in a moderate bend to the right when looking downstream (Fig. 2). The two probes were positioned 300 mm apart and held by a metallic frame sliding on two poles. 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 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 ºC 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 on the experimental procedures are available in CHANSON *et al.* (2003) and BROWN *et al.* (2004).

Table 2 Basic Observations at Eprapah Creek

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

Table 3 Fish and Bird Activities at Eprapah Creek

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

Remarks: During the first two field studies, few YSI6600 data were not recorded once every five minutes when the turbidity sensor wiper cleaned the lens. The problem was not critical and did not affect the data accuracy and timing. The problem was resolved in the last field study when the data were recorded every 2 s. Lastly the clocks of YSI6600 probe and of ADV data acquisition computers were synchronised within one second.

4 FIELD OBSERVATIONS AT EPRAPAH CREEK. (2) BASIC RESULTS

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 was consistent with observed high tides at Victoria Point behind Brisbane bar records, and it was also typical of an estuarine system where the information on tide reversal must travel upstream. 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 Site 2B and the sewage plant : i.e., depth less than 0.3 m to 0.5 m. At very low tides, this "bar" acted as a weir reducing drastically mixing between the upper and lower estuarine zones.

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 mean values, minima and maxima. Water temperature data indicated an increase in water temperature near the middle of the day when 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 in from 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.

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 for 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 in the upstream reach (CHANSON *et al.* 2003). It was likely that some 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 2 studies. Conductivity data showed however some flow stratification 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.

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 Nov.). Around high and low tides, the velocity magnitude was small: i.e., typically less than 10 $\mathrm{cm \cdot s^{-1}}$, 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 (4/04/03 and 24/11/03) with instantaneous velocities of about 0.2 $\mathrm{m \cdot s^{-1}}$ to 0.3 $\mathrm{m \cdot s^{-1}}$. Detailed records showed consistently significant fluctuations with time of both velocity magnitude and direction, with fluctuations in instantaneous velocity directions of typically 20° to 30°. During ebb tides, velocity measurements demonstrated a strong flushing of the estuarine system that contributed to a fair water outflow associated with water 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 (Table 4 , Fig. 3).

Table 4 Short-term fluctuations of turbulent velocity and water quality parameters at 0.5 m beneath the free-surface (Eprapah Creek)

Parameter (1)	Nb data (2)	Median (3)	Std Dev. (4)	Skewnes (5)	Kurtosis (6)	Remarks (7)
4 Apr. 2003 (Site 2B)						
12:29:32 to 12:52:49						Ebb tide (first half).
$\lvert V\rvert$ /cm·s^{-1}:	34,946	12.49	1.99	0.149	0.528	Horizontal velocity amplitude
θ (deg.):	34,946	14.06	9.35	-0.845	2.239	θ = 0 d/s, θ > 0 towards left
Temperature (Celsius):	240	24.23	0.203	2.261	4.366	
Conductivity /ms·cm^{-1}:	240	35.54	1.953	-1.640	1.701	
DO /mg·L^{-1}:	240	4.360	0.123	0.662	-0.659	
pH:	240	7.50	0.078	-1.937	4.039	
Turbidity (NTU):	240	9.90	0.445	0.477	4.366	
13:12:02 to 13:40:00						Mid ebb tide.
$\lvert V\rvert$ /cm·s^{-1}:	41,975	19.92	3.07	0.550	0.180	
θ (deg.):	41,975	13.7	7.03	-0.129	0.280	
Temperature (Celsius):	296	24.30	0.115	0.356	-0.380	
Conductivity /ms·cm^{-1}:	296	31.19	1.54	0.848	0.623	
DO/mg·L^{-1}:	296	3.92	0.088	-0.278	-1.175	
pH:	296	7.24	0.063	0.996	0.818	
Turbidity (NTU):	296	9.70	0.837	2.260	-0.380	
17 Jul. 2003 (Site 2)						
09:02:30 to 09:32:35						Mid flood tide.
$\lvert V\rvert$ /cm·s^{-1}:	44,951	20.46	3.41	0.0906	-0.547	
θ (deg.):	44,951	171.46	5.61	1.218	0.980	
Temperature (Celsius):	338	17.19	0.124	-1.220	0.8415	
Conductivity /ms·cm^{-1}:	338	36.60	1.44	-1.128	0.325	
DO/mg·L^{-1}:	338	6.60	0.114	-0.162	-1.061	
pH:	338	7.36	0.068	-0.966	-0.106	
Turbidity (NTU):	338	10.60	0.74	-0.062	0.250	
09:25:45 to 09:36:00						Mid flood tide. Include one ADV position change
$\lvert V\rvert$ /cm·s^{-1}:	15,001	18.95	3.22	0.419	0.350	
θ (deg.):	15,001	171.15	7.19	0.367	2.941	
Temperature (Celsius):	116	17.29	0.0265	-0.277	-0.255	
Conductivity /ms·cm^{-1}:	116	37.67	0.271	0.193	-0.674	
DO /mg·L^{-1}:	116	6.750	0.0278	-0.143	-0.604	
pH:	116	7.42	0.012	0.368	-0.992	
Turbidity (NTU):	116	11.10	0.438	0.817	0.888	
24 Nov. 2003 (Site 2B)						
10:49:14 to 11:11:40						High tide, start of ebb.
$\lvert V\rvert$ /cm·s^{-1}:	33,661	13.57	2.66	0.453	0.535	
θ (deg.):	33,661	13.05	9.38	0.166	2.19	
Temperature (Celsius):	683	25.21	0.026	0.327	-0.512	
Conductivity /ms·cm^{-1}:	683	54.5	0.16	-0.426	-0.420	
DO /mg·L^{-1}:	683	5.59	0.026	0.440	-1.28	
pH:	683	7.99	0.012	-0.387	-0.701	
Turbidity (NTU):	683	10.90	0.95	1.027	1.904	
12:09:58 to 12:27:34						Mid ebb tide.
$\lvert V\rvert$/cm·s^{-1}:	27,344	18.20	2.54	-0.046	0.308	
θ (deg.):	27,344	2.07	7.79	0.174	0.433	
Temperature (Celsius):	529	25.57	0.0091	-0.343	-0.189	
Conductivity /ms·cm^{-1}:	529	49.83	0.410	0.126	-1.293	
DO /mg·L^{-1}:	529	5.45	0.059	0.152	-1.499	
pH:	529	7.74	0.024	0.0875	-1.360	
Turbidity (NTU):	529	17.30	0.869	0.358	0.218	
14:53:00 to 15:14:00						Low tide, end of ebb tide.
$\lvert V\rvert$ /cm·s^{-1}:	31,895	18.06	2.86	0.148	0.150	
θ (deg.):	31,895	14.19	7.95	1.019	21.92	
Temperature (Celsius):	631	25.85	0.004	0.602	-0.866	
Conductivity /ms·cm^{-1}:	631	43.15	0.0095	-0.178	-0.540	
DO /mg·L^{-1}:	631	5.540	0.069	0.457	-1.141	
pH:	631	7.43	0.0054	0.0938	-0.326	
Turbidity (NTU):	631	29.70	2.10	1.397	5.080	

Figs. 3 and 4 present a short time series of instantaneous measurements of turbulent velocity and water quality parameters on 24 November 2003. Fig. 5 shows the surveyed cross-section of the estuary. Fig. 3 presents instantaneous velocity magnitude |V| and direction θ (in radians), with $\theta = 0$ in the downstream direction and $\theta > 0$ towards the left bank. In Fig. 4, the left vertical axis corresponds to temperature and conductivity data, while the right verticals axis scales the dissolved oxygen content (DO), pH and turbidity. Figs. 3 and 4 illustrate the lesser fluctuations of water quality parameters compared to turbulent velocity fluctuations around mid ebb tide.

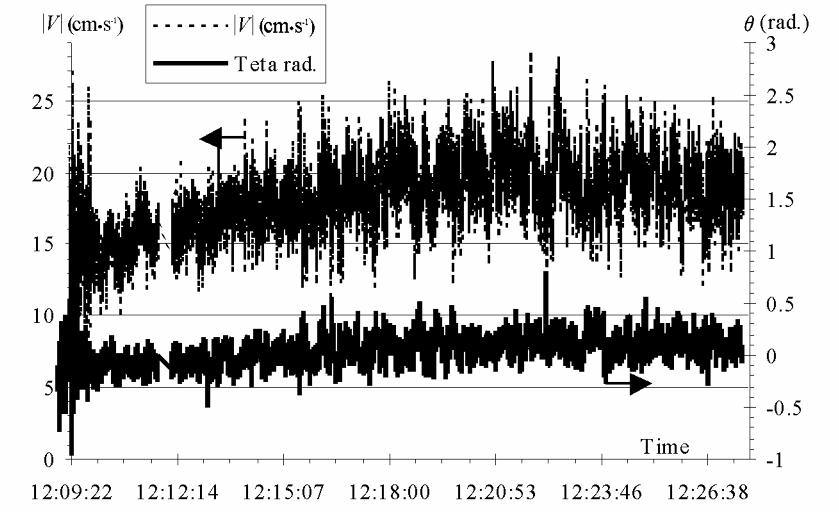

Fig. 3 Instantaneous velocity magnitude |V| (cm·s^{-1}) and direction θ (rad.) at Eprapah Creek on 24 Nov. 2003 at mid ebb tide

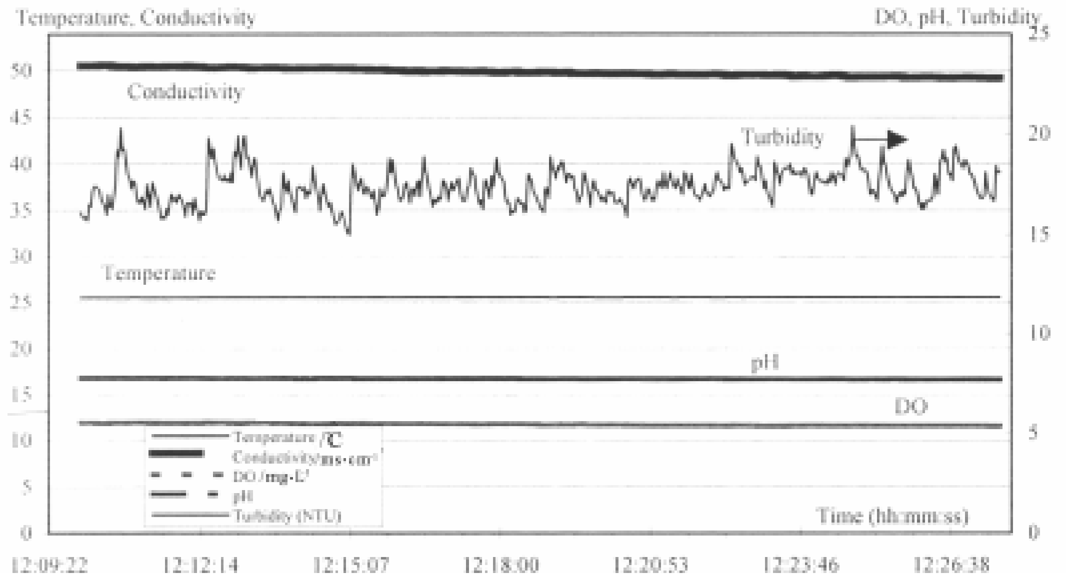

Fig. 4 Instantaneous Water Quality Parameters at Eprapah Creek on 24 Nov. 2003 at Mid Ebb Tide

Importantly, the experimental results showed significantly lesser fluctuations of water quality parameters for all investigations. This is illustrated in Figs. 3 and 4, and documented in Table 4. Table 4 presents a statistical summary of flow properties for intervals of about 20 min. The results highlight large fluctuations of instantaneous velocity direction θ, which is characteristic of the passage of coherent vortical structures. For example, in Fig. 3, the velocity direction range from -55° to +47° with a median value of +2.1° and a standard deviation of 7.8°. The probability distribution functions of θ were further Gaussian that is consistent with random turbulent processes.

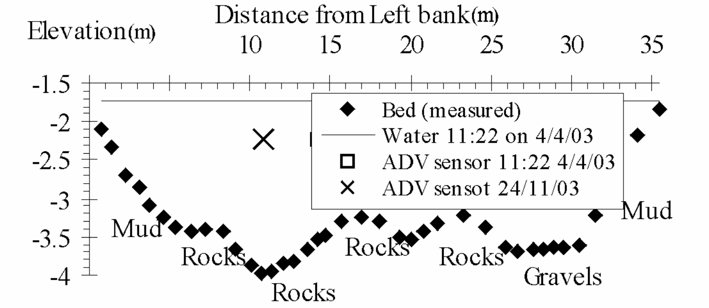

Fig. 5 Surveyed Transverse Cross-Sectional Profile at Site 2B Looking Downstream, Free-Surface Location on 4 April 2003 near High Tide and Corresponding ADV Sensor Locations (4/04/03 and 24//11/03) - Note the Distorted Vertical Scale

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 one third 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. The largest numbers of fish were caught between 10:00 and 17:00. It is most 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. 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 very-large amount of macro invertebrates and crustaceans were also observed during each investigation: i.e., shrimps, prawns, Fiddler crabs, mud crabs.

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, 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. Toad fish behaviour allowed a nice characterisation of such zones where turbulent velocity measurement is nearly impossible. 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 1979, CHANSON 2004a).

5 DISCUSSION: EXPERIENCES AND OUTCOMES

5.1 Practical Considerations

The preparation of field works is a crucial period during which all the instrumentation must be thoroughly calibrated and tested. Present field experience demonstrated recurrent problems with the ADV velocitymeter and some electronic meters. With the ADV velocitymeter, high levels of noise were observed with the 3 velocity components. 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. Further some problem with the vertical velocity component was experienced. Calibration tests in laboratory failed, possibly because of the effects of the wake of the stem. Since the probe was mounted vertically downlooking, vertical velocity data were discarded.

Electronic meters had to be tested and calibrated before each field test. The YSI6600 and YSI6920 probes were the most reliable water quality meters. The YSI6600 and YSI6920 water quality probes were checked each morning and re-calibrated each week on a regular basis. Problems with experienced with cheaper meters. The experience demonstrated that traditional techniques (e.g. pH paper, Secchi disk, titration tests) were reliable and most suitable to field activities in rough conditions.

Another point was the wildlife observations. Most engineering staff and students had very little experience, while some individuals were afraid to handle fish and crustacceans. Training on site and close supervision by wildlife experts and biologists were a basic requirement for the credibility and quality of the ecological surveys.

5.2 Value of Surface (?) Measurements from the Banks

A detailed comparison of hydraulic and water quality measurements conducted from the banks, mid-stream and at a fixed location (Site 2B) was performed for each field study. Depth-averaged water quality parameters were calculated from vertical water quality profiles. Overall similar trends were observed between depth-averaged data, surface water data and time-averaged data (Site 2B). These observations were valid on 3 specific days but should not be extrapolated without further comparative tests. Although such results confirmed that surface water parameters were reasonable indicators of Eprapah Creek health, it is essential to understand that surface water sampling did not provide any information on the flow stratification nor on turbulence characteristics.

5.3 Personal Experiences

Field works provided unique personal experiences to all parties involved, and facilitated interactions between groups with different background and interests. Key interactions included new exchanges between university and local community, between government institutions and universities, between professionals and academics, between technical and academic staff. Field works contributed further to the students' personal development. Field studies complemented traditional lectures and tutorials, and anonymous student feedback demonstrated a very-strong student interest (CHANSON 2004b). Personal student comments supported their enhanced motivation. An international student was very surprised to see a snake passing right in front of her during a wildlife survey; a former member of the army involved in fish sampling said: "*I did not believe that I would ever use survival skills in an* *engineering course*"; a first-class honours female student discovered the intricacies of practical works in harsh subtropical conditions with no fresh water nor toilets on site; she added "*it was as much a matter to mix with the environment as to study river mixing*". Group work contributed 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 were at least as important as the academic experience. Lecturers and professionals should not be complaisant with university hierarchy and administration clerks to cut costs by eliminating field studies.

5.4 Definition of Key (?) Water Quality Indicators ?

Overall the three series of field measurements provided consistently contrasted outcomes. Fish sampling and bird observations suggested a dynamic eco-system. 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 the results demonstrated on-going pollution in the estuary. Clearly a major issue is the definition of so-called "key indicators" which cannot describe the complexity and diversity of sub-tropical estuaries.

6 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 highlighted contrasted outcomes. While some results were positive, others demonstrated on-going pollution. How can we define accurately "key water quality indicators" to describe the diversity of sub-tropical estuaries? Third the field works provided unique personal experiences and fostered interactions between academics, professionals, local community groups and students. Field studies complemented traditional lectures, and such personal experiences are at least as important as the academic experience.

The experience gained at Eprapah Creek brings new lights into the complexity of the estuarine system, but also thought-provoking outcomes. It is clear that basic mixing processes are driven by turbulence. However its impact on a natural system cannot be comprehended without simultaneous measurements of hydrodynamic, water quality and ecological parameters, implying substantial instrumentation, broad-based expertise and human resources. Genuine inter-disciplinary research is essential and it can offer new approaches: e.g., using fish activities to characterise recirculation zones in shallow waters.

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