DEPTH, SALINITY AND TEMPERATURE PROFILING OF VASSE-WONNERUP WETLANDS IN 1998-2000

Report by JAK Lane, AG Clarke & YC Winchcombe
Western Australian Department of Environment and Conservation

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Our environment, our future

Cover photograph of Vasse estuary, surrounded by Busselton townsite and, in the distance, the Tuart Forest National Park.

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SUMMARY

Waterbird surveys were undertaken in 1998-2000 to assess whether the Vasse-Wonnerup wetland system, 190 km south of Perth, Western Australia, continued to meet the 'Ramsar' Criteria under which this system was listed in 1990 as a Wetland of International Importance.

Water depths and salinities are major determinants of wetland use by waterbirds as they greatly affect suitability for feeding, drinking, loafing, refuge, moulting, nesting and the raising of young. The water levels, water depths and salinities of Vasse-Wonnerup vary considerably each year. Levels and depths are highest and salinities lowest in winter and spring due to flushing by seasonal river flows. During the hot, dry months of summer these flows cease, wetland water levels decline and salinities rise. By late summer and autumn large areas of the two largest components of the system — the Vasse and Wonnerup estuaries — are dry and remnant waters are both very shallow and saline-hypersaline.

Floodgates first-installed on the exit channels of the estuaries in 1908 were designed to facilitate discharge of river floodwaters and to prevent the incursion of seawater. Since 1988 the Vasse estuary gates have been partially-opened at times to allow fish escape and to maintain a higher summer-autumn water level than in the preceding eight decades. In recent years the Wonnerup estuary gates have also been partially-opened occasionally to release fish.

Operation of the Vasse estuary floodgates can, at times, be contentious, with some calling for more openings and higher summer-autumn water levels and others arguing for the *status quo*, on the basis that such changes could adversely affect waterbird populations or other values, either natural or artificial.

Because changes to estuary water levels could impact upon suitability for waterbirds, a program of extensive hydrological monitoring was undertaken to coincide with, and continue six months beyond, the 1998-2000 waterbird surveys. This would enable the species-occurrence and abundance of waterbirds to be related to particular water levels, depths and salinities and would extend current knowledge of Vasse-Wonnerup's hydrology, thereby potentially assisting in its management.

Depth, salinity and temperature profiling was conducted at monthly intervals between February 1999 and September 2000, with sampling also in April 1998. Estuary water levels were monitored continuously.

Results reveal that Vasse estuary and Wonnerup estuary water levels fluctuate dramatically between ≈0.0 mAHD[1] and ≈1.1 mAHD during winter, are stabilised at ≈0.4 mAHD in spring, decline steadily in late spring and early summer and reach minimum levels of −0.1 mAHD and −0.4 mAHD respectively by early autumn.

The beds of the estuaries' broadest expanses have elevations of ≤0.5 mAHD (Vasse) and ≈0.5 mAHD (Wonnerup). Consequently, water depths in these parts — which are also those most utilised by waterbirds — are shallow, fluctuating between ≈1.6m and ≈0.2m in winter and ranging from ≈0.4m to 0.0m by summer's end, when large expanses are dry.

River flows flush both estuaries to fresh (1<3 parts per thousand) or very fresh (<1ppt) in winter and salinities remain low until the end of spring. During summer they rise due to leakage and controlled inflow of seawater through the floodgates, due to evapoconcentration, and perhaps due to saline groundwater discharge. By the end of summer the estuaries are saline throughout and by autumn their middle and upper reaches are hypersaline (≥50ppt). Stratification occurs at the onset of winter when very fresh river inflows overlie remnant saline waters until mixing and full flushing occurs.

This report is limited to presentation of the results of the water level, depth, salinity and temperature monitoring program. Further analysis will be required to examine relationships between these parameters and waterbird species occurrence and abundance.

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[1] metres Australian Height Datum, where 0.0 mAHD is approximately mean (average) sea level.

1. INTRODUCTION

Surveys of waterbird species and numbers on the Vasse-Wonnerup wetlands at Busselton, Western Australia, were undertaken in 1998-2000 (Lane *et al.* 2007) to assess whether the Vasse-Wonnerup Ramsar Site continued to meet the Ramsar Criteria under which it was nominated and listed in 1990 as a 'Wetland of International Importance' (Government of Western Australia 1990, 2000).

Water depth greatly affects the use of wetlands by waterbirds by strongly influencing food supply and accessibility and usefulness for loafing, refuge, moulting, nesting and raising of young. Salinity also has a major influence on use by waterbirds as it affects suitability for drinking, especially by very young birds, and the types of foods, both plant and animal, that may be present (Goodsell 1990, Halse *et al.* 1993, Cale *et al.* (2010).

The water levels, water depths and salinities of Vasse-Wonnerup vary considerably each year. Levels — and therefore depths — are highest and salinities lowest in winter and spring due to flushing by seasonal river flows. During the hot, dry months of summer these flows cease, wetland water levels decline and salinities rise. By late summer and autumn large areas of the two largest components of the system — the Vasse and Wonnerup estuaries — are dry and remnant waters are both very shallow and saline to hypersaline (Lane *et al.* 1997).

Floodgates first-installed on the exit channels of the two estuaries in 1908 were designed to facilitate discharge of river floodwaters and to prevent the incursion of seawater. Since 1988 the Vasse estuary gates have at times been partially-opened to allow fish to escape and to maintain a higher summer-autumn water level than in the preceding eight decades (Lane *et al.* 1997). In recent years the Wonnerup estuary floodgates have also been partially-opened occasionally to release fish.

Operation of the Vasse estuary floodgates can, at times, be contentious, with some calling for more openings and higher summer-autumn water levels and others arguing for the *status quo*, on the basis that such changes could adversely affect waterbird populations or other values, either natural or artificial.

Because changes to estuary water levels could impact upon suitability for waterbirds, a program of extensive hydrological monitoring was undertaken to coincide with, and continue six months beyond, most of the 1998-2000 waterbird surveys. This would enable the species-occurrence and abundance of waterbirds to be related to particular water levels, depths and salinities and would extend current knowledge of Vasse-Wonnerup's hydrology, thereby potentially assisting in its management.

2. PROJECT AIM

The principal aim of this study was to collect data that would enable improved understandings to be developed concerning:

- water level, depth and salinity preferences of waterbirds on Vasse-Wonnerup.
- the hydrology of this internationally-recognised wetland system.

3. STUDY AREA

The study area was the Vasse-Wonnerup wetland system, which extends 14 km in an east-north-easterly direction from the centre of Busselton in south-west Western Australia. Water depth, salinity and temperature-profiling was undertaken on the Vasse estuary (c. 350 ha), Wonnerup estuary (c. 300 ha) and the Deadwater (c.17 ha), and at the north-eastern end of Wonnerup Inlet (c. 10 ha) (Figure 1 and Photos 1-30).

Most attention was focussed on the Vasse and Wonnerup estuaries as these support by far the greatest numbers of waterbirds found within the wetland system[1] and it is management of the water levels of one of

[1] For example, in December 1998, when waterbird numbers peaked, 97% were on these two waterbodies (Lane *et al.* 2007).

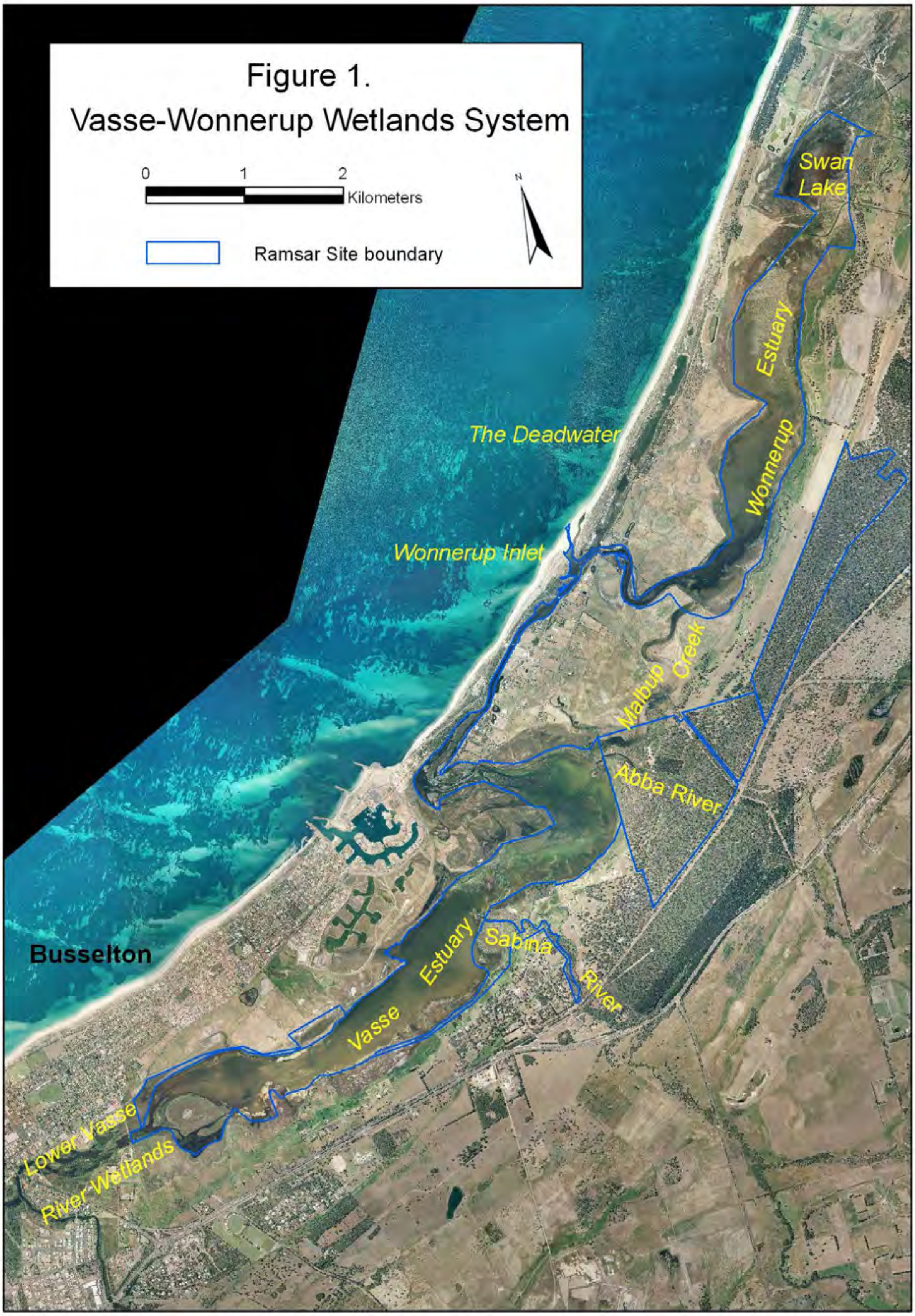

Figure 1. Vasse-Wonnerup wetland system.

these, the Vasse, that is, at times, contentious. Wonnerup Inlet and the Deadwater are far less important for waterbirds and, because they are on the ocean side of the estuaries' floodgates and therefore mostly tidal, there is limited opportunity or concern about managing their levels. Nonetheless, the data collected from the Inlet (which connects the estuaries to the sea) and the Deadwater (a 'blind' lagoon connected to the Inlet) is of value in extending our knowledge of the hydrology of the entire Vasse-Wonnerup wetland system.

4. METHODOLOGIES

Vasse and Wonnerup estuaries were depth, salinity and temperature-profiled monthly from February 1999 to June 1999 and from November 1999 to September 2000, with a limited number of measurements also being made in April 1998 (Figures 4 & 5). The Deadwater and Wonnerup Inlet were profiled in June 1999 and monthly from November 1999 to September 2000 (Figure 6). The precise dates and other details are provided in Appendix 6. Most profiling was undertaken on the same day as the corresponding waterbird survey (Lane *et al.* 1997) or 1-2 days before or after.

Measurements were taken at nine locations ('Sampling Stations') in the Vasse estuary, at one location upstream of Ford Road in the Lower Vasse River Wetlands[1], five in Wonnerup estuary, six in the Deadwater and one at the north-eastern end of Wonnerup Inlet (Figures 2 & 3). The Vasse estuary and Lower Vasse River Wetlands locations were the same as those reported in Appendix 4 of Lane *et al.* (1997).

Locations were found in the field 'by eye' from natural and man-made features, rather than by GPS (Global Positioning System) or location markers. Locations where the waterbodies were narrow could be pin-pointed within a few metres by reference to physical features on or near the shoreline, however locations in the broadest expanses of the two estuaries were re-visited with probable accuracies of only 100-300 metres. While this was not ideal, it is not of concern given the known uniformity of the estuary beds in these parts. An attempt has subsequently been made to determine the approximate coordinates of all locations by GPS and these are presented in Appendix 7.

At each location water depth, salinity and temperature were measured at 0.2m intervals from surface to bottom. The 'surface' and 'bottom' measurements were taken approximately 0.1m below and above respectively, rather than precisely at the surface and bottom.

From February 1999 to November 1999, a 'TPS 90 FLMV Microprocessor Field Analyser' with 'K=10' probe and 5m cable was used to take the depth, salinity and temperature measurements. From December 1999 onwards[2] a 'TPS WP84' meter with 'K=10' probe and 2m cable was used. These instruments were calibrated against a 2ppt (parts per thousand) standard prior to testing of the fresh (1<3ppt) to very fresh (<1ppt)[3] waters at Lower Vasse River Wetlands Station 1 (20m upstream of Ford Road alignment) and 'generally low-salinity waters' elsewhere, and against a 36ppt standard prior to testing 'generally high-salinity waters'.

The April 1998 sampling of Vasse and Wonnerup estuaries was done by the principal author wading to sampling locations and collecting mid-column[4] samples (the water was very shallow) in a small container. The salinities of these and some subsequent backup samples were later determined by J. Busniak and other officers of the Water & Rivers Commission, Bunbury, using a 'Hydrolab Data Sonde 4'.

All other measurements were taken by A. Clarke and all locations were accessed by touring kayak (Photo 41) or, where and when water was too shallow for the kayak, on foot.

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1 This location is geomorphologically part of the Vasse estuary, but hydrologically separate for most of the year. It was also treated as 'not part of Vasse estuary' during the concurrent waterbird surveys. The sampling site was 'at a stick approx 20m from (west of) alignment of Ford Rd – in the excavated channel'.

2 Except on Wonnerup estuary and the Deadwater in March 2000, when a 'WTW' meter borrowed from GeoCatch was used because of temporary calibration difficulties with the 'TPS'.

3 In this report the salinity categories very fresh (<1ppt), fresh (1<3ppt), brackish (3<10ppt), saline (10<50ppt) and hypersaline (≥50ppt) are used, as in Lane *et al.* (2011).

4 The term 'column' is used in wetland and other hydrological literature to indicate an imaginary vertical column of water extending from water surface to bottom. It has no fixed diameter.

Figure 2. Vasse estuary (9) and Lower Vasse River Wetlands (1) sampling locations in 1998-2000.

Figure 3. Wonnerup estuary (5), Wonnerup Inlet (1) and Deadwater (6) sampling locations in 1998-2000.

Immediately before and or after the profiling of each waterbody, the surface water level at the downstream end of that waterbody was determined by taking a visual reading from the appropriate Water Corporation (to mid 1998) or Water & Rivers Commission (mid 1998 onwards) estuary floodgate gauge board (Photos 37 & 38). From mid 1998[1] until 2004[2] there were four sets of Water & Rivers Commission gauge boards, one on the upstream side and one on the downstream side of each of the two sets of floodgates.

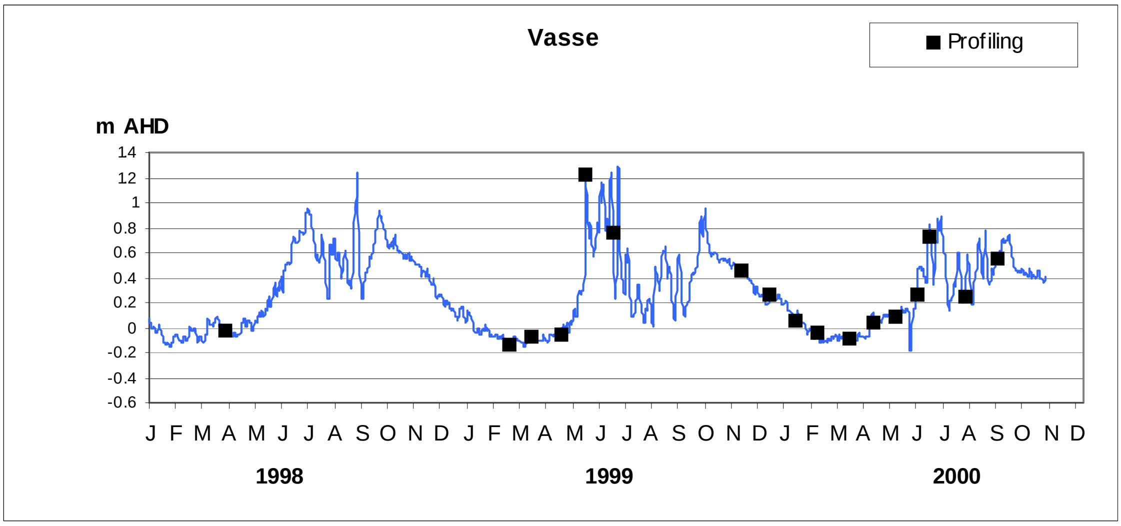

Figure 4. Vasse estuary water levels[3] and profiling dates during 1998-2000. The black squares indicate the dates and water levels at which profiling was undertaken. Note that the period of 27-29 May 1999, during which waterbird surveys, profiling and inundation mapping were conducted, was a period of heavy rain, strong river flow and rapidly rising water levels in the Vasse and Wonnerup estuaries (see Appendix 18).

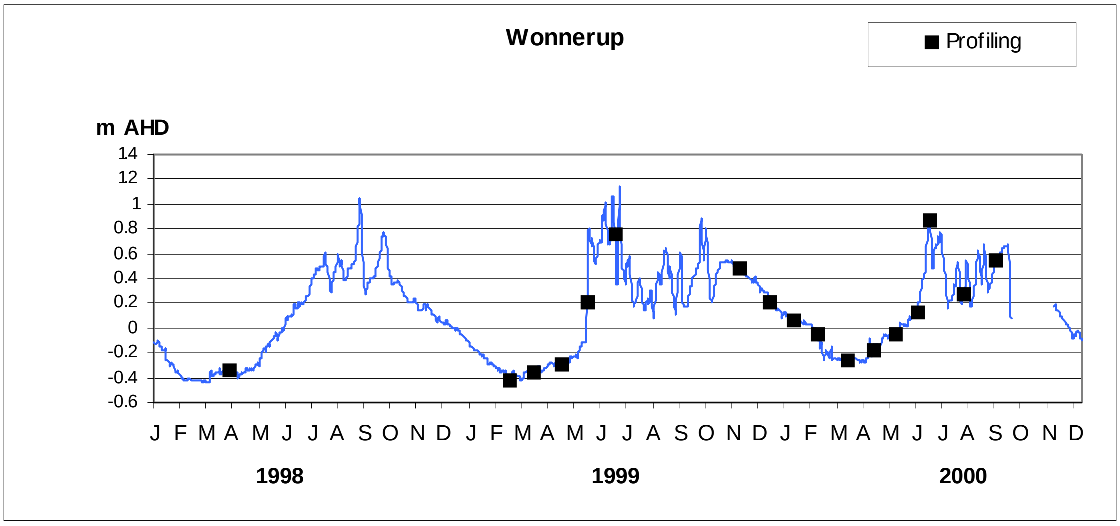

Figure 5. Wonnerup estuary water levels[3] and profiling dates during 1998-2000. The black squares indicate the dates and water levels at which profiling was undertaken.

The upstream gauges measured the water levels in the estuaries and the downstream gauges measured the water level in Wonnerup Inlet and, when water levels were static (see Section 6.2.2), to infer the levels in

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1 The Water & Rivers Commission gauges were installed some time between 19 June and 01 October 1998 (dates inclusive) and replaced the Water Corporation gauges (reference J.Lane's field notebook).

2 The Water & Rivers Commission floodgate gauges were replaced by Water Corporation gauges when the entire Vasse estuary and Wonnerup estuary floodgate structures were replaced by the Water Corporation in 2004.

3 In metres AHD (Australian Height Datum), where 0.00 mAHD is approximately mean sea level. One water level trace is shown in each Figure. This is the daily average level (there being no significant tidal variation in the estuaries) and is from continuous recorders maintained by the authors. Note that the downward spike in Vasse estuary water level in early June 2000 is spurious

the Deadwater. Levels were recorded as corrected[1] height above or below Australian Height Datum (AHD), which is a standardised and official approximation of mean sea level on the Australian coast.

Water levels in the Vasse and Wonnerup estuaries (Figures 4 & 5) were also recorded on a continuous basis using automated 'loggers' that were originally installed by G.B. Pearson of the Department of Conservation & Land Management (now Department of Environment & Conservation) on behalf of the principal author in 1994.

Water levels in Wonnerup Inlet (Figure 6) were recorded on a semi-continuous basis by an automatic recording station (see last paragraph of this Section for more detail) operated by the Water & Rivers Commission at the Vasse estuary floodgates.

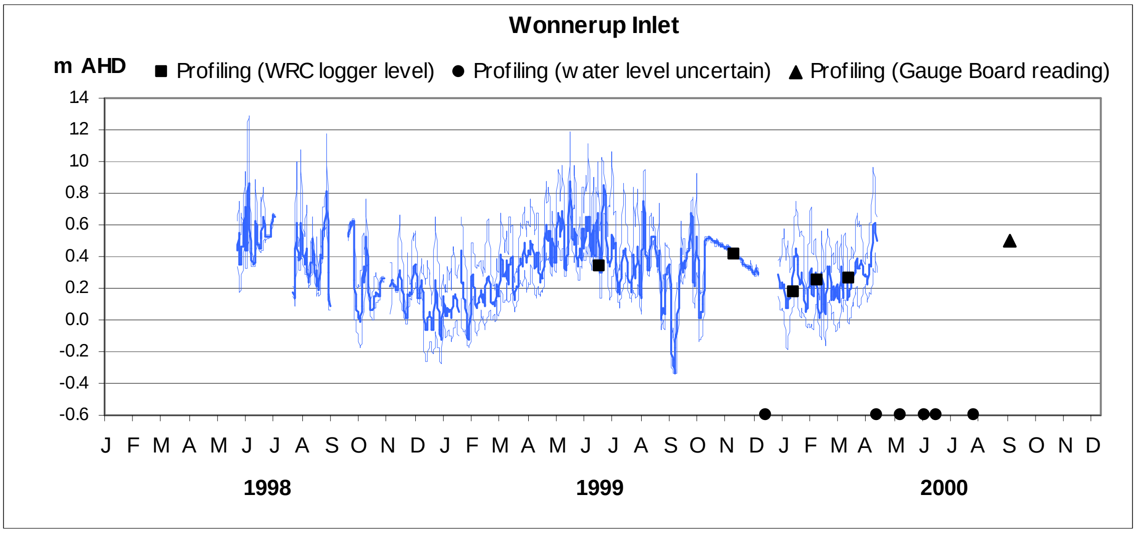

Figure 6. Wonnerup Inlet water levels and Wonnerup Inlet - Deadwater profiling dates during 1998-2000. Three water level traces (WRC logger data) are shown: daily maximum, daily average and daily minimum[2]. The black squares and black triangle indicate the dates and water levels (WRC logger data) at which profiling at the north-eastern end of Wonnerup Inlet and in the Deadwater was undertaken. Water levels are uncertain or unknown on the dates indicated by black circles. Note that the sand bar at the mouth of Wonnerup Inlet was closed from 22 October until 24 December 1999, hence the lack of daily tidal variation apparent at other times.

During the course of either surveying the waterbirds (Lane *et al.* 2007) or profiling the water column of each waterbody, the position of the water's edge within that waterbody was estimated by eye and marked on a map. This was done[3] so that a simple model relating water levels to extents of inundation could be developed for each waterbody.

Data was also being collected by other agencies during the course of this project. Officers from the Water & Rivers Commission (now Department of Water) in Bunbury were monitoring water quality, including phytoplankton abundance and species composition, in the lower reaches of the Vasse and Wonnerup estuaries and in Wonnerup Inlet (Paice 2001). An automatic recording station installed by Water & Rivers Commission[4] at the Vasse estuary floodgates recorded upstream (Vasse estuary) and downstream (Wonnerup Inlet) water levels and water temperature and upstream dissolved oxygen concentrations from April / May 1998 onwards and these data were accessible on the 'world wide web' from January 2001 onwards. Use has been made of WRC's Wonnerup Inlet continuous water level recordings ('WRC logger data') in this report.

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1 Small corrections were needed for each of these gauges.

2 The unusually low water levels of 17-20 September 1999 in Figure 6 are unverified and thought to be incorrect. Unfortunately, there are no gauge board readings or nearby tidal records for this period. Tide recordings at nearby Port Geographe Marina did not begin until 12 June 2002 (source: WA Department of Transport 02 March 2010).

3 In most waterbird survey and or profiling months, but not all, see Appendix 6.

4 This recording station was replaced by Water Corporation recording equipment and telemetry in 2004.

5. SAND BAR, STOPBOARDS AND GATE OPENINGS

The status (open or closed) of the sand bar at the mouth of Wonnerup Inlet (Photo 24) has a substantial effect on the hydrology of the Inlet and the Deadwater (both of which are tidal when the sand bar is open) and also impacts to some extent on the hydrology of the two estuaries, notwithstanding the presence of the floodgates. The history of management of the sand bar, and the Water Corporation's current operational guidelines for both the floodgates and the sand bar, have previously been described (Lane *et al.* 1997).

In 1998-2000 the sand bar was artificially opened (Photo 39) by the Water Corporation on 02 January 1998, 17 December 1998 and 24 December 1999 and in each case the bar remained open until at least mid to late June of the following winter (Table 1). The bar was artificially closed (Photo 40) on 22 October 1999 in order to maintain a required water level in Wonnerup estuary after damage to the floodgates had resulted in floodgate 'stopboards' (see footnote below) being swept away. All dates on which the bar was inspected during this project — and the status of the bar on each occasion — are provided in Appendix 8.

Table 1. Dates of opening and closing of the sand bar at the mouth of Wonnerup Inlet during 1997-2000.

1997-98		**1998-99**		**1999-2000**		
Opened[A]	**Closed[N]**	**Opened[A]**	**Closed[N]**	**Closed[A]**	**Opened[A]**	**Closed[N]**
02 Jan 98	>18 Jun 98	17 Dec 98	>30 Jun 99	22 Oct 99	24 Dec 99	>24 Jun 00

[A] = artificially [N] = naturally > indicates after the given date.

The hydrologies of the two estuaries and, to a lesser extent, Wonnerup Inlet and the Deadwater, were also affected by Water Corporation's installation of floodgate stopboards[1] in spring of each year, their removal in late autumn or early winter of each year and by partial openings of the floodgates each summer-autumn[2] (Photos 33-35). Summary details of installations, removals and openings during the study period are presented in Table 2. Some dates are not known precisely.

Table 2. Dates of stopboard installations and removals and partial floodgate openings during 1997-2000.

	Vasse estuary floodgates			**Wonnerup estuary floodgates**		
Year	**1997-98**	**1998-99**	**1999-00**	**1997-98**	**1998-99**	**1999-00**
Date of installation of stopboards	>01 Aug 97 <10 Oct 97	<02 Oct 98	29 Sep 99	>21 Jul 97 <10 Oct 97	<02 Oct 98	29 Sep 99
Date of removal of stopboards	>26 May 98 <02 Jun 98	27 May 99	15 Jun 00	>26 May 98 <02 Jun 98	27 May 99	15 Jun 00
Date of first partial opening of a gate	18 Jan 98	24 Dec 98	3 Feb 00	18 Jan 98	23 Dec 98	03 Feb 00
Date of last closing of a gate	11 Mar 98	15 Mar 99	15 Feb 00	27 Jan 98	03 Mar 99	25 Feb 00
No. of openings	3	2	2	2	8	3
Longest opening	34 days	79 days	<1 day	hours	hours	hours
Shortest opening	1 day	1 day	<1 day	hours	hours	mins
Total duration of openings	39 days	80 days	<1 day?	hours	hours	hours

> indicates after < indicates before or less than.

Further details (at 1-2 day intervals) of gate and reverse flap gate[3] openings, fish activity, fish releases, bird activity near the floodgates and other relevant observations from 16 December 1998 to 15 April 1999

[1] 'Stopboards' were wooden planks, approximately 8 inches high, 3 inches thick and 6 feet long (20 x 8 x 180cm), that were installed, one on top of the other, with their ends into vertical grooves on either side of each floodgate opening or 'bay', so as to raise the level at which water began flowing through that opening.

[2] Some stopboards were also removed during summer-autumn (e.g. on 18Jan1998) to enable fish to pass and water to flow in either direction when individual gates (usually one) were opened for these purposes.

[3] A single experimental 'reverse flap gate' was first-installed in the Vasse estuary floodgate structure on 23 Jan 1998 and was used occasionally (when the estuary water level was below the target level) in summer-autumn to allow inflow while preventing outflow.

can be found in White (1999). Observations from the same period in 1999-2000 can be found in Elscot (2000a,b). Some of these data are also presented in graphical form in Appendix 17 of this report.

The heights at which the stopboards are installed in both sets of floodgates each spring[1] determine the water levels of the two estuaries very soon afterwards and also influence water levels in subsequent months as cessation of river flows and increasing evaporation rates cause their gradual decline. For this reason the height (i.e. the level of the upper edge) of each stopboard was ascertained by precise measurement in February / April 1998 and May 2000. Stopboard heights were not directly measured in 1998-99 but can be estimated within a range. Mean heights and ranges are presented in Table 3 and individual stopboard heights are presented in Appendix 9.

Table 3. Floodgate stopboard heights during 1997-2000.

	Floodgate stopboard heights (mean and range in mAHD)		
	1997-98	**1998-99[2]**	**1999-00**
Vasse estuary	0.47 (0.41-0.59)	0.48 (0.32-0.63)	0.46 (0.40-0.54)
Wonnerup estuary	0.38 (0.36-0.41)	0.46 (0.32-0.60)	0.39 (0.36-0.44)

Note that it is the height of the lowest board that determines the cease-to-flow level at each set of floodgates each year. For example, in 1997-98, following installation of the stopboards, the cease-to-flow level at the Vasse estuary floodgates was 0.41 mAHD.

6. RESULTS

Summary results of all water depth, salinity and temperature-profiling conducted as part of the formal monitoring program are presented below, together with mapped extents of inundation and salinities and calculated longitudinal depth profiles. Some additional, unrelated profiling of the Vasse and Wonnerup estuaries' exit channels was undertaken by the principal author and various staff of the Water & Rivers Commission, Bunbury, during 1998-2000. Results of that work are presented separately in Appendix 10.

6.1 Water Depths and Water Levels

In this section, some emphasis is placed on the floodgate gauge board readings and the hand-measured water depths at the various Sampling Stations in each waterbody as these are the water level and water depth data that relate most-directly to the waterbird survey data of 1998-2000. Readers are urged to refer to Appendix 1 for an overview of the data on which this section is based.

6.1.1 Vasse estuary

The greatest[3] hand-measured water depth in the Vasse estuary during the course of the project was 2.30m at Station 1 in July 2000 (Table 4 and Appendix 1). The estuary water level (gauge board reading) at this time was 0.73 mAHD, which was 0.56m lower than the 'Absolute Highest' daily average water level of 1.29 mAHD (Table 4 & Figure 4), indicating that the maximum depth actually reached at Station 1 during 1998-2000 was 2.86m (2.30 + 0.56m).

The smallest[3] hand-measured depth recorded was 0.00m (i.e. dry) at Station 9 in April 1998 and Stations 8 and 9 in February 1999, March 1999 and March 2000. The estuary water levels at these times were −0.05, −0.10, −0.08 and −0.07 mAHD respectively. The 'Absolute Lowest' estuary summer-autumn water level (Figure 4) was −0.15 mAHD.

[1] The stopboards are installed before the rivers that discharge into the estuaries cease to flow, usually in late spring. After installation, estuary water levels rise until the upper edges of one or more stopboards are overtopped and 'excess' water flows into (the usually tidal) Wonnerup Inlet.

[2] 1998-99 stopboard heights are approximations. See Appendix 9 for a full explanation.

[3] The words 'greatest' and 'smallest' have been used deliberately in order to distinguish between these hand-measured depths and calculated maximum and minimum depths.

Table 4. Vasse estuary seasonal water levels and water depths during 1998-2000. See text of section 6.1.1 for calculation of maximum water depth (2.86m at Station 1).

	Absolute Lowest & Highest water levels (continuous recorder) (mAHD)[a]	Lowest & Highest measured water levels (gauge board readings) (mAHD)[b]	Greatest hand-measured water depths (m)[c]	Smallest hand-measured water depths (m)[d]
Winter	≈0.05 & 1.29	0.29 & 0.73	2.30 at Stn 1 (Jul 00)	0.28 at Stn 8 (Aug 00)
Spring	0.06 & 1.25	0.47 & 0.50	1.43 at Stn 1 (Nov 99)	0.50 at Stn 8 (Nov 99)
Summer	−0.14 & 0.43	−0.10 & 0.29	1.50 at Stn 1 (Dec 99)	Dry at Stns 8-9 (Feb 99)
Autumn	−0.15 & 1.24	−0.08 & 0.53	1.75 at Stn 1 (May 00)	Dry at Stns 9 (Apr 98), 8-9 (Mar 99, 00)

a = lowest daily av. and highest daily av. in all winters (Jun-Aug), springs etc. of 1998-00 using CALM logger (continuous recorder) data.
b = lowest corrected floodgates gauge board reading and highest corrected floodgates gauge board reading (readings by CALM) on day of profiling (same data as 'water level' columns of Appendix 1) in all winters, springs etc. of 1998-00.
c = greatest depth measured by profiler (AC/JL) at any Station in all winters, springs etc. of 1998-00.
d = smallest depth measured by profiler (AC/JL) at any Station in all winters, springs etc. of 1998-00.

6.1.2 Wonnerup estuary

The greatest hand-measured water depth in Wonnerup estuary during the course of the project was 1.40m at Station 1 in July and Sept 2000 (Table 5 and Appendix 1). The estuary water levels (gauge board readings) at these times were 0.74 and 0.52 mAHD respectively, which were 0.40m and 0.62m lower respectively than the 'Absolute Highest' daily average water level of 1.14 mAHD (Table 5 & Figure 5), indicating that the maximum depth actually reached at Station 1 during 1998-2000 was 2.02m (1.40m + 0.62m).

Table 5. Wonnerup estuary seasonal water levels and water depths during 1998-2000. See text of section 6.1.2 for calculation of maximum water depth (2.02m at Station 1).

	Absolute Lowest & Highest water levels (continuous recorder) (mAHD)[a]	Lowest & Highest measured water levels (gauge board readings) (mAHD)[b]	Greatest hand-measured water depths (m)[c]	Smallest hand-measured water depths (m)[d]
Winter	−0.03 & 1.14	0.23 & 0.74	1.40 at Stn 1 (Jul 00)	0.70 at Stns 3,5 (Jun 00)
Spring	0.07 & 1.04	0.46 & 0.52	1.40 at Stn 1 (Sep 00)	0.80 at Stn 5 (Nov 99)
Summer	−0.43 & 0.42	−0.41 & 0.24	1.20 at Stn 1 (Dec 99)	0.17 at Stns 4,5 (Feb 99)
Autumn	−0.44 & 0.80	−0.40 & 0.10	1.07 at Stn 1 (May 99)	0.09 at Stn 4 (Apr 98)

a, b, c, d explanations are the same as those of Table 4.

The smallest hand-measured depth recorded in Wonnerup estuary was 0.09m at Station 4 in April 1998. The estuary water level (gauge board reading) at this time was −0.36 mAHD. The 'Absolute Lowest' estuary water level was −0.44 mAHD (Figure 5), suggesting that Station 4 would have been only 0.01m (0.09m − 0.08m) deep at that time and the basin in which it is situated (i.e. the central basin) would have been almost entirely dry. Note that, at the time of the waterbird survey and inundation mapping in February 1998 (when no profiling was undertaken), the north-eastern basin *was* dry (Figure 10a).

6.1.3 The Deadwater

The greatest hand-measured water depth in the Deadwater during the course of the project was 2.00m at Stations 3, 5 and 6 in July 2000 (Table 6 and Appendix 1). The Deadwater water level at this time, and the 'Absolute Highest' daily average water level, are unknown, so the maximum depth reached at these Stations during 1998-2000 cannot be calculated.

The smallest hand-measured depth recorded was 0.60m at Station 1 in January 2000 and April 2000. The Deadwater water levels at these times, and the "Absolute Lowest' water level, are unknown, so the minimum depth reached at this Station during 1998-2000 cannot be calculated.

Table 6. Deadwater seasonal water levels and water depths during 1998-2000.

	Greatest hand-measured water depths (m)[a]	Smallest hand-measured water depths (m)[b]
Winter	2.00 at Stns 3, 5-6 (Jul 00)	0.70 at Stn 1 (Jun 99)
Spring	1.73 at Stn 5 (Nov 99)	0.90 at Stn 1 (Nov 99)
Summer	1.70 at Stn 6 (Feb 00)	0.60 at Stn 1 (Jan 00)
Autumn	1.60 at Stn 2 (Mar 00), Stn 5 (May 00)	0.60 at Stn 1 (Apr 00)

a = greatest depth measured by profiler (AC) at any Station in all winters, springs etc. of 1998-00.
b = smallest depth measured by profiler (AC) at any Station in all winters, springs etc. of 1998-00.

6.1.4 *Wonnerup Inlet*

The single Sampling Station of Wonnerup Inlet was located at the north-eastern end of the Inlet, close to the Wonnerup estuary floodgates and the mouth of the Deadwater. Depths recorded here are not considered representative of the entire Inlet, however a brief account of results is warranted.

The greatest hand-measured water depth at the single site during the course of the project was 2.0+m in December 1999 (Appendix 1). The Wonnerup Inlet water level at this time is unknown, so the maximum depth reached at this Station during 1998-2000 cannot be calculated.

The smallest hand-measured depth recorded was 1.00m in January 2000. The water level at this time (0845hrs) was 0.14 mAHD (calculated from Water & Rivers Commission logger data), which was 0.24m higher than the 'Absolute Lowest' daily average Wonnerup Inlet water level during 1998-2000 of approximately −0.10 mAHD (Figure 6), suggesting that the minimum depth at Station 1 during 1998-2000 was ≈0.76m (1.00 − 0.24m).

The gradual rise of ≈0.5m in daily maximum, mean and minimum water levels in Wonnerup Inlet from January 1999 to May 1999 (Figure 6) is noteworthy and presumably reflects a seasonal rise in local mean sea level.

6.1.5 *Lower Vasse River Wetlands*

The single Sampling Station in the Lower Vasse River Wetlands (LVRW; from Ford Road alignment to the check structure (Photo 42) near the Butter Factory Folk Museum) was located in the excavated channel at the eastern (downstream) end of these wetlands, c. 20m upstream of the Ford Road alignment. These wetlands (Photos 1 & 25) fill and discharge into Vasse estuary during periods (usually winter and early spring) of flow in the lower, undiverted section of the Vasse River. The LVRW is connected to the Vasse estuary as one waterbody during most of winter and spring. Significantly, it is not connected to the Vasse estuary during most of summer and autumn, when the estuary water level is lower and its salinity much higher.

The greatest hand-measured water depth at Station 1 during the course of the project was 0.90m in May 1999 (Appendix 1). The Vasse estuary was flooding at this time and the two waterbodies were connected. The Vasse estuary gauge board reading was 0.53 mAHD but the logger reading was ≈1.3 mAHD (see Appendix 18), which approximated the highest level reached during 1998-2000 (Table 4 & Figure 4). The maximum depth reached at Station 1 during 1998-2000 was therefore ≈0.9m.

The smallest hand-measured depth recorded at Station 1 was 0.25m in February 2000. The Vasse estuary water level (gauge board reading) at this time was −0.02 mAHD and the two waterbodies were not connected. Station 1 was also unconnected, and therefore unaffected, when Vasse estuary reached its "Absolute Lowest' summer-autumn water level of −0.15 mAHD (Figure 4).

Depths recorded at Station 1 are not considered representative of the entire LVRW, large parts of which are known to dry in summer-autumn. Since the 1998-2000 study, a continuous water level recorder has been installed (initially by G.B Pearson; replacement by A. Clarke and Y. Winchcombe) at the western end of LVRW, on the downstream side of the check structure in the main channel of the Vasse River, and the bathymetry of the LVRW has been mapped in detail (supervised and assisted by A. Clarke).

6.2 Longitudinal depth profiles

6.2.1 Vasse and Wonnerup estuaries

Approximate longitudinal depth profiles of the Vasse and Wonnerup estuaries can be derived from the depth and water level data reported in section 6.1 by subtracting water levels (mAHD) from water depths (m) to obtain bed levels in mAHD. The resulting profiles are presented in Figures 7 and 8 and the detailed calculations are in Appendix 11.

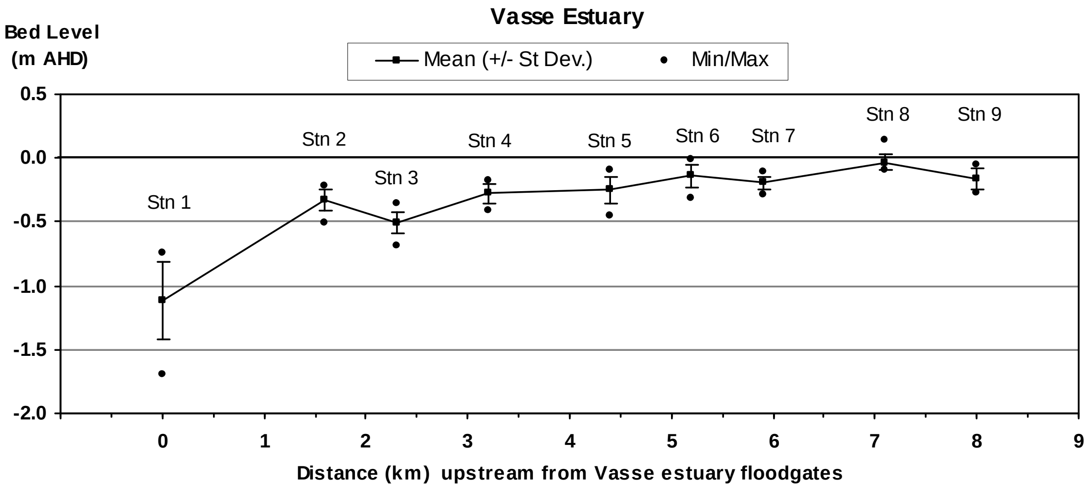

Figure 7. Approximate longitudinal depth profile of Vasse estuary.

It is emphasised that these are *approximate* depth profiles as most were measured from an unstable, wind and wave-affected 'platform' (kayak), with a handheld tape marked at 0.1m increments. Accuracy would also have been impaired at times by wind-induced tilting of water surfaces. Additionally, the number of measuring locations was low in comparison with the length of the waterbodies and some shallow points (see Photos 4 and 19 for examples) between major basins in each estuary were missed.

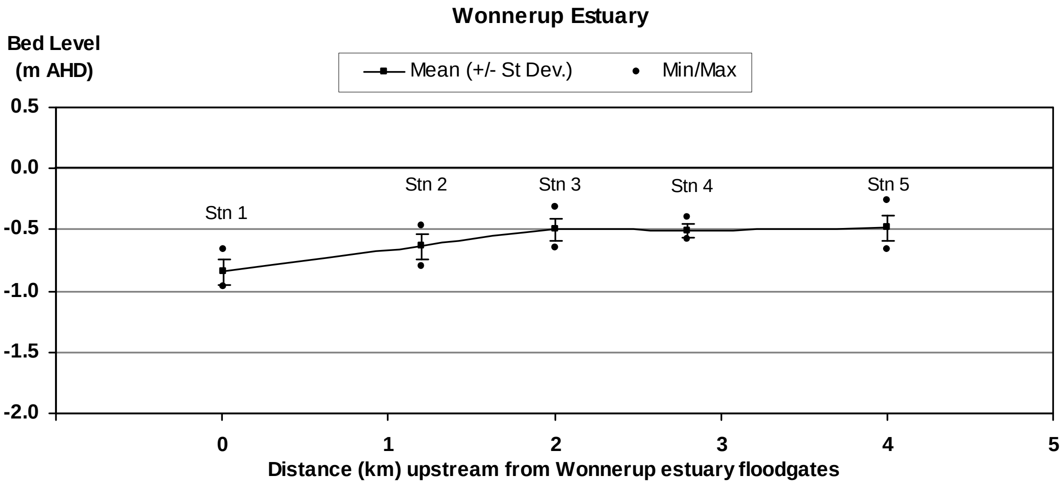

Figure 8. Approximate longitudinal depth profile of Wonnerup estuary.

Longitudinal depth profiling was not a specific objective of the hydrological monitoring project and more-accurate profiles could be derived from the detailed bathymetric mapping that has since been undertaken. Nonetheless, it is still considered useful to present the results of this early work. Comparison of the outputs of the two techniques could prove informative and guide further work.

The deepest of all sampling stations in the Vasse estuary was in the exit channel, immediately upstream of the floodgates. Here the bed depth averaged −1.12 mAHD. The range and standard deviation were large, due partly to the uneven nature of the bed at this location, but also to the difficulty experienced in determining the level at which the water column ended and the bed began at this site of deep, soft muds. Upstream from Vasse estuary Station 1 the bed became progressively shallower, ranging from −0.33 mAHD at Station 2 and −0.28 mAHD at Station 4 to −0.04 mAHD at Station 8. Station 3 was deeper (−0.51 mAHD) than the others, due perhaps to the estuary being narrower and flow rates possibly higher at this location.

The average bed depth at Wonnerup estuary Station 1, immediately upstream of the Wonnerup estuary floodgates, was −0.85 mAHD. Upstream from this station the bed progressively shallowed. It was −0.64 mAHD at the upstream end of the exit channel (Station 2) and at the far end of the south-western basin (i.e. at Station 3) was −0.50 mAHD. The bed levels in the middle of the central and north-eastern basins were −0.51 and −0.48 mAHD respectively. The bed level at the narrow point (Photo 19) separating these last two basins was not determined but is known to be shallower.

6.2.2 The Deadwater

Water levels in the Deadwater were not measured directly during this project and therefore need to be inferred from recordings of water levels in Wonnerup Inlet. This is problematic as the Deadwater is long and narrow with several tight constrictions. It is also very shallow in parts, particularly near its connection with the Inlet. These physical features impede tidal flows into and out of the Deadwater and, it is surmised, frequently result in significant differences in water levels between upper, middle and lower reaches of the Deadwater and between these and the Inlet. For this reason, the only depth data that is considered suitable for attempting to construct a longitudinal depth profile of the Deadwater is that which was collected at times when the sand bar at the mouth of the Inlet was closed and thus preventing tidal fluctuations in the water level of the Inlet.

Gauge board readings and other records indicate that the above was the case on 24 November 1999 and 21 September 2000. On these dates the water levels in the Inlet were 0.41 and 0.50 mAHD respectively. and measured depths in the Deadwater ranged 0.9-1.7m and 1.0-1.6m respectively. From the data collected on these dates it may be deduced (see Appendix 11 for the calculations) that the bed levels at the Deadwater sampling stations ranged from −0.5 mAHD to −1.2 mAHD, with the highest bed level (−0.5 mAHD) being at the entrance to the Deadwater, the lowest bed level (−1.2 mAHD) being in the uppermost reaches, and bed levels of −0.9 mAHD to −1.1 mAHD being encountered in between.

Because there are known to be several shallower sections between these sampling stations, it would be potentially misleading to draw a longitudinal profile of the Deadwater based solely on the project data. This has therefore not been done.

Some additional information relating to the wetlands' depth profiles, bathymetry and hydrology was collected *ad hoc* by the principal author between 1997 and 2000. This is presented in Appendix 12.

6.3 Extent of Inundation

The extents of inundation of the Vasse and Wonnerup estuaries within 0-3[1] days of profiling events and or waterbird surveys (Lane *et al.* 2007) are shown in Figures 9 and 10, together with the estuaries' water levels[2] at those times.

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[1] See Appendix 6 for dates of each activity.

[2] These are floodgate gauge board readings in all cases except Vasse estuary on 25Mar98 & 27May99 and Wonnerup estuary on 26Mar98 & 29May99, when CALM logger data were used instead, due to the lack (in Mar98) of appropriate gauge board readings or (in May 1999) the inappropriateness of gauge board readings due to early flood conditions (see Appendix 18 for explanation).

Within each Figure, the maps are arranged in order of increasing estuary water level (rather than chronologically), as measured at the floodgates located on each estuary's exit channel.

It will be noticed that while, as a general rule, the mapped extent of inundation increases with increasing water levels, there are some variations on this. These variations (e.g. 9f to 9h and 10a to 10b) may be due to one or a combination of factors such as the 'tilting' effect of moderate to strong winds on the water surface (noting that the water level was measured only at the downstream end of each estuary); the effects of rain and river flows (which can, for example put water into partially-isolated upstream basins or pools), 'seiching' (tide-like water level oscillations within the estuaries) and mapping imprecision (the extent of inundation was determined on each occasion 'by eye' and involved some estimation, often at a distance from the water's edge). Mapping was least-precise when water levels were high and adjoining marshes, pools and pastures were flooded. Some estimated extents of inundation at these levels have therefore not been presented.

In 2008-09, the bathymetry of the Vasse-Wonnerup wetlands and adjoining floodplain was mapped in detail by licensed surveyors with logistic support, guidance and assistance provided by A. Clarke. A set of maps with contours at all 0.2 mAHD intervals and some 0.1 mAHD intervals has been produced. The authors propose to use these bathymetric maps to prepare maps showing theoretical extents of inundation at a variety of water levels. While these 'theoretical maps' will be more accurate than the 'actual maps' of Figures 9 and 10, and will certainly cover a wider range of possible water levels (from −0.5 mAHD to 2.0 mAHD and above), the 'actual maps' will aid in their interpretation, for example by showing the behaviour (in terms of water depth and extent of inundation) of basins that become disconnected at low estuary water levels.

6.3.1 Vasse estuary

When the water level in Vasse estuary was low (−0.10 to −0.08 mAHD), surface water was largely confined to the lower reaches of the estuary, from the floodgates to the Sabina River delta (Figures 9a-c). In the middle reaches upstream of the Sabina River delta the area of inundation was limited to a narrow zone on the northern (ocean) side of the estuary. Remaining parts of the middle reaches, and all of the upper reaches, were dry.

At water levels of −0.05 to 0.02 mAHD (Figures 9d-h), the upper reaches were at times (late summer to early autumn, thus 25Mar98, 01Apr98, 27Apr99) dry and at other times (22Feb00, 29Apr00) partially inundated. Unseasonal rains, wind-induced tilting or declining evaporation rates might account for this variability.

The upper reaches were not consistently inundated until water levels of 0.12 mAHD (Figure 9i) and above. At 0.12 mAHD almost all bare areas of the estuary bed were inundated; only very narrow strips along sections of shoreline and a small area at the far western end of the estuary remained exposed.

At 0.27 to 0.29 mAHD (Figures 9j-k) several pools in the large samphire marsh area opposite the mouth of the Abba River and all of the estuary bed at the far western end became inundated.

At the much higher level of ≈1.3 mAHD (Figure 9l), the entire estuary and adjoining floodplain, comprising samphires, sedges, remnant melaleucas and privately-owned paddocks of introduced pasture grasses, were extensively flooded (see Photos 25-29 for the extent of flooding under similar conditions in July 1995).

As a matter of interest, in the lowest reaches of the Vasse estuary there is a small bay opposite Estuary View Drive (Photo 10). When the estuary water level is low, many small mounds made by 'tube worms' of the polychaete family Serpulidae are revealed. In the summer preceding the present study, these mounds were first-exposed at a water level of c. 0.10 mAHD. Because of the curious nature of these mounds, the opportunity is taken in Appendix 13 of this report to present some detail concerning them.

Figure 9a. -0.10 mAHD, 26 February 1999

Figure 9b. -0.08 mAHD, 25 February 1998

Figure 9c. -0.08 mAHD, 29 March 2000

Figure 9d. -0.05 mAHD, 1 April 1998

Figure 9e. -0.05 mAHD, 27 April 1999

Figure 9f. 0.00 mAHD, 22 February 2000

Figure 9g. +0.01 mAHD, 29 April 2000

Figure 9h. +0.02 mAHD, 25 March 1998

Figure 9i. +0.12 mAHD, 25 January 2000

Figure 9j. +0.27 mAHD, 29 December, 1999

Figure 9k. +0.29 mAHD, 14 August, 2000

Figure 9l. Approx. 1.3 mAHD, 27 May 1999

6.3.2 *Wonnerup estuary*

When the water level in Wonnerup estuary was low (−0.41 mAHD), about half the width of the central basin was inundated (Figures 10a-b) and a narrow channel of water extended to the central basin from the floodgates (Photo 13), along the centreline of the estuary's exit channel (Photos 13 & 14) and across the dry south-western basin (Photos 14 & 15). On one occasion (26Feb98) the north-eastern basin was dry, but on another (25Feb99) it was partially-inundated though disconnected from the central basin. Similar to the uppermost reaches of the Vasse estuary, the north-eastern basin of the Wonnerup behaves somewhat independently of the lower basins when it becomes disconnected at low water levels.

At −0.36 mAHD (Figure 10c), the waters of the central basin connected to the area of partial inundation in the north-eastern basin. Water in the south-western basin remained confined to a narrow channel.

At −0.34 to −0.30 mAHD (Figures 10d-e) the extent of inundation in the central and north-eastern basins increased and the south-western basin became ≈50% inundated.

The extent of inundation of the three basins further increased at higher water levels (Figures 10f-i) until at 0.12 mAHD the bed of the south-western basin was almost fully-covered and its waters became connected to those of the eastern arm of Malbup Creek.

At 0.23 to 0.24 mAHD (Figures 10j-k) all of the bed and some fringing vegetation (rushes and samphires) of the estuary was inundated.

When the water level reached ≈0.8 mAHD (Figure 10l), the bed and fringing vegetation of all three basins plus the network of channels at the estuary's south-western end were extensively inundated.

Figure 10a. -0.41 mAHD, 26 February 1998

Figure 10b. -0.41 mAHD, 25 February 1999

Figure 10c. -0.36 mAHD, 1 April 1998

Figure 10d. -0.34 mAHD, 26 March 1998

Figure 10e. -0.30 mAHD, 28 April 1999

Figure 10f. -0.10 mAHD, 30 March 2000

Figure 10g. -0.06 mAHD, 23 February 2000

Figure 10h. -0.05 mAHD, 29 April 2000

Figure 10i. +0.12 mAHD, 27 January 2000

Figure 10j. +0.23 mAHD, 20 June 2000

Figure 10k. +0.24 mAHD, 29 December 1999

Figure 10l. Approx. 0.8 mAHD, 29 May 1999

6.4 Salinity

Readers are urged to refer to Appendix 2 for an overview of the data on which the following section is based.

6.4.1 Vasse estuary

The highest measured surface salinity in the Vasse estuary during the course of the project (note that in 1998 measurements were made on only one occasion) was 95ppt at Station 9 in April 1999 (Table 7). The water level at this time was −0.05 mAHD and the water depth at the Station was 0.03m.

The lowest surface salinity recorded was 0.4ppt at Stations 2, 8 and 9 in June 1999 and Station 9 in September 2000. The water levels (gauge board readings) at these times were 0.56m and 0.50m respectively and the water depths at the Stations were 0.92, 0.61, 0.84 and 0.77m respectively.

Table 7. Vasse estuary seasonal salinities during 1998-2000.

	Maximum surface salinity (ppt)	Minimum surface salinity (ppt)
Winter	23 at Stn 2 (Jun 00)	0.4 at Stns 2,8,9 (Jun 99)
Spring	3 at Stn 5 (Nov 99)	0.4 at Stn 9 (Sep 00)
Summer	90 at Stn 7 (Feb 99)	4 at Stns 5-8 (Dec 99)
Autumn	95 at Stn 9 (Apr 99)	2 at Stn 9 (May 99)

It can be seen from Table 7 that the salinities of Vasse estuary are not well-described by seasonal maxima and minima alone, due to the considerable variability within all seasons except spring. A textual approach, read in conjunction with Appendix 2, is more revealing. Thus:

- From February to April 1999 salinities increased from lower to upper reaches of the estuary, probably due to higher rates of salt concentration (due to evaporation) in the shallower upper reaches. The lower reaches were saline, while the middle and upper reaches were hypersaline (≥50ppt) throughout.
- In May 1999, at the onset of flooding (see Appendix 18), the horizontal salinity gradient was broken down and salinities were reduced by the onset of heavy rains and strong river flows.
- In June and November 1999 (and probably all intervening months) there was no significant horizontal gradient and salinities were low [very fresh (<1ppt) in June and fresh (<3ppt) in November] due to the flushing effect of winter rains and river flows and high water levels persisting in late spring.
- From December 1999 to February 2000 there was a gradient of higher to lower salinities from lower to upper reaches, probably due to leakage and limited controlled inflows (February only – see Table 2) of seawater through the floodgates. Salinities throughout the estuary (i.e. at all Stations) also increased from month to month.
- In March 2000 the salinity gradient was reversed again (highest salinities in upper reaches) and the estuary was saline-hypersaline, as in February-April of the previous year.
- Salinities slowly declined and the gradient reversed again (lowest salinities in upper reaches) from April to June 2000.
- From July to September 2000 the system was flushed to brackish (in July) and ‘fresh – very fresh’ (August – September) by winter rains and river flows, similar to winter-spring of the previous year, though note that flushing was two months later (in this respect, see also Figure 4) and was not to ‘very fresh’ throughout, as in June 1999.

Salinity stratification greater than 2ppt was evident (see Appendix 3) in Vasse estuary in:

- March 1999 at Stations 4, 5 and 6 (surface to bottom differences of 6-16ppt).
- April 1999 at Station 3 (surface to bottom difference of 6ppt).
- May 1999 at Stations 2-7 and 9 (surface to bottom differences of 3-16ppt) due to the onset of heavy rains and flooding (see Appendix 18).
- December 1999 and June-September 2000 at Stations 1 (all five months) and 2 (July only) (surface to bottom differences of 3-12ppt), probably due to leakage of seawater past the estuary floodgates.

The surface salinities and theoretical extents of inundation (based on recent bathymetric mapping – see Section 6.3, paragraph 4) of Vasse estuary in selected months of autumn, winter and spring 1999 are presented in map form in Figure 11 in order to further illustrate the dramatic changes that occur.

6.4.2 Wonnerup estuary

The highest measured surface salinity in the Wonnerup estuary during the course of the project (note that in 1998 measurements were made on only one occasion and unreliable measurements were obtained in March 2000) was 98ppt at Station 5 in February 1999 (Table 8). The water level at this time was −0.41 mAHD and the water depth at the Station was 0.17m.

The lowest surface salinity recorded was 0.3ppt at Stations 2, 3 and 5 in June 1999. The water level at this time was 0.58m and the water depths at the Stations were 1.17, 1.05 and 1.13m respectively.

Table 8. Wonnerup estuary seasonal salinities during 1998-2000.

	Maximum surface salinity (ppt)	Minimum surface salinity (ppt)
Winter	26 at Stn 1 (Jun 00)	0.3 at Stns 2,3,5 (Jun 99)
Spring	3 at Stns 1-4 (Nov 99)	1 at Stns 2-5 (Sep 00)
Summer	98 at Stn 5 (Feb 99)	4 at Stn 5 (Dec 99)
Autumn	91 at Stn 5 (Mar 99)	18 at Stn 2 (May 99)

Salinities and salinity gradients in Wonnerup estuary followed very similar patterns to those exhibited by Vasse estuary over the same period. As in the Vasse, these are not well-described by seasonal maxima and minima alone, due to the considerable variability within all seasons except spring. A textual approach, read in conjunction with Appendix 2, is more revealing. Thus:

- The estuary was saline-hypersaline from February to April 1999 with highest salinities in the upper reaches.
- The estuary was almost completely flushed to very fresh (<1ppt) in June 1999 and salinities stayed low (fresh-brackish) until November of that year.
- Salinities rose progressively during summer-autumn of 1999-00, with a gradient of higher to lower salinities from lower to upper reaches (the reverse of the autumn 1999 gradient).
- Salinities remained high (but not as high as in late summer – autumn of the previous year, when the estuary's middle and upper reaches were hypersaline) until May 2000 and then declined due to winter rains and river flows to reach freshness in August and September. Note however that, as in the Vasse, the flushing was two months later than in the previous year (in this respect, see also Figure 5) and was not to 'very fresh' throughout, as in June 1999.

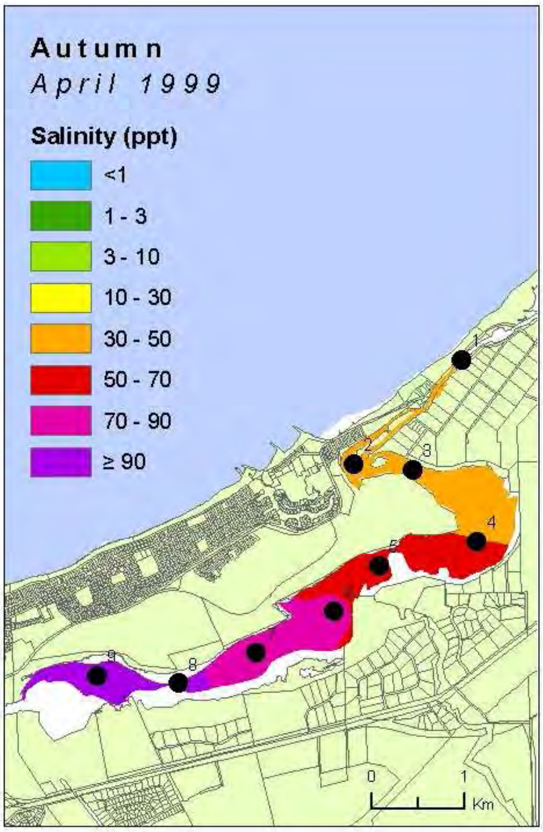
Salinity stratification was also evident (see Appendix 3) in Wonnerup estuary, as in the Vasse, being most-pronounced in May 1999 and occurring most-frequently in the lowest reaches (Station 1 and 2), probably due to leakage of seawater past the estuary floodgates.

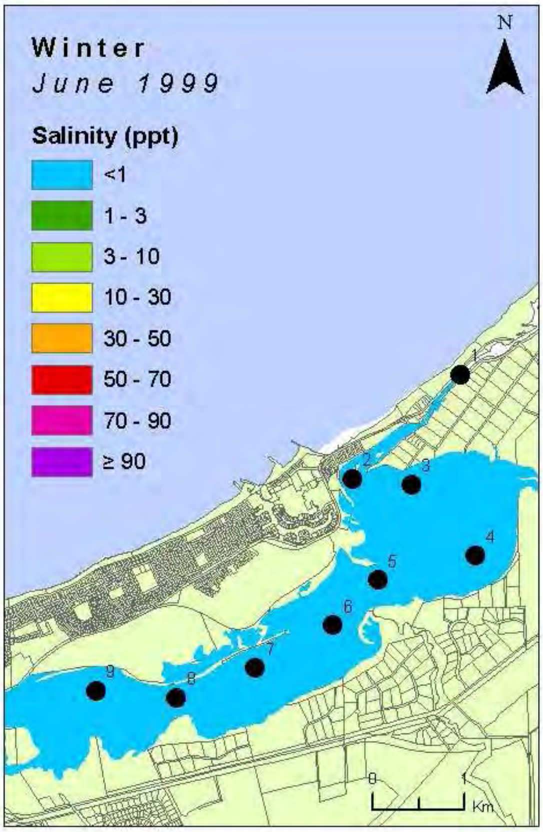
The surface salinities and theoretical extents of inundation of Wonnerup estuary in selected months of autumn, winter and spring of 1999 are presented in map form in Figure 12 in order to further illustrate the dramatic changes that occur.

6.4.3 The Deadwater

The highest measured surface salinity in the Deadwater during the course of the project (note that no measurements were made in 1998 and unreliable measurements were obtained in March 2000) was 37ppt at Stations 1 and 5 in April 2000 (Table 9). The water level at this time is unknown, however the water depths at the two Stations were 0.60m and 1.40m respectively.

The lowest surface salinity recorded was 3ppt at Station 1 in November 1999. The water level at this time was 0.41 mAHD and the water depth at the Station was 0.90m.





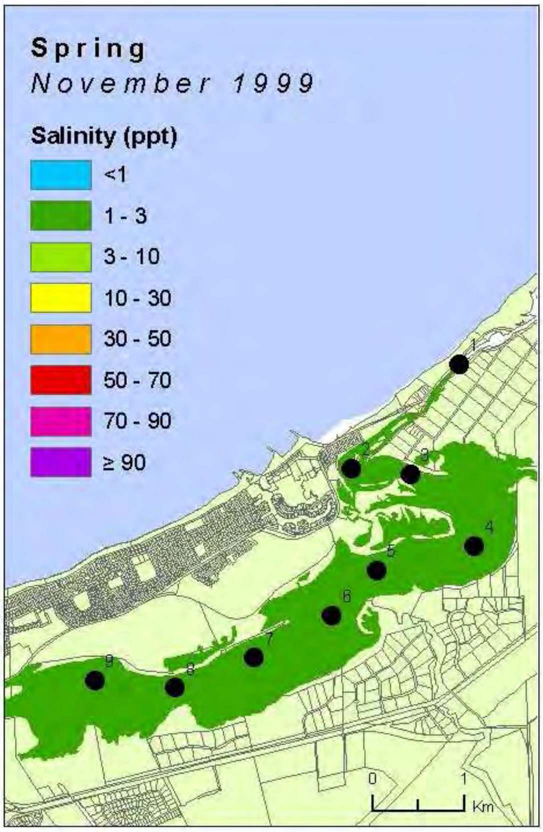
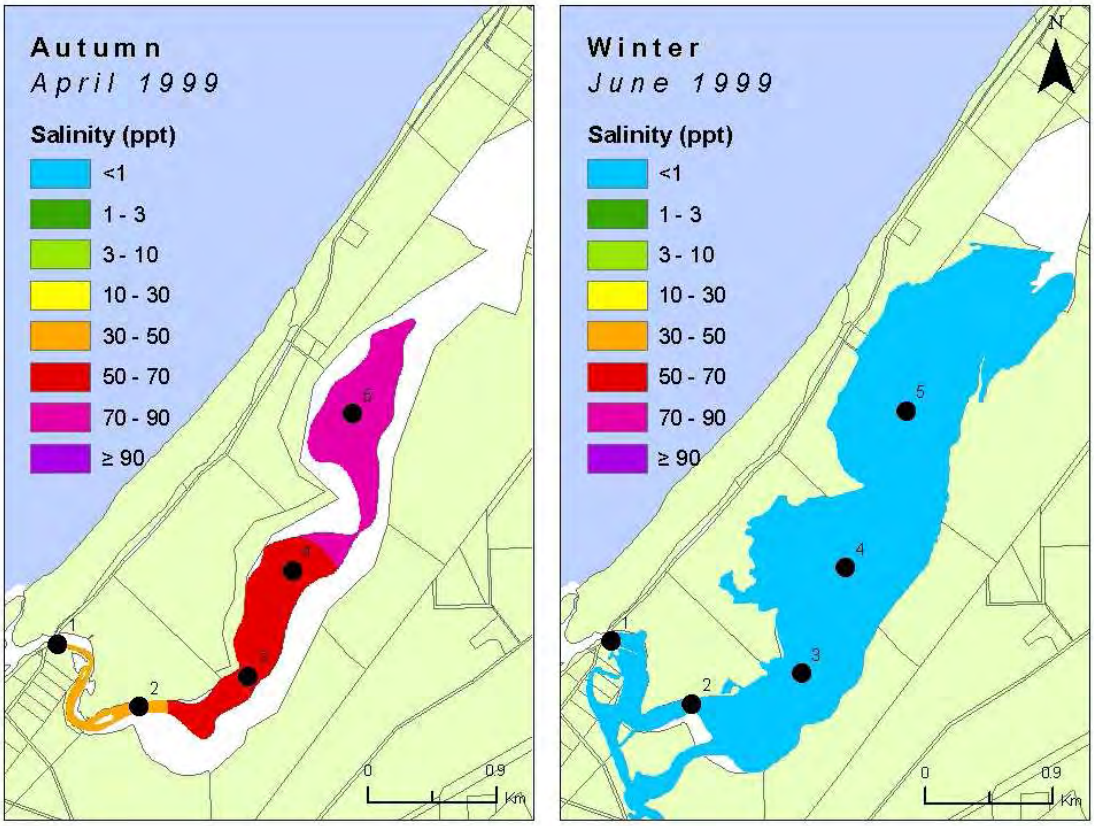


Figure 11. Autumn, winter and spring surface salinities of Vasse estuary in 1999. During summer, surface salinities change dramatically, from near-fresh to saline.

The water extents (areas of inundation) in these three maps have been determined using recent bathymetric mapping and the water levels at the times of profiling.



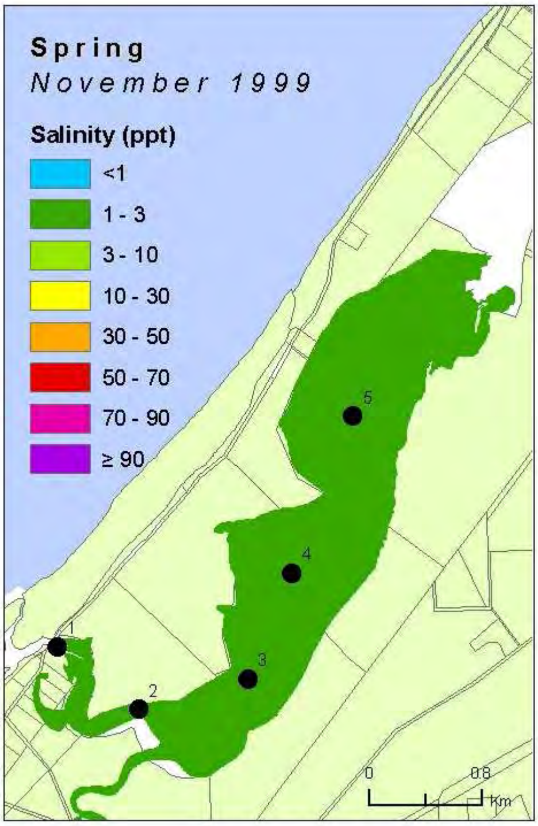
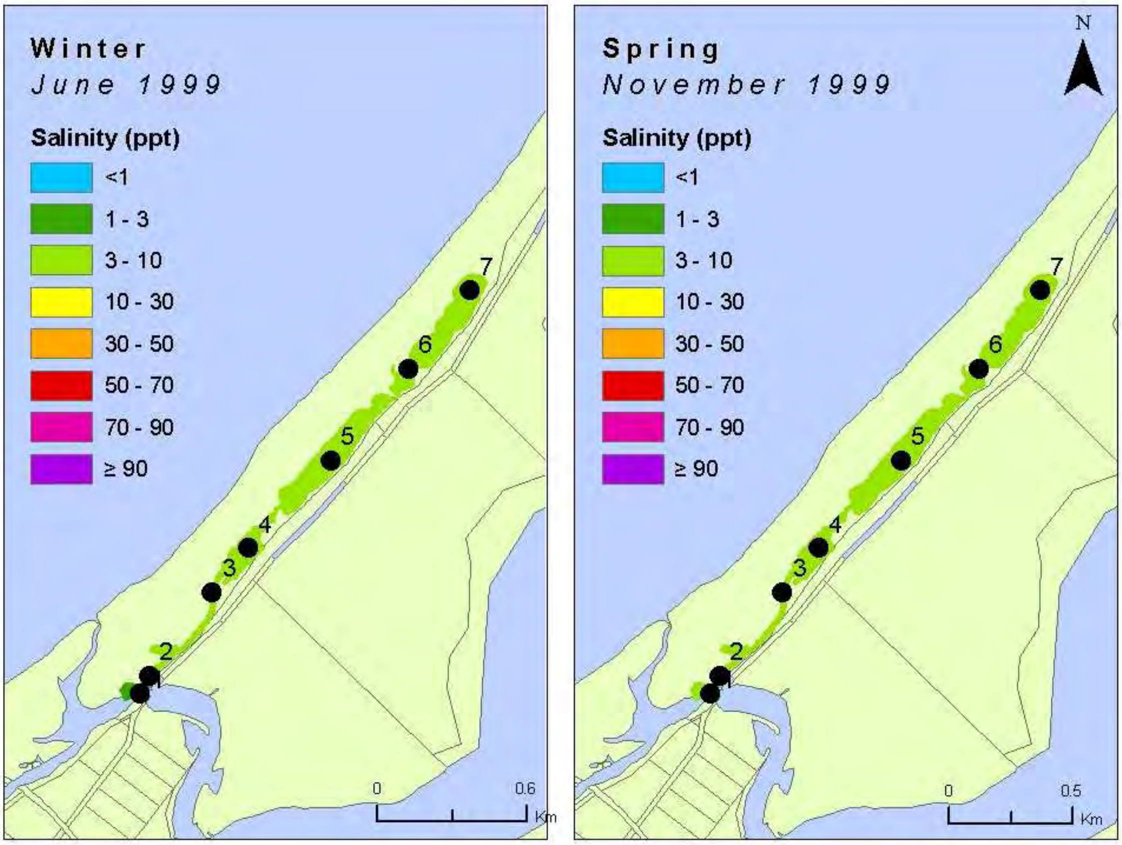


Figure 12. Autumn, winter and spring surface salinities of Wonnerup estuary in 1999. During summer, surface salinities change dramatically, from near-fresh to saline.

The water extents (areas of inundation) in these three maps have been determined using recent bathymetric mapping and the water levels at the times of profiling.



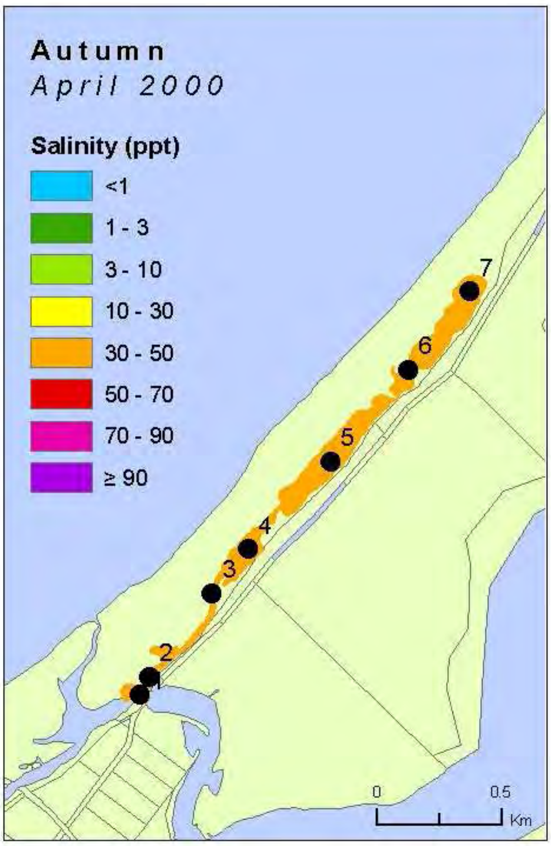


Figure 13. Winter, spring and autumn surface salinities of the Deadwater in 1999-2000. During summer, surface salinities are predominantly saline.

Unlike the Vasse and Wonnerup estuaries which have floodgates on their exit channels, the Deadwater is tidal, though not when the sand bar closes at the mouth of Wonnerup Inlet. Tidal exchange prevents Deadwater salinities from reaching the very high values that are common in the middle and upper reaches of the Vasse and Wonnerup estuaries by the end of summer and in autumn. The pattern of salinity change observed in the Deadwater was as follows (to be read in conjunction with Appendix 2).

- In June 1999, Deadwater salinities were brackish (3<10ppt) due to flushing by winter rains and very fresh (<1ppt) discharge from the estuaries into Wonnerup Inlet, from where water makes its way into the Deadwater. Note that at this time the Deadwater was not entirely flushed, with higher salinities (9ppt) at the surface and salt water (28ppt) still present beneath the surface at the far end (Station 6).
- In November 1999 salinities were low throughout and probably had been so since June/July. A horizontal gradient was still evident, with salinities increasing from 3ppt at the mouth to 7ppt at the far end.
- One month later, salinities were approaching that of seawater (c. 35ppt) and there was a gradient of increasing salinity from upper to lower reaches, due no doubt to tidal flushing following artificial opening of the sand bar six days before the December 1999 measurements were taken.
- Salinities remained at or about seawater concentration from January to April 2000 due to frequent tidal flushing negating evapoconcentration and thus preventing hypersalinisation.
- Salinities declined in May 2000 and (irregularly) in subsequent months, but not to the generally-fresh concentrations that the estuaries exhibited in August and September 2000.

Table 9. Deadwater seasonal salinities during 1999-2000.

	Maximum surface salinity (ppt)	Minimum surface salinity (ppt)
Winter	36 at Stns 4,6 (Jul 00)	4 at Stns 1-3 (Jun 99)
Spring	9 at Stn 2 (Sep 00)	3 at Stn 1 (Nov 99)
Summer	35 at Stn 6 (Feb 00)	22 at Stns 5-6 (Dec 99)
Autumn	37 at Stns 1,5 (Apr 00)	24 at Stn 3 (May 00)

Stratification was evident (see Appendix 3) throughout the Deadwater in July 2000, with much higher bottom salinities recorded at Stations 3-6 than previously. The collected data offer no explanation for these uncharacteristically high readings or the exceptionally high bottom salinity at Station 1 in Wonnerup Inlet at the same time. Estuary salinities in June and July 2000 were not as high as the Deadwater bottom salinities of July 2000 so the estuaries do not appear to have been the source.

Stratification was also evident at several Stations in the Deadwater in August and September 2000. This stratification was probably due to the interaction of tidal seawater with low salinity discharge from Wonnerup estuary and, to some extent, the Vasse estuary.

The surface salinities and theoretical extents of inundation of the Deadwater in selected months of winter, spring and autumn of 1999-2000 are presented in map form in Figure 13 in order to further illustrate the changes that occur.

6.4.4 Wonnerup Inlet

The highest measured surface salinity recorded in Wonnerup Inlet during the course of the project (note that no measurements were made in 1998 and unreliable measurements were obtained in March 2000) was 37ppt at Station 1 (the only sampling site in Wonnerup Inlet) in April 2000. The water level at this time is unknown, however the water depth at this Station was 1.30m.

The lowest surface salinity recorded was 0.8ppt at Station 1 in June 1999. The water level at this time was 0.34 mAHD (calculated from Water & Rivers Commission logger data) and the water depth at this Station was 1.60m.

Like the Deadwater, but unlike the Vasse and Wonnerup estuaries which have floodgates on their exit channels, Wonnerup Inlet is tidal, except for those times (usually months at a time) when the sand bar at its mouth is closed. This prevents its salinities from reaching the very high values that are common in the middle and upper reaches of the Vasse and Wonnerup estuaries by the end of summer and in autumn. The pattern of salinity change observed in Wonnerup Inlet was as follows (to be read in conjunction with Appendix 2).

- In June 1999 the salinity at Station 1 was very fresh (<1ppt) due to even-fresher discharge from the Wonnerup and Vasse estuaries.
- In November 1999 salinity at Station 1 remained low due to continued low salinity flow from the estuaries.
- One month later, salinity was approaching that of seawater (c. 35ppt), due to tidal flushing following artificial opening of the sand bar six days before the salinity was measured.
- Salinity remained at or about seawater concentration from January 2000 to April 2000 due to continued tidal flushing.
- Salinity at Station 1 dropped somewhat in May 2000. Deadwater salinities also dropped, but the estuaries' salinities did not. Why Wonnerup Inlet and Deadwater salinities were lower is not immediately obvious. Perhaps localised autumn rainfall had more effect, directly or indirectly, on these two waterbodies than on the estuaries.
- In June 2000 Wonnerup Inlet salinity was at seawater concentration again.
- In July 2000 surface salinity was lower, similar to those of Wonnerup estuary but not Stations 2-6 of the Deadwater (which were higher) or Vasse estuary (which were lower).
- In August and September 2000 Station 1 salinities were very similar to those of the Deadwater and much higher than those of the two estuaries, no doubt again due to tidal influence.

Stratification was pronounced (see Appendix 3) at Station 1 in July, August and September 2000. This stratification was probably due to the interaction of tidal seawater with lower salinity discharge from Wonnerup estuary and, to some extent, the Vasse estuary and perhaps the complicating effect of tidal discharge from the Deadwater. The exceptionally high (54ppt) bottom salinity in July 2000 cannot be explained by the project data.

6.4.5 Lower Vasse River Wetlands

The highest measured surface salinity recorded at Station 1 (the only sampling site) of the Lower Vasse River Wetlands (LVRW) during the course of the project (note that in 1998 measurements were made on only one occasion) was 2ppt in January 2000 (Appendix 2). The water level in the Vasse estuary at this time was 0.06 mAHD and the water depth at the Station was 0.30m. These two waterbodies were not connected.

The lowest surface salinity recorded at Station 1 was 0.1ppt in March 2000. The water level in Vasse estuary at this time was −0.07m, but the water depth at the Station was 0.40m. Again, the Vasse estuary and the LVRW were not connected at this time, as evidenced on this occasion by Stations 8 and 9 of Vasse estuary being dry.

There was no stratification greater than 0.1ppt at Station 1 of the LVRW on any sampling occasion (Appendix 3).

6.5 Water Temperature

6.5.1 Vasse estuary

The highest measured surface temperature in the Vasse estuary during the course of the project (note that no measurements were made in 1998) was 32 °C at Stations 7 and 8 in February 1999 and February 2000 respectively (Table 10 and Appendix 4). The water levels at these times were −0.10 and −0.02 mAHD respectively and the water depths at the Stations were 0.07 and 0.04m respectively.

The lowest surface temperature recorded was 12 °C at Station 3 in May 2000. The water level at this time was 0.06 mAHD and the water depth at the Station was 0.60m.

General patterns were for temperatures to be lowest (12-16 °C) from June (1999) or May (2000) to

August (2000) and highest (22-32 °C) from November to February (noting that no measurements were taken in October[1]). Extremely high temperatures (32 °C) were recorded only in very shallow waters in the upper reaches of the estuary in late summer (February of both years).

Table 10. Vasse estuary seasonal temperatures during 1999-2000.

	Max. surface temperature (°C)	Min. surface temperature (°C)
Winter	16 at Stn 4 (Jun 99)	13 at Stns 5-9 (Jun 00), 6,7 (Jul 00), 5,8 (Aug 00)
Spring	24 at Stns 1,4,6-9 (Nov 99)	16 at Stns 5,7-9 (Sep 00)
Summer	32 at Stns 7 (Feb 99), 8 (Feb 00)	21 at Stn 3 (Feb 00)
Autumn	24 at Stns 5-7 (Mar 00)	12 at Stn 3 (May 00)

In winter months (June-August) there was very little variation (1-2 °C) in water temperature throughout the estuary. Horizontal variation was most pronounced (10-11 °C) in February of each year when ambient temperatures were high and some Stations were very shallow while others were not.

Temperature stratification greater than 2 °C was apparent (Appendix 5) on only one occasion, in April 1999 at Station 3 (surface 14 °C, bottom 17 °C).

6.5.2 Wonnerup estuary

The highest measured surface temperature in the Wonnerup estuary during the course of the project (note that no measurements were made in 1998) was 34 °C at Stations 2-5 in February 1999 (Table 11 and Appendix 4). The water level at this time was −0.41 mAHD and the water depths at these Stations were 0.18, 0.24, 0.17 and 0.17m respectively.

The lowest surface temperature recorded was 12 °C at Station 2 in May 2000. The estuary water level at this time was 0.00 mAHD and the water depth at the Station was 0.80m.

Table 11. Wonnerup estuary seasonal temperatures during 1999-2000.

	Max. surface temperature (°C)	Min. surface temperature (°C)
Winter	16 at Stn 1 (Aug 00)	13 at Stn 1 (Jun 99)
Spring	22 at Stns 1,3,4 (Nov 99)	17 at Stn 1 (Sep 00)
Summer	34 at Stns 2-5 (Feb 99)	22 at Stns 1-3,5 (Dec 99)
Autumn	25 at Stns 2-3,5 (Mar 00)	12 at Stn 2 (May 00)

General patterns were for temperatures to be lowest (12-16 °C) from June (1999) or April (2000) to August (2000) and highest (21-34 °C) from November to March (noting that no measurements were taken in October). Extremely high temperatures (34°C) were recorded only when estuary waters were very shallow (0.17-0.24m) in late summer of 1999.

In all profiling months except February 1999 (when the deeper waters near the floodgates were 6 °C cooler than the waters of the broad expanses of the estuary) there was very little variation (1-3 °C) in water temperature throughout the estuary.

Temperature stratification greater than 2 °C was apparent (Appendix 5) on only one occasion, in May 1999 at Station 1 (surface 20 °C, bottom 17 °C).

6.5.3 The Deadwater

The highest measured surface temperature in the Deadwater during the course of the project (note that no measurements were made in 1998) was 29 °C at Station 4 in December 1999 (Table 12 and Appendix 4). The water level at this time is unknown, however the water depth at the Station was 0.80m.

[1] Although no profiling was undertaken in the month of October during the 1998-2000 study period, the wetlands were profiled in October 2007. As a matter of interest, these data are presented in Appendix 14.

The lowest surface temperature recorded was 14 °C at Stations 1-6 in June 1999, Stations 3-5 in April 2000, Stations 3-6 in May 2000, Stations 2-6 in June 2000, Stations 1-6 in July 2000 and Station 5 in August 2000. The water levels at these times are unknown.

Table 12. Deadwater seasonal temperatures during 1999-2000.

	Max. surface temperature (°C)	Min. surface temperature (°C)
Winter	16 at Stn 3 (Aug 00)	14 at Stns 1-6 (Jun 99), 2-6 (Jun 00), 1-6 (Jul 00), 5 (Aug 00)
Spring	28 at Stns 4,5 (Nov 99)	19 at Stns 4-5 (Sep 00)
Summer	29 at Stn 4 (Dec 99)	23 at Stns 1,3 (Jan 00)
Autumn	23 at Stns 1-6 (Mar 00)	14 at Stns 3-5 (Apr 00), 3-6 (May 00)

General patterns were for temperatures to be lowest (14-16 °C) from April to August and highest (22-29 °C) from November to March (noting that no measurements were taken in October).

In all months except November 1999 (when surface temperatures varied by up to 6 °C) there was very little variation (1-3 °C) in water temperature throughout the Deadwater.

Temperature stratification greater than 2 °C was apparent (Appendix 5) on only one occasion, in November 1999 at Stations 4 and 6 (surface and bottom temperatures 28-25 °C and 26-23 °C respectively).

6.5.4 Wonnerup Inlet

The highest measured surface temperature recorded in Wonnerup Inlet during the course of the project (note that no measurements were made in 1998) was 26 °C at Station 1 (the only sampling site in Wonnerup Inlet) in November 1999 and February 2000 (Appendix 4). The water levels at these times were 0.41 and 0.22 mAHD respectively (calculated from Water & Rivers Commission logger data) and the water depths were 1.90 and 1.60m respectively.

The lowest surface temperature recorded was 14 °C in June 1999 and July 2000. The water levels at these times were 0.34 mAHD (calculated from Water & Rivers Commission logger data) and (July) unknown and the water depths were 1.60 and 2.00m respectively.

General patterns were for temperatures to be lowest (14-16 °C) from April to August and highest (22-26 °C) from November to March (noting that no measurements were taken in October). Temperature stratification greater than 2 °C was apparent (Appendix 5) on only one occasion, in November 1999 (surface 26 °C, bottom 23 °C).

6.5.5 Lower Vasse River Wetlands

The highest measured surface temperature recorded at Station 1 (the only sampling site in the Lower Vasse River Wetlands) during the course of the project (note that no measurements were made in 1998) was 29 °C in January 2000 (Appendix 4). The water level in the Vasse estuary at this time was 0.06 mAHD and the water depth at the Station was 0.30m.

The lowest surface temperature recorded at Station 1 was 12 °C in August 2000. The water level in Vasse estuary at this time was 0.29m and the water depth at the Station was 0.60m.

Temperature stratification greater than 2 °C was apparent (Appendix 5) on only one occasion, in November 1999 (surface 26 °C, bottom 23 °C).

7. DISCUSSION

7.1 Depths, salinities and temperatures of Vasse-Wonnerup wetlands

7.1.1 Water levels, depths, longitudinal profiles and extents of inundation

Water levels — and therefore water depths — in Vasse-Wonnerup wetlands may change dramatically over very short time periods of days or even hours. Changes are frequent in Wonnerup Inlet and the Deadwater whenever the sand bar at the mouth of the Inlet is open and these two waterbodies are exposed to the tidal influences, both astronomic and barometric, of the sea. Large and rapid changes in water levels are also frequent in the Vasse and Wonnerup estuaries, however here they are mainly confined to winter and early spring. During these months water levels rise and peak during periods of strong river inflow and fall when river flows slacken and estuary waters discharge through the floodgates to the sea. Because in these months the floodgates only allow outflow, the levels in the estuaries trend towards the lowest of sea tide levels. The result is water level changes of up to 0.5m within days and 1.0m or more in just a few weeks. These are very substantial changes in waterbodies as shallow as the two estuaries.

During late spring and summer, water levels in the two estuaries are much less variable, firstly stabilising and then declining slowly, due to the combined effects of stopboard installation, cessation of river flows and rising evaporation rates. A small but steady rise in levels occurs during autumn, probably due to surface and groundwater seepage, declining evaporation rates and increasing rainfall.

Because of the high frequency and, at times, substantial magnitude of the water level changes it would be preferable to characterise them by analysis of continuous recordings, preferably over a number of years, rather than the monthly measurements reported here. This, however, is beyond the primary purpose of the present report, which is to relate waterbird species-occurrence and abundance during late spring, summer and autumn (when occurrence and abundance are highest and water level fluctuations least) to the depths and salinities occurring at the time of the monthly bird surveys. The emphasis of this report then, has been on the monthly recordings — and in particular the measured water depths at each sampling station, i.e. at representative locations throughout the wetlands — rather than on the continuously-recorded water level data from this period (1998-2000) [1].

<u>Vasse estuary and the Lower Vasse River Wetlands</u>

Water depths at the times the waterbird surveys were conducted were generally less than 1.0m, and frequently less than 0.5m, in all parts of Vasse estuary, except at the floodgates where they were most commonly 1.0 - 1.5m. The longitudinal profile of Vasse estuary's bed, calculated on the basis of depth and water level measurements, shows that most of the bed of the estuary is less than 0.5m below mean sea level and in the upper reaches is less than 0.2m. Mapping of the extents of inundation during profiling and waterbird survey months of 1998-2000 revealed that when water levels are at their lowest, around −0.1 mAHD in late summer and early autumn, all of the uppermost reaches and a large portion of the middle reaches are dry. It is not until the water level reaches 0.1 mAHD that the entire bed of the estuary is inundated. At levels higher than 0.1 mAHD the fringing and adjacent pools and marshes and (ultimately) the pastures of the floodplain are progressively flooded.[2]

Depths in the Lower Vasse River Wetlands (LVRW) were measured at only one location, in the channel at the eastern end of these wetlands. The recorded depths are not necessarily representative of the LVRW and are therefore not further considered here. Since the 1998-2000 study, a continuous water level recorder has been installed in the LVRW and the bathymetry of this area has been mapped in detail (see footnote 2 below). These activities will assist future study.

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[1] The authors do have continuous water level recordings for the Vasse and Wonnerup estuaries from 1992 to the present, and have access to similar data collected by other agencies over shorter time periods from Wonnerup Inlet. These reveal dramatic year-to-year differences in water levels and patterns of water level fluctuations, due largely to year-to-year differences in rainfalls and river flows. These data therefore warrant separate analysis and reporting.

[2] The inundation-mapping that was undertaken as part of this project was 'by eye' and often at a distance and was therefore approximate. In 2008-09, surveyors were engaged to map the bathymetry of the Vasse-Wonnerup wetland system and adjoining lands in considerable detail. With these maps it will be possible to predict the extent of inundation at a variety of water levels with much greater accuracy than in the past.

Wonnerup estuary

Water depths in the Wonnerup estuary at the times the waterbird surveys were conducted were broadly similar to those in the Vasse estuary. They were mainly less than 1.0m, and often less than 0.5m, in all parts of the estuary, except at the floodgates where they more-frequently exceeded 1.0m. The longitudinal profile of Wonnerup estuary's bed, calculated on the basis of depth and water level measurements, reveals that most of the bed of this estuary, at least along the centreline, is slightly deeper than that of the Vasse, the bed at the three sampling stations in the broad expanses of the estuary being approximately 0.5m below mean sea level. Mapping of the extents of inundation during 1998-2000 revealed that when water levels are at their lowest, around −0.4 mAHD in late summer and early autumn[1], water remains in the exit channel, in the centre of the central basin, and in a narrow channel connecting the two. At this level, some surface water may also remain in the north-eastern basin, although this is variable as the central and north-eastern basins disconnect at levels lower than approximately −0.36 mAHD. At a level of approximately −0.1 mAHD most of the bed of the estuary is inundated, but it is not until the level reaches approx. 0.1 mAHD that the entire bed is covered. At water levels higher than approx. 0.1 mAHD the fringing and adjacent pools and marshes and (ultimately) the pastures of the floodplain are progressively flooded.

The Deadwater and Wonnerup Inlet

The Deadwater is deeper than both the Vasse and Wonnerup estuaries. Depths measured at the times of profiling were generally greater than 1.0m, and occasionally greater than 1.5m, along most of the length of this waterbody. The longitudinal profile of the Deadwater's bed, calculated on the basis of depth and water level measurements, reveals that much of the bed, at least along the centreline, is at −0.9 to −1.1 mAHD. The extent of inundation of the Deadwater was not mapped during 1998-2000. Being a steeper-sided and relatively deep channel connected to the ocean for most of the year, little of its bed is exposed, even at low tide.

Depths in Wonnerup Inlet were measured at only one location, at the north-eastern end. The recorded depths are not necessarily representative of the entire Inlet and are therefore not considered further here. Since the 1998-2000 study, the bathymetry of this area has been mapped in detail (see footnote 2 of previous page) and the Water Corporation has installed continuous water level recorders on the Inlet (and estuary) sides of both the Vasse estuary and Wonnerup estuary floodgates. These will assist future study.

7.1.2 Salinities

Vasse estuary and the Lower Vasse River Wetlands

The data collected during 1998-2000 have shown that Vasse estuary can be completely flushed to 'very fresh' (<1ppt) by river through-flows in winter and that salinities remain low throughout the estuary until the end of spring. Salinities steadily rise throughout the estuary during summer due to leakage and some controlled inflow of seawater through the floodgates, due to evapoconcentration and perhaps due to saline groundwater discharge. During this time there is a gradient of higher salinities in the lower reaches (where seawater input is occurring) to lower salinities in the upper reaches. By the end of summer salinities may be at, near, or well above, seawater salinity throughout the estuary. During autumn further evapoconcentration occurs, particularly in the shallower middle and upper reaches, and salinities in these reaches can be two or more times that of seawater. The precise timing of this annual cycle can vary from year to year, depending upon the timing of onset of winter rains and river flows. Very limited stratification occurs and this is principally at the onset of late autumn or winter rains, when fresh river inflows may overlie denser saline estuary waters for a short period before mixing.

The waters of the Lower Vasse River Wetlands remain very fresh (<1ppt) to fresh (1<3ppt) throughout the year due to the flushing effect of local rainfall and Lower Vasse River flows and the LVRW's disconnection from the Vasse estuary at low estuary water levels (when estuary salinities may be saline-hypersaline).

Lane *et al.* (1997) presented (Appendix 4 of that report) a compilation of all previously-known salinity records from Vasse estuary. These mainly fell into two periods, multiple-point records from 1987-89 and 1994-97, plus four single-point records from 1978, 1982 and 1985. The winter, spring and summer records from 1978-97 are broadly similar to those of this report, however there are several intriguing

[1] The water level in Wonnerup estuary is allowed to decline approximately 0.3m lower than that of the Vasse during late summer – early autumn (Lane *et al.* 1997).

differences (both higher and lower values) in autumn data that could warrant further investigation, noting that it was in early 1989 that the Vasse estuary floodgates were first partially-opened on a frequent basis in summer (Lane *et al.* 1997).

Wonnerup estuary

The 1998-2000 data show that Wonnerup estuary salinities exhibit the same pattern of change during winter, spring, summer and autumn as those of the Vasse estuary, with the same mechanisms operating (flushing, leakage, controlled inflow, evapoconcentration and perhaps saline groundwater discharge). The salinity values are also very similar, ranging from very fresh in winter to saline-hypersaline in summer and autumn. One noticeable difference between the estuaries is that flushing began somewhat later in both years in the Wonnerup than in the Vasse, possibly reflecting differences in the size and character of the two estuaries' modern-day catchments. Stratification is very limited in Wonnerup estuary and, like the Vasse, is most significant at the onset of winter rains and freshwater flows.

The only pre-1998 Wonnerup estuary salinity data known to the authors are from 1978 (one single-point record), 1995 and 1996 (two single-point records each) and 1997 (one complete horizontal profile) (see Appendix 16). These data are similar to those collected in the same months at the same sampling sites and in the same seasons as those collected in 1998-2000, taking into account the water levels (when recorded) at the times of sampling.

The Deadwater and Wonnerup Inlet

The Deadwater is a long, narrow waterbody connected to the ocean via Wonnerup Inlet and is tidal except when the sand bar at the mouth of the Inlet closes. No watercourses discharge directly into the Deadwater, however it may receive some discharge from the Vasse and Wonnerup estuaries indirectly via Wonnerup Inlet. The Deadwater therefore has salinities at or near those of seawater when the bar is open and the estuaries are not discharging river waters; but has lower salinities (approaching freshness) when the estuaries *are* discharging. Horizontal gradients can occur at times of freshening (due to direct precipitation in autumn-winter and fresh estuary discharge in winter-spring) or salinisation (due to seawater inflow). Stratification may occur, in particular when lower salinity discharges from the estuaries overlie seawater.

Salinities at the single sampling site at the north-eastern end of Wonnerup Inlet between the Wonnerup estuary floodgates and the mouth of the Deadwater, were generally very similar to those of the Deadwater, responding in similar fashion to estuary discharges and opening of the sand bar. They ranged in value from very fresh to saline and were, at times, stratified, when estuary discharges in winter and spring overlied seawater.

A very limited amount of Deadwater and Wonnerup Inlet salinity data were collected by Water & Rivers Commission staff prior to (mainly in 1998-99) the present study (1999-2000), however these have not been accessed by the authors for comparison. The authors are not aware of any other pre- June 1999 data from these two waterbodies.

7.1.3 Temperatures

Vasse estuary and the Lower Vasse River Wetlands

Data collected during 1999 and 2000 have shown that Vasse estuary water temperatures generally range from around 13-14 °C in winter to 22-25 °C in summer. The only exception to this pattern is in late summer, when temperatures in the very shallow mid to upper reaches of the estuary may occasionally reach 32 °C. Temperature stratification was almost non-existent (at least during the daylight hours of sampling) with vertical differences, where they occurred, generally no more than 1 °C. This can largely be attributed to the very shallow nature of the estuary.

Temperatures at the single sampling station in the Lower Vasse River Wetlands were similar to those of the Vasse estuary, generally ranging from 13-24 °C, and exceptionally as high as 27-29 °C.

Wonnerup estuary

The temperature regime of the Wonnerup estuary is very similar to that of the Vasse, both in terms of the general range of temperatures recorded (13-25 °C) and the pattern of seasonal change (lowest in winter; highest in summer). As in the Vasse, the highest temperature (34 °C) occurred in the shallower parts of the estuary when the water level was at its lowest. Stratification was virtually non-existent, at least at the times (daylight hours) of sampling.

The Deadwater and Wonnerup Inlet

Temperatures in the Deadwater were similar to those of the Vasse and Wonnerup estuaries, though with slightly higher or lower temperatures in some survey months of spring and summer, perhaps due mainly to differences in timing of surveys, as Deadwater surveys were often conducted at a different time of the day than the estuary surveys. Although comparable data are limited (due to the Deadwater not being profiled in February 1999), it appears unlikely that Deadwater temperatures would often, if ever, reach the extremes (32-34 °C) recorded in the two estuaries in late summer, as its waters are nearly always deeper and subject to tidal exchange.

Water temperatures at the single sampling site at the north-eastern end of Wonnerup Inlet were very similar to those of the Deadwater, in particular to those of the nearest Deadwater sampling station (Deadwater Station 1). They were probably not representative of the entire Inlet, as this station was situated near the mouths of the Deadwater and Wonnerup estuary, and some distance from the mostly-tidal mouth of the Inlet where sea temperatures could be expected to have a strong influence.

7.2 Depths, salinities and use of Vasse-Wonnerup by waterbirds

Waterbird numbers and species-occurrence on Vasse-Wonnerup vary dramatically from season to season each year, with bird numbers lowest in winter (several thousand) and peaking in summer (up to 37,500) (Lane 1990, Lane *et al.* 2007). These fluctuations are due in large part to the seasonal and episodic movements of resident (Australian) breeding species such as ducks and to the annual migrations of shorebirds with breeding grounds in the northern hemisphere. However they are also partly a consequence of seasonal changes in the suitability of Vasse-Wonnerup as a waterbird habitat, due to changes in water levels, water quality (including salinity) and food supply.

The two largest components of Vasse-Wonnerup, the Vasse and Wonnerup estuaries, support by far the greatest numbers of waterbirds found within this wetland system. Unlike the Deadwater and Wonnerup Inlet, which are tidal, these two waterbodies function in similar fashion to semi-permanent lakes, filling in winter, stabilising in spring and then shallowing and partially drying in summer. This lake-like behaviour is due to the presence, since 1908, of floodgates on the estuaries' exit channels allowing the outflow of river floodwaters but largely preventing the incursion of seawater.

There is some capacity to manipulate the water levels of the Vasse and Wonnerup estuaries by operation of the floodgates and from time to time requests are received to do so. Because such changes could affect a range of natural and artificial values, including the suitability of this Ramsar-listed system for waterbirds, it is desirable to develop an understanding of the effects that various water levels and salinities could have.

The primary objective of the hydrological monitoring that is the subject of this report was to enable the species-occurrence and abundance of waterbirds on the Vasse and Wonnerup estuaries to be related to the estuaries' changing water levels, water depths and salinities. In this report we have presented the results of the 1998-2000 hydrological monitoring program. Further work will be required to relate these data to those of the 1998-2000 waterbird surveys.

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Photo credits: Photos 1 & 3-21 were taken by AG Clarke; 2 by Dot Scott; 24-42 by JAK Lane, and 22 & 23 by Gilbert Stokman.

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PHOTOS

Photo 1: Lower Vasse River Wetlands at western end of Vasse estuary (22Feb2010; view E from Causeway Rd).

Photo 2: Vasse estuary (29Apr2006; NE from Bussell Hwy).

Photo 3: Sabina River delta, Vasse estuary, Port Geographe canals development (22Feb2010; NW from Barracks Dve).

Photo 4: Vasse estuary (22Feb2010; N from Barracks Dve).

Photo 5: Vasse estuary (22Feb2010; NE from Barracks Dve).

Photo 6: Vasse estuary [22Feb2010; N from Rushleigh Rd).

Photo 7: Vasse estuary, Abba River, Malbup Creek (22Feb2010; NW from Tuart Forest National Park).

Photo 8: Malbup Creek (22Feb2010; NW from Tuart Forest NP).

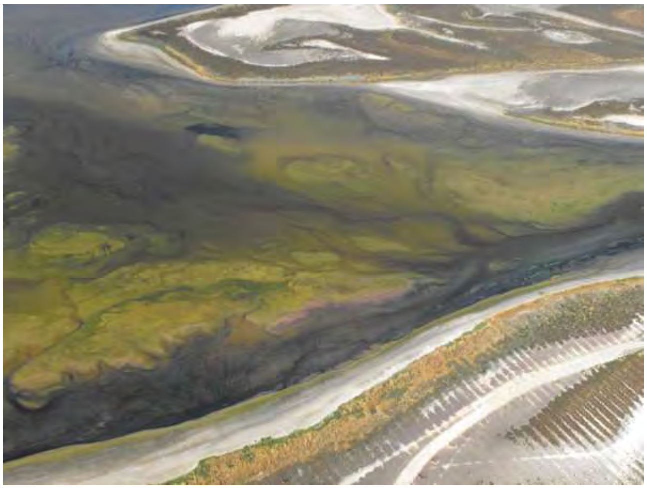


Photo 9: Vasse estuary (22Feb2010; SW from Lockville Rd).

Photo 10: Vasse estuary at Estuary View Dve (22Feb2010; SE from Layman Rd).

Photo 11: Vasse estuary (22Feb2010; SE from Geographe Bay).

Photo 12: Vasse estuary exit channel and floodgates (22Feb2010; S from Geographe Bay).

Photo 13: Wonnerup estuary exit channel (22Feb2010; S from the coast).

Photo 14: East arm of Malbup Creek, south-west basin and exit channel of Wonnerup estuary (22Feb2010; NW from Tuart Forest NP)

Photo 15: Wonnerup estuary south-west basin and exit channel (22Feb2010; NW from Tuart Forest NP).

Photo 16: Wonnerup estuary south-west and central basins (22Feb2010; NW from Tuart Forest NP).

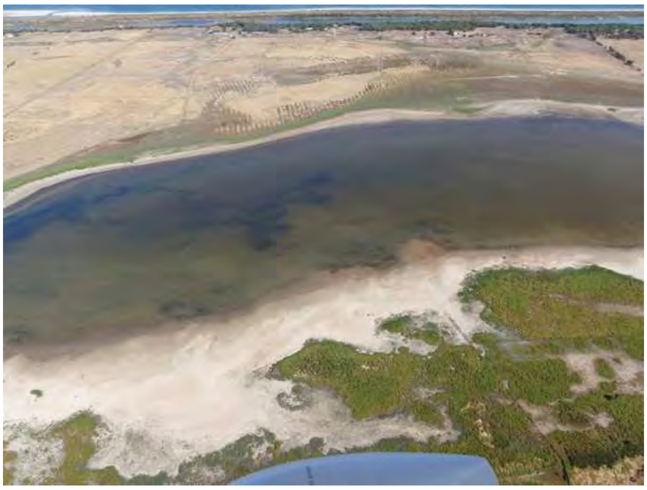


Photo 17: Wonnerup estuary central basin (22Feb2010; NW from Tuart Forest NP).

Photo 18: Wonnerup estuary central basin (22Feb2010; view SW along length of estuary).

Photo 19: Wonnerup estuary north-east basin (22Feb10; view NW)

Photo 20: Wonnerup estuary north-east basin (22Feb10; view NW)

Photo 21: Wonnerup estuary north-east and central basins (22Feb10; SE from Geographe Bay).

Photo 22: Deadwater, Wonnerup estuary, Malbup Creek east arm and Wonnerup estuary (12Feb2009; NE from Malbup Island).

Photo 23: Wonnerup Inlet, Deadwater, Wonnerup estuary (12Feb2009; NE from Wonnerup townsite).

Photo 24: Sand bar at mouth of Wonnerup Inlet (03Nov1999; S from Geographe Bay).

Photo 25: Vasse estuary and Lower Vasse River Wetlands in flood (21July1995; view W). The broken straight line is the Ford Rd (unconstructed) alignment.

Photo 26: Vasse estuary floodplain in flood (21July1995; SE from Avocet Blvd).

Photo 27: Vasse estuary floodplain in flood (21July1995; view W from estuary).

Photo 28: Vasse estuary and Malbup Island in flood (21July1995; W from Layman Rd)

Photo 29: Malbup Island and Layman Rd in flood (21July1995; view W).

Photo 30: Layman Rd in flood (05July1999; view SE)

Photo 31: Vasse estuary floodgates discharging river flood waters (14Jun1999).

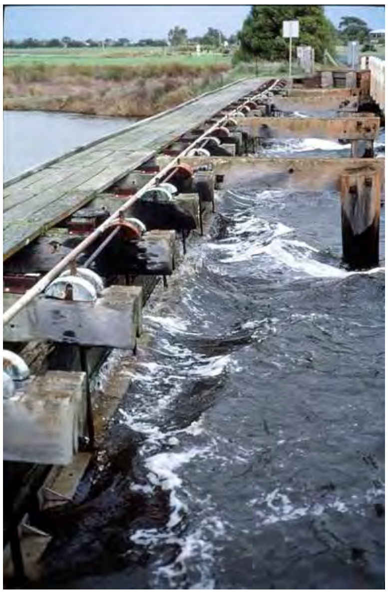


Photo 32: Wonnerup estuary floodgates almost overtopped by ocean storm surge (01Jul2000).

Photo 33: Vasse estuary floodgate temporary winch setup (16May1999).

Photo 34: Wonnerup estuary floodgate winched partially open for fish release (27Jan1998).

Photo 35: Manual removal of Wonnerup estuary floodgate stopboards for fish release (18Jan1998).

Photo 36: Leakage of seawater through Vasse estuary floodgates at high tide (16May1999).

Photo 37: Former *Water Corporation* Vasse estuary gauge board at floodgates (25Jan1998).

Photo 38: Subsequent *Water & Rivers Commission* Vasse estuary gauge boards at floodgates (16May1999).

Photo 39: *Water Corporation* contractor opening Wonnerup Inlet sand bar (02Jan1998).

Photo 40: *Water Corporation* contractors closing Wonnerup Inlet sand bar (22Oct1999).

Photo 41: Alan Clarke profiling depth, salinity and temperature in Wonnerup estuary exit channel (27May1999).

Photo 42: Flow through recently-opened 'check structure' on Vasse River at Butter Factory Folk Museum (03Apr1998).

APPENDICES

APPENDIX 1. Measured depths in Vasse-Wonnerup wetlands in 1998-2000. Refer to Figures 2 & 3 for locations of Sampling Stations (1-9, etc.).

VASSE ESTUARY											LVR	WONNERUP ESTUARY							WONNERUP INLET			DEADWATER					
Date	Water Level (m) *	1	2	3	4	5	6	7	8	9	1	Date	Water Level (m) *	1	2	3	4	5	Date	Water Level (m) #	1	1	2	3	4	5	6
01.04.98	**−0.05**	-	-	*0.36*	*0.32*	*0.15*	*0.25*	*0.18*	*0.02*	*DRY*	-	*01.04.98*	**−0.36**	-	-	-	*0.09*	*0.10*									
26.02.99	**−0.10**	1.07	0.18	0.26	0.16	0.07	0.18	0.07	DRY	DRY	0.35	25.02.99	**−0.41**	0.41	0.18	0.24	0.17	0.17									
26.03.99	**−0.08**	1.35	0.21	0.40	0.21	0.37	0.14	0.12	DRY	DRY	0.33	25.03.99	**−0.40**	0.48	0.35	0.18	0.18	0.20									
29.04.99	**−0.05**	0.83	0.22	0.45	0.25	0.25	0.26	0.18	0.04	0.03	0.30	28.04.99	**−0.30**	0.60	0.40	0.26	0.26	0.23									
27.05.99	**0.53**	1.20	0.80	1.10	0.83	0.82	0.63	0.68	0.60	0.76	0.90	27.05.99	**0.10**	1.07	0.63	0.53	0.63	0.66									
29.06.99	**0.56**	-	0.92	1.25	0.90	0.93	0.67	0.85	0.61	0.84	0.86	29.06.99	**0.58**	1.26	1.17	1.05	1.12	1.13	30.06.99	**0.34**	1.60	0.70	0.93	1.70	1.17	1.40	1.80
25.11.99	**0.47**	1.43	0.85	1.10	0.70	0.80	0.55	0.63	0.50	0.70	0.70	24.11.99	**0.46**	1.35	1.20	1.07	0.96	0.80	24.11.99	**0.41**	1.90	0.90	1.40	1.60	1.20	1.73	1.60
30.12.99	**0.29**	1.50	0.80	0.80	0.50	0.40	0.30	0.40	0.15	0.50	0.50	30.12.99	**0.24**	1.20	0.90	0.70	0.80	0.80	30.12.99		2.00+	0.80	1.20	1.40	0.80	1.60	1.40
28.01.00	**0.06**	1.00	0.40	0.50	0.23	0.15	0.12	0.30	0.10	0.23	0.30	27.01.00	**0.12**	0.80	0.60	0.43	0.55	0.55	28.01.00	**0.18**	1.00	0.60	1.10	1.20	0.80	0.80	1.50
24.02.00	**−0.02**	1.20	0.20	0.40	0.18	0.22	0.15	0.15	0.04	0.15	0.25	23.02.00	**−0.06**	0.90	0.50	0.30	0.40	0.60	23.02.00	**0.25**	1.60	0.70	1.40	1.30	1.00	1.20	1.70
31.03.00	**−0.07**	1.20	0.30	0.50	0.20	0.20	0.15	0.12	DRY	DRY	0.40	30.03.00	**−0.10**	0.80	0.60	0.50	0.30	0.40	30.03.00	**0.26**	1.40	0.80	1.60	1.30	1.10	1.50	1.40
29.04.00	**0.01**	0.80	0.23	0.50	0.20	0.17	0.10	0.12	0.06	0.12	0.35	29.04.00	**−0.05**	0.70	0.60	0.40	0.40	0.40	29.04.00		1.30	0.60	1.30	1.30	1.20	1.40	1.50
25.05.00	**0.06**	1.75	0.35	0.60	0.38	0.38	0.12	0.20	0.09	0.20	0.30	26.05.00	**0.00**	0.94	0.80	0.58	0.56	0.53	26.05.00		1.40	0.80	1.50	1.36	1.30	1.60	1.40
19.06.00	**0.41**	1.28	0.70	0.96	0.75	0.55	0.55	0.65	0.35	0.50	0.66	20.06.00	**0.23**	1.00	0.80	0.70	0.80	0.70	20.06.00		1.60	1.00	1.40	1.40	1.60	1.60	1.60
03.07.00	**0.73**	2.30	1.20	1.25	0.90	0.90	0.90	0.90	0.80	1.00	0.80	04.07.00	**0.74**	1.40	1.20	1.20	1.20	1.00	04.07.00		2.00	1.20	1.40	2.00	1.60	2.00	2.00
14.08.00	**0.29**	1.17	0.70	0.88	0.70	0.64	0.38	0.50	0.28	0.53	0.60	14.08.00	**0.30**	1.20	1.10	0.80	0.83	0.75	14.08.00		2.00	0.90	1.20	1.40	1.40	1.60	1.40
21.09.00	**0.50**	1.24	0.80	1.00	0.85	0.81	0.61	0.72	0.55	0.77	0.79	21.09.00	**0.52**	1.40	1.15	1.00	1.03	0.84	21.09.00	**0.50**	1.50	1.00	1.37	1.50	1.50	1.40	1.60

LVR = Lower Vasse River Wetlands.

* Floodgate gauge board readings (corrected). Note that these may differ from the CALM logger recordings as the estuary loggers were located 1-3 km upstream from the floodgates. The difference was substantial in the exceptional circumstances of 27 May 1999, when Vasse estuary was flooding and the CALM logger reading was ≈1.3 mAHD whereas the gauge reading was 0.53 mAHD (see Appendix 18).

\# Water & Rivers Commission automated recording station ('logger') readings from the downstream (Wonnerup Inlet) side of the Vasse estuary floodgates (see page 7).

Key to Colour Shades

DRY	<0.5m	0.5<1m	1<1.5m	1.5<2m	≥2m

APPENDIX 2. Measured salinities (parts per thousand) in Vasse-Wonnerup wetlands during 1998-2000. Refer to Figures 2 & 3 for locations of Sampling Stations (1-9 etc.).

	VASSE ESTUARY											LVR	WONNERUP ESTUARY							WONNERUP INLET			DEADWATER						
Salinity	**Date**	**Water Level (m) ^**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**1**	**Date**	**Water Level (m) ^**	**1**	**2**	**3**	**4**	**5**	**Date**	**Water Level (m) #**	**1**	**1**	**2**	**3**	**4**	**5**	**6**	**Comments**
Middle	*01.04.98*	**−0.05**	-	*23*	*26*	*27*	*31*	*31*	*35*	*38*	*DRY*	*1*	*01.04.98*	**−0.36**	-	-	-	*32*	*35*										Sandbar at mouth of Wonnerup Inlet was opened on 02Jan98. Remained open until at least 18Jun98.
Surface Bottom	26.02.99	**−0.10**	40 41	46 46	47 47	50 50	55 55	80 80	90 90	DRY	DRY	0.4 0.4	25.02.99	**−0.41**	38 38	44 43	61 61	76 76	98 98										Sandbar at mouth of Wonnerup Inlet was opened on 17Dec98. Remained open until 22Oct99.
Surface Bottom	26.03.99	**−0.08**	40 39	42 42	44 44	50 63	52 58	58 74	75 76	DRY	DRY	0.3 0.3	25.03.99	**−0.40**	38 38	41 41	49 49	71 71	91 91										
Surface Bottom	29.04.99	**−0.05**	38 38	43 43	44 50	50 50	57 58	71 72	75 76	94 94	95 95	0.3 0.3	28.04.99	**−0.30**	38 38	49 54	65 68	69 69	88 88										
Surface Bottom	27.05.99	**0.53**	32 33	21 24	10 24	5 21	8 20	9 12	13 20	16 16	2 11	0.5 0.4	27.05.99	**0.10**	22 33	18 25	23 23	26 29	23 30										Stopboards were removed from floodgates on 27May99.
Surface Bottom	29.06.99	**0.56**	0.6 0.6	0.4 0.8	0.5 0.5	0.6 0.7	0.7 0.8	0.7 0.8	0.5 0.9	0.4 0.4	0.4 0.4	0.4 0.4	29.06.99	**0.58**	0.4 2	0.3 0.3	0.3 0.4	0.4 0.4	0.3 0.4	30.06.99	**0.34**	0.8 0.8	4 4	4 4	4 7	6 8	8 10	9 28	
Surface Bottom	25.11.99	**0.47**	2 2	2 2	2 2	2 2	3 3	2 2	2 2	1 1	0.8 0.9	0.3 0.3	24.11.99	**0.46**	3 3	3 3	3 3	3 3	2 2	24.11.99	**0.41**	3 3	3 3	5 5	5 5	6 6	7 7	7 7	Stopboards were installed in floodgates on 29Sep99. Sandbar at mouth of Wonnerup Inlet was closed artificially on 22Oct99 and raised water levels.
Surface Bottom	30.12.99	**0.29**	15 18	8 8	6 8	5 5	4 4	4 4	4 4	4 4	- -	- -	30.12.99	**0.24**	16 20	10 12	8 11	5 5	4 4	30.12.99		29 32	30 31	28 28	26 29	26 26	22 25	22 23	Sandbar at mouth of Wonnerup Inlet was opened on 24Dec99. Remained open until at least 24Jun00.
Surface Bottom	28.01.00	**0.06**	25 27	16 16	16 16	15 15	13 13	10 9	9 9	9 9	8 8	2 2	27.01.00	**0.12**	26 27	18 21	17 17	13 13	9 9	28.01.00	**0.18**	33 33	33 33	33 33	33 33	33 33	32 33	33 33	
Surface Bottom	24.02.00	**−0.02**	34 34	33 33	33 33	29 28	29 28	29 30	29 29	30 30	27 27	0.4 0.4	23.02.00	**−0.06**	33 33	33 33	23 24	23 23	21 21	23.02.00	**0.25**	33 33	33 33	33 33	34 33	34 34	34 34	35 35	
Surface Bottom	31.03.00	**−0.07**	35 35	37 37	40 41	44 44	48 48	56 56	60 60	DRY	DRY	0.1 0.1	30.03.00	**−0.10**	29* 29*	31* 31*	33* 33*	32* 32*	32* 32*	30.03.00	**0.26**	29* 29*	29* 29*	29* 29*	29* 29*	30* 30*	30* 30*	31* 30*	
Surface Bottom	29.04.00	**0.01**	34 34	33 33	34 34	38 39	40 40	42 42	42 42	34 34	4 4	0.5 0.5	29.04.00	**−0.05**	31 31	31 31	33 33	37 37	36 36	29.04.00		37 36	37 36	36 36	36 36	36 35	37 36	33 37	
Surface Bottom	25.05.00	**0.06**	37 37	35 35	36 36	35 35	36 36	38 38	38 38	30 30	24 24	0.5 0.5	26.05.00	**0.00**	35 35	36 36	36 36	36 36	30 30	26.05.00		28 28	25 25	32 32	24 30	29 29	26 26	25 30	
Surface Bottom	19.06.00	**0.41**	21 25	23 23	20 21	21 21	18 18	17 17	17 17	6 6	5 5	0.7 0.7	20.06.00	**0.23**	26 28	17 17	19 19	24 24	22 22	20.06.00		35 35	35 35	32 32	28 28	26 26	22 24	24 24	Stopboards were removed from floodgates on 15Jun00.
Surface Bottom	03.07.00	**0.73**	3 11**	5 9	5 7	4 4	5 5	5 6	6 7	6 6	5 7	0.5 0.5	04.07.00	**0.74**	14 17	11 11	10 10	11 11	12 12	04.07.00		11 54	17 18	29 35	28 48	36 46	35 48	36 41	
Surface Bottom	14.08.00	**0.29**	4 16	2 2	2 2	1 1	2 2	2 2	2 2	1 1	1 1	1 1	14.08.00	**0.30**	2 22	1 8	1 1	2 2	2 2	14.08.00		13 32	13 31	13 15	14 26	13 17	13 13	13 13	
Surface Bottom	21.09.00	**0.50**	2 5	2 3	0.9 1	0.7 0.7	1 1	1 1	1 1	0.6 0.6	0.4 0.4	0.3 0.3	21.09.00	**0.52**	2 11	1 5	1 2	1 1	1 1	21.09.00	**0.50**	6 18	6 10	9 10	8 9	8 8	8 8	8 8	

Although only surface and bottom salinities are presented in this Appendix, both salinity and temperature were measured at 0.2m intervals from surface to bottom and these data have been retained.

* There were problems with calibration of the salinity meter on 30.03.00. According to the meter, the 36ppt standard solution had a salinity of 27.5ppt. These readings are uncorrected.

** This single measurement (at Vasse estuary Sampling Station 1 on 03.07.00) was not at the bottom, but instead was at a depth of 1.8m, this being the maximum length of the instrument cable in use at the time. The actual depth to bottom was 2.3m.

^ Floodgate gauge board readings (corrected). Note that these may differ from the CALM logger recordings as the estuary loggers were located 1-3 km upstream from the floodgates. The difference was substantial in the exceptional circumstances of 27 May 1999, when Vasse estuary was flooding and the CALM logger reading was ≈1.3 mAHD whereas the gauge reading was 0.53 mAHD (see Appendix 18).

Water & Rivers Commission automated recording station ('logger') readings from the downstream (Wonnerup Inlet) side of the Vasse estuary floodgates (see page 7).

Key to Colour Shades:	<1ppt	1<3ppt	3<10ppt	10<50ppt	≥50ppt
	Very Fresh	Fresh	Brackish	Saline	Hypersaline

APPENDIX 3. Measured salinities (parts per thousand) in Vasse-Wonnerup wetlands during 1998-2000. Refer to Figures 2 & 3 for locations of Sampling Stations (1-9 etc.).
Bottom salinities have been colour-shaded where stratification (>2 ppt differences surface to bottom) occurred.

	VASSE ESTUARY											LVR	WONNERUP ESTUARY							WONNERUP INLT			DEADWATER						
Salinity	**Date**	**Water Level (m) ^**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**1**	**Date**	**Water Level (m) ^**	**1**	**2**	**3**	**4**	**5**	**Date**	**Water Level (m) #**	**1**	**1**	**2**	**3**	**4**	**5**	**6**	**Comments**
Middle	*01.04.98*	**−0.05**	-	*23*	*26*	*27*	*31*	*31*	*35*	*38*	*DRY*	*1*	*01.04.98*	**−0.36**	-	-	-	*32*	*35*										Sandbar at mouth of Wonnerup Inlet was opened on 02Jan98. Remained open until at least 18Jun98.
Surface Bottom	26.02.99	**−0.10**	40 41	46 46	47 47	50 50	55 55	80 80	90 90	DRY	DRY	0.4	25.02.99	**−0.41**	38 38	44 43	61 61	76 76	98 98										Sandbar at mouth of Wonnerup Inlet was opened on 17Dec98. Remained open until 22Oct99.
Surface Bottom	26.03.99	**−0.08**	40 39	42 42	44 44	50 63	52 58	58 74	75 76	DRY	DRY	0.3 0.3	25.03.99	**−0.40**	38 38	41 41	49 49	71 71	91 91										
Surface Bottom	29.04.99	**−0.05**	38 38	43 43	44 50	50 50	57 58	71 72	75 76	94 94	95 95	0.3 0.3	28.04.99	**−0.30**	38 38	49 54	65 68	69 69	88 88										
Surface Bottom	27.05.99	**0.53**	32 33	21 24	10 24	5 21	8 20	9 12	13 20	16 16	2 11	0.5 0.4	27.05.99	**0.10**	22 33	18 25	23 23	26 29	23 30										Stopboards were removed from floodgates on 27May99.
Surface Bottom	29.06.99	**0.56**	0.6 0.6	0.4 0.8	0.5 0.5	0.6 0.7	0.7 0.8	0.7 0.8	0.5 0.9	0.4 0.4	0.4 0.4	0.4 0.4	29.06.99	**0.58**	0.4 2	0.3 0.3	0.3 0.4	0.4 0.4	0.3 0.4	30.06.99	**0.34**	0.8 0.8	4 4	4 4	4 7	6 8	8 10	9 28	
Surface Bottom	25.11.99	**0.47**	2 2	2 2	2 2	2 2	3 3	2 2	2 2	1 1	0.8 0.9	0.3 0.3	24.11.99	**0.46**	3 3	3 3	3 3	3 3	2 2	24.11.99	**0.41**	3 3	3 3	5 5	5 5	6 6	7 7	7 7	Stopboards were installed in floodgates on 29Sep99. Sandbar at mouth of Wonnerup Inlet was closed artificially on 22Oct99 and raised water levels.
Surface Bottom	30.12.99	**0.29**	15 18	8 8	6 8	5 5	4 4	4 4	4 4	4 4	- -	- -	30.12.99	**0.24**	16 20	10 12	8 11	5 5	4 4	30.12.99		29 32	30 31	28 28	26 29	26 26	22 25	22 23	Sandbar at mouth of Wonnerup Inlet was opened on 24Dec99. Remained open until at least 24Jun00.
Surface Bottom	28.01.00	**0.06**	25 27	16 16	16 16	15 15	13 13	10 9	9 9	9 9	8 8	2 2	27.01.00	**0.12**	26 27	18 21	17 17	13 13	9 9	28.01.00	**0.18**	33 33	33 33	33 33	33 33	33 33	32 33	33 33	
Surface Bottom	24.02.00	**−0.02**	34 34	33 33	33 33	29 28	29 28	29 30	29 29	30 30	27 27	0.4 0.4	23.02.00	**−0.06**	33 33	33 33	23 24	23 23	21 21	23.02.00	**0.25**	33 33	33 33	33 33	34 33	34 34	34 34	35 35	
Surface Bottom	31.03.00	**−0.07**	35 35	37 37	40 41	44 44	48 48	56 56	60 60	DRY	DRY	0.1 0.1	30.03.00	**−0.10**	29* 29*	31* 31*	33* 33*	32* 32*	32* 32*	30.03.00	**0.26**	29* 29*	29* 29*	29* 29*	29* 29*	30* 30*	30* 30*	31* 30*	
Surface Bottom	29.04.00	**0.01**	34 34	33 33	34 34	38 39	40 40	42 42	42 42	34 34	4 4	0.5 0.5	29.04.00	**−0.05**	31 31	31 31	33 33	37 37	36 36	29.04.00		37 36	37 36	36 36	36 36	36 35	37 36	33 37	
Surface Bottom	25.05.00	**0.06**	37 37	35 35	36 36	35 35	36 36	38 38	38 38	30 30	24 24	0.5 0.5	26.05.00	**0.00**	35 35	36 36	36 36	36 36	30 30	26.05.00		28 28	25 25	32 32	24 30	29 29	26 26	25 30	
Surface Bottom	19.06.00	**0.41**	21 25	23 23	20 21	21 21	18 18	17 17	17 17	6 6	5 5	0.7 0.7	20.06.00	**0.23**	26 28	17 17	19 19	24 24	22 22	20.06.00		35 35	35 35	32 32	28 28	26 26	22 24	24 24	Stopboards were removed from floodgates on 15Jun00.
Surface Bottom	03.07.00	**0.73**	3 11**	5 9	5 7	4 4	5 5	5 6	6 7	6 6	5 7	0.5 0.5	04.07.00	**0.74**	14 17	11 11	10 10	11 11	12 12	04.07.00		11 54	17 18	29 35	28 48	36 46	35 48	36 41	
Surface Bottom	14.08.00	**0.29**	4 16	2 2	2 2	1 1	2 2	2 2	2 2	1 1	1 1	1 1	14.08.00	**0.30**	2 22	1 8	1 1	2 2	2 2	14.08.00		13 32	13 31	13 15	14 26	13 17	13 13	13 13	
Surface Bottom	21.09.00	**0.50**	2 5	2 3	0.9 1	0.7 0.7	1 1	1 1	1 1	0.6 0.6	0.4 0.4	0.3 0.3	21.09.00	**0.52**	2 11	1 5	1 2	1 1	1 1	21.09.00	**0.50**	6 18	6 10	9 10	8 9	8 8	8 8	8 8	

Although only surface and bottom salinities are presented in this Appendix, both salinity and temperature were measured at 0.2m intervals from surface to bottom and these data have been retained.

* There were problems with calibration of the salinity meter on 30.03.00. According to the meter, the 36ppt standard solution had a salinity of 27.5 ppt. These readings are uncorrected.

** This single measurement (at Vasse estuary Sampling Station 1 on 03.07.00) was not at the bottom, but instead was at a depth of 1.8m, this being the maximum length of the instrument cable in use at the time. The actual depth to bottom was 2.3m.

^ Floodgate gauge board readings (corrected). Note that these may differ from the CALM logger recordings as the estuary loggers were located 1-3 km upstream from the floodgates. The difference was substantial in the exceptional circumstances of 27 May 1999, when Vasse estuary was flooding and the CALM logger reading was ≈1.3 mAHD whereas the gauge reading was 0.53 mAHD (see Appendix 18).

\# Water & Rivers Commission automated recording station ('logger') readings from the downstream (Wonnerup Inlet) side of the Vasse estuary floodgates (see page 7).

APPENDIX 4. Measured temperatures (°C) in Vasse-Wonnerup wetlands during 1998-2000. Refer to Figures 2 & 3 for locations of Sampling Stations.

	VASSE ESTUARY											LVR	WONNERUP ESTUARY							WONNERUP INLET			DEADWATER						
Salinity	**Date**	**Water Level (m) ^**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**1**	**Date**	**Water Level (m) ^**	**1**	**2**	**3**	**4**	**5**	**Date**	**Water Level (m) #**	**1**	**1**	**2**	**3**	**4**	**5**	**6**	**Comments**
Surface Bottom	26.02.99	**−0.10**	25 25	22 22	22 22	24 24	28 28	27 27	32 32	DRY	DRY	27 27	25.02.99	**−0.41**	28 28	34 34	34 34	34 34	34 34										Sandbar at mouth of Wonnerup Inlet was opened on 17Dec98. Remained open until 22Oct99.
Surface Bottom	26.03.99	**−0.08**	20 20	18 18	18 18	18 20	18 18	18 19	21 21	DRY	DRY	21 21	25.03.99	**−0.40**	22 22	22 22	22 22	22 22	23 23										
Surface Bottom	29.04.99	**−0.05**	17 17	15 15	14 17	15 15	15 15	16 16	18 19	22 22	22 22	20 20	28.04.99	**−0.30**	20 20	21 21	22 22	22 22	23 23										
Surface Bottom	27.05.99	**0.53**	17 17	17 17	- -	18 17	18 17	18 17	18 17	18 18	18 17	17 17	27.05.99	**0.10**	20 17	20 18	19 19	19 19	19 19										Stopboards were removed from floodgates on 27May99.
Surface Bottom	29.06.99	**0.56**	14 14	14 14	14 13	16 14	14 14	15 13	15 13	14 14	15 14	14 14	29.06.99	**0.58**	13 13	14 13	14 12	14 13	14 13	30.06.99	**0.34**	14 13	14 14	14 14	14 14	14 14	14 15	14 16	
Surface Bottom	25.11.99	**0.47**	24 23	23 23	23 23	24 24	23 23	24 24	24 24	24 24	24 24	26 23	24.11.99	**0.46**	22 22	21 21	22 22	22 22	- -	24.11.99	**0.41**	26 23	26 25	24 23	22 23	28 25	28 24	26 23	Stopboards were installed in floodgates on 29Sep99. Sandbar at mouth of Wonnerup Inlet was closed artificially on 22Oct99 and raised water levels.
Surface Bottom	30.12.99	**0.29**	28 27	25 25	24 24	25 25	24 24	24 24	23 23	23 23	- -	- -	30.12.99	**0.24**	22 22	22 23	22 23	23 23	22 22	30.12.99		25 25	26 25	27 27	27 27	29 29	28 29	28 29	Sandbar at mouth of Wonnerup Inlet was opened on 24Dec99. Remained open until at least 24Jun00.
Surface Bottom	28.01.00	**0.06**	26 25	24 24	23 23	25 25	25 25	25 25	25 25	28 28	26 26	29 27	27.01.00	**0.12**	26 25	27 25	25 25	25 25	25 24	28.01.00	**0.18**	22 23	23 23	24 23	23 24	24 24	24 24	24 24	
Surface Bottom	24.02.00	**−0.02**	23 23	22 22	21 22	22 22	22 22	22 22	23 22	32 32	24 24	26 26	23.02.00	**−0.06**	25 25	25 25	25 25	25 25	25 24	23.02.00	**0.25**	26 25	26 26	26 26	26 25	26 26	26 25	25 25	
Surface Bottom	31.03.00	**−0.07**	20 20	22 22	21 21	23 23	24 24	24 24	24 24	DRY	DRY	24 24	30.03.00	**−0.10**	24 22	25 24	25 25	24 24	25 25	30.03.00	**0.26**	23 22	23 22	23 23	23 22	23 22	23 22	23 23	
Surface Bottom	29.04.00	**0.01**	16 16	15 16	14 15	16 16	16 16	19 19	17 17	19 19	19 19	18 17	29.04.00	**−0.05**	14 14	13 13	14 14	14 14	14 14	29.04.00		15 15	16 15	15 15	14 14	14 16	14 14	15 15	
Surface Bottom	25.05.00	**0.06**	14 15	13 13	12 13	14 15	13 13	15 15	15 15	15 15	16 16	16 16	26.05.00	**0.00**	14 14	12 12	13 13	13 13	13 13	26.05.00		15 14	16 15	15 15	14 14	14 14	14 14	14 14	
Surface Bottom	19.06.00	**0.41**	14 14	14 14	14 14	14 14	13 13	13 13	13 13	13 13	13 13	13 13	20.06.00	**0.23**	14 14	14 14	14 14	14 14	14 14	20.06.00		15 15	15 15	14 14	14 14	14 14	14 14	14 14	Stopboards were removed from floodgates on 15Jun00.
Surface Bottom	03.07.00	**0.73**	14 14*	14 14	14 14	14 14	14 14	13 13	13 14	14 14	14 14	13 13	04.07.00	**0.74**	14 14	14 14	14 14	14 14	14 14	04.07.00		14 15	14 14	14 14	14 14	14 15	14 15	14 14	
Surface Bottom	14.08.00	**0.29**	14 14	15 15	14 14	14 14	13 13	14 14	14 14	13 13	14 14	12 12	14.08.00	**0.30**	16 15	15 14	15 15	15 15	14 14	14.08.00		16 14	15 15	15 15	16 15	15 15	14 15	15 15	
Surface Bottom	21.09.00	**0.50**	18 17	17 18	17 16	17 16	16 16	17 16	16 16	16 16	16 16	15 15	21.09.00	**0.52**	17 18	18 17	18 17	18 17	18 17	21.09.00	**0.50**	18 18	20 20	21 20	20 19	19 18	19 17	20 18	

Although only surface and bottom temperatures are presented in this Appendix, both salinity and temperature were measured at 0.2m intervals from surface to bottom and these data have been retained.

* This single measurement (at Vasse estuary Sampling Station 1 on 03.07.00) was not at the bottom, but instead was at a depth of 1.8m, this being the maximum length of the instrument cable in use at the time. The actual depth to bottom was 2.3m.

^ Floodgate gauge board readings (corrected). Note that these may differ from the CALM logger recordings as the estuary loggers were located 1-3 km upstream from the floodgates. The difference was substantial in the exceptional circumstances of 27 May 1999, when Vasse estuary was flooding and the CALM logger reading was ≈1.3 mAHD whereas the gauge reading was 0.53 mAHD (see Appendix 18).

Water & Rivers Commission automated recording station ('logger') readings from the downstream (Wonnerup Inlet) side of the Vasse estuary floodgates (see page 7).

Key to Colour Shades

DRY	11-15 °C	16-20 °C	21-25 °C	26-30 °C	31-35 °C

APPENDIX 5. Measured temperatures (°C) in Vasse-Wonnerup wetlands during 1998-2000. Refer to Figures 2 & 3 for locations of Sampling Stations (1-9 etc.). Bottom temperatures have been colour-shaded where stratification (>2 °C differences surface to bottom) occurred.

	VASSE ESTUARY											LVR	WONNERUP ESTUARY							WONNERUP INLET			DEADWATER						Comments
Salinity	Date	Water Level (m) ^	1	2	3	4	5	6	7	8	9	1	Date	Water Level (m) ^	1	2	3	4	5	Date	Water Level (m) #	1	1	2	3	4	5	6	
Surface Bottom	26.02.99	**−0.10**	25 25	22 22	22 22	24 24	28 28	27 27	32 32	DRY	DRY	27 27	25.02.99	**−0.41**	28 28	34 34	34 34	34 34	34 34										Sandbar at mouth of Wonnerup Inlet was opened on 17Dec98. Remained open until 22Oct99.
Surface Bottom	26.03.99	**−0.08**	20 20	18 18	18 18	18 20	18 18	18 19	21 21	DRY	DRY	21 21	25.03.99	**−0.40**	22 22	22 22	22 22	22 22	23 23										
Surface Bottom	29.04.99	**−0.05**	17 17	15 15	14 17	15 15	15 15	16 16	18 19	22 22	22 22	20 20	28.04.99	**−0.30**	20 20	21 21	22 22	22 22	23 23										
Surface Bottom	27.05.99	**0.53**	17 17	17 17	- -	18 17	18 17	18 17	18 17	18 18	18 17	17 17	27.05.99	**0.10**	20 17	20 18	19 19	19 19	19 19										Stopboards were removed from floodgates on 27May99.
Surface Bottom	29.06.99	**0.56**	14 14	14 14	14 13	16 14	14 14	15 13	15 13	14 14	15 14	14 14	29.06.99	**0.58**	13 13	14 13	14 12	14 13	14 13	30.06.99	**0.34**	14 13	14 14	14 14	14 14	14 14	14 15	14 16	
Surface Bottom	25.11.99	**0.47**	24 23	23 23	23 23	24 24	23 23	24 24	24 24	24 24	24 24	26 23	24.11.99	**0.46**	22 22	21 21	22 22	22 22	- -	24.11.99	**0.41**	26 23	26 25	24 23	22 23	28 25	28 24	26 23	Stopboards were installed in floodgates on 29Sep99. Sandbar at mouth of Wonnerup Inlet was closed artificially on 22Oct99 and raised water levels.
Surface Bottom	30.12.99	**0.29**	28 27	25 25	24 24	25 25	24 24	24 24	23 23	23 23	- -	- -	30.12.99	**0.24**	22 22	22 23	22 23	23 23	22 22	30.12.99		25 25	26 25	27 27	27 27	29 29	28 29	28 29	Sandbar at mouth of Wonnerup Inlet was opened on 24Dec99. Remained open until at least 24Jun00.
Surface Bottom	28.01.00	**0.06**	26 25	24 24	23 23	25 25	25 25	25 25	25 25	28 28	26 26	29 27	27.01.00	**0.12**	26 25	27 25	25 25	25 25	25 24	28.01.00	**0.18**	22 23	23 23	24 24	23 24	24 24	24 24	24 24	
Surface Bottom	24.02.00	**−0.02**	23 23	22 22	21 22	22 22	22 22	22 22	23 22	32 32	24 24	26 26	23.02.00	**−0.06**	25 25	25 25	25 25	25 25	25 24	23.02.00	**0.25**	26 25	26 26	26 26	26 25	26 26	26 25	25 25	
Surface Bottom	31.03.00	**−0.07**	20 20	22 22	21 21	23 23	24 24	24 24	24 24	DRY	DRY	24 24	30.03.00	**−0.10**	24 22	25 24	25 25	24 24	25 25	30.03.00	**0.26**	23 22	23 22	23 23	23 22	23 22	23 22	23 23	
Surface Bottom	29.04.00	**0.01**	16 16	15 16	14 15	16 16	16 16	19 19	17 17	19 19	19 19	18 17	29.04.00	**−0.05**	14 14	13 13	14 14	14 14	14 14	29.04.00		15 15	16 15	15 15	14 14	14 16	14 14	15 15	
Surface Bottom	25.05.00	**0.06**	14 15	13 13	12 13	14 15	13 13	15 15	15 15	15 15	16 16	16 16	26.05.00	**0.00**	14 14	12 12	13 13	13 13	13 13	26.05.00		15 14	16 15	15 15	14 14	14 14	14 14	14 14	
Surface Bottom	19.06.00	**0.41**	14 14	14 14	14 14	14 14	13 13	13 13	13 13	13 13	13 13	13 13	20.06.00	**0.23**	14 14	14 14	14 14	14 14	14 14	20.06.00		15 15	15 15	14 14	14 14	14 14	14 14	14 14	Stopboards were removed from floodgates on 15Jun00.
Surface Bottom	03.07.00	**0.73**	14 14*	14 14	14 14	14 14	14 14	13 13	13 14	14 14	14 14	13 13	04.07.00	**0.74**	14 14	14 14	14 14	14 14	14 14	04.07.00		14 15	14 14	14 14	14 14	14 15	14 15	14 14	
Surface Bottom	14.08.00	**0.29**	14 14	15 15	14 14	14 14	13 13	14 14	14 14	13 13	14 14	12 12	14.08.00	**0.30**	16 15	15 14	15 15	15 15	14 14	14.08.00		16 14	15 15	15 15	16 15	15 15	14 15	15 15	
Surface Bottom	21.09.00	**0.50**	18 17	17 18	17 16	17 16	16 16	17 16	16 16	16 16	16 16	15 15	21.09.00	**0.52**	17 18	18 17	18 17	18 17	18 17	21.09.00	**0.50**	18 18	20 20	21 20	20 19	19 18	19 17	20 18	

Although only surface and bottom temperatures are presented in this Appendix, both salinity and temperature were measured at 0.2m intervals from surface to bottom and these data have been retained.

* This single measurement (at Vasse estuary Sampling Station 1 on 03.07.00) was not at the bottom, but instead was at a depth of 1.8m, this being the maximum length of the instrument cable in use at the time. The actual depth to bottom was 2.3m.

LVR = Lower Vasse River Wetlands.

^ Floodgate gauge board readings (corrected). Note that these may differ from the CALM logger recordings as the estuary loggers were located 1-3 km upstream from the floodgates. The difference was substantial in the exceptional circumstances of 27 May 1999, when Vasse estuary was flooding and the CALM logger reading was ≈1.3 mAHD whereas the gauge reading was 0.53 mAHD (see Appendix 18).

\# Water & Rivers Commission automated recording station ('logger') readings from the downstream (Wonnerup Inlet) side of the Vasse estuary floodgates (see page 7).

APPENDIX 6. Dates of water column profiling, inundation mapping and waterbird surveys on Vasse-Wonnerup wetlands in 1998-2000.

	Feb 98	Mar 98	Apr 98	Dec 98	Jan 99	Feb 99	Mar 99	Apr 99	May 99	Jun 99	Nov 99	Dec 99	Jan 00	Feb 00	Mar 00	Apr 00	May 00	Jun 00	Jul 00	Aug 00	Sep 00
VASSE ESTUARY																					
Profiling			01			26	26	29	27	29	25	30	28	24	31	29	25	19	03	14	21
Inundation	25	25	01			26		27	27			29	25	22	29	29		19	03	14	
Waterbirds	25	25	28	29	27	24	24	27	28		23	29	25	22	29						
LOWER VASSE RIVER WETLANDS																					
Profiling						26	26	29	27	29	25	30	28	24	31	29	25	19	03	14	21
Waterbirds				29	27	24	24	27	28			29	25 28	22	29						
WONNERUP ESTUARY																					
Profiling			01			25	25	28	27	29	24	30	27	23	30	29	26	20	04	14	21
Inundation	26	26	01			25		28	29			29	27	23	30	29		20		14	
Waterbirds	26	25	29	30	28	25	25	28	29		24	29	27	23	30						
THE DEADWATER																					
Profiling										30	24	30	28	23	30	29	26	20	04	14	21
Waterbirds				30	28	25	25	28	29		24	30	27	23	3Apr						
WONNERUP INLET																					
Profiling										30	24	30	28	23	30	29	26	20	04	14	21
Waterbirds				30	28	25	25	28	29		24	30	27	23	30						

NOTES

1. Cells in the above Table contain the date on which each waterbody was profiled (depth, salinity and temperature), had its extent of inundation mapped, or had its waterbird population surveyed (Lane *et al.* 2007).
2. Profiling of the Lower Vasse River Wetlands was limited to one location in the excavated channel at the eastern (downstream) end of these wetlands, c. 20m upstream of the Ford Road alignment.
3. Profiling of Wonnerup Inlet was limited to the north-eastern end, at a single sampling site between the Wonnerup Estuary floodgates and the mouth of the Deadwater.

APPENDIX 7. Global Positioning System (GPS) coordinates of Vasse-Wonnerup sampling locations in 1998-2000.

The locations of all 1998-2000 profiling stations were first established and subsequently re-visited during the study period by visual reference to various natural and man-made features nearby or at a distance, rather than by GPS (Global Positioning System) or location markers. Locations where the waterbodies were narrow could be pinpointed to within tens of metres or better. It was more difficult, however, to consistently locate positions on the broad expanses of the estuaries by visual means and in these situations the location of individual profiling stations varied by as much as several hundred metres. In February and October 2007 attempts were made to 'fix' the approximate positions of the 1998-2000 profiling stations by handheld GPS. The results, presented below, demonstrate the difficulty that was experienced in visually pinpointing the locations of (at least) Vasse estuary profiling stations 5-7 and Wonnerup estuary station 4. The GPS datum was WGS 84. All eastings and northings were within Zone 50 and the manufacturer's claimed accuracy of the handheld GPS unit was ± several metres.

Vasse estuary

	26 February 2007		23 October 2007			Difference (Feb minus Oct) (in metres)	
Profiling Station	**Northings**	**Eastings**	**Northings**	**Eastings**		**Northings**	**Eastings**
1	6 278 880	352 846	6 278 859	352 831		21	15
2	6 277 696	351 705	6 277 727	351 712		−31	−7
3	6 277 778	352 127	6 277 750	352 160		28	−33
4	6 277 148	353 151	6 277 109	353 145		39	6
5	6 276 639	351 814	6 276 815	352 063		−176	−249
6	6 276 209	351 243	6 276 174	351 387		35	−144
7	6 275 679	350 285	6 275 782	350 524		−103	−239
8			6 275 391	349 395			
9			6 275 470	348 424			
***LVRW 1**			6 275 031	347 746			

* Lower Vasse River Wetlands (Station 1)

Wonnerup estuary

	26 February 2007		23 October 2007			Differences (Feb minus Oct) (in metres)	
Profiling Station	**Northings**	**Eastings**	**Northings**	**Eastings**		**Northings**	**Eastings**
1	6 279 569	354 007	6 279 561	354 008		8	−1
2	6 279 157	354 670	6 279 145	354 650		12	20
3	6 279 342	355 376	6 279 350	355 382		−8	−6
4	6 280 006	355 691	6 280 111	355 847		−105	−156
5			6 281 206	356 003			

Deadwater

	22 or 23? October 2007	
Profiling Station	**Northings**	**Eastings**
1	6 279 674	353 978
2	6 280 029	354 231
3	6 280 190	354 351
4	6 280 559	354 702
5	6 280 895	355 016
6	6 281 227	355 264

Wonnerup Inlet

	22 or 23? October 2007	
Profiling Station	**Northings**	**Eastings**
1	6 279 601	353 960

APPENDIX 8. Status of Sand Bar at mouth of Wonnerup Inlet from July 1997 to October 2000

Listed below are the dates on which the sand bar at the mouth of Wonnerup Inlet (Photos 23 & 24) was inspected by J. Lane during the period July 1997 to September 2000. These cover the entire period (April 1998 to September 2000) in which profiling was undertaken for this report and some months (July 1997 to March 1998) leading up to this period. The status of the bar in these 'lead up' months potentially affected (though indirectly, due to the presence of the floodgates) the salinities of the Vasse and Wonnerup estuaries in April 1998. The inspections were related primarily to efforts to minimise fish mortalities in Vasse-Wonnerup (see Lane *et al.* 1997) rather than the profiling work of this report, hence their high frequency.

1997

21-22 Jul	Open
10 Oct	Open
19 Nov	Closed*
24 Nov	Closed*
06 Dec	Closed
09-15 Dec	Closed
16 Dec	Closed*
17-31 Dec	Closed

1998

01 Jan	Closed
02 Jan	Opened*
03-12 Jan	Open
13 Jan	Open
14-18 Jan	Open
19 Jan	Open
20-27 Jan	Open
29-31 Jan	Open
01-20 Feb	Open
22-27 Feb	Open
01-03 Mar	Open
05-07 Mar	Open
10-12 Mar	Open
15 Mar	Open
17 Mar	Open
30 Mar	Open
02-03 Apr	Open
06 Apr	Open
09 Apr	Open
11 Apr	Open
13 Apr	Open
17 Apr	Open
24 Apr	Open
28 Apr	Open

1998 contd.

02 May	Open
07 May	Open
09 May	Open
11 May	Open
17 May	Open
20 May	Open
26 May	Open
29 May	Open
18 Jun	Open
02 Oct	Closed
26 Nov	Open*
01 Dec	Open
15-16 Dec	Open
17 Dec	Opened*
19 Dec	Open
21-26 Dec	Open
28 Dec	Open
30-31 Dec	Open

1999

08 Jan 1999	Open
14 Jan	Open
16 Jan	Open
19 Jan	Open
26-27 Jan	Open
30 Jan	Open
02 Feb	Open
06 Feb	Open
26 Feb	Open
01 Mar	Open
03 Mar	Open
20 Mar	Open
23 Apr	Open
28 Apr	Open

1999 contd.

16 May	Open
26 May	Open
22 Jul	Open
20 Sep	Open
21 Oct	Open
22 Oct	Closed*
23-24 Oct	Closed
27 Oct	Closed
29 Oct	Closed
23 Nov	Closed
16 Dec	Closed
18 Dec	Closed
20 Dec	Closed*
22 Dec	Closed
24 Dec	Opened*
26 Dec	Open
28 Dec	Open
30 Dec	Open

2000

06 Jan 2000	Open
13 Jan	Open
20 Jan	Open
10 Feb	Open
18 Feb	Open
25 Feb	Open
04 Mar	Open
14 Mar	Open
20 Mar	Open
03 Apr	Open
30 Apr	Open
24 Jun	Open
Mid Sep	Closed
c. 06 Oct	Opened*

* Additional details

19 Nov 97: 'At high tide there would have been a very long (c. 300m) narrow (down to 2m) connection to the sea …'

24 Nov 97: High tide observed overtopping sand bar at 1645 hrs.

16 Dec 97: High tide 'last night' overtopped the sand bar.

02 Jan 98: The sand bar was opened by a Water Corporation contractor at 1600hrs. Water flowed out strongly. Cut through bar was approximately 14m wide and '2ft deep'.

26 Nov 98: Opening described as narrow (5m at narrowest) and shallow (c. 0.2m deep at Inlet end).

17 Dec 98: Open. Water Corp contractor excavated a wider and deeper channel through the sand bar.

22 Oct 99: Bar artificially closed due to Wonnerup estuary floodgate stopboards being washed out of two bays.

20 Dec 99: Closed. Work starts on repairing Wonnerup estuary floodgates' damaged bays and replacing stopboards.

24 Dec 99: Opened by Water Corp at 1300-1400hrs.

c. 06 Oct 00: Bar artificially opened to lower water levels in the estuaries.

NOTE

Where span of dates (e.g. 21-22 Jul 97) is indicated, the sand bar was inspected at least once each day within entire span.

APPENDIX 9. Heights of stopboards and sills in Vasse and Wonnerup estuary floodgates in 1997-98, 1998-99 and 1999-2000.

1997-98

Heights of stopboards in Vasse estuary floodgates and Wonnerup estuary floodgates as measured by J. Lane on 03 April 1998 and 20 February 1998 respectively. Bays are numbered sequentially from south end to north end (Vasse; 14 bays) and north-east end to south-west end (Wonnerup; 11 bays). These boards were in place from "between 01Aug97 & 10Oct97" until "between 26May98 & 02Jun98" (see Table 2 of this report).

Bay	Vasse board heights (mAHD)	Wonnerup board heights (mAHD)	Wonnerup sill heights (mAHD)
1	0.45	0.36	–0.39
2	0.46	0.38	–0.38
3	0.43	0.41	–0.37
4	0.59	0.39	–0.38
5	0.48	0.38	–0.38
6	0.41	0.39	–0.36
7	0.44	0.38	–0.37
8	Stopboards removed months earlier	0.38	–0.38
9	0.48	-	–0.38
10	0.42	-	–0.39
11	0.45	0.36	–0.40
12	0.45		
13	0.53		
14	0.49		
Mean	**0.468**	**0.381**	**–0.380**
Range	**0.41 - 0.59**	**0.36 - 0.41**	**–0.36 - −0.40**

The sill heights (cease-to-flow levels of bay openings when boards are not in place) of the Wonnerup estuary floodgates were also measured on 20 February 98.

1998-99

The heights of the stopboards were not measured in 1998-99, however some relevant observations were made. Thus, on 02 October 1998, when the Vasse estuary water level was 0.64 mAHD, "water level is above all boards in all bays". And at Wonnerup estuary on the same day, when the water level was 0.61 mAHD, "all boards are in place but seem to be set at widely differing heights in some cases. Water level is above the top of the boards in most bays". On 26 November 1998, when the water level in the Vasse estuary was 0.31 mAHD, "water level [was] below all boards" and on the Wonnerup estuary, with the water level at 0.18m, "water level [was] below all boards".

From the above notes we can deduce that in 1998-99 all Vasse estuary floodgate stopboards were set at heights somewhere between 0.32 and 0.63 mAHD (the midpoint of this 'range' being 0.475 mAHD). Most Wonnerup estuary floodgate stopboards were set within the 'range' 0.32-0.60 mAHD (noting that all were above 0.31 mAHD). The midpoint of this latter 'range' is 0.46 mAHD.

1999-2000

Heights of stopboards in Vasse and Wonnerup estuary floodgates as measured by A. Clarke on 25 May 2000 and 26 May 2000 respectively. Bays are numbered sequentially from south end to north end (Vasse) and north-east end to south-west end (Wonnerup). These boards were in place from 29 September 1999 to 15 June 2000. 'Mean' and 'Range' do not include 'Reverse flap', 'No boards' or '?' bays.

Bay	Vasse board heights (mAHD)	Wonnerup board heights (mAHD)
1	0.45	0.36
2	0.47	0.38
3	0.44	0.39
4	0.40	0.44
5	0.49	0.39
6	0.45	0.40
7	0.44	0.39
8	Reverse flap	0.38
9	0.48	No boards
10	0.45	0.37
11	0.46	0.37
12	0.54	
13	0.48	
14	?	
Mean	**0.462**	**0.387**
Range	**0.40-0.54**	**0.36 - 0.44**

APPENDIX 10. Additional profiling of Vasse and Wonnerup estuaries' exit channels.

Vasse estuary exit channel: 13 January 1998

This profiling was undertaken by J. Busniak (Water & Rivers Commission, Bunbury) and J. Lane (Department of Conservation & Land Management, Busselton, plus press-ganged anchor-weighers Garrett (8 yrs) and Chloé (7 yrs) ('No, not the floodgates again please Dad!'). A boat was used to profile the Vasse estuary exit channel from the Vasse estuary floodgates (upstream side) to Estuary View Drive, that is, from sampling Station 1 to Station 2 (approx.) of this report. The profiling was undertaken at 1254-1324 hrs and was aimed principally at recording Dissolved Oxygen concentrations (not reported here) due to concerns about fish. The estuary water level at the time was −0.08 mAHD.

Salinity (parts per thousand)

	100m	200m	Ballarat Rd (850m)	Est. View Dve
Surface	13	13	14	13
Bottom	15	16	16	-

Temperature (°C)

	100m	200m	Ballarat Rd (850m)	Est. View Dve
Surface	26	28	28	28
Bottom	26	25	26	-

Vasse estuary exit channel: 19 January 1998

This profiling was also undertaken by J. Busniak and J. Lane. A boat was used to profile the Vasse estuary exit channel from the Vasse estuary floodgates (upstream side) to a point 200m upstream, that is from sampling Station 1 part-way to Station 2. The profiling was undertaken at 1141-1215 hrs and was aimed principally at counting dead fish (mullet) and recording Dissolved Oxygen concentrations (not reported here). The estuary water level at the time was −0.10 mAHD.

Salinity (parts per thousand)

	50m	100m	200m
Surface	19	18	17
Bottom	18	15	17

Temperature (°C)

	50m	100m	200m
Surface	25	25	26
Bottom	24	24	23

Vasse estuary exit channel: 16 December 1998

Water & Rivers Commission officers profiled Dissolved Oxygen, Temperature, Salinity and pH on the upstream side of the floodgates at 1155-1202 hrs.

Depth (m)	Temp. (°C)	Salinity (ppt)
Surface	27	17
0.5	27	17
1.0	26	28
1.2	25	29

Vasse estuary exit channel: 08 January 1999

This profiling was also undertaken by J. Busniak and J. Lane. A punt was used to profile the Vasse estuary exit channel from the Vasse estuary floodgates (upstream side) to Estuary View Drive, that is from sampling Station 1 to Station 2 (approx). The profiling was undertaken at 0424-0521hrs using a 'Hydrolab D/S 4' and was aimed principally at recording early morning Dissolved Oxygen concentrations (not reported here) due to concerns about fish. The estuary water level at the time was 0.05 mAHD.

Salinity (parts per thousand)

	Probe (10m)	Palm Tree 1st (110m)	Fence Post	Bend / Pwr Pole (430m)	Left Hand Jetty (570m)	Vas. Est 2 (850m)	Channel Jnctn (1.1 km)	Post Est. View Dve
Surface	27	26	26	26	25	25	24	23
Bottom	31	27	30	29	29	28	26	-

Vasse estuary exit channel: 08 January 1999 Continued.

Temperature (°C)

	Probe (10m)	Palm Tree 1st (110m)	Fence Post	Bend / Pwr Pole (430m)	Left Hand Jetty (570m)	Vas. Est 2 (850m)	Channel Jnctn (1.1 km)	Post Est. View Dve
Surface	22	21	22	22	21	22	22	21
Bottom	23	23	24	24	23	22	22	-

Vasse estuary exit channel: 26 February 2000

This profiling was undertaken by C. Webb (Water & Rivers Commission, Bunbury) and J. Lane. A punt was used to profile the lowest 260 metres of the Vasse estuary exit channel, from sampling Station 1 part way to Station 2. The profiling was undertaken at 0655–0714 hrs and was aimed principally at recording early morning Dissolved Oxygen concentrations (not reported here) due to concerns about fish. The estuary water level at the time was −0.04 mAHD.

Temperature (°C)

	Floodgates (2m)	Railway Irons (75m)	Strainer Posts (260m)
Surface	21	21	21
Bottom	21	21	21

Depth (metres)

	Floodgates (2m)	Railway Irons (75m)	Strainer Posts (260m)
Surface	0.0	0.0	0.0
Bottom	2.30	0.65	1.27

Wonnerup estuary exit channel: 26 February 2000

This profiling was also undertaken by C. Webb and J. Lane. A punt was used to profile the lowest 265 metres (approx.) of the Wonnerup estuary exit channel, from sampling Station 1 part-way to Station 2. The profiling was undertaken at 0601-0626 hrs and was aimed principally at recording early morning Dissolved Oxygen concentrations (not reported here) due to concerns about fish. The estuary water level at the time was −0.08 mAHD.

Temperature (°C)

	Floodgates (2m)	Ramsar Sign (25m)	Metal Pole	Power Line (135m)	Bank (265m?)
Surface	20	19	19	18	18
Bottom	20	19	19	18	18

Depth (metres)

	Floodgates (2m)	Ramsar Sign (25m)	Metal Pole	Power Line (135m)	Bank (265m?)
Surface	0.0	0.0	0.0	0.0	0.0
Bottom	0.9	0.7	0.8	0.7	0.4

APPENDIX 11. Calculation of Vasse estuary, Wonnerup estuary and Deadwater longitudinal depth profiles.

Longitudinal depth profiles of each waterbody may be calculated by deducting surface water levels (in mAHD) from measured water depths. The data and calculations are presented below and the results are presented in Section 6.2 in the main body of this report.

		Vasse Estuary																		LVRW	
Station		**1**		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**9**		**1**	
Distance (km)		**0.01**		**1.6**		**2.3**		**3.2**		**4.4**		**5.2**		**5.9**		**7.1**		**8.0**		**9.2**	
Date	**W L**	**D**	**-ve BL**	**D**	**-ve BL**	**D**	**-ve BL**	**D**	**-ve BL**	**D**	**-ve BL**	**D**	**-ve BL**	**D**	**-ve BL**	**D**	**-ve BL**	**D**	**-ve BL**	**D**	**-ve BL**
01.04.98	**-0.05**					0.36	0.41	0.32	0.37	0.15	0.2	0.25	0.3	0.18	0.23	0.02	0.07	0	0.05		
26.02.99	**-0.10**	1.07	1.17	0.18	0.28	0.26	0.36	0.16	0.26	0.07	0.17	0.18	0.28	0.07	0.17	0	0.1	0	0.1	0.35	0.45
26.03.99	**-0.08**	1.35	1.43	0.21	0.29	0.4	0.48	0.21	0.29	0.37	0.45	0.14	0.22	0.12	0.2	0	0.08	0	0.08	0.33	0.41
29.04.99	**-0.05**	0.83	0.88	0.22	0.27	0.45	0.5	0.25	0.3	0.25	0.3	0.26	0.31	0.18	0.23	0.04	0.09	0.03	0.08	0.3	0.35
27.05.99	*0.53*	*1.2*	*0.67*	*0.8*	*0.27*	*1.1*	*0.57*	*0.83*	*0.3*	*0.82*	*0.29*	*0.63*	*0.1*	*0.68*	*0.15*	*0.6*	*0.07*	*0.76*	*0.23*	*0.9*	*0.37*
29.06.99	**0.56**			0.92	0.36	1.25	0.69	0.9	0.34	0.93	0.37	0.67	0.11	0.85	0.29	0.61	0.05	0.84	0.28	0.86	0.3
25.11.99	**0.47**	1.43	0.96	0.85	0.38	1.1	0.63	0.7	0.23	0.8	0.33	0.55	0.08	0.63	0.16	0.5	0.03	0.7	0.23	0.7	0.23
30.12.99	**0.29**	1.5	1.21	0.8	0.51	0.8	0.51	0.5	0.21	0.4	0.11	0.3	0.01	0.4	0.11	0.15	-0.14	0.5	0.21	0.5	0.21
28.01.00	**0.06**	1.0	0.94	0.4	0.34	0.5	0.44	0.23	0.17	0.15	0.09	0.12	0.06	0.3	0.24	0.1	0.04	0.23	0.17	0.3	0.24
24.02.00	**-0.02**	1.2	1.22	0.2	0.22	0.4	0.42	0.18	0.2	0.22	0.24	0.15	0.17	0.15	0.17	0.04	0.06	0.15	0.17	0.25	0.27
31.03.00	**-0.07**	1.2	1.27	0.3	0.37	0.5	0.57	0.2	0.27	0.2	0.27	0.15	0.22	0.12	0.19	0	0.07	0	0.07	0.4	0.47
29.04.00	**0.01**	0.8	0.79	0.23	0.22	0.5	0.49	0.2	0.19	0.17	0.16	0.1	0.09	0.12	0.11	0.06	0.05	0.12	0.11	0.35	0.34
25.05.00	**0.06**	1.75	1.69	0.35	0.29	0.6	0.54	0.38	0.32	0.38	0.32	0.12	0.06	0.2	0.14	0.09	0.03	0.2	0.14	0.3	0.24
19.06.00	**0.41**	1.28	0.87	0.7	0.29	0.96	0.55	0.75	0.34	0.55	0.14	0.55	0.14	0.65	0.24	0.35	-0.06	0.5	0.09	0.66	0.25
03.07.00	**0.73**	2.3	1.57	1.2	0.47	1.25	0.52	0.9	0.17	0.9	0.17	0.9	0.17	0.9	0.17	0.8	0.07	1.0	0.27	0.8	0.07
14.08.00	**0.29**	1.17	0.88	0.7	0.41	0.88	0.59	0.7	0.41	0.64	0.35	0.38	0.09	0.5	0.21	0.28	-0.01	0.53	0.24	0.6	0.31
21.09.00	**0.50**	1.24	0.74	0.8	0.3	1.0	0.5	0.85	0.35	0.81	0.31	0.61	0.11	0.72	0.22	0.55	0.05	0.77	0.27	0.79	0.29
Min			0.74		0.22		0.36		0.17		0.09		0.01		0.11		-0.14		0.05		0.07
-SD			0.82		0.25		0.43		0.20		0.14		0.06		0.14		-0.02		0.08		0.19
Avg			1.12		0.33		0.51		0.28		0.25		0.15		0.19		0.04		0.16		0.30
+SD			1.41		0.42		0.60		0.35		0.35		0.23		0.24		0.10		0.24		0.40
Max			1.69		0.51		0.69		0.41		0.45		0.31		0.29		0.10		0.28		0.47
SD			0.30		0.08		0.08		0.08		0.10		0.09		0.05		0.06		0.08		0.10

mAHD = metres Australian Height Datum, where 0.0 mAHD is approximately mean (average) sea level.

LVRW = Lower Vasse River Wetlands

WL = Water Level in mAHD

D = Depth in metres

-ve BL = D minus WL = negative Bed Level in mAHD (e.g. –ve BL of 1.17 indicates estuary bed level at this Station is −1.17 mAHD).

Avg. = Average (mean)

SD = Standard Deviation

-**SD** = Average minus Standard Deviation

+**SD** = Average minus Standard Deviation

Note
The measurements made on 27.05.99 have not been used in the longitudinal depth profile calculations due to the extreme unevenness of the water surface at the time of profiling.

APPENDIX 11 contd.

		Wonnerup Estuary									
Station		1		2		3		4		5	
Distance (km)		0.01		1.2		2.0		2.8		4.0	
Date	WL	D	-ve BL	D	-ve BL	D	-ve BL	D	-ve BL	D	-ve BL
01.04.98	**-0.36**							0.09	0.45	0.1	0.46
25.02.99	**-0.41**	0.41	0.82	0.18	0.59	0.24	0.65	0.17	0.58	0.17	0.58
25.03.99	**-0.40**	0.48	0.88	0.35	0.75	0.18	0.58	0.18	0.58	0.2	0.6
28.04.99	**-0.30**	0.6	0.9	0.4	0.7	0.26	0.56	0.26	0.56	0.23	0.53
27.05.99	**0.10**	1.07	0.97	0.63	0.53	0.53	0.43	0.63	0.53	0.66	0.56
29.06.99	**0.58**	1.26	0.68	1.17	0.59	1.05	0.47	1.12	0.54	1.13	0.55
24.11.99	**0.46**	1.35	0.89	1.2	0.74	1.07	0.61	0.96	0.5	0.8	0.34
30.12.99	**0.24**	1.2	0.96	0.9	0.66	0.7	0.46	0.8	0.56	0.8	0.56
27.01.00	**0.12**	0.8	0.68	0.6	0.48	0.43	0.31	0.55	0.43	0.55	0.43
23.02.00	**-0.06**	0.9	0.96	0.5	0.56	0.3	0.36	0.4	0.46	0.6	0.66
30.03.00	**-0.10**	0.8	0.9	0.6	0.7	0.5	0.6	0.3	0.4	0.4	0.5
29.04.00	**-0.05**	0.7	0.75	0.6	0.65	0.4	0.45	0.4	0.45	0.4	0.45
26.05.00	**0.00**	0.94	0.94	0.8	0.8	0.58	0.58	0.56	0.56	0.53	0.53
20.06.00	**0.23**	1.0	0.77	0.8	0.57	0.7	0.47	0.8	0.57	0.7	0.47
04.07.00	**0.74**	1.4	0.66	1.2	0.46	1.2	0.46	1.2	0.46	1.0	0.26
14.08.00	**0.30**	1.2	0.9	1.1	0.8	0.8	0.5	0.83	0.53	0.75	0.45
21.09.00	**0.52**	1.4	0.88	1.15	0.63	1.0	0.48	1.03	0.51	0.84	0.32
Min			0.66		0.46		0.31		0.4		0.26
-SD			0.74		0.53		0.41		0.45		0.38
Avg			0.85		0.64		0.50		0.51		0.48
+SD			0.95		0.74		0.59		0.57		0.59
Max			0.97		0.8		0.65		0.58		0.66
SD			0.11		0.11		0.09		0.06		0.11

		Deadwater											
Station		1		2		3		4		5		6	
Distance (km)		0.01		0.45		0.65		1,05		1.6		2.05	
Date	W L	D	-ve BL	D	-ve BL	D	-ve BL	D	-ve BL	D	-ve BL	D	-ve BL
24.11.99	**0.41**	0.9	0.49	1.4	0.99	1.6	1.19	1.2	0.79	1.73	1.32	1.6	1.19
26.02.99	**0.50**	1.0	0.50	1.37	0.87	1.5	1.0	1.5	1.0	1.4	0.9	1.6	1.1
Min			0.49		0.87		1.0		0.79		0.9		1.1
Avg			0.50		0.93		1.10		0.90		1.11		1.15
Max			0.50		0.99		1.19		1.0		1.32		1.19

The only depth data considered suitable for attempting to construct a longitudinal depth profile of the Deadwater is that which was collected at times when the sand bar at the mouth of the Inlet was closed, thus preventing tidal fluctuations and imbalances in the water level of the Inlet. See Section 6.2 for further explanation.

APPENDIX 12. Additional information concerning depth profiles, bathymetry and hydrology of Vasse-Wonnerup wetlands and associated rivers.

These notes have been extracted from J.Lane's field notebooks and other records.

<u>Mon 04 Aug 1997</u> 'At 1728hrs the water was flowing over Layman Road from Vasse estuary into Wonnerup estuary to a depth of 1cm (measured with tape). Over the road at this depth for distance of approx 10 metres. This was at the southernmost end of the low section of Layman Road before it rises near Wonnerup House entrance'. (See Photo 30 for more-extensive flooding of Layman Road on 05 July 1999).

<u>Fri 10 Oct 1997</u> At 1540hrs. 'Water flowing fairly strongly through both sets of culverts of Malbup Creek under Layman Road from Vasse estuary to Wonnerup estuary'.

<u>Wed 17 Dec 1997</u> "A-frame" apparatus to open flap valve (floodgate) of 'Bay 8' of Vasse estuary floodgates was installed today. (See Photo 33 for this apparatus).

<u>Fri 09 Jan 1998</u> 'New board (metric) reads −0.167m at 0731hrs. Old board (imperial) reads +2ft 3 13/16 inches (=0.706m). So if 2ft 3 13/16 inches equals RL 102ft 3 13/16 inches, then RL 100.00 = −0.167 – 0.706 = −0.873 mAHD'

<u>Fri 23 Jan 1998</u> 'Reverse flap valve' first installed in Vasse estuary floodgates today.

<u>Sat 28 Feb 1998</u> Walked from just south of Abba River mouth most of the way to Sabina River mouth. 'Water's edge did <u>not</u> reach fringing vegetation at any point'. [Vasse estuary water level reading (corrected) at the floodgates was −0.125 mAHD at 0550hrs on this day].

<u>Wed 01 Apr 1998</u> Ford Road at 0925 hrs. Water is restricted to excavated channel upstream of Ford Rd and (also restricted to excavated channel) for c. 15m downstream of Ford Rd. Location 9 is dry. [Vasse estuary water level reading (corrected) at the floodgates was −0.05 mAHD at 1408hrs on this day].

<u>Fri 03 Apr 1998</u> Junction of Malbup Creek and Vasse estuary. Winds calm. There is 90m (paced) of [moist] ground between waters at the west end of Malbup Creek and the waters of Vasse estuary. This [exposed] ground is only slightly (5-10cm?) elevated. The water level in Vasse estuary is higher than that in Malbup Creek. [Estuary water level reading (corrected) at Vasse estuary floodgates was −0.05 mAHD at 0650 hrs on 03 April 1998] The 'connection' is wide (approx 20m) and bare. Patterns on exposed sediments / sand indicate that the estuary overflowed the high point at some stage in past 12 months and flowed strongly enough into Malbup Creek to redistribute sediments / sand for 20-40 metres. … Sampled Malbup Creek 'mid-stream' (midway along fenceline crossing it — in front of CALM bird hide — depth here is c. 15cm. Sampled mid-column. (See Photos 7 & 8 for Malbup Creek and connection with Vasse estuary).

<u>Fri 03 Apr 1998 contd.</u> Abba River is connected (continuous surface water) to Vasse estuary at the moment. Shallowest point between the two is 10-11cm deep (i.e. water depth here is 10-11cm). [Estuary water level reading (corrected) at Vasse estuary floodgates was −0.05 mAHD at 0650 hrs on 03 April 1998] Winds still calm. Bottom here is firm sand with some dead sea shells. No flow in or out of [Abba River]. Sampled Abba River on east bank opposite where tree transect of 1997 is. Sample depth was approximately mid-column (i.e. sampled at c. 40cm). … Back to vehicle … at 0910 hrs. (See Photo 7 for Abba River connection with Vasse estuary).

<u>Thurs 09 Apr 1998</u> Ford Road at 0726 hrs. Water is flowing over the road alignment and downstream into the estuary. There is continuous water into the distance (estuary).

<u>Sat 11 Apr 1998</u> Ford Road at 0950 hrs. Water is flowing downstream across the Ford Road alignment and into the Vasse estuary.

<u>Mon 13 Apr 1998</u> Ford Road at 1743 hrs. Water is flowing across the Ford Road alignment and towards the Vasse estuary. Seems 1-2cm deeper on upstream side than when last checked.

<u>15 Apr 1998</u> Lower Vasse River Wetlands at 1415-1510 hrs. C. Webb / B. Driscoll of Water & Rivers Commission (now Department of Water), Bunbury, using a 'Hydrolab', measured temperature, dissolved oxygen, pH, salinity, conductivity and turbidity of grab samples from locations at/near Butter Factory Folk Museum, Taylor Rd, Pioneer Cove and Ford Rd. Surface salinities were 0.0, 0.5, 0.5 and 1.1 ppt respectively. Sampling was done for J. Lane of CALM (now DEC), Busselton.

<u>Fri 17 Apr 1998</u> Ford Road at 2135-2140 hrs. Water is still flowing downstream across the Ford Road alignment. No frogs heard.

<u>22 Apr 1998</u> Lower Vasse River Wetlands at 1319-1350 hrs. C. Webb / B. Driscoll of Water & Rivers Commission (now Department of Water), Bunbury, using a 'Hydrolab', measured temperature, dissolved oxygen, pH, salinity, conductivity and turbidity of grab samples from locations at/near Ford Rd, Pioneer Cove, Taylor Rd and Butter Factory Folk Museum. Surface salinities were 1.2, 0.8, 0.9 and 0.8 ppt respectively. Sampling was done for J. Lane of CALM (now DEC), Busselton.

<u>28 April – 5 May 1998</u> The wooden Wonnerup estuary and Vasse estuary floodgate flaps were replaced with steel flaps on 28 April and 4-5 May respectively. (See Photos 34 & 36 for wooden and steel flaps).

<u>Fri 15 Jan 1999</u> Mouth of Sabina River at 0735 hrs. River channel was full of water but mouth had approx 15-20m wide 'bar' separating it from the waters of the estuary. Elevation of the 'bar' [i.e. height of upper surface above water level] was approx 20cm. [Vasse estuary water level reading (corrected) at the floodgates was 0.00 mAHD at 0618hrs on this day].

<u>Tues 22 Feb 2000</u> 'At the current Vasse estuary water level (1040hrs) Malbup Creek is shallowly and narrowly connected [by continuous water] to the Vasse estuary'. [Vasse estuary water level reading (corrected) at the floodgates was 0.00 mAHD at 0630hrs on this day].

<u>Wed 29 Mar 2000</u> 'Malbup Creek is <u>not</u> connected [by continuous water] to Vasse estuary at the current [c. 1030hrs] water level'. [Vasse estuary water level reading (corrected) at the floodgates was −0.08 mAHD at 0705hrs on this day].

<u>Sat 10 Jun 2000</u> Big storm. Vasse estuary floodgates gauges at 1035 hrs read (corrected) −0.13 mAHD (corrected) on the upstream (estuary) side and 1.23 mAHD (corrected) on the downstream (Wonnerup Inlet) side. Wind was estimated at 50 knots and from NNE. Water was 'lapping over top of flap valves', 'constantly over horizontal top edge' and water was 'gushing in'. Wonnerup estuary floodgates downstream (Wonnerup Inlet) gauge read (corrected) 1.22 mAHD at 1047 hrs.

<u>Wed 20 Jun 2000</u> There was a strong WSW wind and rain while profiling the Deadwater, hence the sketchiness of some records.

<u>Tues 15 Aug 2000</u> Salinities and temperatures measured (starting at 1523 hrs) at **Vasse River** Causeway were 683 ppm and 14.2 °C at 0.1m depth and 1.4 ppt at 1.4m depth (depth of bottom >1.4m); **Sabina River** 721 ppm and 14.1 °C at both 0.1m depth and 0.3m depth (bottom); **Abba River** 292 ppm and 14.0 °C at 0.1m and 1.4m (depth of bottom >1.4m); **Ludlow River** 252 ppm and 13.1 °C at 0.1m and 1.2m (bottom).

APPENDIX 13. Water levels and exposure of tube worm 'islands' in the lower Vasse estuary.

In the lowest reaches of the Vasse estuary, opposite Estuary View Drive (Photo 10), there is a small bay (200 x 300m) that, like the remainder of the lowest reaches, retains water all year round. When the estuary water level is low, typically in summer-autumn, many small (c. 1-2 metre diameter) mounds or islands are exposed and these are utilised by tens or even hundreds of waterbirds as roosting and, in the case of some bird species, feeding sites. These islands are entirely composed of calcareous tubes made by 'tube worms' of the polychaete family Serpulidae. The worms themselves have not been identified beyond family level but it is thought that they probably belong to the genus *Ficopomatus* (pers. comm. Dr G. Morgan of WA Museum, 02 September 1991). Tube worms can apparently tolerate a wide range of salinities, but if an upper or lower limit is reached the worms die and the tubes crumble.

The tube worms of the lower Vasse estuary appear to be very sensitive to water levels, as many of the flat-topped islands become exposed within a very narrow water level range. In 1997-98, J.Lane recorded the number of island mounds exposed at various water levels so that the upper limit of that range could be determined. These observations and some conclusions are presented below.

<u>21 Jul 1997 (1623hrs)</u> 'Counted **51** (complete count) islands exposed (only just, all by only 1-3cm) in the bay of Vasse estuary in front of Estuary View Drive (Wonnerup). It is flat calm and sunny – has been like this for past 1 ½ weeks!' Estuary water level (floodgates gauge board) at 1631 hrs was **0.10 mAHD**.

<u>10 Oct 97 (1400-1450hrs)</u> 'Estuary View Drive. Water level well over islands'. Estuary water level (floodgates gauge board) at 1511 hrs was **0.52 mAHD.**

<u>19 Dec 97 (1310-1430hrs)</u> 'Islands covered but some shallow enough for roosting. One has an Australian Shelduck standing ankle deep'. Estuary water level (floodgates gauge board) at 0632 hrs was **0.15 mAHD.**

<u>21 Dec 97 (0706hrs)</u> 'No islands exposed but some are being stood on, e.g. by Australian White Ibis and Australian Shelduck'. Estuary water level (floodgates gauge board) at 0633 hrs was **0.13 mAHD.**

<u>24 Dec 97 (0729hrs)</u> 'Islands are still covered, though now Silver Gulls are able to stand 'ankle deep' on several of them'. Estuary water level (floodgates gauge board) at 0645 hrs was **0.105 mAHD.**

<u>25 Dec 97 (1648hrs)</u> 'Islands still covered'. Estuary water level (floodgates gauge board) at 1652 hrs was **0.105 mAHD**.

<u>26 Dec 97 (0652hrs)</u> '**56** islands exposed – all by no more than 1cm. This is the very first time these islands have been exposed all summer. Yesterday they were all covered. Standing on the exposed islands are Common Greenshank, Grey Teal, Black-winged Stilt, Little Black Cormorant, Little Pied Cormorant and Australian Shelduck'. Estuary water level (floodgates gauge board) at 0721 hrs was **0.09 mAHD.**

<u>28 Dec 97 (0634hrs)</u> 'This morning there are **80** (counted) just-exposed islands in the bay in front of Estuary View Drive'. Estuary water level (floodgates gauge board) at 0645 hrs was **0.085 mAHD.**

<u>29 Dec 97 (0729hrs)</u> '**c. 134** 'islands' exposed (wholly or partly) in Vasse estuary from Estuary View Drive'. Islands being used by Grey Teal, Common Greenshank, Black-winged Stilt, Pacific Black Duck, Little Black Cormorant, Australian Shelduck, Australian White Ibis and Little Pied Cormorant. The greenshank and stilt are feeding on the islands'. Estuary water level (floodgates gauge board) at 0703 hrs was **0.06 mAHD.**

<u>07 Jan 98 (0735hrs)</u> 'Counted **168** islands exposed. Many of these are exposed by c. 10cm'. Estuary water level (floodgates gauge board) at 1631 hrs was **−0.04 mAHD.**

APPENDIX 13 Continued.

Summary of water levels and number of islands exposed

Date	**21/07**	**10/10**	**19/12**	**21/12**	**24/12**	**25/12**	**26/12**	**28/12**	**29/12**	**07/01**
Water Level	0.10	0.52	0.15	0.13	0.105	0.105	0.09	0.085	0.06	−0.04
No. Islands Exposed	0	0	0*	0*	0*	0	56	80	c. 134	168

* No islands exposed, but some birds are standing on them, 'ankle deep'.

From the above it can be concluded that, in 1997-98, the upper limit for exposure of tube worm islands at the Estuary View Drive location on the Vasse estuary was a water level of 0.090-0.105 mAHD. The large number of islands that became exposed within a very narrow range of levels (thus c. 270 islands within 4.5cm) indicates a high level of sensitivity to water level, at least at the upper end of the range.

Summer-autumn water levels in the Vasse estuary have been managed within a narrower range since 1998 than in the decade or so previously (see Lane *et al.* 1997 for current and historical management regimes). It would be interesting to observe whether the tube worm islands are currently (2011) exposed at the same levels as in 1997-98 or whether some change has occurred. Other studies, such as the distribution of tube worm islands within the estuary, the range of water depths (estuary bed levels) in which they occur, the salinities they currently tolerate and the identity (to species) of the worms themselves, could also be rewarding.

APPENDIX 14. Profiling undertaken in October 2007.

During 1998-2000, profiling was undertaken in every month except October. October profiling was, however, undertaken seven years later, in 2007. Because of their potential relevance to this report, these data are presented below.

It is noteworthy that Vasse estuary and Lower Vasse River Wetlands surface salinities on 23 October 2007 were almost identical to those of 25 November 1999 and were only slightly higher than those of 21 September 2000. Wonnerup estuary surface salinities were almost identical to those of 21 September 2000 and were lower than those of 24 November 1999. Deadwater surface salinities were almost identical to those of 14 August 2000 and were higher than those of 24 November 1999 and 21 September 2000.

Vasse estuary, 23 Oct 2007

Floodgates u/s gauge read 0.40 mAHD at 1640hrs.

Station	Time		Depth (m)	Temp. (°C)	Salinity (ppt)
1	1635	S	0.03	21.9	2.4
		B	1.20	18.6	2.4
2	1610	S	0.03	22.1	2.2
		B	0.72	22.2	2.2
3	1600	S	0.03	21.3	1.9
		B	0.87	21.3	1.9
4	1545	S	0.03	21.4	2.0
		B	0.8	21.4	2.0
5	1525	S	0.03	22.8	3.0
		B	0.73	21.2	3.3
6	1510	S	0.03	23.0	3.0
		B	0.66	21.1	3.0
7	1455	S	0.03	23.2	2.8
		B	0.62	21.2	2.9
8	1435	S	0.03	22.9	2.1
		B	0.41	23.0	2.1
9	1420	S	0.03	22.5	1.3
		B	0.57	20.6	1.3
LVRW1	1400	S	0.03	23.1	0.9
		B	0.60	21.5	0.9

Wonnerup Inlet, 23 Oct 2007.

Wonnerup estuary f/gates d/s gauge 0.01 mAHD at 1130hrs.

Station	Time		Depth (m)	Temp. (°C)	Salinity (ppt)
1	1143	S	0.03	19.4	4.9
		B	0.80	18.6	13.1

Wonnerup estuary, 23 Oct 2007

Floodgates u/s gauge read 0.41 mAHD at 1121hrs.

Station	Time		Depth (m)	Temp. (°C)	Salinity (ppt)
1	1110	S	0.03	18.4	1.5
		B	1.40	17.8	1.5
2	1050	S	0.03	18.4	1.4
		B	1.10	17.8	1.4
3	1035	S	0.03	18.2	1.4
		B	1.00	17.9	1.4
4	1013	S	0.03	18.0	1.4
		B	0.90	17.7	1.4
5	0930	S	0.03	17.4	1.4
		B	0.83	17.2	1.4

Deadwater, 23 Oct 2007

Wonnerup estuary f/gates d/s gauge 0.01 mAHD at 1130hrs.

Station	Time		Depth (m)	Temp. (°C)	Salinity (ppt)
1	1154	S	0.03	22.6	7.1
		B	0.47	21.7	14.2
2	1208	S	0.03	24.0	13.5
		B	1.15	21.9	17.0
3	1220	S	0.03	20.8	13.5
		B	1.20	19.4	13.5
4	1235	S	0.03	21.2	12.9
		B	0.70	21.0	13.0
5	1245	S	0.03	21.7	12.4
		B	0.70	20.7	12.7
6	1300	S	0.03	21.1	12.3
		B	1.40	18.9	12.5

LVRW = Lower Vasse River Wetlands
S = Surface; B = Bottom.
Stations are those of this report (Figures 2 & 3).

APPENDIX 15. Profiling undertaken in February 2007.

The first known extensive longitudinal salinity profiling of Vasse estuary in summer-autumn was undertaken on 24 February 1989 by the Busselton Peace and Environment Group with the samples being analysed by the Water Authority of Western Australia (Lane *et al.* 1997, p45). This work was repeated on 26 February 2007 by A. Clarke while determining the coordinates of the 1998-2000 Sampling Stations (which are intentionally in the same locations as the 1989 sites) by hand-held GPS (see Appendix 7). The results of the February 2007 profiling are presented here for the record.

Vasse estuary, 26 Feb 2007

Floodgates u/s gauge read −0.09 mAHD at 1105hrs (JL).

Station	Time		Depth (m)	Temp. (°C)	Salinity (ppt)
1	1043	S	0.2		39
		B	1.0		33
2	1130	S	0.05		46
		B	0.14		46
3	1145	S	0.05	22.6	52
		B	0.36	22.6	58
4	1200	S	0.05	22.8	60
		B	0.32	22.8	60
5		S	0.05	24.6	69
		B	0.13	24.6	73
6		S	0.05	23.8	82
		B	0.2	23.8	82
7		S	0.05	24.0	92
		B	0.13	24.0	92
8		S			
		B			
9		S			
		B			
LVRW1		S			
		B			

LVRW = Lower Vasse River Wetlands

S = Surface; B = Bottom.

Stations are those of this report (Figures 2 & 3).

Stations 5, 6 and 7 were sampled in heavy rain.

Stations 5 and 6 were in a separate waterbody from that of Stations 1-4.

Station 7 may or may not have been in same waterbody as Stations 5 and 6. It was not possible to be certain in the rain.

Wonnerup estuary, 26 Feb 2007

Floodgates u/s gauge read −0.42 mAHD at 1120hrs (JL).

Station	Time		Depth (m)	Temp. (°C)	Salinity (ppt)
1	1520	S	0.05	24.0	43
		B	0.45	24.0	43
2	1550	S	0.05	27.1	84
		B	0.25	27.1	88
3	1610	S	0.05	29.2	113
		B	0.13	29.2	113
4	1630		0.05	30.0	117
5			DRY		

APPENDIX 16. Historical Wonnerup estuary salinity records.

A. Summary list of all known, measured salinities (ppt) in Wonnerup estuary from earliest European settlement to 1997. Refer to Figure 3 of main report for location of sampling points. Refer to table below for results of fortnightly monitoring at location 1 in 1996-97.

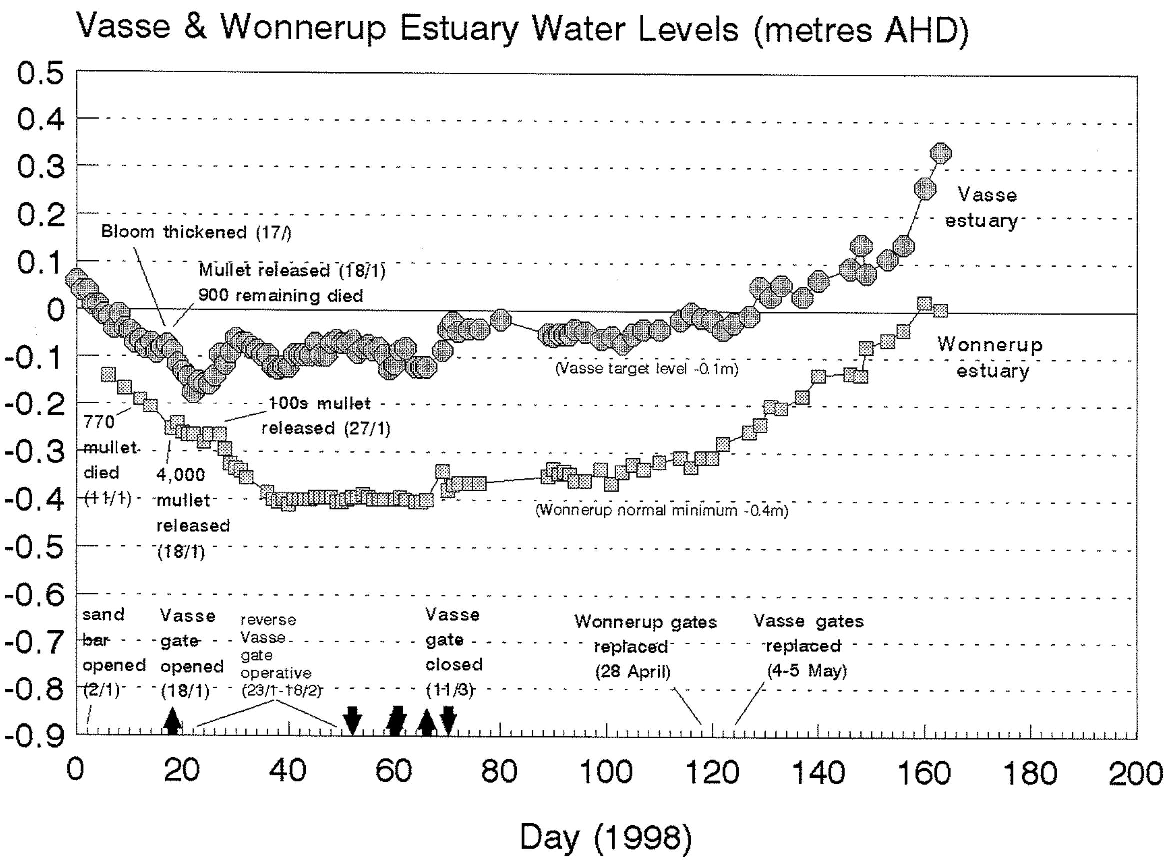
Date	Sampling Stations					Water level (mAHD)	Comments	Source
	1	2	3	4	5			
18.10.78	2	-	-	-	-	-		CALM
18.12.95	33	-	23	-	-	-		
05.01.96	34	-	-	-	8	0.02		CALM
18.03.97	36	40	42	27	25	−0.18	Floodgates leaking	CALM

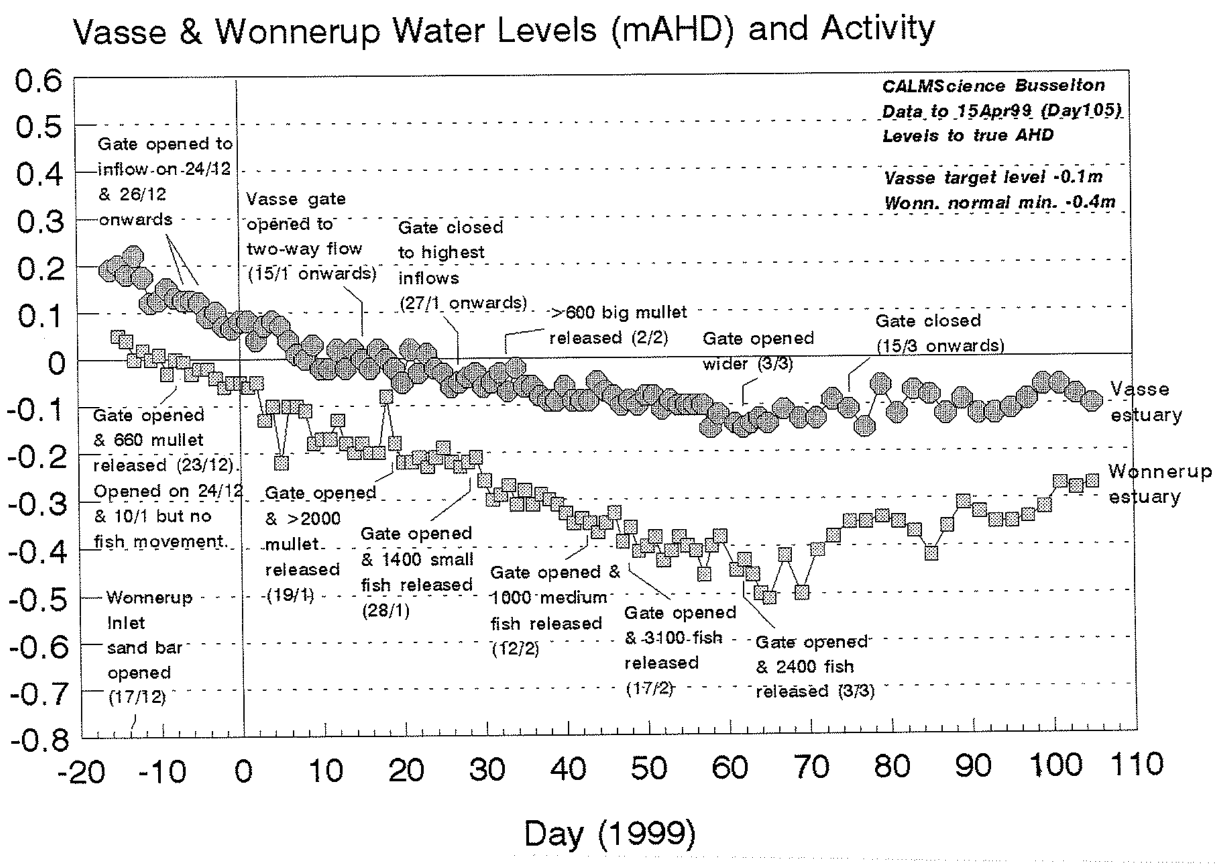
B. Average monthly surface salinity (ppt) on upstream side of Wonnerup estuary floodgates (Sampling Station 1) in 1996-97. Not apparent from this table is a sudden decrease in salinity (from 31ppt on 3rd June to 5ppt on 24th June) that occurred following commencement of river flow in winter 1997 (Data source: K. Hardcastle, Water & Rivers Commission, Bunbury).

Month	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Salinity	1	2	14	8	17	31	35	40	40	36	18	7

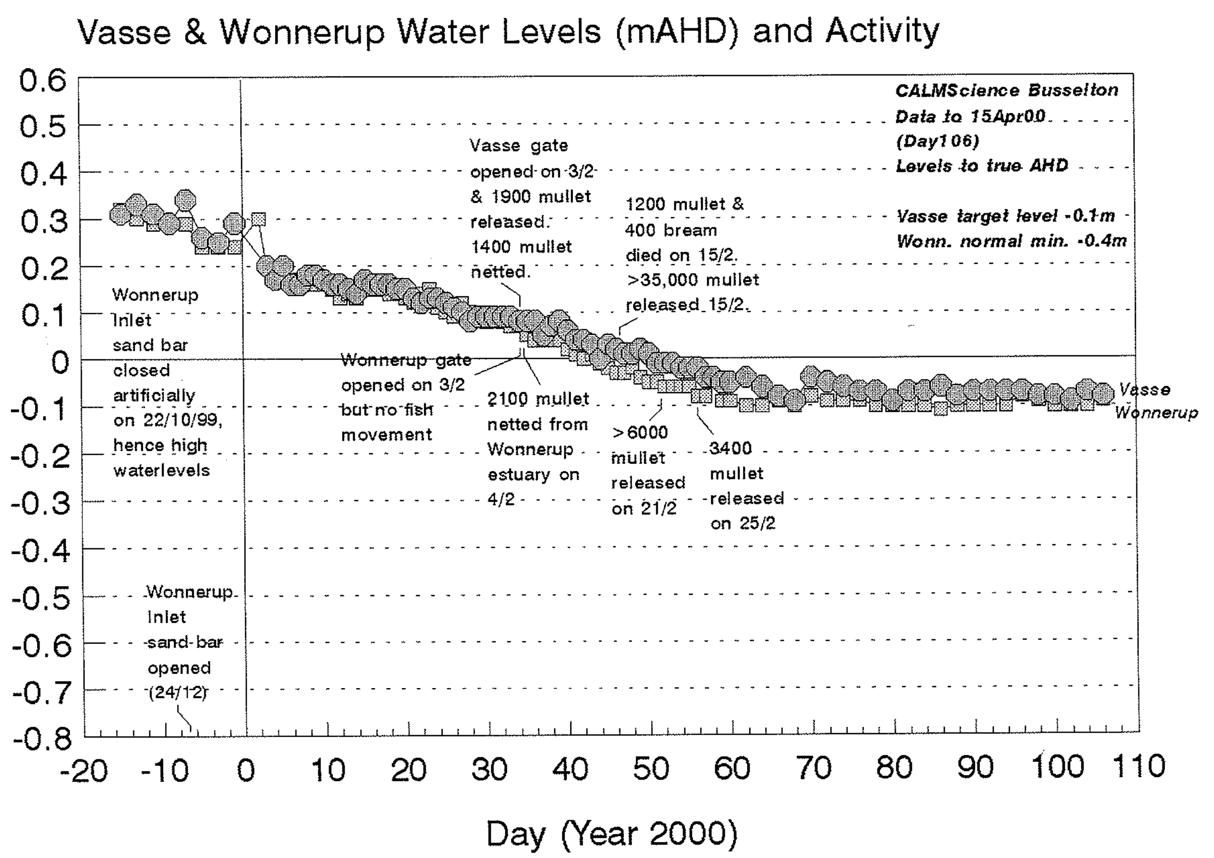
APPENDIX 17. Vasse-Wonnerup water levels, sand bar and floodgate openings and closures, fish deaths and releases, etc., in 1998, 1999 and 2000.

On the next two pages are graphs of water level data and various activities and events related to fish deaths and releases during 1998, 1999 and 2000. These graphs were originally prepared by J. Lane to keep members of the Vasse Estuary Technical Working Group informed of developments as they occurred. The graphs are reproduced in this report because of their relevance to the water depth and salinity profiling work undertaken by the authors during 1998-2000 and to make the fish death and release information more widely available.





Vasse & Wonnerup Water Levels (mAHD) and Activity
CALMScience Busselton
Data to 15Apr99 (Day105)
Levels to true AHD
Vasse target level -0.1m
Wonn. normal min. -0.4m
Gate opened to inflow on 24/12 & 26/12 onwards
Vasse gate opened to two-way flow (15/1 onwards)
Gate closed to highest inflows (27/1 onwards)
>600 big mullet released (2/2)
Gate opened wider (3/3)
Gate closed (15/3 onwards)
Vasse estuary
Wonnerup estuary
Gate opened & 660 mullet released (23/12). Opened on 24/12 & 10/1 but no fish movement.
Gate opened & >2000 mullet released (19/1)
Gate opened & 1400 small fish released (28/1)
Gate opened & 1000 medium fish released (12/2)
Gate opened & 3100 fish released (17/2)
Gate opened & 2400 fish released (3/3)
Wonnerup Inlet sand bar opened (17/12)
Day (1999)



Vasse & Wonnerup Water Levels (mAHD) and Activity
CALMScience Busselton
Data to 15Apr00 (Day106)
Levels to true AHD
Vasse target level -0.1m
Wonn. normal min. -0.4m
Vasse gate opened on 3/2 & 1900 mullet released. 1400 mullet netted.
1200 mullet & 400 bream died on 15/2. >35,000 mullet released 15/2.
Wonnerup Inlet sand bar closed artificially on 22/10/99, hence high waterlevels
Wonnerup gate opened on 3/2 but no fish movement
2100 mullet netted from Wonnerup estuary on 4/2
>6000 mullet released on 21/2
3400 mullet released on 25/2
Vasse
Wonnerup
Wonnerup Inlet sand bar opened (24/12)
Day (Year 2000)

APPENDIX 18. Flood Event and Water Levels of late May 1999.

This graph shows the water level responses of the Vasse and Wonnerup estuaries and Wonnerup Inlet to substantial rainfall and river flows in late May 1999 (Busselton rainfall 10mm, 68mm & 20mm in the 24hrs to 9am of 26th, 27th & 28th May respectively). Changing winds and, in the case of Wonnerup Inlet, tides and a low barometric pressure, no doubt also played a part. The differences in water levels between the estuaries' gauge boards and corresponding continuous water level recorders is notable — particularly on the Vasse estuary — and is due to the gauges being located at the estuary outlets (floodgates) and the continuous recorders being 1-3 km upstream.