



**Southern Seawater Desalination
Plant – Marine Investigations**

Historical Water Quality Review

January 2008



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Historical Water Quality Review

Prepared for

Water Corporation

Prepared by

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January 2008

Report No. 663_001/1

Client: Water Corporation

Revisions history

Version	Author	DISTRIBUTION			REVIEW	
		Recipients	No. Copies & Format	Date	Reviewer	Date
1	C. Hart	G. Shiell	1x doc	9/1/08	G. Shiell	10/1/08
2	C. Hart	B. Hegge	1x doc	11/1/08	B. Hegge	11/1/08
3	C. Hart	D. Luketina F. Faskel D. Couton	1x pdf	11/1/08	D. Luketina	15/1/08
4	C. Hart	D. Luketina	1x pdf	18/1/08	D. Luketina	24/1/08
FINAL	C. Hart	D. Luketina & F. Faskel D. Couton	3x hardcopy 1x pdf 1x pdf	24/1/08		

Status

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1. Background Information

1.1. Introduction

The Water Corporation of Western Australia (Water Corporation) is currently planning to construct a second large-scale desalination plant, the Southern Seawater Desalination Plant (SSDP), to provide the Perth metropolitan and surrounding areas with an additional drinking water source.

Oceanica Consulting Pty Ltd (Oceanica) was commissioned by the Water Corporation to prepare a review of historical marine monitoring data in the region of the proposed SSDP site to assist with the preparation of the Public Environmental Review (PER) for this proposal.

Additional marine monitoring has been conducted around the Bunbury and Binningup areas, for the following facilities, including:

- Bunbury wastewater treatment plant (WWTP);
- Collie Power Station ocean outfall, and;
- Millennium Chemicals outfall.

Data from these marine monitoring surveys provide a useful indication of the background water quality characteristics that would be expected at the proposed SSDP site. The Bunbury WWTP outfall is located approximately 30 km south of the proposed SSDP site and both the Collie Power Station and Millennium Chemicals outfalls are located approximately 10 km south of the proposed SSDP site (see Figure 1.1). The locations of the monitoring sites for these outfalls are shown in Figure 1.2 and Figure 1.3. This report presents a review and comparison of the physical and nutrient data collected as part of these additional programmes with the data from the proposed site collected as part of the 2007 Binningup sampling.

Two types of data (physical and biochemical) are included in this review. Stratification (density difference between the surface and near the seabed) of the ambient waters can affect the mixing and dilution of the discharge plume. In shallow waters, temperature and salinity are the two parameters which largely govern the density of seawater. The biochemical data enables a measure of any impact of the discharge on the surrounding environment.

1.2. Monitoring Data included in the Review

The following data sets are included in the review:

- Bunbury Background studies - Conductivity temperature depth (CTD) sampling from background studies for the Bunbury Wastewater Treatment Plant (WWTP) conducted in March & October 1999, February & October 2000, March 2001, and February 2002 (DAL 2000 (1999-2000 data));
- Bunbury Ocean Outfall Monitoring (BOOM) programme - Nutrient and chlorophyll data from reference sites in the BOOM programme conducted in January, April, and October each year between October 2002 and April 2007 (DALSE 2003, Oceanica 2004, Oceanica 2005, Oceanica 2006, Oceanica 2007a);
- 2006 Collie Power Station marine monitoring - CTD sampling conducted as part of the 2006 marine monitoring programme of the Collie Power Station ocean outfall (Maunsell Aecom 2007), and;
- 2007 Binningup sampling - CTD profiles as well as nutrient and chlorophyll data from four marine water quality monitoring surveys conducted at the proposed site for the SSDP during March, July, September, and October 2007 (KBR 2007).

In addition, 17 years of marine monitoring data is available relating to the Kemerton Ocean Outfall. This data was compiled and analysed by Oceanica for Millennium Inorganic Chemicals Ltd, between 1989 and 2006. Permission to access this data was not received in time to allow the inclusion of this data in the review. However, to provide an example of this dataset, the water quality section of the 2006 Kemerton Ocean Outfall Environmental Monitoring Programme report (Oceanica 2007b) is included as Appendix A.

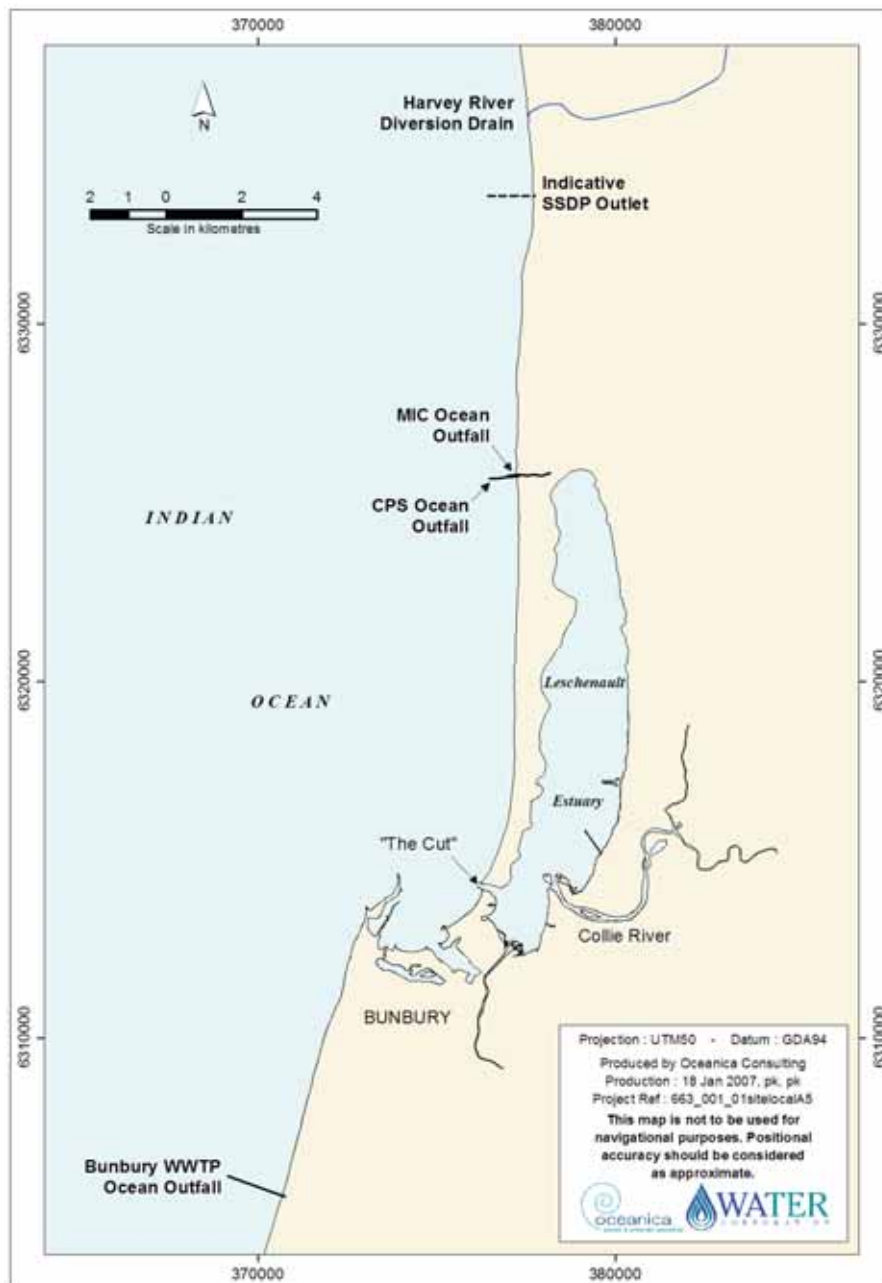


Figure 1.1 Locations of outlets to which included datasets applies

1.3. Scope of Work

Oceanica Consulting Pty Ltd (Oceanica) was commissioned by the Water Corporation to prepare a review of historical marine monitoring data in the region of the proposed SSDP site to assist with the preparation of the Public Environmental Review (PER) for this proposal. Oceanica was engaged to undertake the following tasks which comprise the scope of work:

- Review historical water quality data from Bunbury WWTP background studies with a focus on: salinity, temperature, dissolved oxygen (DO), nutrients and chlorophyll-a;
- Review additional relevant data consisting of 2007 Binningup sampling data and Colлие Power Station Ocean Outfall monitoring data and discuss this in context of Bunbury data, highlighting consistencies and differences;
- Summarise local conditions for winds, currents, and waves based on WNI Science & Engineering (WNI) studies for the Bunbury WWTP;
- Outline seasonal and regional trends and key factors determining water quality in the area and possible local influences, and;
- Provide raw data for inclusion in the SSDP dataset.

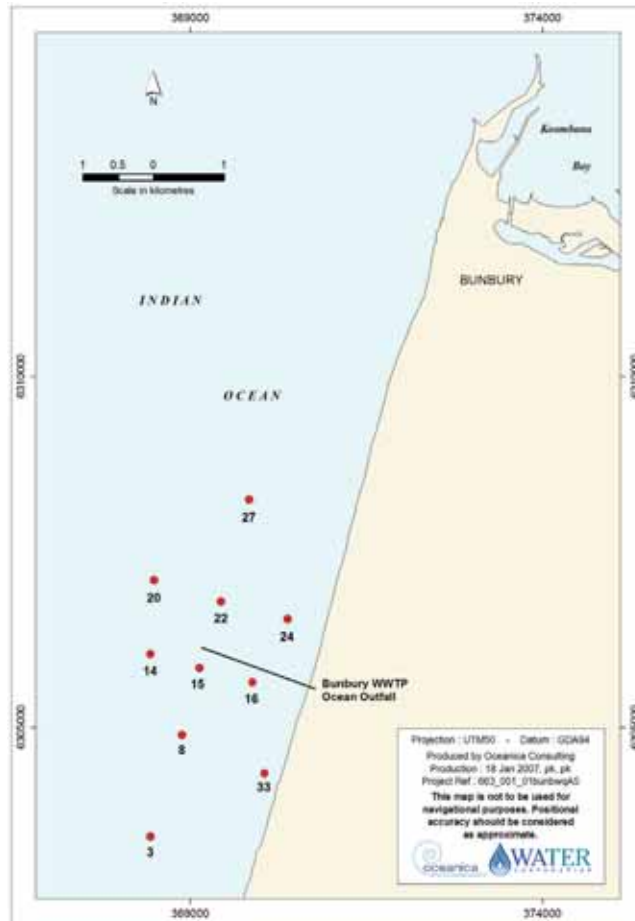


Figure 1.2 Monitoring sites locations for the Bunbury background studies

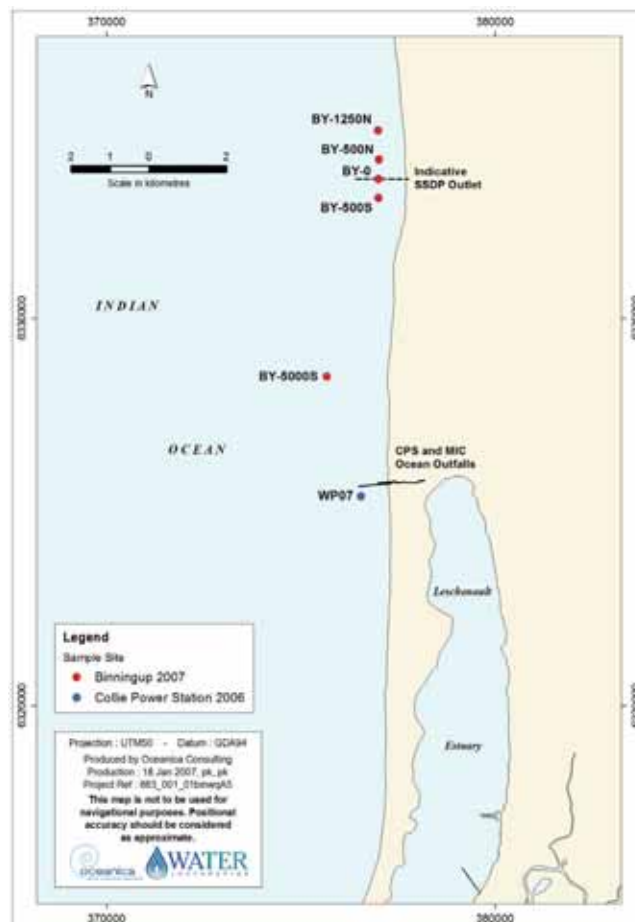


Figure 1.3 Monitoring site locations for the Collie Power Station outfall and the SSDP site

2. Data

2.1. Physical Parameters

CTD measurements of physical parameters including temperature, salinity, and dissolved oxygen (DO) have been conducted as part of the Bunbury background studies (DAL 2000), the 2006 Collie Power Station marine monitoring (Maunsell Aecom 2007), and the 2007 Binningup SSDP site sampling (KBR 2007). These datasets are summarised in Sections 2.1.1, 2.1.2 and 2.1.3.

2.1.1. Bunbury Background Studies

The density profiles from the Bunbury baseline studies data are shown in Figure 2.1.

Summary statistics (minimum, median, 5th and 20th percentiles, median, 80th and 95th percentiles, and maximum) for temperature, salinity, DO, and density from the Bunbury background studies are presented in Table 1. This data indicates slightly warmer temperatures at the surface than at the bottom during the October surveys and almost no difference in salinity between the surface and the bottom of the water column during any of the surveys. This data also shows that the DO concentration is generally greater at the surface than at depth and higher in February/March relative to October.

Table 1 Summary of physical parameter data from Bunbury background studies

Survey Month	Depth	Parameter	Min	5 th %ile	20 th %ile	Median	80 th %ile	95 th %ile	Max
October	Surface	Temperature [°C]	16.5	16.5	16.7	17.1	18.0	18.2	18.2
		Salinity [psu]	34.7	34.7	34.7	34.8	35.1	35.1	35.1
		DO [mg/L]	6.2	6.2	6.2	6.3	8.0	8.0	8.0
		Density [kg/m ³]	1025.3	1025.3	1025.3	1025.3	1025.4	1025.5	1025.5
	Bottom	Temperature [°C]	16.2	16.2	16.2	16.3	17.5	17.6	17.6
		Salinity [psu]	34.8	34.8	34.8	34.9	35.1	35.2	35.2
		DO [mg/L]	5.4	5.4	5.8	5.8	7.9	8.0	8.0
		Density [kg/m ³]	1025.5	1025.5	1025.5	1025.5	1025.5	1025.6	1025.6
Feb/March	Surface	Temperature [°C]	22.1	22.1	22.2	22.7	22.9	23.1	23.2
		Salinity [psu]	36.0	36.0	36.1	36.3	36.6	36.6	36.7
		DO [mg/L]	7.2	7.2	7.4	8.0	8.2	8.3	8.4
		Density [kg/m ³]	1024.7	1024.7	1024.8	1025.1	1025.2	1025.2	1025.3
	Bottom	Temperature [°C]	22.0	22.0	22.0	22.7	22.9	23.1	23.2
		Salinity [psu]	36.0	36.0	36.1	36.3	36.6	36.7	36.7
		DO [mg/L]	7.2	7.2	7.4	7.9	8.2	8.4	8.4
		Density [kg/m ³]	1024.7	1024.7	1024.8	1025.2	1025.2	1025.3	1025.3

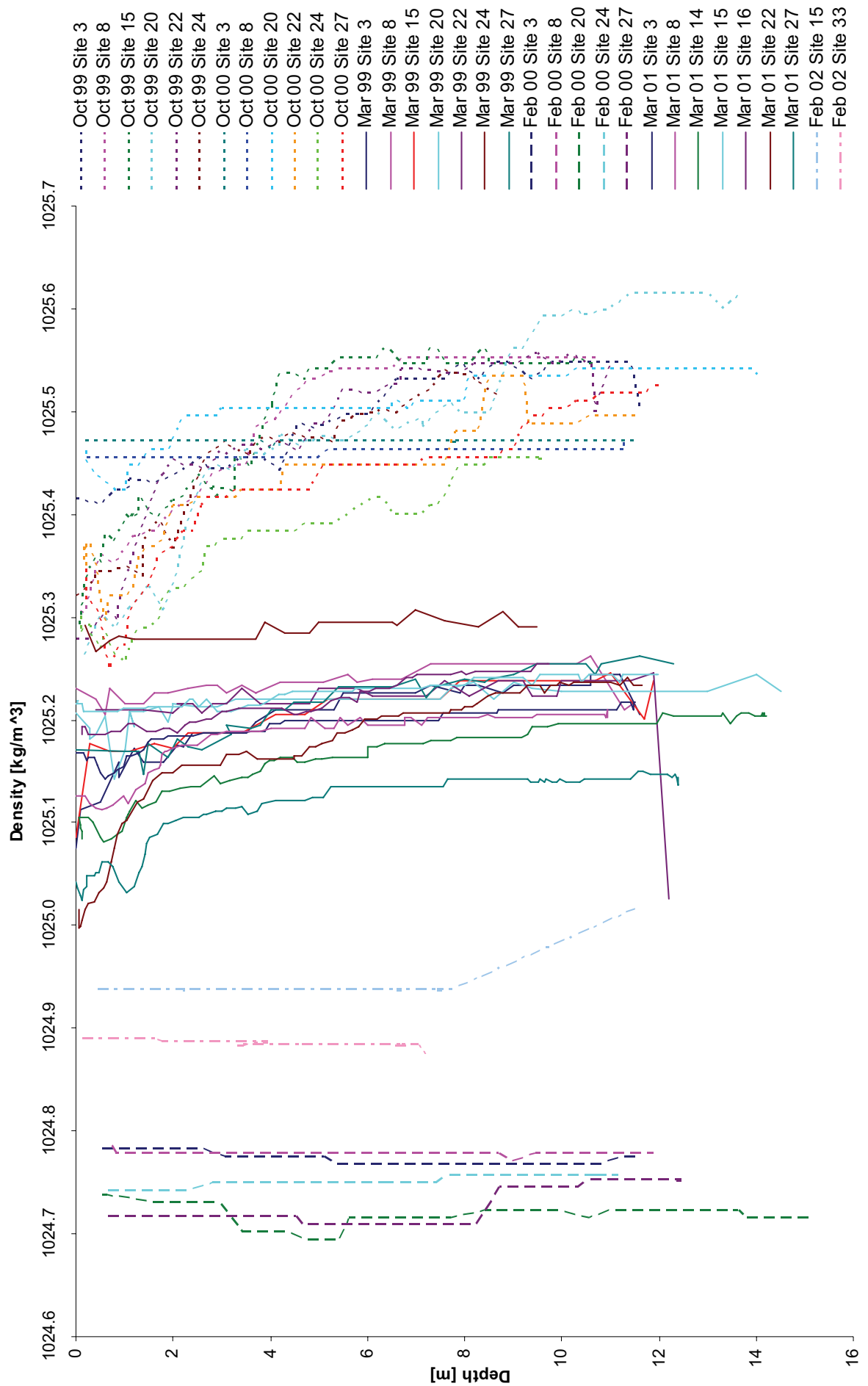


Figure 2.1 Density profiles from Bunbury background studies data

2.1.2. Collie Power Station Ocean Outfall Monitoring

Temperature, salinity and DO data is collected as part of the Collie Power Station ocean outfall monitoring program conducted by Maunsell Aecom for Transfield BRW Services. The 2006 monitoring programme is detailed in Maunsell Aecom (2007) and the data from the reference site is reviewed here. The Collie Power Station discharges wastewater into the ocean via an ocean outfall which is situated approximately 700 m offshore in 10 m of water. As part of the marine water quality monitoring programme, CTD profiles are sampled at eight sampling sites. The sites are sampled on one day each year and the 2006 sampling was conducted on 28 November 2006. Only one of these sites can be considered a reference site; thus only the data from that site (located south of the outlet) can be included in this review as background data. The results from the 2006 monitoring programme for the reference site are shown in Table 2.

Table 2 Summary of Collie Power Station ocean outfall reference site sampling (28/11/06)

Max Depth [m]	Temperature [°C]			Salinity [psu]			DO [mg/L]		
	Max	Min	Average (±Standard Error)	Max	Min	Average (±Standard Error)	Max	Min	Average (±Standard Error)
9.16	22.41	21.89	22.21 (0.01)	35.97	35.75	35.85 (0.00)	7.57	7.35	7.43 (0.00)

Maunsell Aecom (2007) noted that temperature stratification was evident at the reference site due to solar radiation. It was also noted that no distinct salinity stratification was evident and DO was found to be highly variable with in the water column with elevated levels between 5 and 7 m depth at the reference site.

2.1.3. 2007 Binningup Sampling

CTD measurement of physical parameters including temperature, salinity and DO were collected as part of the 2007 Binningup sampling conducted by KBR (2007). Profiles were sampled during each of the March, July, September, and October sampling periods. The results of this sampling are detailed in KBR (2007). KBR (2007) reported that no strong stratification was observed during any of the four sampling periods.

2.2. Biochemical Parameters

2.2.1. Bunbury Ocean Outlet Monitoring (BOOM) Reference Site Data

Monitoring of nutrients and chlorophyll-a is undertaken as part of the BOOM programme at four reference sites to the south of the Bunbury WWTP outlet. Sampling is undertaken three times per year in January (summer), April (autumn), and October (spring). Data sampled between October 2002 and April 2007 is included in this review. Table 3 presents summary statistics of ammonia, filterable reactive phosphorous (FRP), nitrate + nitrite and chlorophyll-a from surface samples.

Table 3 Summary statistics of BOOM reference sampling

Season	Parameter	Number of Samples	Mean	Standard Deviation
Autumn (April)	Ammonia [µg N/L]	19	2.53	1.45
	FRP [µg P/L]	19	4.11	1.56
	Nitrate and Nitrite [µg N/L]	19	3.42	1.12
	Chlorophyll-a [µg/L]	19	0.47	0.21
Spring (October)	Ammonia [µg N/L]	19	2.21	1.28
	FRP [µg P/L]	19	4.37	1.12
	Nitrate and Nitrite [µg N/L]	19	3.16	1.61
	Chlorophyll-a [µg/L]	18	0.83	0.58
Summer (January)	Ammonia [µg N/L]	19	1.5	0.00
	FRP [µg P/L]	19	3.74	1.10
	Nitrate and Nitrite [µg N/L]	19	2.53	1.12
	Chlorophyll-a [µg/L]	19	0.15	0.05

2.2.2. 2007 Binningup Sampling

Summary statistics of the four sampling dates in the 2007 Binningup water quality sampling is presented in Table 4.

Table 4 Summary statistics for 2007 KBR Binningup sampling

Month	Parameter	Mean	Standard Deviation	Number of Samples
March 2007	Ammonia [$\mu\text{g N/L}$]	5.33	6.07	15
	FRP [$\mu\text{g P/L}$]	2.93	0.46	15
	Nitrate and Nitrite [$\mu\text{g N/L}$]	2.40	1.55	15
	Chlorophyll-a [$\mu\text{g/L}$]	-	-	0
July 2007	Ammonia [$\mu\text{g N/L}$]	12.00	9.61	15
	FRP [$\mu\text{g P/L}$]	6.00	0.85	15
	Nitrate and Nitrite [$\mu\text{g N/L}$]	10.07	3.31	15
	Chlorophyll-a [$\mu\text{g/L}$]	0.83	0.37	15
September 2007	Ammonia [$\mu\text{g N/L}$]	3.00	0.00	15
	FRP [$\mu\text{g P/L}$]	3.67	0.62	15
	Nitrate and Nitrite [$\mu\text{g N/L}$]	2.00	0.00	15
	Chlorophyll-a [$\mu\text{g/L}$]	1.75	1.24	15
October 2007	Ammonia [$\mu\text{g N/L}$]	5.40	4.91	15
	FRP [$\mu\text{g P/L}$]	4.80	6.82	15
	Nitrate and Nitrite [$\mu\text{g N/L}$]	2.47	1.06	15
	Chlorophyll-a [$\mu\text{g/L}$]	2.63	3.40	15

2.3. Wind, Waves, and Oceanography

WNI Science and Engineering (WNI) conducted investigations of the oceanographic environment around the proposed Bunbury WWTP (as part of the background environmental investigations for the Bunbury WWTP Ocean Outfall) between 1999 and 2000. These investigations were designed to gain an understanding of the physical factors affecting circulation and water column characteristics in the waters around the outfall location.

This work comprised the deployment of two current meters at locations offshore of the Bunbury WWTP. Data was measured continuously over two periods:

- March 5 to July 30, 1999
- January 13 to March 5, 2000

These investigations are detailed in WNI (2000) and the following is a summary of the findings from these investigations. Circulation in the region was found to be influenced by a combination of forces including: wind stress, sea level fluctuations (tides, seiches, continental shelf waves and meteorological effects), short period wind waves and swell waves, density gradients and larger scale oceanic circulation features (mainly the Leeuwin Current).

2.3.1. Wave Climate

WNI (2000) found that the wave climate of Bunbury was dominated by swell and wind waves. The waters around Bunbury are open to the west and north-west and as such it is waves travelling from these directions that reach the Bunbury area least affected by shoaling and refraction. Wind waves from these directions are generated by low pressure systems and associated cold fronts, which are common during the winter months.

The swells which predominantly affect the Bunbury region are created in fetch areas associated with low pressure systems in the Southern Ocean. These systems are a constant feature of the southern Indian Ocean and thus the south-westerly swells prevail in the wave climate of the Bunbury region. These swells are prevented from travelling directly into the Bunbury region by Cape Naturaliste but can be refracted around the Cape with some attenuation (see Figure 2.2). Swells from the west or north-west are generated in fetch areas ahead of these cold fronts, which can extend northwards of these low pressure systems. If they occur at the same time, swells from this direction may combine with existing wind waves to produce higher resultant waves.

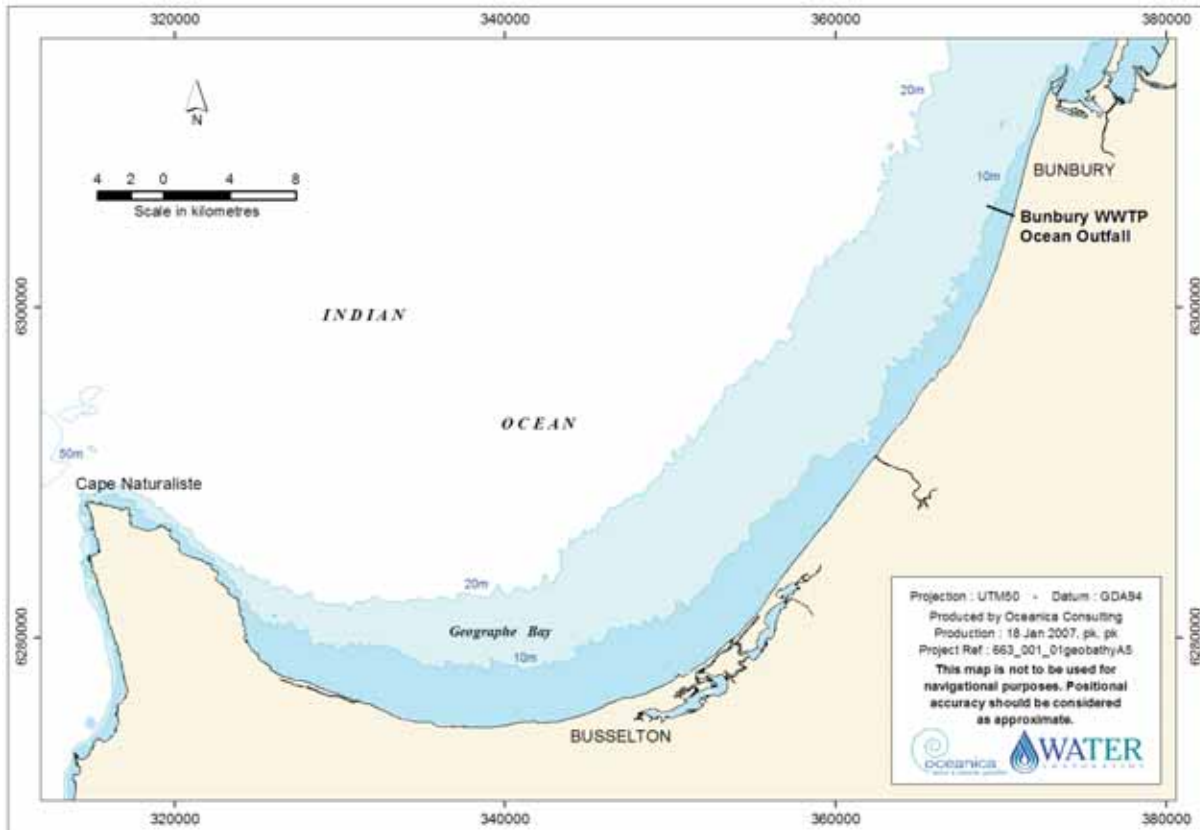


Figure 2.2 Bathymetry between Cape Naturaliste and the Bunbury WWTP site

Currents (Stokes Drift) associated with wave motion (see Bowden 1983) were estimated to be insignificant for typical conditions but could become comparable to wind-driven velocities under extreme wave conditions. Current velocities due to Stokes Drift are likely to only be an important factor for larger, locally generated short period (wind) waves.

2.3.2. Wind Climate

WNI (2000) observed that wind stress is the dominant driving force in terms of the hydrodynamics of the region. Fahrner and Pattiaratchi (1994) found that wind speeds are likely to be too low to affect circulation patterns for only 5-10% of the time and periods of calm conditions generally last less than 12 hours. Winds are seasonal with a strong southerly component in summer and a strong westerly component in winter. Sea and land breezes are experienced frequently at Bunbury. Seasonal events that were recorded in the measurements included land and sea breezes, heat troughs, dissipating tropical cyclones, high pressure systems and extra-tropical cyclones.

2.3.3. Currents

WNI (2000) found that current flows off Bunbury are generally weak and variable with speeds predominantly less than 0.01 m/s. The maximum current speed recorded during the investigations was 0.3 m/s during a storm event in June 1999. Currents were predominantly oriented alongshore and constrained by local bathymetry and the coastline. Residual drift was observed to be north in summer and south in winter.

Tides in the Bunbury area are mixed but predominantly diurnal. Bunbury has a microtidal range, largely due to the close proximity of an amphidromic point offshore of Cape Naturaliste. Tidal forcing was found to be low and its influence on water currents was estimated to be in the order of 0.01 m/s. Continental shelf waves are experienced in the area and these were estimated to contribute currents of up to 0.2 m/s. Seiches and storm surge may occasionally generate currents slightly stronger than the tides, but the magnitude is still likely to be small. Density currents were found to be insignificant in the Bunbury area.

The Leeuwin Current was found to exert an influence on the oceanographic circulation of the Bunbury area in the winter months, predominantly in the form of a residual southward drift. This influence is variable and likely to be less than 0.05 m/s.

3. Discussion

3.1. Physical Parameters

The density profiles measured as part of the Bunbury background studies clearly show two patterns (Figure 2.1). A seasonal pattern was evident whereby density was lowest during the February profiles, higher in the March profiles and then highest in the October profiles. The second pattern is in the degree of stratification visible in the profiles. The February profiles have near-vertical density profiles, indicating a very well-mixed water column, while the March profiles show a slight decrease in the density in the upper part of the water column. A greater degree of stratification was then evident in the October profiles which show a slightly larger decrease in surface densities. From examination of temperature and salinity profiles of this data (see Appendix B), it appears that the stratification observed in October, and to a lesser degree March, is temperature-driven and most likely due to solar warming of the surface waters.

The 2006 Collie Power Station monitoring, which was conducted on a single day in late November, also found evidence of slight density stratification and that this could be attributed to temperature differences. No evidence of salinity stratification was found. This slight temperature stratification was attributed to solar warming of the surface waters.

The 2007 Binningup sampling conducted around the proposed SSDP site found no evidence of any significant stratification during any of the four sampling periods.

The Bunbury background studies found that DO was variable within the water column, though it was generally higher during summer and lower during winter, and higher at the surface than at the bottom. The 2006 Collie Power Station monitoring found that DO was variable in the water column and a peak in DO between 5 and 7 m depth (Maunsell Aecom 2007). The 2007 Binningup sampling also found that DO varied in the water column and decreased with depth (KBR 2007).

The Bunbury background studies show that the waters offshore of Bunbury were cooler and of lower salinity during October, and warmer and of higher salinity during February and March. The 2006 Collie Power Station monitoring recorded values for temperature, salinity, and DO which were between the values recorded in October and February/March sampling under the BOOM programme. This is consistent with the 2006 Collie Power Station sampling being conducted at the end of November.

3.2. Biochemical Parameters

Biochemical concentrations from the BOOM and the 2007 Binningup monitoring programmes were similar. Although, some higher mean values were recorded in the vicinity of Binningup, these values were also characterised by higher standard deviations. In general, nutrient data was characterised by seasonal variation, with concentrations of nutrients and chlorophyll-a being higher during the winter months and lower during the summer months. This is possibly due to higher rainfall in winter which may result in greater nutrient flow from the land into the ocean. These higher nutrient concentrations in the ocean waters may then result in an increase in the concentration of phytoplankton and other marine primary producers (as measured by chlorophyll-a).

3.3. Variation along the Coastline

Bathymetry along the coastline between Cape Naturaliste and the proposed SSDP site is shown in Figure 2.2 and Figure 3.1. Figure 3.1 clearly shows that the bathymetry is very similar offshore of the Bunbury WWTP site and the proposed SSDP site. Figure 3.1 shows how the predominant south-westerly swells are prevented from directly impacting on the Bunbury site as discussed in WNI (2000). The close proximity of the proposed SSDP site to the Bunbury WWTP site, combined with the very similar offshore bathymetry, indicate a similar wind and swell wave regime to that observed at the Bunbury site in WNI (2000) can

be expected at the proposed SSDP site. The absence of any large topographical features (e.g. mountain ranges) in the vicinity of either site suggests that a similar wind climate can also be expected at the proposed SSDP site given the close proximity of the sites and the similar coastal orientation at the two sites.

One feature which may cause some differences in the water characteristics between the two sites is the presence of different large freshwater sources in the vicinity of both sites. The Harvey River Diversion Drain discharges freshwater into the ocean approximately 2 km north of the proposed SSDP site while The Cut links the Leschenault Inlet with the ocean approximately 10 km north of the Bunbury WWTP site. The Leschenault Inlet receives freshwater inflows from a number of rivers, including the Collie River. A surface buoyant freshwater plume has been observed radiating outwards from The Cut up to 4 km offshore, gradually mixing with the surrounding seawater (Luketina & Imberger 1987). Once the plume has mixed sufficiently with the surrounding seawater it will cease to radiate outwards and will then be subject to ambient ocean currents. This plume could then potentially influence the characteristics of the water column at either the Bunbury WWTP or SSDP sites under the influence of the seasonal current regime discussed in section 2.3.3 above. The Harvey River Diversion Drain outflow may influence the water column characteristics at the SSDP site via a similar process.

When the proximity of the sites, the bathymetry, and the wind and wave climates are all considered, the water column, oceanographic and meteorological conditions between the Bunbury WWTP, Collie Power Station, and proposed SSDP site should be comparable.

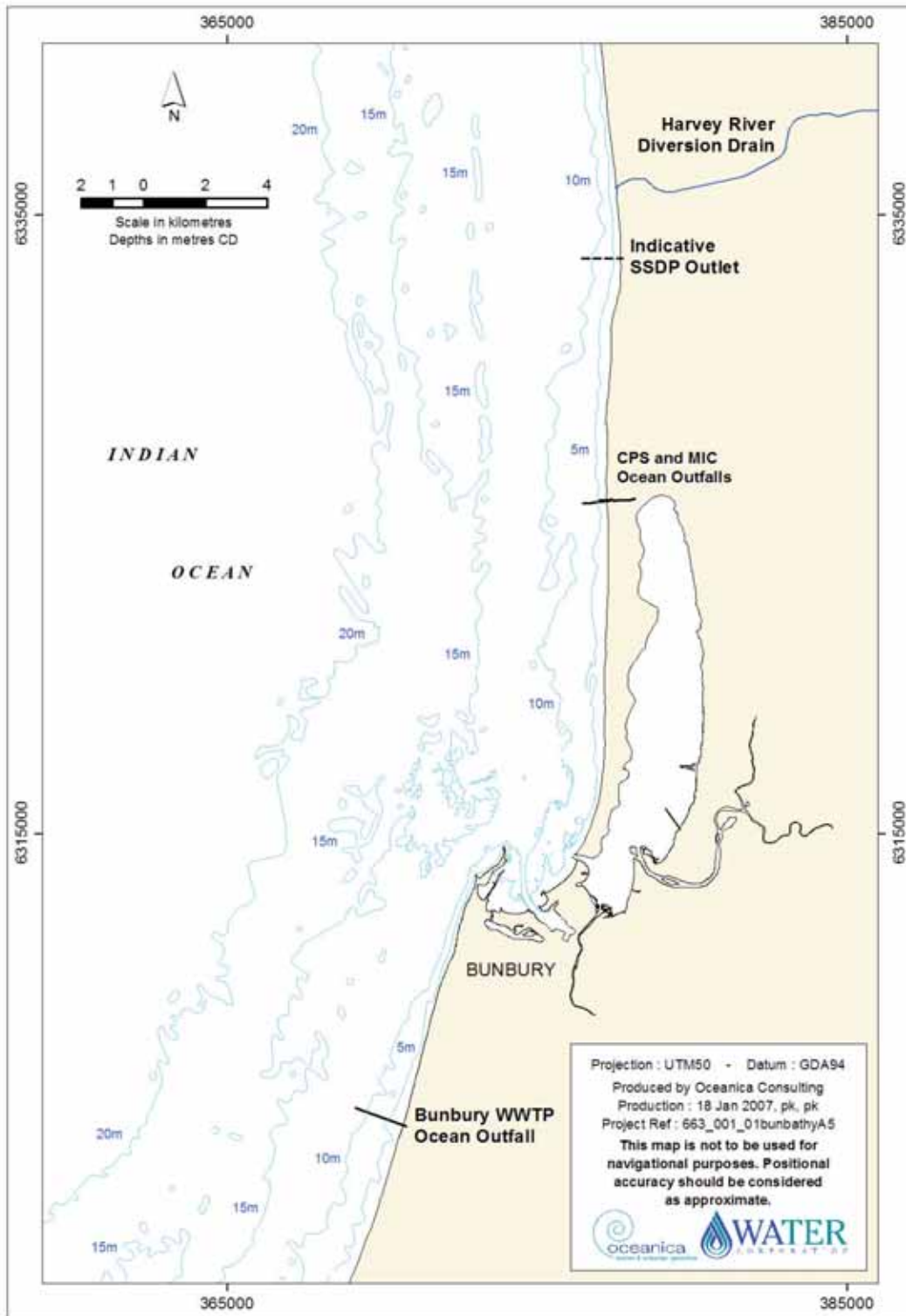


Figure 3.1 Bathymetry offshore of Bunbury and Binningup sites

4. Conclusions

Historical data from marine monitoring surveys conducted in close proximity to the proposed site for the SSDP provides a useful indication of the background water quality characteristics that would be expected at the SSDP site. Comparison between this historical data and recent data from sampling at the proposed site shows that the datasets are generally consistent and thus relevant to the proposed SSDP site.

The available data suggests that whilst slight density stratification has been observed (up to 0.1 kg/m^3), it is generally driven by a temperature gradient (i.e. through the solar warming of the surface waters) and limited to the winter months. One possible explanation for why slight temperature gradients are only observed in winter, and not in summer as would logically be expected, is that the wind stress from the strong sea breezes during summer may be sufficient to overcome the passive solar warming, resulting in mixing of the water column. The available data contains no evidence of salinity stratification and shows that the waters in the region are generally warmer, saltier and of lower density during summer, and cooler, less saline, and of higher density during the winter months. However, some salinity stratification may be experienced during heavy rainfall events and the subsequent increase in freshwater flows out of The Cut and the Harvey River Diversion Drain, the latter of which may affect the waters at the proposed SSDP site.

The nutrient concentrations from the BOOM programme are similar to those observed during the 2007 Binningup sampling. This data indicates seasonal variation in nutrients and chlorophyll-a concentrations, with higher concentrations during the winter months and lower concentrations in summer. This may be associated with higher nutrient flow from land into the ocean during winter. However, it appears that the proposed SSDP site has generally slightly higher ammonia and chlorophyll-a concentrations. One possible explanation is that the proposed SSDP site may be influenced by winter runoff out of the Harvey River Diversion Drain to the north (when the residual ocean drift is to the south) and summer runoff from the Collie River out of The Cut to the south (when the residual ocean drift is to the north).

Oceanographic investigations found that wind stress is by far the most important driving force affecting coastal hydrodynamics. The wind climate is seasonal, with a strong southerly component in summer and a strong westerly component in winter. Sea and land breezes are likely to be experienced frequently in the area around the SSDP site.

Currents in the region are generally weak, but there is a residual drift northwards in summer and southwards in winter. Currents are predominantly in the longshore direction, constrained by local bathymetry and the coastline. Tides are mixed but mainly diurnal; however, tidal forcing was found to be low and its influence on water currents is estimated to be in the order of 0.01 m/s . Seiches and storm surge may contribute to currents in the region but the magnitude is likely to be small. Density currents have been found to be insignificant in the Bunbury region.

The influence of the Leeuwin Current in the waters around Bunbury is variable but stronger in the winter months when the Leeuwin Current flow is strongest (WNI 2000). This influence is predominantly in the form of a residual drift south, but is likely to be less than 0.05 m/s (WNI 2000)

5. Acknowledgements

KBR provided the 2007 Binningup sampling data for comparison in this review. **Verve Energy** provided the 2006 Collie Power Station marine monitoring data. **Millennium Inorganic Chemicals** provided the Kemerton Ocean Outfall monitoring data.

This report was prepared by **Colin Hart** (Oceanica) and reviewed by **Mark Bailey, Bruce Hegge** and **Glenn Shiell** (all Oceanica) and **David Luketina** (Water Corporation). **Phillip Kindleysides** (Oceanica) provided GIS support and **Hayley Perhavec** (Oceanica) formatted the report.

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Appendix A

Kemerton Ocean Outfall Environmental Monitoring Programme 2006 Water Quality Results

3. Water Quality Results and Interpretation

3.1. Background

The objectives of the water column profiles and initial dilution modelling programme are to:

1. Characterise the physical-chemical water column parameters (temperature, pH, salinity, and dissolved oxygen);
2. Assess water quality (radionuclides);
3. Examine the extent of influence of the discharged plume; and
4. Assess the performance of the ocean outfall by determining the dilution and dispersion characteristics of the process wastewater.

Water column profiles, water sampling and initial dilution modelling are undertaken once per year during summer (January to March). This is consistent with the current approach adopted elsewhere by the Environmental Protection Authority where monitoring is focused on the summer (i.e. non river-flow) period (e.g. Environmental Protection Authority 2005a, 2005b).

3.2. Methods

3.2.1. Characterisation of process wastewater

Millennium undertakes continuous measurement of the volume, pH, electrical conductivity, temperature and turbidity of the process wastewater discharge. This information is compared against Licence Conditions and used in the initial dilution modelling of the process wastewater plume (Section 3.2.3).

A chemical contaminant analysis including metals and nutrients was completed on a grab sample of the process wastewater collected on 7 March 2006.

3.2.2. Monitoring sites

Table 3.1 and Figure 3.1 present the site location and coordinates for the March 2006 Kemerton ocean outfall water quality survey. These sites were recorded using a handheld global positioning system (GPS). The central site, KDIFF, and the dilution sites, D1 to D4, were first identified by a diver prior to marking the survey point with a GPS.

Table 3.1 March 2006 Kemerton ocean outfall survey site locations (GDA94, UTM50)

Site	Easting	Northing
KDIFF	376971	6325758
K20N	376971	6325778
K20E	376991	6325758
K20S	376971	6325738
K20W	376951	6325758
K1000N	376971	6326758
K1000S	376971	6324758
Dilution Sites		
D1	376971	6325763
D2	376971	6325761
D3	376971	6325757
D4	376971	6325754
Plume Tracking Sites		
T1	377046	6325610
T2	377074	6325580
T3	377098	6325540



Figure 3.1 Location of monitoring sites for Kemerton ocean outfall, January–March 2006

3.2.3. Water quality

Surface drogue movement

At the commencement of the water quality survey, a surface drogue was deployed over the centre of the operational outfall diffuser. The location of the drogue was recorded at intervals throughout the water quality survey using a handheld GPS. Surface drogue tracking provides an accurate estimate of mean surface current, and this information is used in the initial dilution modelling.

Initial dilution modelling

The CORMIX and VPLUMES programmes are initial dilution models accepted for use by the United States Environmental Protection Agency (<http://www.epa.gov/>). The *initial dilution phase* occurs from point of discharge to a point of maximum rise or fall (e.g. reaching the surface of the water body).

These numerical models are designed to model the near-field behaviour of plumes—that is, the behaviour in the region where the plume first jets into the surrounding waters and then (in the case of positively buoyant plumes) rises and mixes with the surrounding waters. These models capture simple features concerning the surrounding environment such as depth at point of discharge, net current and wind speed. However, because the models do not take into account broader scale bathymetry and hydrodynamics, these models generally do not accurately predict the far-field behaviour—that is, the behaviour after the plume has reached the surface or is fully mixed in the water column. Three-dimensional baroclinic or barotropic hydrodynamic models are required to better estimate far-field behaviour.

The UM3 initial dilution model, which is part of the Visual Plumes (VPLUMES) suite of dilution models (Frick *et al.* 2001), was applied to the discharge from the Kemerton ocean outfall diffuser for the ambient conditions and process wastewater flows at the time of the water quality survey. The model set-up parameters selected to represent the outlet diffuser, flows and ambient conditions at Kemerton at the time of the water quality survey are presented in Table 3.2.

Table 3.2 Initial dilution model set-up parameters for the Kemerton ocean outfall, 7 March 2006

Parameter	Kemerton ocean outfall
Diffuser characteristics	
Port diameter	0.05 m
Number of open ports ⁽¹⁾	4 open (6 total)
Port spacing ⁽²⁾	2.7 m
Diffuser pipe diameter	0.25 m
Port orientation	Horizontal
Water depth	7.5 m
Ambient conditions at time of sampling	
Temperature ⁽³⁾	Surface 24.2°C Bottom 23.2°C
Salinity ⁽³⁾	Surface 36.36 Bottom 36.34
Surface current ⁽⁴⁾	Speed 0.04 ms ⁻¹ Bearing 146°
Discharge characteristics	
Flow	126.9 m ³ h ⁻¹
Temperature	35.9°C
Salinity ⁽⁵⁾	25.9

- Notes:
1. The number of active diffuser ports was recorded by field staff during a dive over the outfall during the March survey.
 2. Port spacing has been determined as the average distance between active ports (the designed port spacing is 2 m).
 3. Ambient temperature and salinity profiles are taken from site K20W.
 4. Surface current and direction are determined from the movement of the surface drogue.
 5. The salinity of the process wastewater in practical salinity units (psu) was estimated from the measured electrical conductivity, using a conversion factor of 0.6.

The surface drogue tracking provides an accurate estimate of mean surface current with good agreement among velocities calculated from the three observations taken over the duration of the water quality survey. The mean direction⁶ of the surface current was also estimated from the surface drogue tracking locations. These mean surface currents were used to synthesise vertical velocity profiles based on the findings of WNI (2000), who installed current meters at 2 m and 7.5 m above the seabed approximately 900 m offshore from the end of the diffuser of the Water Corporation's Bunbury ocean outfall. The difference between the mean currents at these depths was used as an indication of a likely linear decrease in current speeds from the surface to the seabed.⁷ It was estimated that the current speed drops by approximately 4.9% per metre depth. There were no current measurements undertaken at the Kemerton ocean outfall as part of the WNI study, therefore the difference between mean currents at Bunbury was used as an indication of the likely linear decrease in current speeds at Kemerton.

Near-field dilutions

The dilution which the plume receives as it rises from the point of discharge to the surface is the initial dilution. Minimum near-field dilutions of the process wastewater plume were estimated from the field measurements of water quality parameters (i.e. radium-226). The minimum near-field dilutions were determined as:

$$\text{Minimum Dilution} = \frac{\text{Process wastewater Concentration}}{\text{Highest Concentration} - \text{Mean Background Concentration}}$$

Where:

- "Process wastewater concentration" is the measured concentration of radium-226 in the discharged process wastewater;
- "Highest concentration" is the highest concentration of radium-226 measured at any one sampling site located within 20 m of the outfall diffuser; and
- "Mean background concentration" is the average concentration of radium-226 at the upstream reference site.

It should be noted that the location of the water samples may not exactly sample the maximum radium-226 concentration as the plume rises to the water surface. If the maximum concentration was not sampled, the actual near-field dilution may be slightly less than that calculated.

The VPLUMES model provides an estimate only of the initial dilution and the calculations from field measurements may suggest over and/or under predictions. For this reason, the modelling results and measured field dilutions should be used together to provide the likely range of dilutions which may occur in the vicinity of the diffuser.

Water column structure

Sampling locations

Profiles of the physical-chemical water column parameters were taken at three plume tracking sites and four dilution sites (Figure 3.1). The three plume tracking sites were located in the direction of the prevailing flow conditions as established through the surface drogue movement on the day of the survey—i.e. in the assumed direction of the process wastewater plume. The profiles taken across the Kemerton diffuser were accurately positioned using a diver and marker (float) lines. This allowed for the profiling instrument to be guided vertically through the water column within approximately one metre of the intended position. On two of the profiles, D2 and D3, the diver guided the probe directly past active diffuser ports to gain direct near-field measurement of the discharge plume within centimetres of the diffuser port (Figure 3.2).

⁶ The current direction was assumed to remain constant throughout the water column.

⁷ Two sets of ambient conditions are set in the model, one at the surface (0 m) and one at approximately one metre above the seabed. The current speed is set to linearly decrease to zero from this depth.

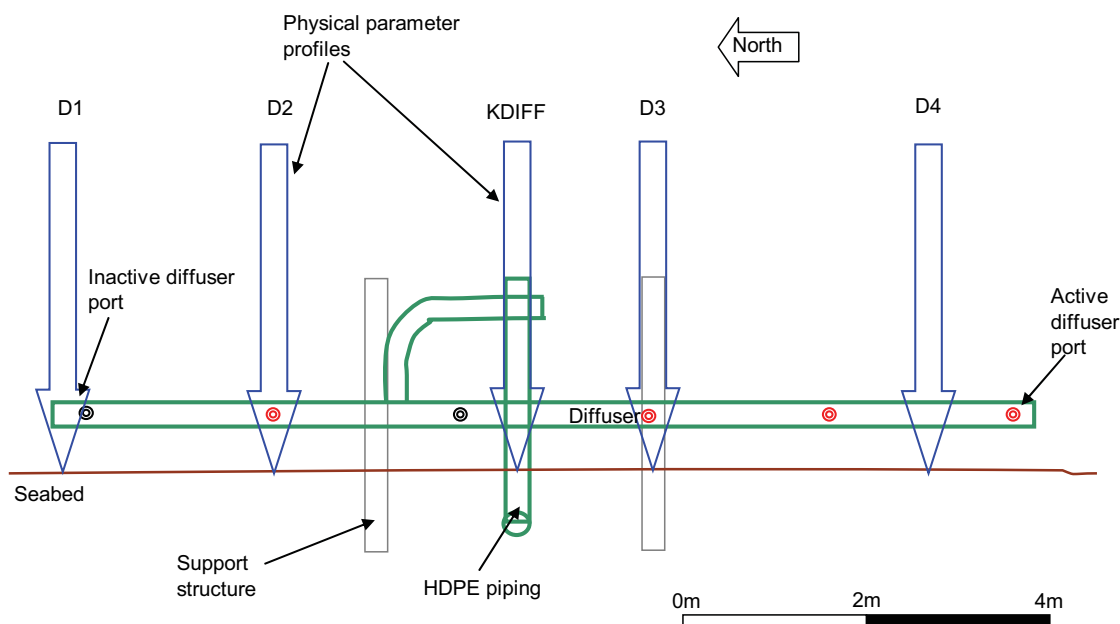


Figure 3.2 Schematic representation of the Kemerton ocean outfall diffuser showing the position of physical profiles taken on 7 March 2006

Profiles were also taken from one site within the mixing zone (immediate vicinity of the diffuser [site KDIFF]), four sites located at the edge of the mixing zone (20 m north [site K20N], south [site K20S], east [site K20E] and west [site K20W] of the diffuser), and at two reference sites located outside the mixing zone (1,000 m north [site K1000N] and south [site K1000S] of the diffuser) (Figure 3.1).

Sample collection

A YSI 6600 multi-parameter water quality sensor was lowered through the water column at each of the sites to provide information on the physical structure of the water column. At each site the following water column profile measurements were obtained: temperature, pH, salinity and dissolved oxygen.

Data analysis and presentation

The water column structure data for each sampling site were compiled and presented as line and surface contour charts. The surface charts were prepared using Matlab Version 6.1 (Release 12.1). The information from these profiles was used to examine the spatial extent of the influence of the discharged process wastewater plume.

Water quality sampling

Sampling locations

Water samples for analysis of radium-226 were collected from one site within the mixing zone (immediate vicinity of the diffuser [site KDIFF]), four sites located at the edge of the mixing zone (20 m north [site K20N], south [site K20S], east [site K20E] and west [site K20W] of the diffuser), and at two reference sites located outside the mixing zone (1,000 m north [site K1000N] and south [site K1000S] of the diffuser) (Figure 3.1).

Sample collection and analysis

Triplicate depth-integrated water samples for radium-226 analysis were collected in pre-cleaned analytical quality polyethylene containers supplied by the analytical laboratory and acidified with 5 ml of nitric acid (as prescribed in Australian Standard AS/NZS 5667.1:1998 and AS/NZS 5667.9:1998). Samples were kept on ice while in transit to the analytical laboratory.

The radium-226 analyses were undertaken by Western Radiation Services using the NATA accredited, LTP3 Radium-226 (de-emanation and photon counting) analytical method. The detection limit for radium-226 measurement was 3 mBqL⁻¹.

Data analysis and presentation

The radium-226 data for each sampling site is presented in tabular form. This information is compared against relevant guidelines and previous year's data.

For the purposes of calculating statistics and data presentation, concentrations below the reporting limit were assumed to be equal to the reporting limit (e.g. <3 mBqL⁻¹ becomes 3 mBqL⁻¹).

3.3. Results

3.3.1. Characterisation of process wastewater

The characteristics of the Kemerton ocean outfall process wastewater measured during the water quality survey on 7 March 2006 are presented in Table 3.3 and Table 3.4. The process wastewater analysis meets the Licence Conditions listed in Table 2.6 for volume, pH, total suspended solids and total dissolved solids. Manganese concentrations measured over the 12 month period from 1 January 2006 to 31 December 2006 (Table 3.5) satisfy the limits specified in the Licence Conditions.

Comparison of the ANZECC/ARMCANZ (2000) guidelines for contaminants in marine waters against the concentrations measured in the process wastewater show that the wastewater meets the 80% species protection guideline for vanadium, the 90% species protection guideline for copper, and the 99% species protection guidelines for cadmium, chromium, mercury, nickel, lead and zinc prior to discharge into the ocean (Table 3.4Table 3.4). As discussed in Section 2.1, the level of protection generally assigned to within the mixing zones of outfalls is the ANZECC/ARMCANZ (2000) 80% species protection guideline—specifically for those toxicants identified as having the potential to adversely bioaccumulate or biomagnify (cadmium, mercury and nickel), with higher levels of protection for contaminants applicable at the edge of mixing zones. Millennium's ocean outfall would satisfy these conditions prior to discharge in most cases, that is, prior to any dilution that will occur once released into the ocean. Reliable national guidelines are presently unavailable for many contaminants (due to lack of toxicity data from which to derive guidelines), and for some of these contaminants ANZECC/ARMCANZ (2000) offers instead 'Low Reliability Values' (LRVs) that were derived using conservative assessment factors—with the caveat that the LRVs are not to be used as default guidelines, but as indicative working levels until more data are available to derive a reliable guideline.

Table 3.3 Physical characteristics of the Kemerton process wastewater, 7 March 2006

Parameter ⁽¹⁾	Measurement/Concentration
Flow rate (m ³ h ⁻¹)	126.9 ⁽²⁾
pH	7.5
Electrical conductivity (µS _{cm} ⁻¹)	43,200
Temperature (°C)	35.9 ⁽²⁾
Turbidity (NTU)	29
Total suspended solids (mgL ⁻¹)	29
Total dissolved solids (mgL ⁻¹)	23,200

Note: 1. Flow rate, temperature and total dissolved solids measured by Millennium. All other parameters measured by external laboratories and data supplied to Millennium.
2. Maximum hourly flow rate and maximum daily temperature have been presented.

Table 3.4 Chemical characteristics of the Kemerton process wastewater, 7 March 2006

Parameter ⁽¹⁾	Wastewater Concentration (mgL ⁻¹)	ANZECC/ARMCANZ (2000) Guidelines (mgL ⁻¹) Level of protection (% Species)					Level of protection met <u>before</u> any dilution
		99%	95%	90%	80%	LRV ⁽²⁾	
Metallics							
Aluminium	1.7	ID ⁽³⁾	ID	ID	ID	0.0005	Not available
Calcium	8,370	n.d. ⁽⁴⁾	n.d.	n.d.	n.d.	n.d.	Not available

Parameter ⁽¹⁾	Wastewater Concentration (mgL ⁻¹)	ANZECC/ARMCANZ (2000) Guidelines (mgL ⁻¹) Level of protection (% Species)					LRV ⁽²⁾	Level of protection met before any dilution
		99%	95%	90%	80%			
Cadmium	0.0006	0.0007	0.0055	0.014	0.036	-	99%	
Chromium	0.005 ⁽⁵⁾	0.0077 (Cr III) 0.00014 (Cr VI)	0.0274 (Cr III) 0.004 (Cr VI)	0.0486 (Cr III) 0.020 (Cr VI)	0.0906 (Cr III) 0.085 (Cr VI)	-	99% (Cr III)	
Copper	0.002	0.0003	0.0013	0.003	0.008	-	90%	
Iron	0.25	ID	ID	ID	ID	0.3	Not available	
Mercury	<0.0001	0.0001	0.0004	0.0007	0.0014	-	99%	
Magnesium	12	n.d.	n.d.	n.d.	n.d.	n.d.	Not available	
Manganese	0.54	ID	ID	ID	ID	n.d.	Not available	
Sodium	4,190	n.d.	n.d.	n.d.	n.d.	n.d.	Not available	
Nickel	0.003	0.007	0.070	0.200	0.560	-	99%	
Lead	<0.001	0.0022	0.0044	0.0066	0.012	-	99%	
Selenium	<0.001	ID	ID	ID	ID	0.003 (Total Se)	Not available	
Titanium	0.073	n.d.	n.d.	n.d.	n.d.	n.d.	Not available	
Vanadium	0.26	0.050	0.100	0.160	0.280	-	80%	
Zinc	<0.001	0.007	0.015	0.023	0.043	-	99%	
Non-metallics								
Chloride	19,500	n.d.	n.d.	n.d.	n.d.	n.d.	Not available	
Nutrients								
Ammonium	<1 ⁽⁶⁾	0.500	0.910	1.200	1.700	-	Detection limit not low enough for comparison against guidelines	
Nitrate	<0.2	ID	ID	ID	ID	0.7	Not available	
Total Phosphorus	<0.1	n.d.	n.d.	n.d.	n.d.	n.d.	Not available	
Radionuclides								
Radium-226 (mBqL ⁻¹)	2,518	n.d.	n.d.	n.d.	n.d.	n.d.	Not available	
Radium-228 (mBqL ⁻¹)	9,622	n.d.	n.d.	n.d.	n.d.	n.d.	Not available	
Other								
Sulphate	210	n.d.	n.d.	n.d.	n.d.	n.d.	Not available	
Calcium Carbonate, CaCO ₃	<1	n.d.	n.d.	n.d.	n.d.	n.d.	Not available	
Bicarbonate, HCO ₃	15	n.d.	n.d.	n.d.	n.d.	n.d.	Not available	

- Notes:
1. All parameters measured by external laboratories and data supplied to Millennium.
 2. LRV = Low reliability value. LRV's are not to be used as default guidelines, and hence no comment on the concentrations of the parameter in the wastewater meeting or not meeting the LRV concentration is made (i.e. "Not available" in the final column).
 3. ID = Insufficient data to derive a reliable national trigger value.
 4. n.d. = Not defined in ANZECC/ARMCANZ (2000).
 5. Measured value is for total chromium
 6. Ammonium results were not available for samples taken on 7 March 2006. Values from samples analysed in January 2006 are presented instead.

Table 3.5 Concentrations of manganese (mgL⁻¹) measured in the Kemerton ocean outfall discharge stream from 1 January 2006 to 31 December 2006

January	February	March	April	May	June
2.56	2.22	0.73	0.93	1.48	0.82
0.97	1.32	0.51	0.56	0.80	0.98
4.12	2.14	0.68	0.64	0.70	1.00
1.99	0.79	0.55	0.81	1.28	1.23
3.96	1.08	0.47	0.71	1.12	0.42
1.87	0.14	1.22	0.36	1.06	0.67
2.38	1.36	0.87	0.42	0.99	0.26
2.00	1.39	0.26	0.52	0.94	3.40
1.40	0.62	0.55	0.70	1.40	1.14
	0.67	0.60	0.32	1.36	1.26
		0.76	0.35	1.28	2.67
		0.64	0.43	1.00	3.80
		0.43	0.74	0.62	
		0.94	1.55	1.86	
		0.67		1.08	
				0.53	
				1.60	
July	August	September	October	November	December
7.00	0.68	1.34	0.82	0.56	0.73
5.20	0.61	1.08	1.01	1.01	0.74
1.27	0.71	1.88	3.93	0.88	0.63
0.92	0.78	1.38	2.16	0.44	1.54
2.00	0.78	1.07	1.97	3.26	0.73
0.76	0.42	1.42	1.22	1.94	0.98
0.80	0.68	0.54	1.49	2.22	1.09
0.65	0.78	1.04	5.90	0.46	0.43
1.12	0.63	0.68	1.51	3.46	0.42
1.18	0.64	0.53	1.19	2.10	0.58
1.08	1.04	0.47	1.47	2.44	1.05
	0.64	0.63	5.60	0.99	0.55
	0.72	0.69	1.21	0.72	0.63
	0.33		0.82	1.15	0.44
	0.67		0.75	0.94	0.50
			0.45	0.68	
			0.69	0.65	
			0.69		

3.3.2. Surface drogue movement

The surface drogue released above the outfall diffuser during the water quality survey drifted in a south-easterly direction (Figure 3.1) with an average velocity of 0.04 ms⁻¹. Therefore it is expected that the discharged process wastewater would be advecting to the south of the diffuser.

3.3.3. Initial dilution modelling

For the ambient conditions at the time of the water quality survey on 7 March 2006, the modelling predicted an average initial dilution of 1:106, and a centreline dilution of 1:75 (Figure 3.3 (a)). The plume was predicted to first reach the surface within approximately five metres (horizontal distance) from the discharge point above the seafloor (see the ambient boundary⁸ of the plume in Figure 3.3 (b)). The full model output is included in Appendix C.

⁸ The ambient boundary corresponds to the plume boundary at which concentrations are estimated to be equal to ambient conditions.

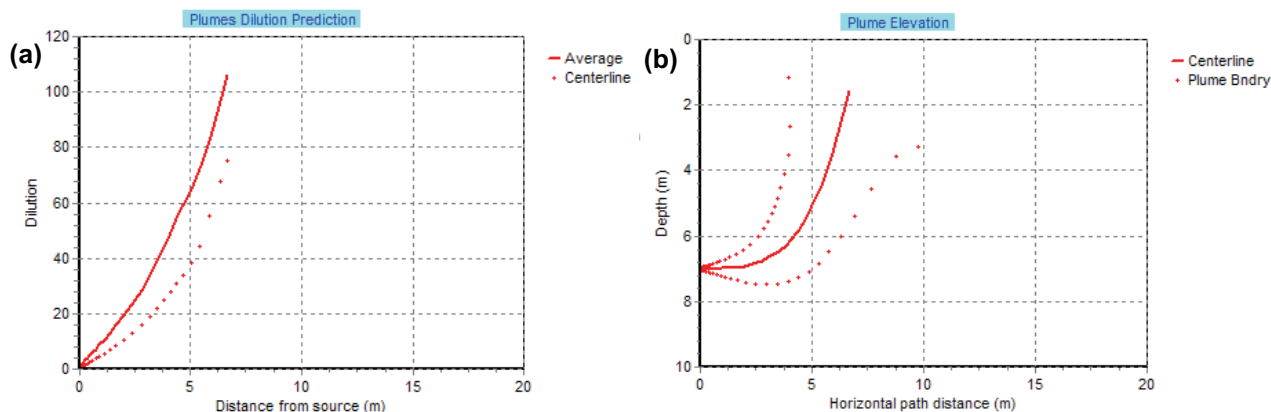


Figure 3.3 UM3 initial dilution modelling results for (a) predicted average and centreline dilutions, and (b) predicted plume elevation trajectory, during the water quality survey at Kemerton, 7 March 2006

3.3.4. Near-field dilution

The background concentration for radium-226 was taken from reference site K1000N, as this was the reference site located upstream of the assumed flow direction of the process wastewater plume. The highest individual concentration was from sites KDIFF and K20N (Table 3.7). Therefore, the following values have been used in the near-field dilution calculation:

- "Process wastewater concentration" = 2,518 mBqL⁻¹;
- "Highest concentration" = 21 mBqL⁻¹; and
- "Mean background concentration" = 1.5 mBqL⁻¹.

Using these values in the equation from Section 3.2.3, gives a near-field dilution of 1:129. This estimate of near-field dilution is consistent with the results from the initial dilution modelling above.

3.3.5. Water column structure

Surface and bottom measurements of salinity, temperature and pH, and bottom dissolved oxygen measurements as required in Licence Condition W9 (Licence No. 6078/10) are shown in Table 3.6. The raw data for the physical profiles is included in Appendix D. ANZECC/ARMCANZ (2000) guidelines specify a lower limit of 90% saturation for dissolved oxygen levels and a pH range of 8.0-8.4 for inshore "slightly disturbed" marine waters (Table 2.1). As shown in Table 3.6 all Kemerton ocean outfall sites satisfied both the pH and dissolved oxygen guidelines during the March 2006 survey.

Table 3.6 Surface and bottom salinity, temperature and pH measurements, and bottom dissolved oxygen measurements at water quality sites, Kemerton ocean outfall, 7 March 2006

Site	Temperature (°C) ⁽¹⁾		Salinity ⁽¹⁾		pH ⁽¹⁾		Dissolved oxygen (%) ⁽²⁾
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Bottom
KDIFF	23.19	23.16	36.30	36.33	8.1	8.1	100
K20N	23.95	23.19	36.33	36.36	8.1	8.1	99
K20E	23.98	23.21	36.29	36.36	8.1	8.1	99
K20S	23.38	23.16	36.26	36.34	8.1	8.1	98
K20W	24.01	23.16	36.19	36.34	8.1	8.1	99
K1000N	24.31	23.24	36.20	36.36	8.1	8.1	97
K1000S	24.48	23.17	36.10	36.32	8.1	8.1	100
D1	23.48	23.17	36.29	36.31	8.0	8.0	100
D2	23.33	24.04	36.25	35.71	8.0	8.0	99
D3	23.22	23.41	36.28	36.19	8.1	8.0	97
D4	23.22	23.15	36.29	36.35	8.1	8.1	100
T1	23.89	23.17	36.24	36.33	8.1	8.1	100

Site	Temperature (°C) ⁽¹⁾		Salinity ⁽¹⁾		pH ⁽¹⁾		Dissolved oxygen (%) ⁽²⁾
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Bottom
T2	24.10	23.20	36.24	36.34	8.1	8.1	98
T3	24.47	23.27	36.27	36.37	8.1	8.1	98

Note: 1. For temperature, salinity and pH 'surface' measurements are taken 0.5 m below the water surface, and 'bottom' measurements are taken 0.5 m above the seabed.
2. Bottom dissolved oxygen concentration is the median value of all measurements taken between 0-0.5 m above the seabed.

The profiles taken directly over diffuser ports (D2, D3) show strong signatures of the plume, with peaks in all four physical parameters observed (Figure 3.4). However, sites D1 and D4 are taken between active ports and do not show any indication of the discharged wastewater. The very localised influence of the plume is clear in Figure 3.5, showing a north-south transect with the plume temperature-salinity signature only evident within metres of the diffuser ports. The maximum temperature of the discharge recorded on 7 March 2006 was 35.9°C, and the peak in the water temperature profile in front of an active port was only approximately 1.5-2°C above ambient, indicating that a high level of mixing has already occurred. Similarly with salinity, the process wastewater had a salinity of approximately 26, while the decrease in the water salinity profile was only 1.5-2 below ambient conditions.

Some degree of natural temperature stratification is present at most sites excepting those within the immediate vicinity of the outfall: KDIFF, D1, D2, D3 and D4 (Figure 3.4 to Figure 3.8). This suggests that the discharged process wastewater is acting to locally mix the water column and break down this stratification. The site at the southern edge of the mixing zone boundary (K20S) doesn't show the same level of stratification as the other boundary sites, and may also be being influenced by the mixing resulting from the wastewater plume.

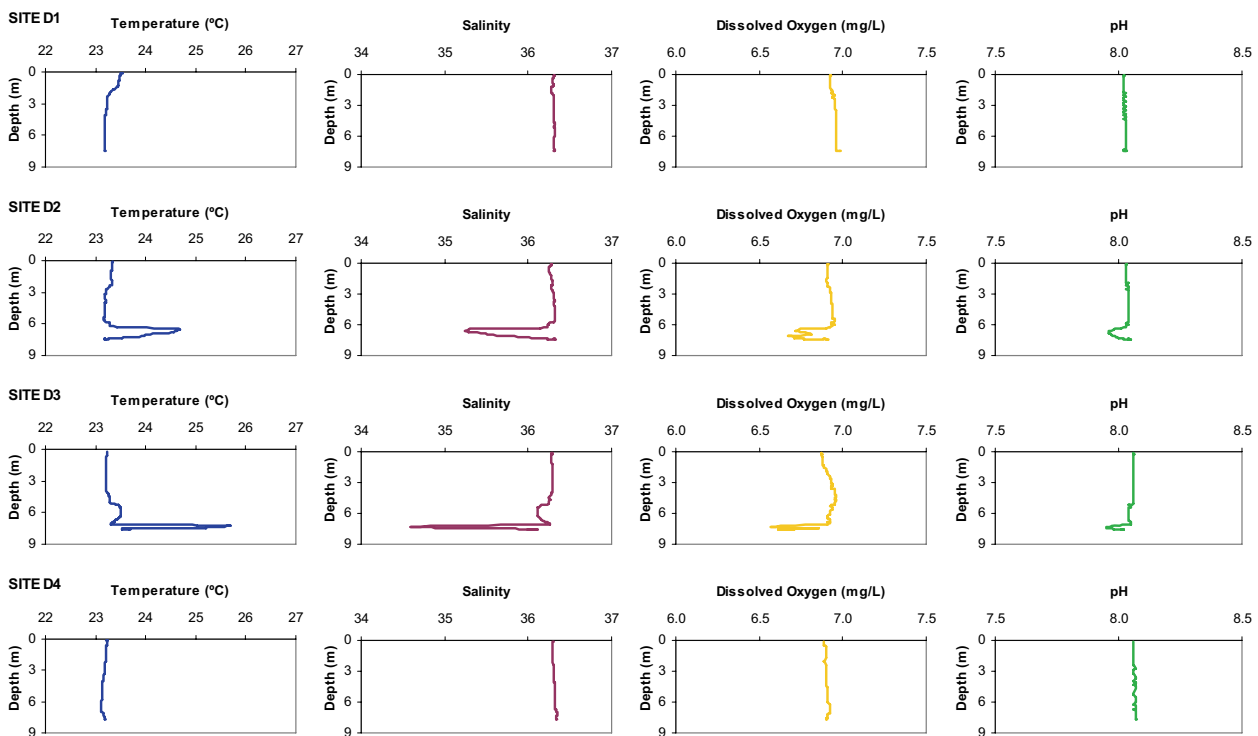


Figure 3.4 Temperature, salinity, dissolved oxygen and pH profiles at dilution sites (D1, D2, D3, D4) at the Kemerton ocean outfall, 7 March 2006

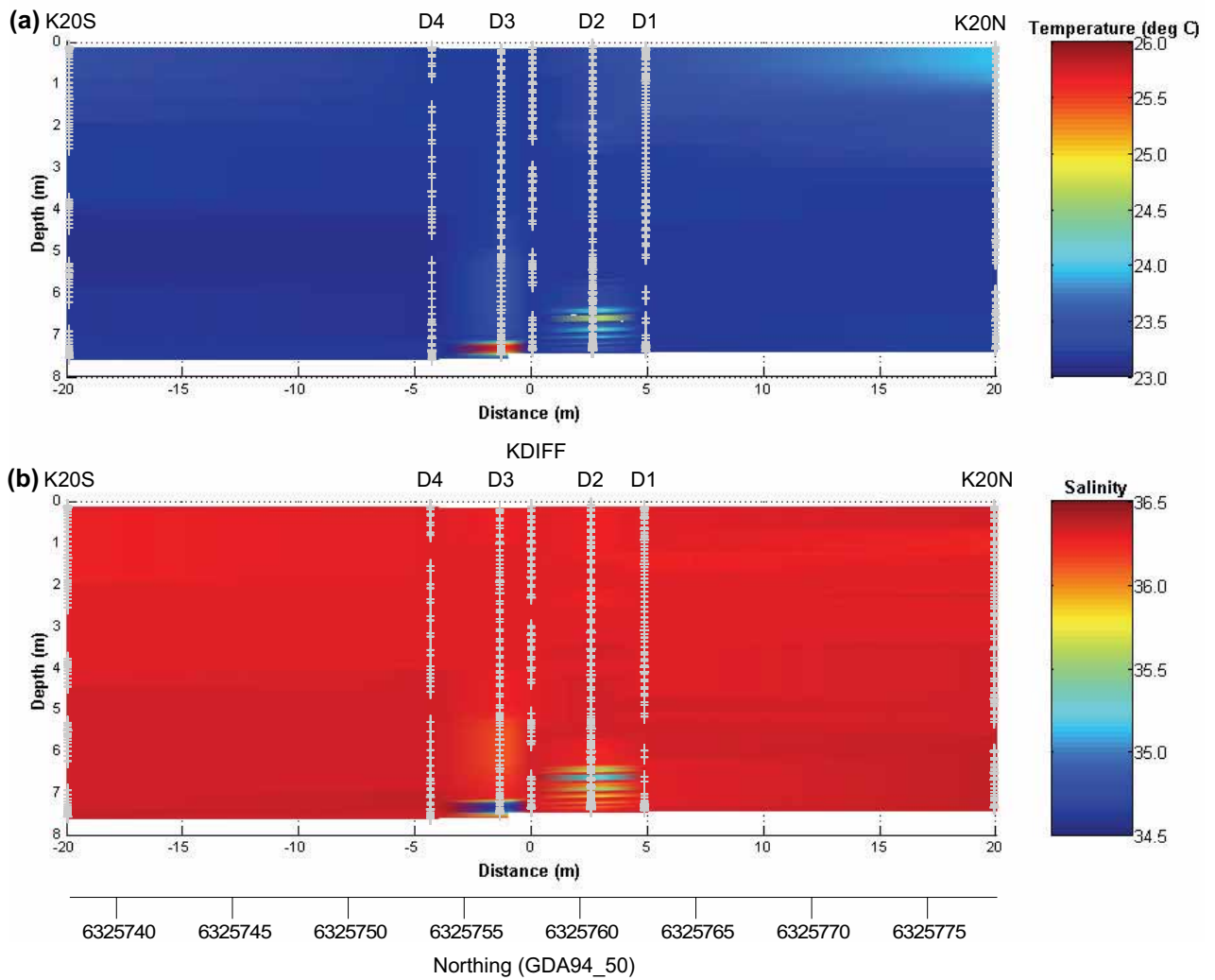


Figure 3.5 (a) Temperature and (b) salinity profiles along a south to north transect during the March 2006 water quality survey at Kemerton ocean outfall

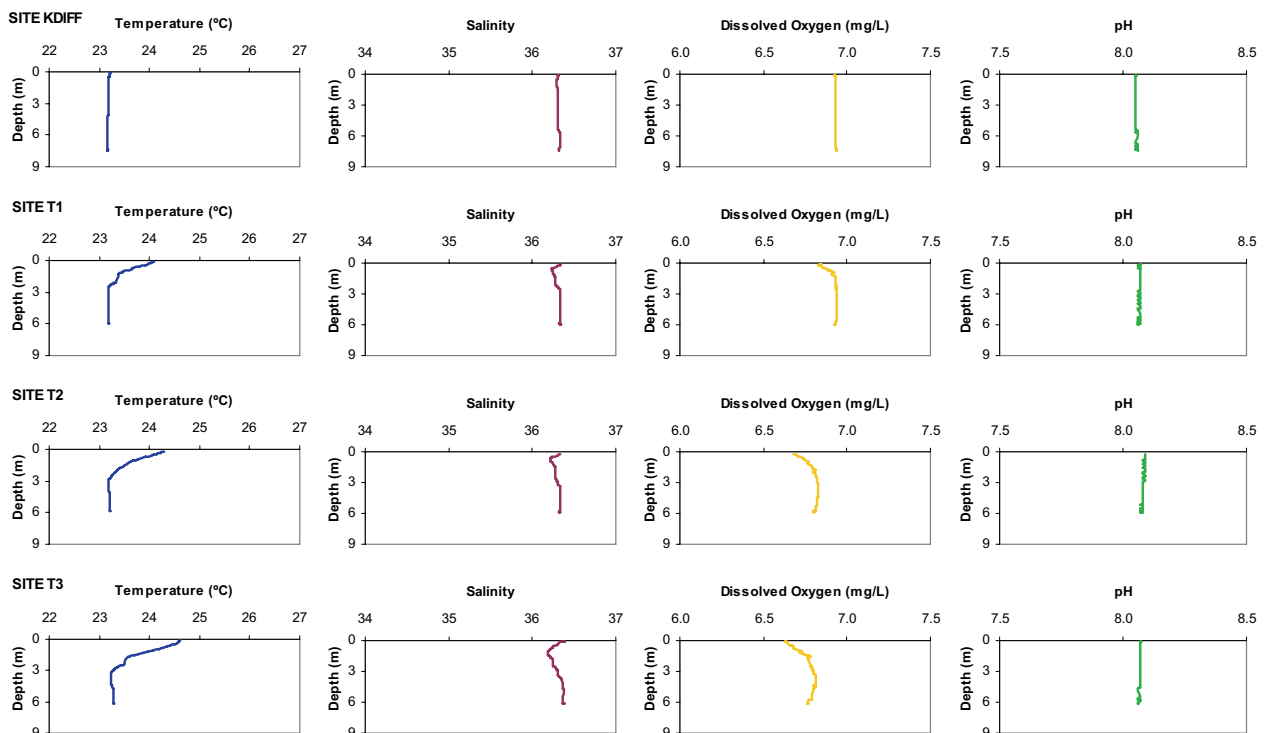


Figure 3.6 Temperature, salinity, dissolved oxygen and pH profiles at plume tracking sites (KDIFF, T1, T2, T3) at the Kemerton ocean outfall, 7 March 2006

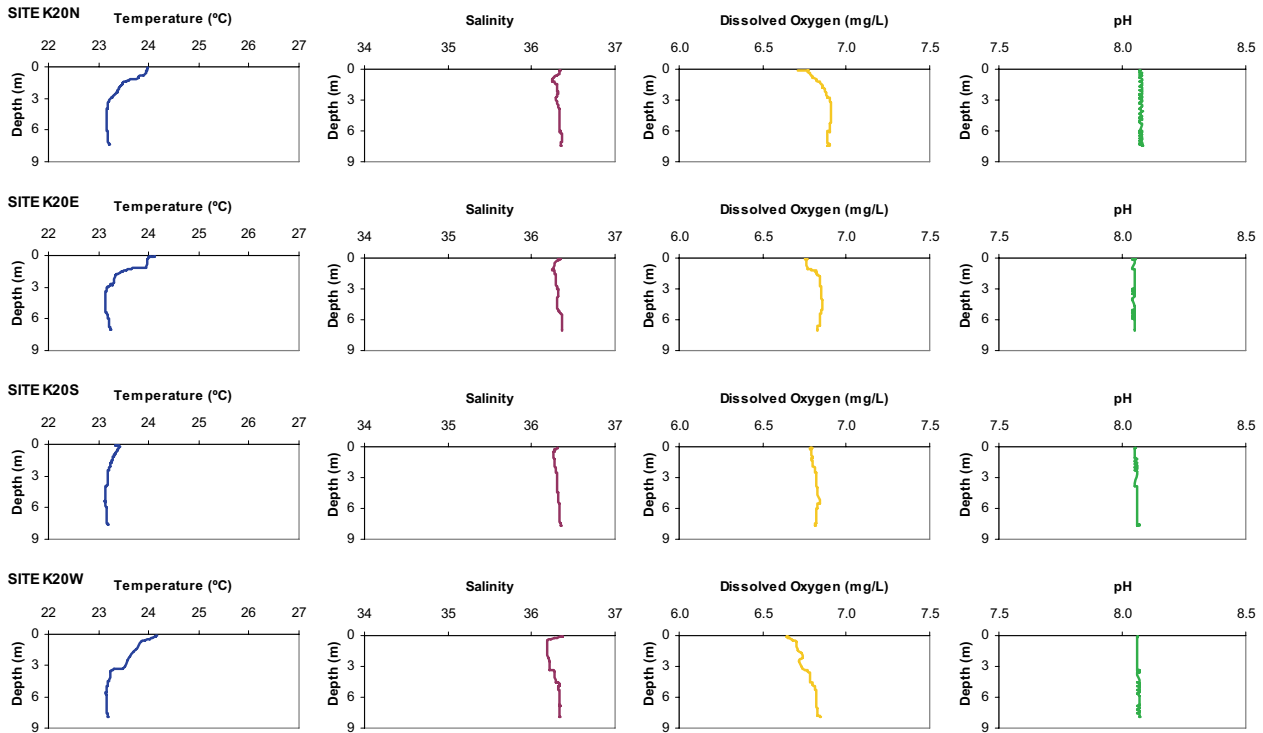


Figure 3.7 Temperature, salinity, dissolved oxygen and pH profiles at mixing zone boundary sites (K20N, K20E, K20S, K20W) at the Kemerton ocean outfall, 7 March 2006

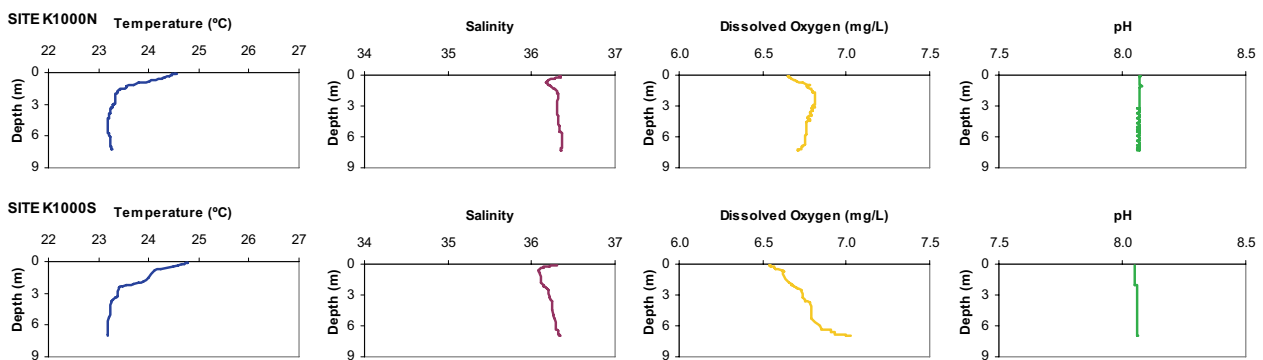


Figure 3.8 Temperature, salinity, dissolved oxygen and pH profiles at reference sites (K1000N, K1000S) at the Kemerton ocean outfall, 7 March 2006

3.3.6. Water quality

The concentrations of radium-226 in the waters surrounding the Kemerton ocean outfall were relatively low, ranging from $<3 \text{ mBqL}^{-1}$ to $21 \pm 10 \text{ mBqL}^{-1}$ (Table 3.7). The highest individual measurement of radium-226, $21 \pm 10 \text{ mBqL}^{-1}$, was recorded in one of the replicate samples from site KDIFF and also site K20N. There is little variation between the sites themselves—the sites within and at the edge of the mixing zone show radium-226 concentrations similar to those of the two reference sites.

No radium-226 criteria are defined in ANZECC/ARMCANZ (2000), however measured levels are well below the previous guideline of $<400 \text{ mBqL}^{-1}$ set in ANZECC (1992). For comparative purposes only, the radium-226 concentrations have been compared to current recreational and drinking water guidelines:

- Typical radium concentrations in small groundwater drinking supplies can be up to, or exceeding, 500 mBqL^{-1} , while radium concentrations in surface water drinking supplies are typically below 20 mBqL^{-1} (NHMRC 2004). All the mean concentrations (Table 3.7) are below those values typically found in drinking water sources. The annual allowable dose from drinking waters is 1 mSy^{-1} ; the radium-226 concentrations around the

Kemerton ocean outfall would only account for approximately 0.4% of this annual dose limit.

- The recommended gross alpha activity allowable for recreational purposes is $<100 \text{ mBqL}^{-1}$. Radium-226 is an alpha-emitter, and all measured concentrations are well below this limit for recreational use. Note: radium-226 may not be the only alpha-emitting radionuclide present in the water samples.

Table 3.7 Radium-226 concentrations in depth-integrated water samples at sites surrounding the Kemerton ocean outfall, 7 March 2006

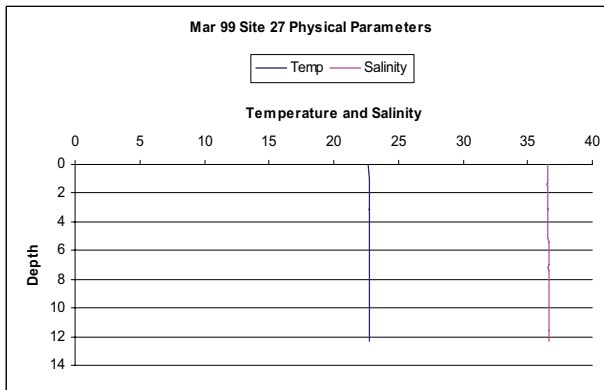
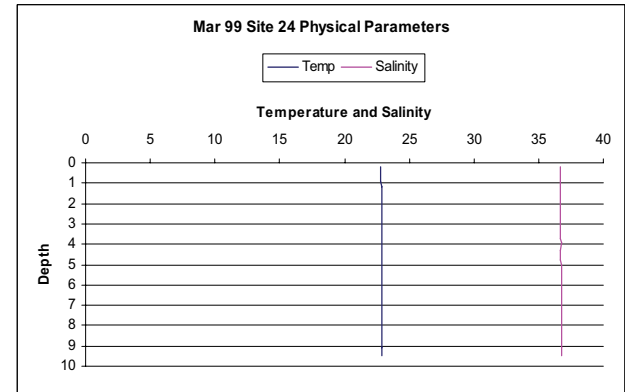
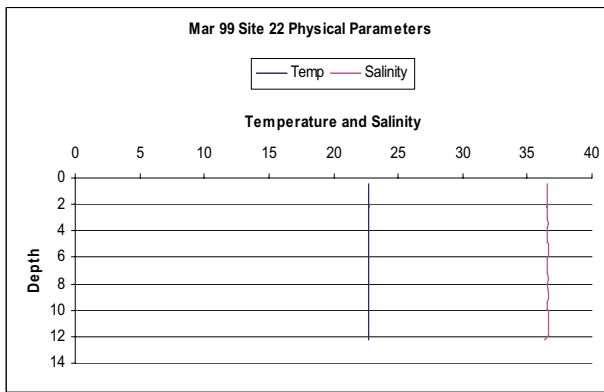
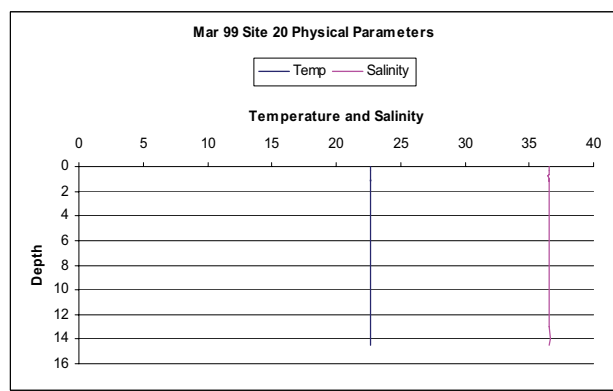
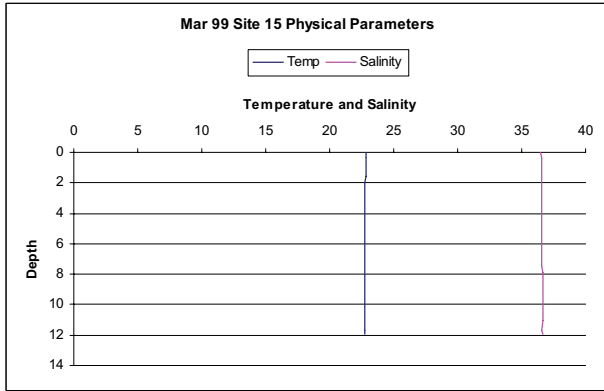
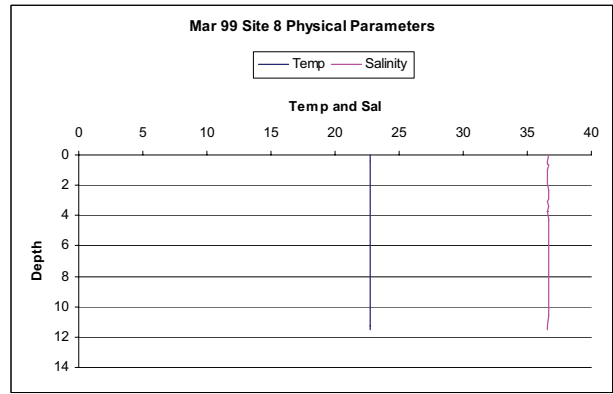
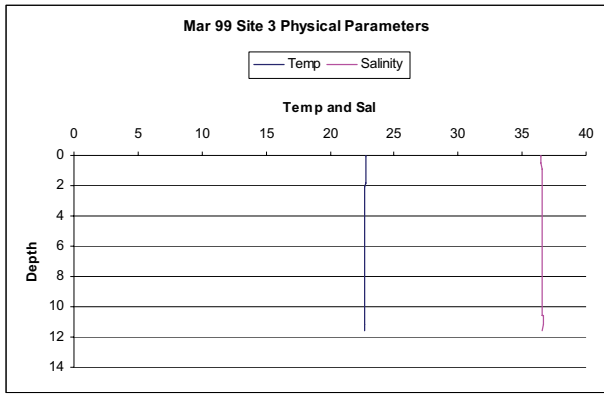
Site	Replicate	Concentration (mBqL^{-1}) ⁽¹⁾	Mean Concentration (mBqL^{-1}) ⁽²⁾
K1000N	A	4±2	3
	B	<3	
	C	<3	
K20N	A	21±10	14
	B	18±7	
	C	<3	
K20E	A	<3	3
	B	<3	
	C	<3	
KDIFF	A	10±4	16
	B	21±10	
	C	16±6	
K20W	A	19±7	12
	B	5±2	
	C	11±5	
K20S	A	<3	4
	B	5±3	
	C	<3	
K1000S	A	10±5	9
	B	11±6	
	B (lab rep)	13±7	
	C	<3	

Notes: 1. Concentrations are presented as a measured value ± measurement error.
2. Mean concentrations are calculated using measured values only.

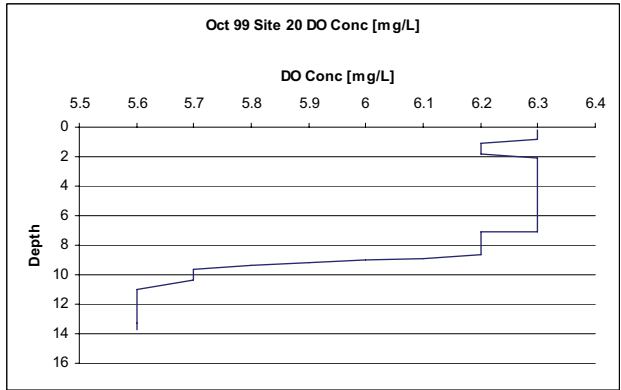
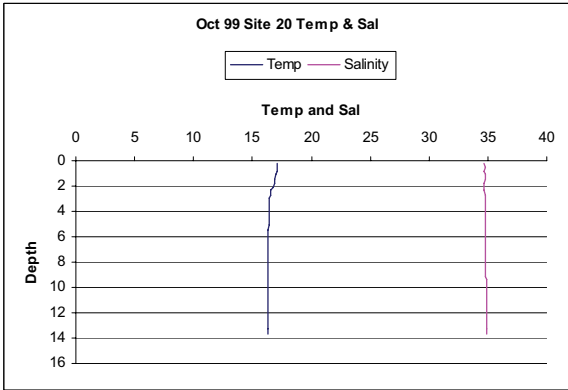
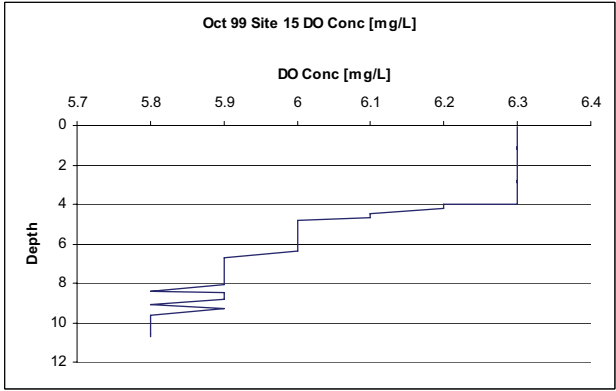
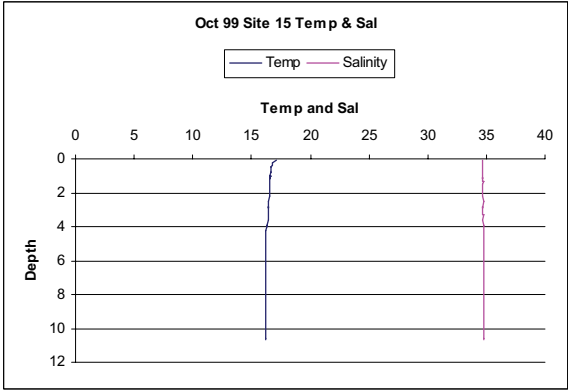
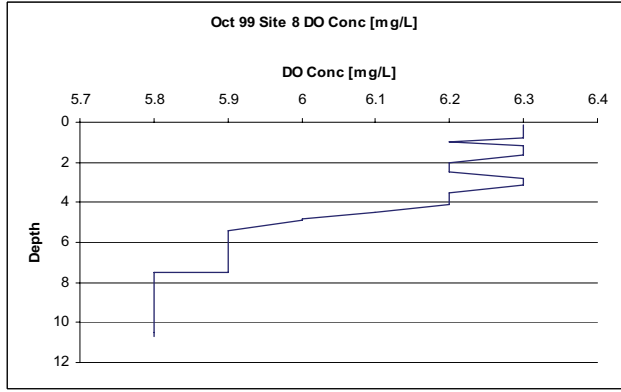
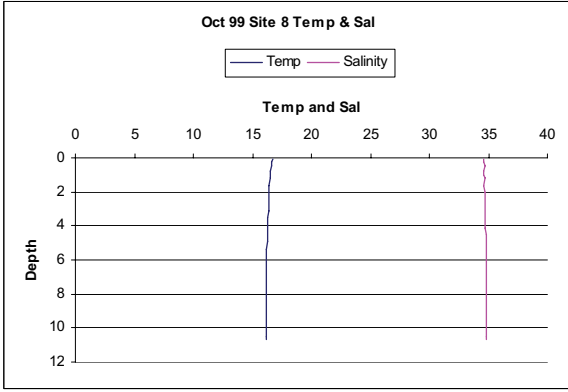
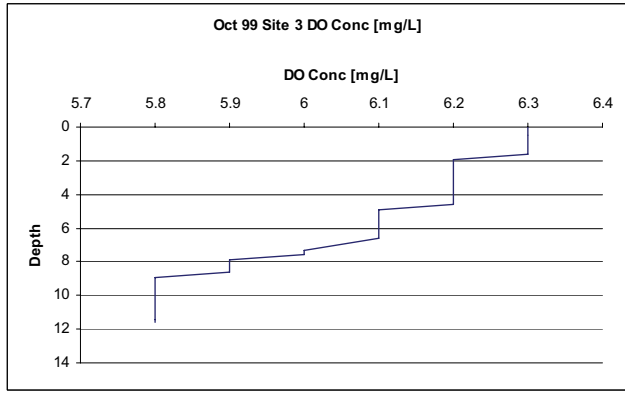
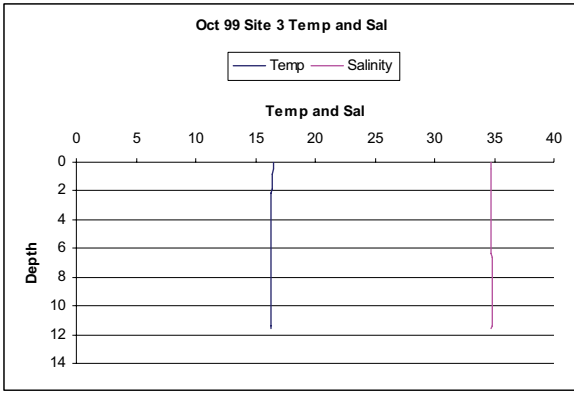
Appendix B

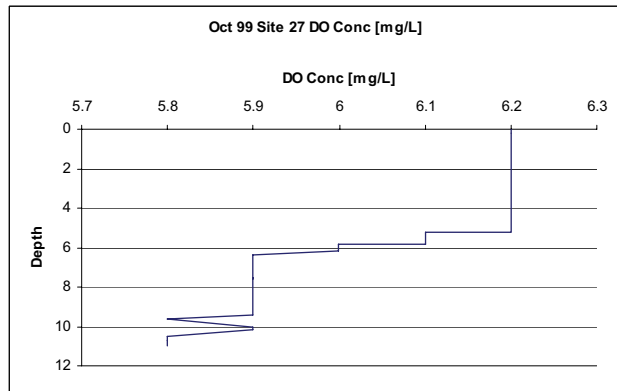
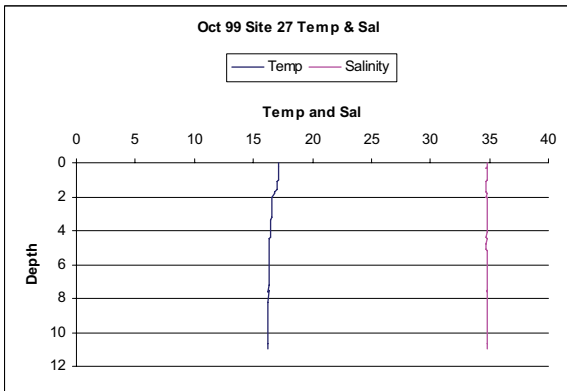
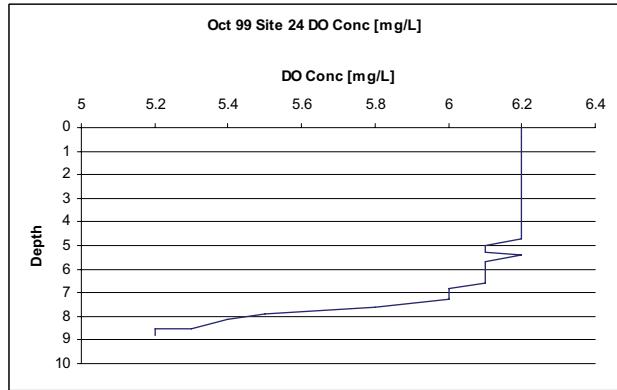
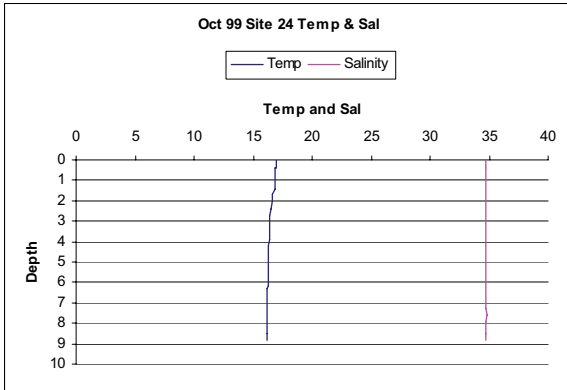
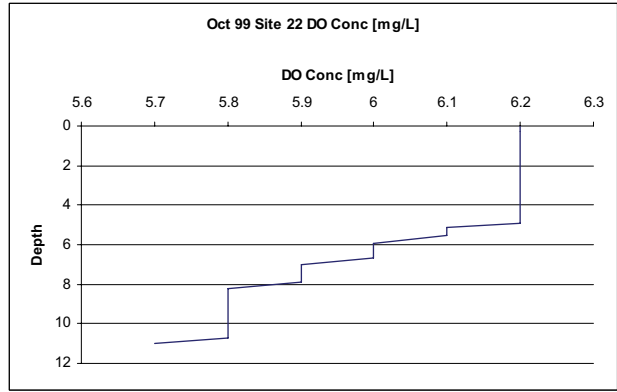
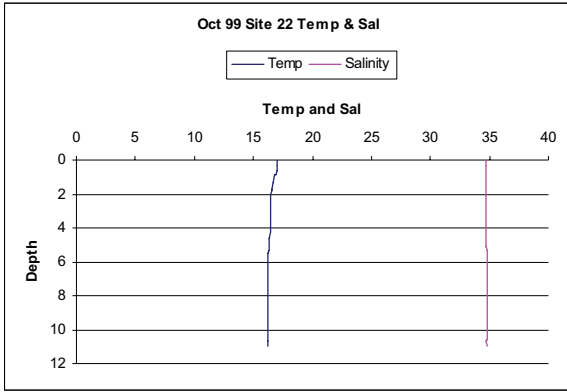
Temperature, Salinity, and DO Profiles from Bunbury Background Studies

March 99 Profiles

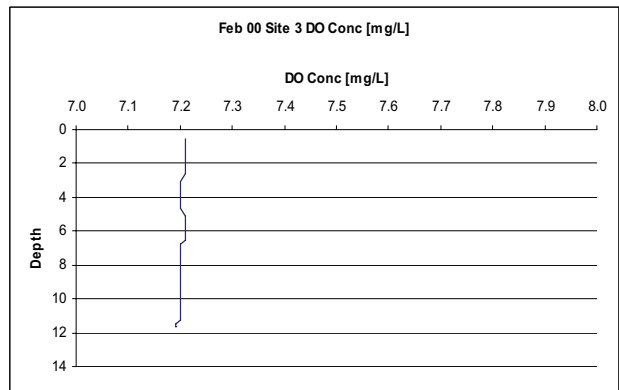
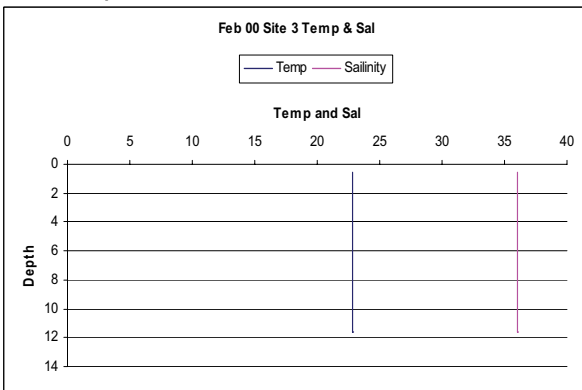


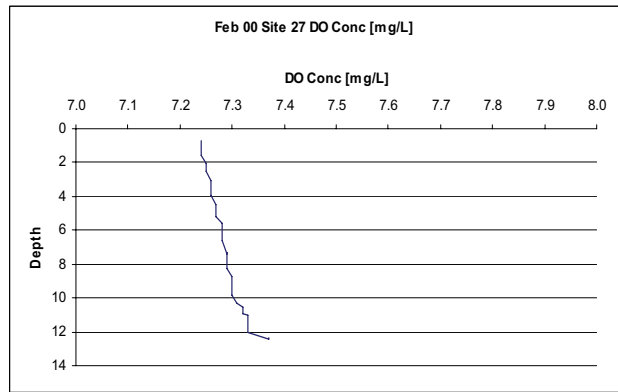
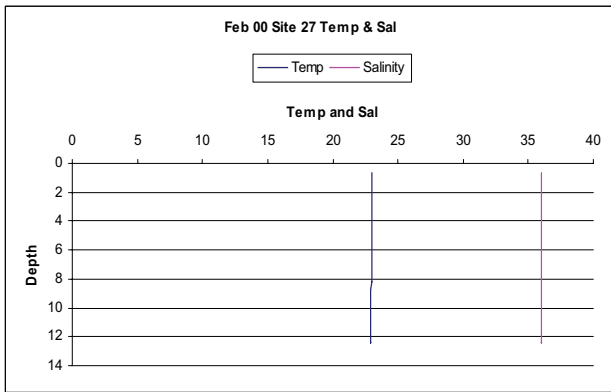
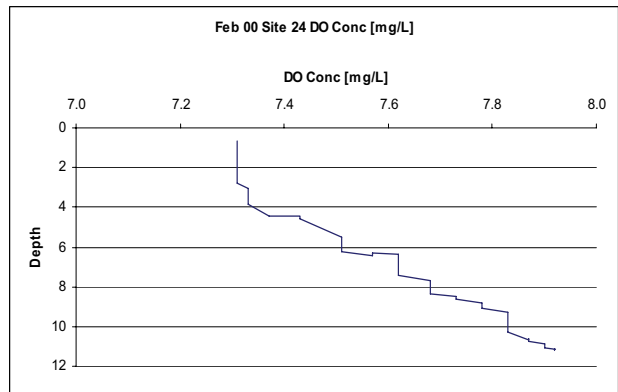
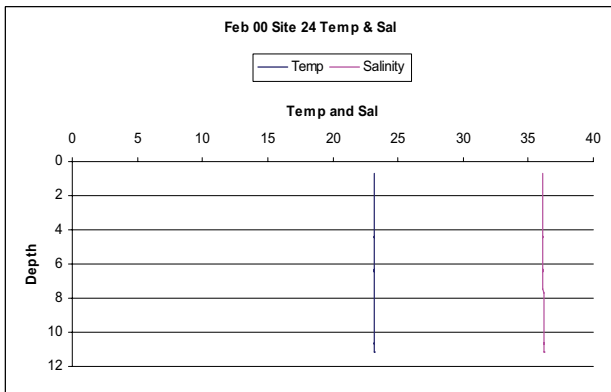
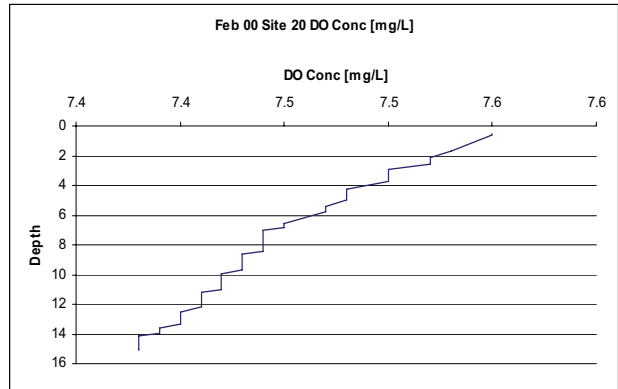
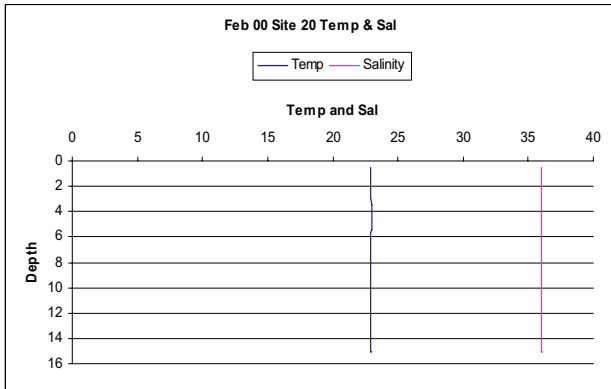
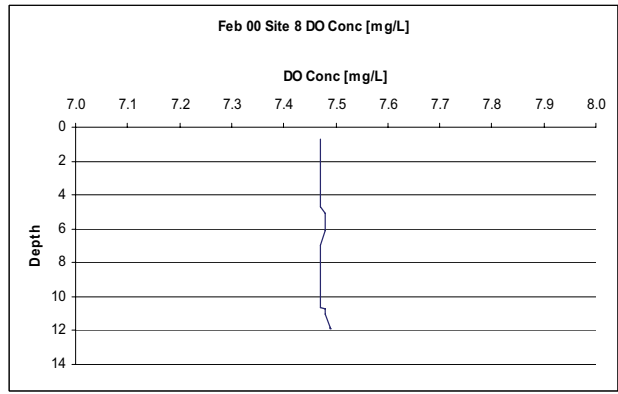
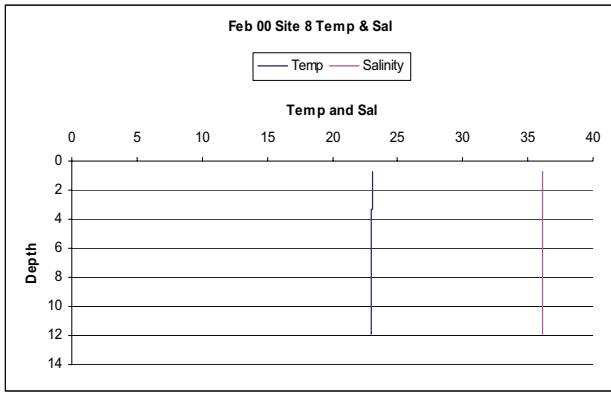
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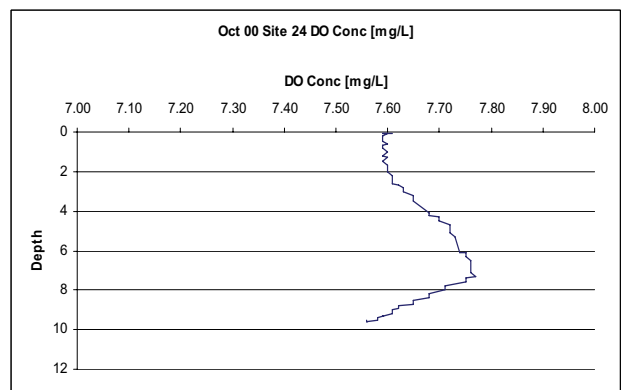
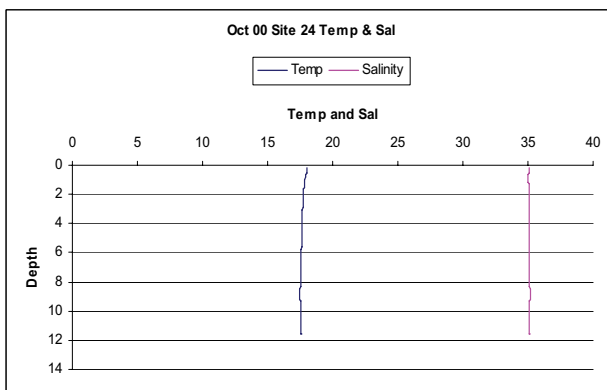
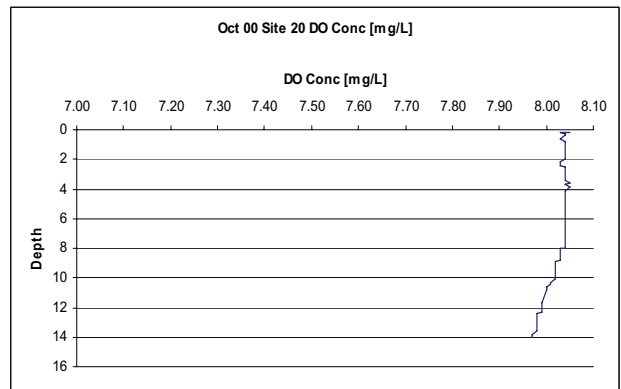
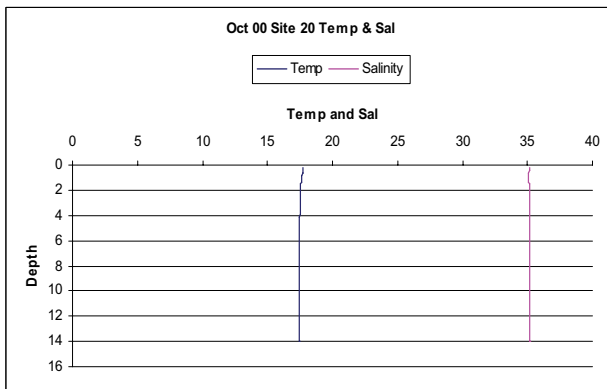
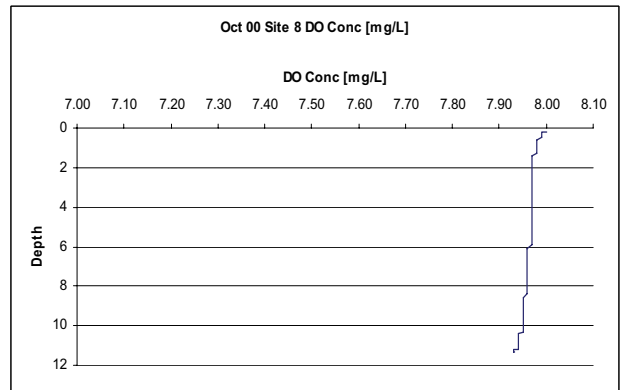
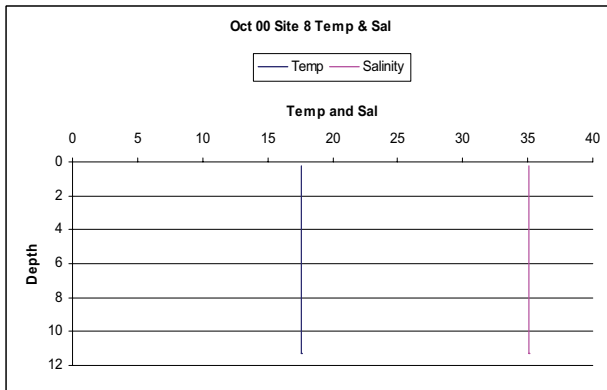
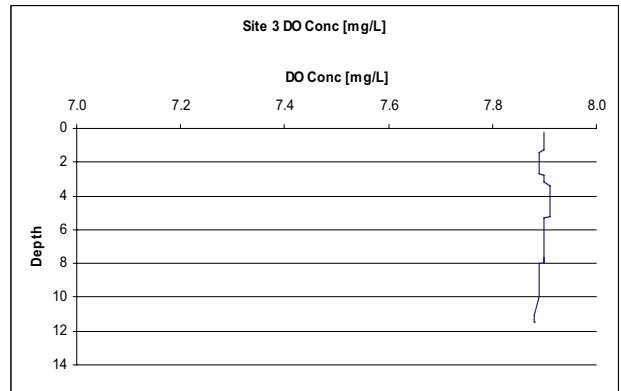
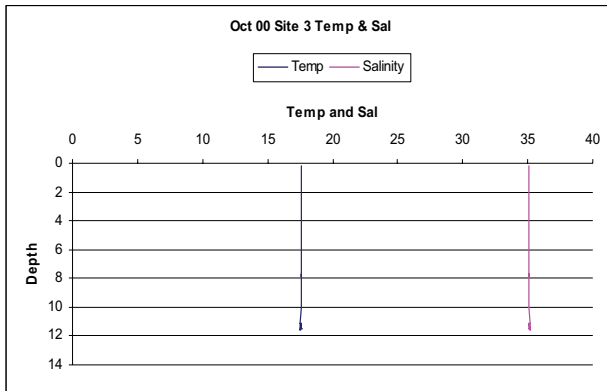


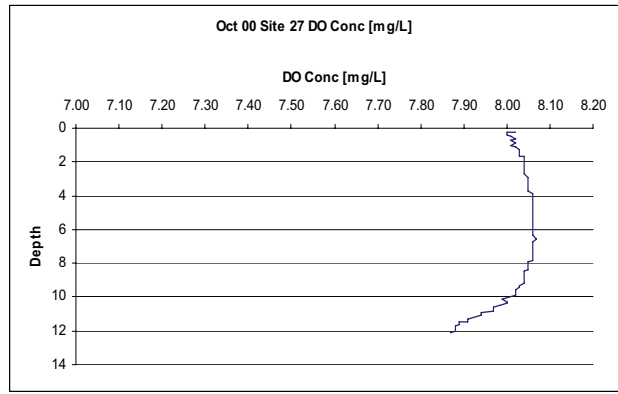
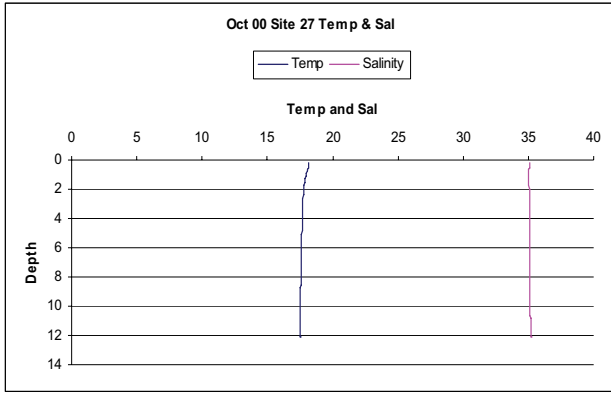
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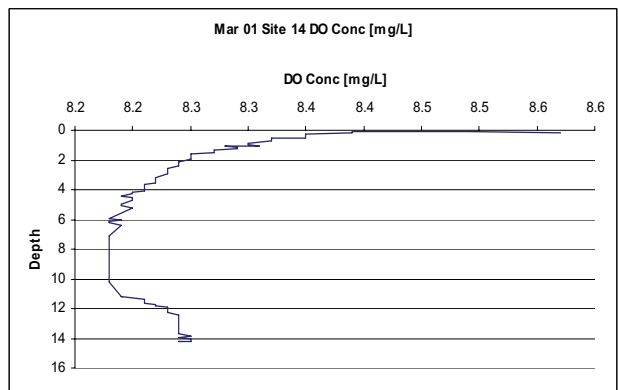
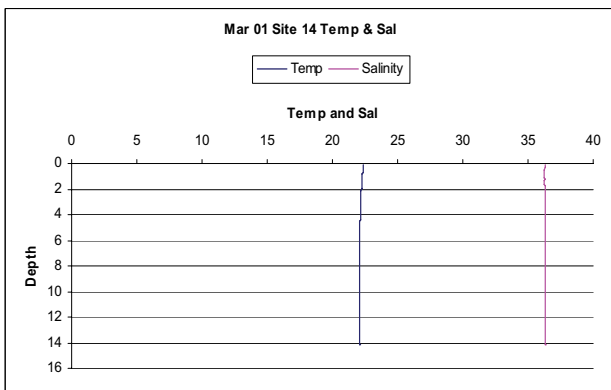
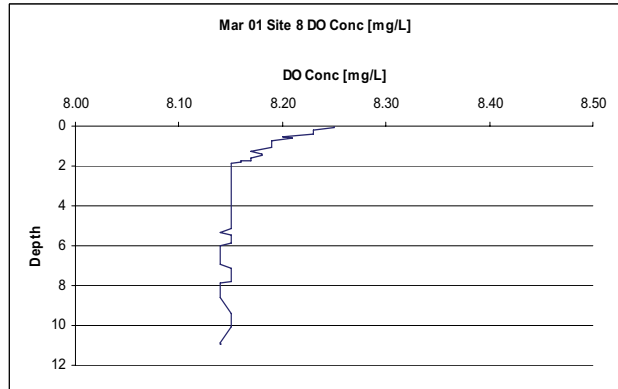
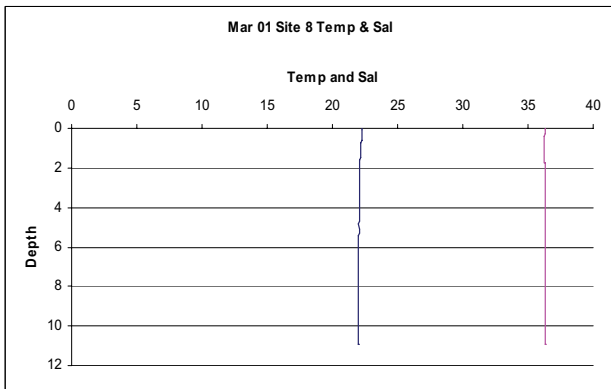
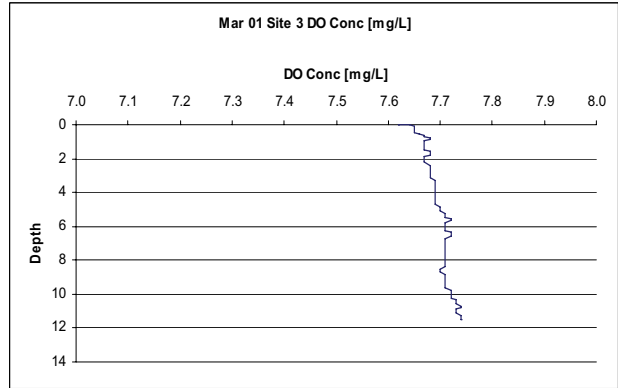
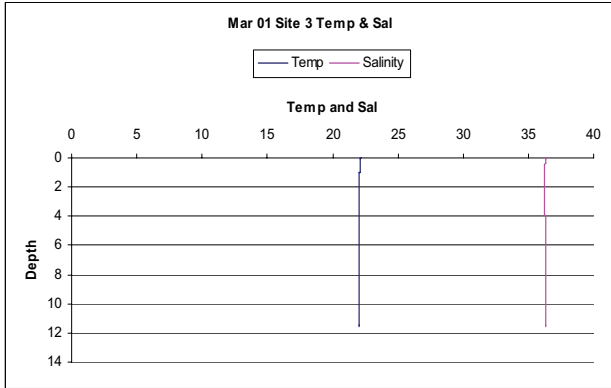


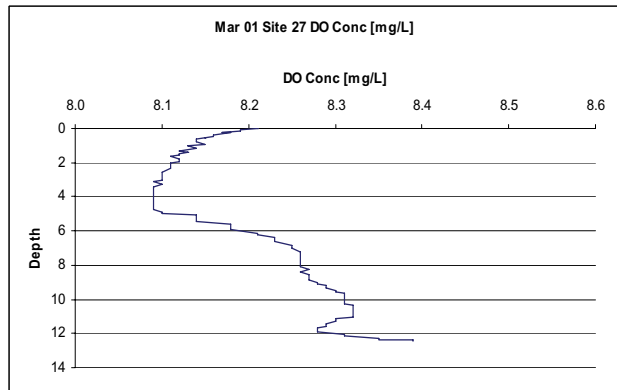
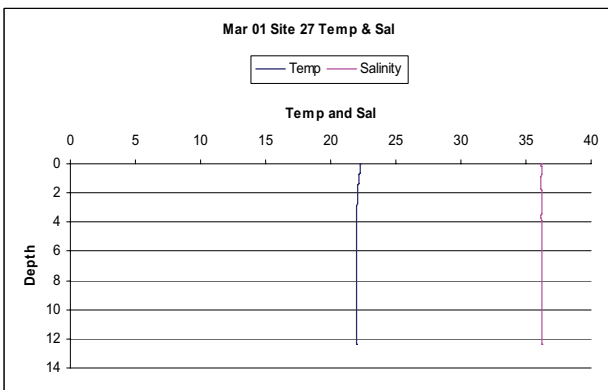
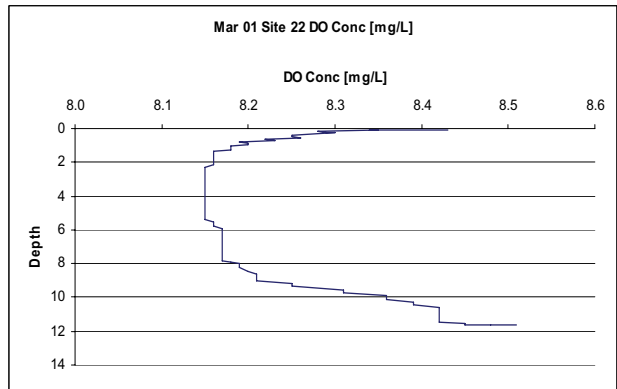
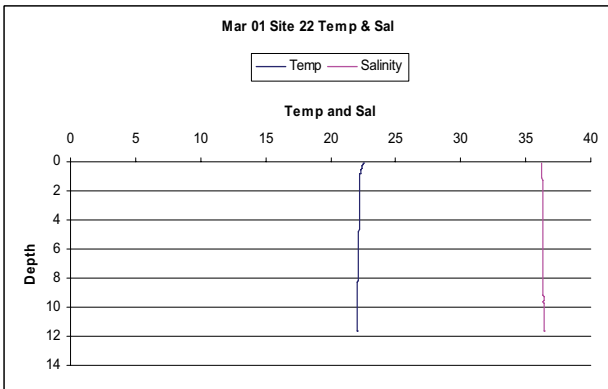
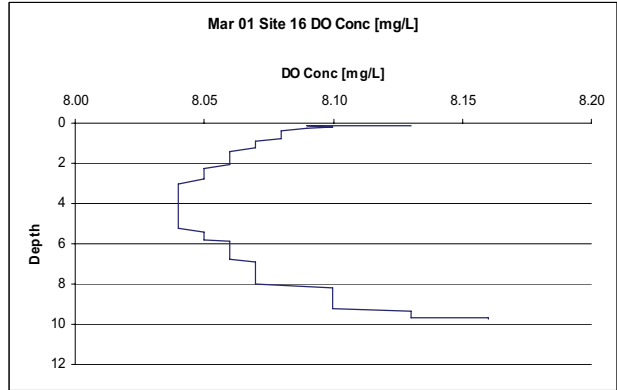
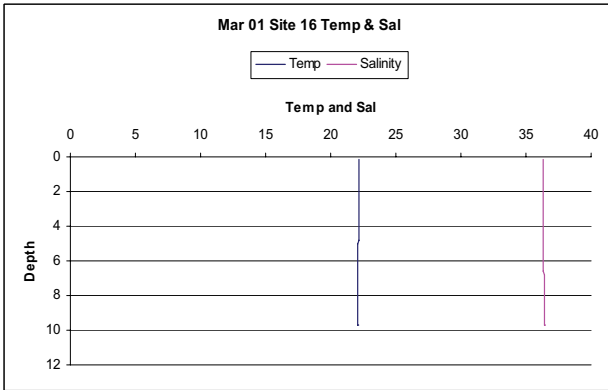
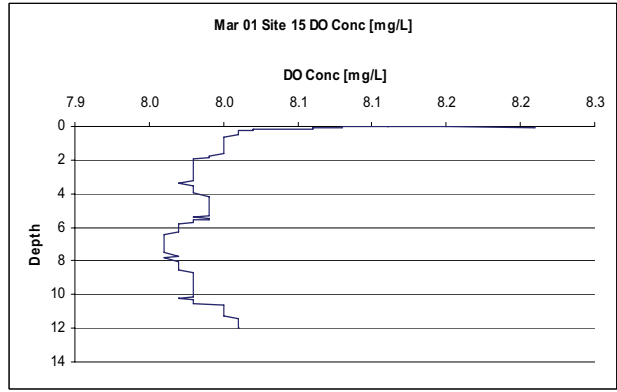
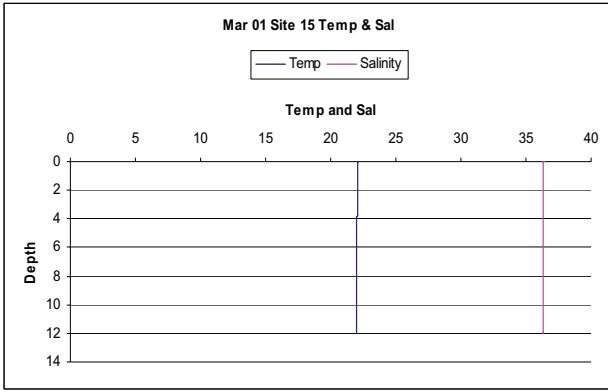
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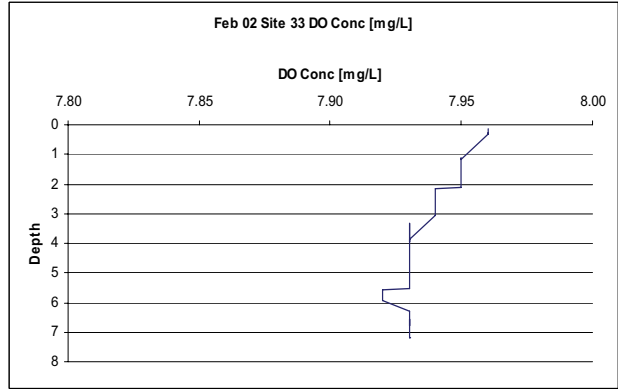
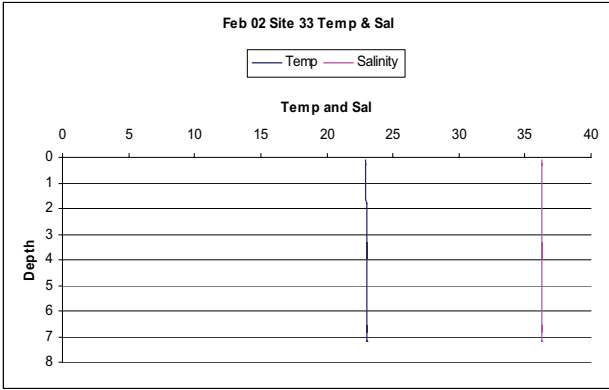
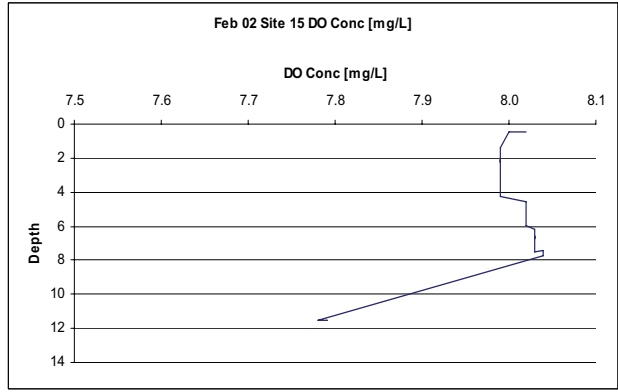
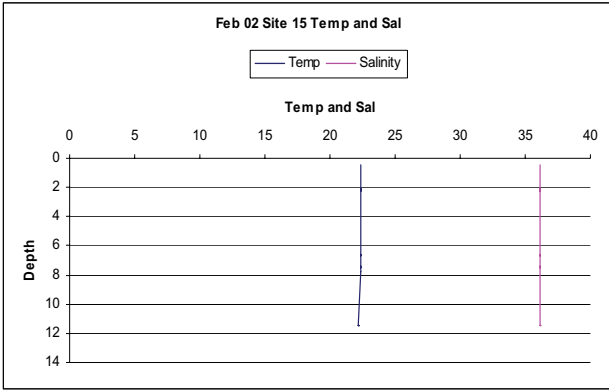


March 2001 Profiles





February 2002 Profiles





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