MARINE MANAGEMENT SUPPORT:
MID WEST

FLUSHING STUDY OF THE MONKEY MIA LAGOON AND ADJACENT WATERS, WESTERN AUSTRALIA, 19-23 APRIL 1998

Data Report: MMS/MW/SBMP - 13/1998

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SUMMARY

This report presents the results from the second oceanographic field study of the flushing behaviour of the Monkey Mia lagoon and adjacent waters conducted in April 1998 by CALM under World Heritage Property Area funding. The data was collected using eight cross-vane drifter drogues which moved as a part of the flow fields driven principally by tides and winds within the Monkey Mia lagoon and adjacent waters. A conductivity-temperature-depth (CTD) probe was used to obtain opportunistic vertical conductivity-temperature profiles throughout the water column. A portable weather station was installed for the extent of the field survey to measure various meteorological factors including amount of solar radiation, wind speed and direction, temperature and rainfall.

The investigation was conducted in collaboration with the University of New South Wales where a model of circulation and dispersion patterns was implemented for the Monkey Mia lagoon and adjacent waters. This data set, in association with the results of the initial flushing study (Blyth *et al*, 1997) have been used to guide the choice of model, the testing of its performance, and the validation of predictive simulations of the dispersion and flushing of contaminants introduced into the lagoon and adjacent waters under typical wind and tide conditions.

Investigation into the hydrodynamics of the Monkey Mia lagoon and adjacent waters was motivated by the need for managers to have a better technical understanding of the potential threats to the conservation values of the lagoon posed by introduced contaminants. These threats include: accidental and deliberate spills from vessels (sullage containing nutrients and pathogens, hydrocarbons from re-fueling facilities, onboard tank spillages and engine exhausts), wastes from boat maintenance activities, seepage of contaminated interstitial water (such as fertilizers and pesticides from lawns and gardens), water-borne marine pests and contaminants from remote but hydrodynamically linked sources (eg. aquaculture and shipping from around the bay) and substances such as suntan lotions (see Murex Consultants, 1996).

The key results of this study were:

- Drogue clusters from deployments A and D were driven out of and then back into the Monkey Mia lagoon with the respective ebb and flood of the tide along a north-east to south-west direction.
- Drogues often returned to and/or traveled past their respective points of release with the full ebb and flood cycle.
- Surface drogues, deployed with bottom drogues, moved apart from bottom drogues and traced a separate but approximately parallel path.
- Some surface drogues initially moved under wind-forcing irrespective of the tide direction and then turned to flow with the strengthening ebb or flood tide.
- A vertical temperature structure was recorded by the CTD probe at 61% of the 53 profile sites.

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Direction

- Keiran McNamara - Director, Nature Conservation Division, CALM
- Dr Chris Simpson - Manager, Marine Conservation Branch (MCB), Nature Conservation Division, CALM

CALM Regional Collaboration

- Kelly Gillen - Manager, Midwest Region
- Paul Brown - Manager, Gascoyne District\
- Roxanne Shadbolt - Monkey Mia Visitor Centre

University of New South Wales collaboration

- Dr David Luketina - Water Research Laboratory, University of NSW

Funding and resources

- Funding of $15,000 has been provided by the World Heritage Unit of the Commonwealth Department of the Environment, Sport and Territories.
- CTD probe from WNI Engineering
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GIS

- Ray Lawrie - Marine Information Officer, Marine Conservation Branch, CALM
- Rodney Nowrojee - Geographic Information Services Section, Information Management Branch, CALM

Data

- *Water level data* - Tides and Waves Section, Maritime Division, Transport WA.
- *CTD data processing* - Gavin Wark and Richard Layley, WNI Engineering, WA.

Field survey

- Kevin Bancroft - Marine Conservation Officer, Marine Conservation Branch (MCB), CALM
- Tim Daly - Technical Officer, Marine Conservation Branch (MCB), CALM

1 INTRODUCTION

1.1 Aim

The aim of the study was to collect additional hydrodynamic data of the Monkey Mia lagoon and adjacent waters that will (i) complement data previously collected, and (ii) enable an intensive characterisation of the hydrodynamics of lagoonal waters by validation and implementation of computer-based hydrodynamic models.

1.2 Background

Monkey Mia is one of Western Australia's most important nature-based tourism destinations (Figure 1). Over 80,000 people are attracted to Monkey Mia every year by the opportunity to interact closely with the dolphins that visit the lagoon almost daily. The number of visitors has caused concern related to the potentially harmful effects of anthropogenically introduced contaminants. This concern dates back to the late 1980's when leachates from septic tanks were implicated in the disappearance and death of dolphins in the Monkey Mia region (Environmental Protection Authority, 1989). This incident, and the associated management implications, motivated investigations into the nutrient and microbiological status of the lagoonal waters (Environmental Protection Authority, 1989; Trayler and Shephard, 1993), and a recent review by Murex Consultants Pty Ltd (1996) on the environmental impacts of tourism at Monkey Mia. These studies highlighted the need for careful management of the pressures that accompany the high rate of human usage at Monkey Mia. The practices of boat users are amongst these pressures, and include sullage discharge, boat refueling, and boat maintenance (such as hull-scraping) all occurring within close proximity of the dolphin interaction area.

There was a requirement, therefore, to acquire an understanding of the hydrodynamic characteristics of the Monkey Mia lagoon and adjacent waters in order to develop numerical models for the prediction of flushing and concentration fields of undesirable substances, such as contaminants, in the water (see Blyth, 1997; Luketina, Lyons and King, 1998).

This study follows on from an initial flushing study conducted within the Monkey Mia lagoon and adjacent waters in 1996 (D'Adamo, 1996; Blyth *et al* 1997; Blyth, 1997), the aim of which was to develop a better understanding of the general hydrodynamics of the Monkey Mia region. It complements the 1996 results in providing information that allows a more detailed understanding of the seasonal characteristics of the hydrodynamics of the lagoon. The results of the two studies combined allow validation and implementation of numerical hydrodynamic models as implemented first by the University of Western Australia and then by the University of New South Wales.

2 SITE SELECTION, METHODS AND EQUIPMENT

2.1 Site selection

Figure 2 presents the bathymetry of the Monkey Mia lagoon and the adjacent waters of Red Cliff Bay, and the location of the drogue deployment sites. Note the 5 meter contour parallel to the coast north-west of Monkey Mia, the location of the sand banks to the north and east of Monkey Mia lagoon, and the approximate locations of the initial sites for each drogue deployment.

The purpose of the drogue deployments was to simulate the release of a contaminant during particular tidal phases and at specific points within the lagoon and Red Cliff Bay. Each of the drogue deployment sites were chosen in consideration of both tidal phase and the bathymetry of the lagoon and Bay, as indicated by the field notes in Table 1.

2.2 Methods and equipment

2.2.1 Meteorology and CTD profiles

Meteorological data was obtained through the installation of an Environdata Weathermaster 2000 meteorological data recorder. This portable weather station was installed on the roof of the Blue Lagoon

Pearls' pontoon roof in Red Cliff Bay so as to obtain accurate local meteorological data. The unit was set to record the weather conditions every ten minutes. The data were then downloaded onto a laptop and were processed and graphed using Microsoft Excel following the completion of the field survey.

Deployment	Drogue positioning
A 20/4/98	*Cluster release midway between jetty and bank opposite. In at 0700 (High Water), out at 1600 (High Water).* Aim: To investigate the dynamic behaviour of a patch that is released near the dolphin feeding area during an ebb/flood phase and, in particular, to determine whether the patch re-enters the dolphin interaction area or flows out into Red Cliff Bay.
B 21/4/98	*Cluster release off Cape Rose near the shelf. Release drogues at 5m contour. In at 1100 (21/4 - LW), out at 0100 (22/4 - HW).* Aim: To investigate the dynamic behaviour of a patch that is released relatively close to the shore off Cape Rose (north west of Monkey Mia) during an ebb/flood phase and, in particular, to determine whether the patch that enters Red Cliff Bay 'escapes' during the subsequent ebb and, if so: • how much of the patch remains close to the coast, and • how much is dispersed offshore.
C 22/4/98	*Line release in an east-west alignment across Red Cliff Bay, passing through 1996 site M23 (co-ords: 25°46.0' 133°41.80'). In at 1400 (22/4 - LW), out at 0100 (23/4 - HW).* Aim: to investigate the dynamics of a 'wall of water' that initially sits across Red Cliff Bay and is driven first further into the Bay (towards Monkey Mia), and then out (north). In particular, to determine whether some of it runs parallel to the shore and some of it crosses the offshore bank and gets caught up in the strong channel currents.
D 23/4/98	*Periodic release (of surface drogues only) midway between jetty and bank opposite every 45 minutes. In at 1100 (LW), out at 2200 (HW).* Aim: To simulate the fate of a continuous injection source near the Monkey Mia jetty and, in particular, to determine whether any crosses the bank and flows north or re-enters or stays in the vicinity of the injection point.

Table 1 Field notes detailing drogue deployment positioning and possible outcomes following deployment.

CTD profiles were obtained opportunistically during the tracking of the drogues so that any hydrodynamically significant water structure could be recorded. Coordinates of the position of each profile were recorded so as to be able to map temperature and density gradients throughout the Monkey Mia lagoon and Red Cliff Bay.

2.2.2 Drogue deployments

Eight cross-vane drifter drogues were deployed from the boat at the sites indicated in Table 1 to measure current flow. The drogue vanes were square with four drogues having $2x2m^2$ vanes ('deep' drogues) and four $1x1m^2$ vanes ('shallow' or 'surface' drogues). The vanes were attached to an aluminium cross constructed of two aluminium tubes pinned at their centres and held end to end by nylon rope. Weights were fixed to the bottom of each drogue to ensure they remained vertical when suspended in the water. The top of the drogue was attached to a 30cm hemispherical buoy to which a flag was attached for sighting. A 50cm line was used between the top of the $2x2m^2$ drogues and the buoy to sit the vanes deeper in the water column.

The changing positions of the drogues were recorded at approximately 20-30 minute intervals using a Differential GPS (DGPS). The DGPS consisted of a SCOUTMASTER GPS attached to an OMNISTAR de-modulator which resulted in DGPS readings accurate to better than 15 m of true drogue positions (the DGPS has an intrinsic error of better than +/- 5 m and the vessel is approximately 10 m in length). Drogue tracking areas were chosen to give a broad data coverage for the purposes of model validation and calibration and also to yield direct current data in key locations (e.g. within the lagoon and in areas of flow constriction such as around sand banks, as indicated in Figure 2). The tables of the raw drogue data are presented in Appendix 1.

3 RESULTS

3.1 Meteorology

The meteorology of the Monkey Mia region was recorded during the duration of the field survey using a Weathermaster 2000 portable weather station, installed as indicated in section 2.2.1. This device recorded air temperature, wind speed and direction and solar radiation. The plots of the data collected (Figures 3 (i) to (iv)) show that typical meteorological patterns (Logan and Brown (1986); Australian Bureau of Statistics (1989)) were predominant during the survey period. Daily maxima of 25 - 28°C were recorded with minima of 17 - 19°C each night (Figure 3 (i)). Winds (Figures 3 (ii) and (iii)) were predominantly in the SW to SE quadrant with average speeds of 8 ms^{-1} during the afternoons. Solar radiation (Figure 3 (iv)) averaged 500 W m^{-2} during the survey period.

3.2 Currents

3.2.1 Data acquisition and processing

Current data were obtained by tracking drogues that were deployed at the sites shown in Figure 2 and according to the deployment program outlined in Table 1. The drogue data were transferred from raw hand-written data sheets to electronic data files. The drogue data were then processed for GIS-based plotting using a package developed by Mr Rod Nowrojee (GIS Officer, Information Management Branch, CALM) and Mr Ray Lawrie (Marine Information Officer, Marine Conservation Branch, CALM) and the GIS input data files are reproduced in Appendix 2 (files containing all drogue data grouped to show the sequence of position fixes for each individual drogue run, the speed of travel for each of the segments within a drogue run and also the mean speed between deployment and retrieval for each drogue run, in chronological sequence). A users' manual for the drogue data processing package has been prepared by Mr Nowrojee (see Nowrojee, 1997). All drogue data have been plotted in Figures 4 (i) to (v).

3.2.2 Key results

The key features of the drogue results for each day under the main wind regime experienced during the survey (weak to moderate sea-breeze winds from the south-west to south-east quadrant) are as follows:

Monday 20/04/98 (Figure 4 (i)):

- Drogue clusters were driven out of and then back into the Monkey Mia lagoon with the respective ebb and flood of the tide along a north-east to south-west direction.
- Surface drogues moved apart from bottom drogues and traced a separate but approximately parallel path.
- Bottom drogues returned to and traveled past approximate point of release.

Tuesday 21/04/98 (Figures 4 (ii) & (iii)):

- Drogue clusters were driven into and then out of Monkey Mia lagoon with the respective flood and ebb along a south-east to north-west path.
- Surface drogues again moved apart from bottom drogues and 'returned' to within 300m of the point of release.
- Bottom drogues returned to within 1km of the point of release.

Wednesday 22/04/98 (Figure 4 (iv)):

- Bottom drogues initially moved south from the point of release, driven by the flood tide.
- Surface drogues were initially forced north under wind-forcing due to SSE winds at 10-15 knots.

- All drogues ultimately moved along a NNW path with the ebb tide.

Thursday 23/04/98 (Figure 4 (v)):

- All drogues that were released followed a north-westerly path under the forcing of the ebb tide.
- During the ensuing flood tide all drogues flowed back along a south easterly path parallel to and sometimes close to the original path.
- Four of the drogues (D2, D3, D4, and D6) ran aground in shallow water and were replaced by $1x1m^2$ drogues to continue tracking the flow of the current with the flood tide.
- Three drogues (D1, D5, and D7) flowed back past their point of release and ran aground on the sand bank east of the Monkey Mia lagoon.

3.3 Salinity-temperature

Salinity-temperature (ST) profiling using the CTD probe was performed opportunistically in conjunction with the drogue tracking exercises. However, as a result of an electronic malfunction on the CTD probe, no salinity data were recorded. A substantial set of temperature profiles were collected throughout the study region, the positions of which are shown in Figure 5. The temperature data were written automatically to electronic files by the CTD probe's internal software (Appendix 3). These data were processed by WNI Engineering and are presented as a series of vertical temperature versus depth plots in Appendix 4.

The data were collected to provide information on the potential for vertical temperature and therefore salinity and density stratification to form and influence the hydrodynamics of the water. The presence of vertical stratification can influence the vertical flow structure and, depending on the strength of the stratification, can isolate deeper water from surface wind-driven currents and mixing. This data is therefore important when modeling or determining the effects of a contaminant spill.

The plots of the temperature data (Appendix 4) show that vertical temperature differences of magnitude 0.01 - 0.1°C were present in the water column at 38% of the sites, temperature variations of magnitude 0.1 - 1°C were present at 23% of the sites, while variations >1°C were recorded at <1% of the sites (4 sites). The remaining sites showed no vertical temperature variance.

Without the corresponding salinity data, however, it cannot be assumed that these temperature variations represent any form of vertical stratification, as vertical salinity differences can occur independently of temperature (D'Adamo, *pers comm.*).

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